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14. ABSTRACT The Pacific Northwest Defense Coalition (PNDC) has been working since 2007 to create, launch and maintain the NWConnectory, an online buyer-supplier network for the Pacific Northwest industrial and technology companies across all industries at every level of the supply chain. What began as an earmark in the 2007 Defense Appropriations Bill has grown to become a regional economic development tool that gives economic development professionals unprecedented access to near real-time information on the businesses that are operating in their region. The purpose of the NWConnectory is to create a regional buyer-supplier network that will connect businesses to each other and enable them to strengthen their supply chain with in the region. The NWConnectory also provides information about the industrial and technology base of the Pacific Northwest economy, and includes profiles of other critical assets including federal labs, university and private research centers. This funding is a major part of building the research and teaching capacity of the faculty at the Lundquist College of Business to engage with the Industry in the Pacific Northwest (in particular with firms in the manufacturing eco-system of defense supply chains). Special emphasis was placed to increase the manufacturing competitiveness in the region by engaging in problem solving projects with firms, offering experiential education that can train and excite students to pursue thriving careers in operations and supply chain management, and undertake research to address the problems of import to the industry. A major emphasis was also placed on engaging in interdisciplinary and multi-disciplinary endeavors when possible. A special effort was made to build gainful collaboration between faculty in the areas of operations and marketing to study problems at the operations-marketing interface and also in areas such as sustainability. Six major deliverables have been submitted as part of the final report for OEI-DLA-DoD 2010 initiative.		

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15. SUBJECT TERMS

Pacific Northwest regional manufacturing buyer-supplier online search engine & database/network, Process Analysis, Forecasting, Capacity Planning, Sourcing, Procurement, Manufacturing, Distribution, Inventory Management, Pricing, Green Products, Product Line Design, Supply Chain Disruption, Sustainable Business Practices, The goal of the evaluation conducted by Pacific Research and Evaluation for Work Systems Inc. (WSI) was to identify whether three trainings funded by the Department of Defense are likely to have a lasting effect on the defense contractors, resulting in continued process improvement. Specifically, WSI was interested in an evaluation that assessed the application of training skills and demonstrates that the applied principles learned in the training result in a process or manufacturing change within the organization.

Common themes emerged across the three trainings which included positive feedback from the trainings as well as areas for improvement. Positive feedback received across all training was related to the focus of training content on lean concepts. Results of the interviews showed that employees feel the content of the training and the six sigma principles are very relevant to the manufacturing industry. The instructors received positive feedback across all trainings as well, even when employees were unsure of how the training could be used on the job,. Finally, employees across all trainings responded positively to bringing multiple organizations together in the trainings.

Suggestions for improvement were related to a lack of resources to facilitate transfer of training concepts back to the job. Specifically, results showed that a lack of supervisor buy-in or knowledge of lean concepts inhibited transfer. Additional time allocated to applying the concepts on the job and the availability of software programs used in the training are other resources that could improve training transfer. Finally, when train the trainer courses were included in the training suite, it was difficult for interviewees to make the connection between this training and process improvement outcomes.

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1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g., 30-06-1998; xx-08-1998; xx-xx-1998.

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15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

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Northwest Manufacturing Initiative

Contract: SP4701-11-C-0002

Mr. Rick Evans, Principal Investigator

**Organization for Economic Initiatives, Inc.
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31 July 2014

Final Report

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Approved for public release; distribution unlimited.

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**DLA Contracting Services Office
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Foreword

The Organization for Economic Initiatives, Inc. (OEI) is pleased to submit this final progress report for SP4701-11-C-0002. We have provided both performance and fiscal oversight for the entire project, including the partner organizations of the University of Oregon, Worksystems Inc. and the Pacific Northwest Defense Coalition. Our oversight included project monitoring, site visits, and financial and performance reviews. This final report provides the details on both our collaborative research into sustainable defense supply chain and operations management. The University of Oregon's emphasis was on increasing the manufacturing competitiveness of the region by attracting students through experiential education in operations, marketing, and sustainability. Worksystems' efforts focused on the application of proven and highly effective workforce training models to improve the capabilities and responsiveness of Pacific Northwest defense manufacturers. This included evaluating various manufacturing training systems for effectiveness in realizing continual process improvements. The Pacific Northwest Defense Coalition continued to refine the Northwest Connector, creating an effective, user-friendly regional buyer-supplier network. Statements of the problems studied and summaries of the most important results can be found in the Executive Summaries of our collaborative partners. The detailed research data and specific applied training models can be found in the appendices.

Pacific Northwest Defense Coalition Executive Summary

The Northwest Connector is an online database containing detailed profiles of Pacific Northwest companies across all industries at every level of the supply chain. The purpose of the NWConnector is to create a regional buyer-supplier network that will connect businesses to each other and enable them to strengthen their supply chain within the region. The NWConnector also provides information about the industrial and technology base of the Pacific Northwest economy, and includes profiles of other critical assets including federal labs, university and private research centers. The Pacific Northwest Defense Coalition (PNDC) has been working since 2007 to create, launch and maintain the NWConnector. The PNDC staff is currently composed of an Executive Director, Program Director, Procurement Counselor, and Program Coordinator; who are all dedicated to the maintenance and outreach of the NWConnector. As of today, PNDC still plans on maintaining the NWConnector till the end of 2014. There are several plans in place to secure additional funding to maintain the NWConnector past the 2014 mark.

University of Oregon Executive Summary

This funding is a major part of building the research and teaching capacity of the faculty at the Lundquist College of Business to engage with the Industry in the Pacific Northwest (in particular with firms in the manufacturing eco-system of defense supply chains). Special emphasis was placed to increase the manufacturing competitiveness in the region by engaging in problem solving projects with firms, offering experiential education that can train and excite students to pursue thriving careers in operations and supply chain management, and undertake research to address the problems of import to the industry. A major emphasis was also placed on engaging in interdisciplinary and multi-disciplinary endeavors when possible. A special effort was made to build gainful collaboration between faculty in the areas of operations and marketing to study problems at the operations-marketing interface and also in areas such as sustainability.

Six major deliverables have been submitted as part of the final report for OEI-DLA-DOD 2010 initiative. These include:

- 1) Summary of 17 Field-Based Experiential Learning Projects
- 2) Technical Manuscript (research paper) titled, "Society or the Environment? Understanding How Consumers Perceive Corporate Sustainability Initiatives"
- 3) Technical Manuscript (research paper) titled, "Making the Monopolist's Product Line Green: The Effects of Consumers' Opposing Perceptions of Recycled Content, Material Cost Savings, and the Diseconomies of Scope in Production"
- 4) Technical Manuscript (research paper) titled, "Balancing Production and Distribution in Paper Manufacturing"
- 5) Technical Manuscript (research paper) titled, "Timing and Signaling Considerations for Recovery from Supply Chain Disruption"
- 6) Technical Manuscript (research paper) titled, "Immediate versus Delayed Price Discounts"

Four additional projects have been initiated as a direct result of the research supported by this funding and are outlined at the end. We next provide a brief summary on each of the six deliverables. The principal investigator, collaborating faculty, and doctoral students funded via this grant have been listed in the reports.

Field projects dealt with problem solving and analysis on issues such as forecasting, process layout analysis and design, bottleneck analysis, quality control, inventory management, sourcing and procurement, capacity planning, justifying capital investments related to manufacturing, production planning and control, warehouse location or layout, and transportation logistics. A special effort was made to seek problems that address environmental issues in supply chain management. These sponsored projects were undertaken in Spring, 2011, Winter/Spring 2012, and Spring, 2013 as part of the course in Supply Chain Management or Operations Management Practicum.

Demand Forecasting at Shady Peeps
MBA Team: Geo Lee, Rusten Gomez, Nandini Mitra, Jaren May
Industry Sponsor: Caleb Org, CFO, Shady Peeps, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 577, Spring 2011

Freight as a Profit Center: A Feasibility Study for Myers Container
UG Team: Adam Walp, Grant Small, Wade Jelinek, Milaine Dickinson
Industry Sponsor: Cody Stavig, Plant Manager, Owner; and Dustin Ma, Accounting Associate, Myers Container, Portland, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2011

Supply Chain Analysis for gDiapers
UG Team: Lance Keith, Stacie Dillingham, Sean Evert, and Bryon Abblitt
Industry Sponsor: Jeff Harvey, Director of Operations; Jolynn Mitchell, VP Merchandizing, gDiapers, Portland, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2011

Evaluating Procurement: Material Sourcing, Use, and Disposal at Monaco RV
MBA Team: Lauren Schwartz, Amanda Rhodes, Gaby Zhu, Cassidy Williams, Andy Fenstermacher
Industry Sponsor: Dennis Girod, Plant Manager, Coburg, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 577, Spring 2011

Optimizing Shipping and Inventory Management at Visionary Lenses
UG Team: Emmanuel Luvert, Andrew Marshall, Tyler DeMuth, Yan Gao
Industry Sponsor: Caleb Org, CFO, Eugene, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2011

Analysis of Warehouse Expansion Options
MBA Team: Brian Oehler, Brad Puglio, Neil Vance, Claire Williams, Tiffany Yep
Industry Sponsor: Joe Iaigulli, VP Supply Chain Management, Kettle Foods
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2011

Analyzing Dismantling and Testing Processes at Next Step Recycling
UG Team: Katarina Ivezic, Yunru Wu, Ge Song, Yujie Tang, Blake Sedgley, Ty Kouri
Industry Sponsor: Lorraine Kerwood, Executive Director, Next Step Recycling, Eugene, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2012

Warehouse Layout Design at Shady Peeps
MBA Team: Jennifer Adams, Troy Beck, Andy Behl, Peter Kaupert
Industry Sponsor: Caleb Iorg, CFO, Shady Peeps, Eugene, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 577, Spring 2012

Effects of Hard-to-Recondition Containers on Efficiency at Myers Container
UG Team: Rodd Danpour, Mitchell Eckberg, Kerin Green, Amber Liu, Hogan Scholten
Industry Sponsor: Cody Stavig, Plant Manager, Owner, Myers Container, Portland, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2012

Order Process Fulfillment Analysis for Visionary Lenses

UG Team: Dominic De Martini, Arunava Chaterjee, Stephen Witbeck, Taylor Hughes, Elizabeth May

Industry Sponsor: Caleb Iorg, CFO, Visionary Lenses, Eugene, OR

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 477, Spring 2012

Paint Room Materials Flow at Ulven Companies: Analysis and Recommendations

UG Team: Christopher McClellan, Cody Kuntz, Sam Schwab, Ben Goodman, Lane Seals

Industry Sponsor: Mike Ulven, C.O.O., Rick Russ, Sales, Tom Wright-Hay, Lean Consultant, OMEP

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 477, Spring 2012

Next Step Recycling: Supply Chain and Operational Analysis and Recommendations

MBA Team: Kevin Klein, Blake Scott, Andrew White, Ahmed Alhaddad, Jeff Mathews

Industry Sponsor: Lorraine Kerwood, Executive Director, Next Step Recycling, Eugene, OR

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 577, Spring 2012

Process Capacity Analysis at Ninkasi Brewing Company

MBA Team: Bryan Schoen, Monir Jalili, Jake Heckathorn, Thomas Schwenger

Industry Sponsor: Jessica Jones, Director of Business Process Improvement

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 577, Spring 2012

Paint Process Analysis at Bulk Handling Systems

UG Team: Kerin Green, Ty Kouri, Mitchell Eckberg

Industry Sponsor: Ryan McGinnis, Quality Manager, Bulk Handling Systems, Eugene, OR

Faculty Adviser: Nagesh N. Murthy

DSC Practicum, Winter/Spring, 2012

Reducing Overlap in Product Lines at Skookum

UG Team: Jordan Anzaldo, Ana Ibanez, Ian Needham, Jake Thomas, Eddie Zhu

Industry Sponsor: Chris Reddy, General Manager, Ulven Companies; Rick Russ, Operations Manager, Ulven Companies

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 477, Spring 2013

Evaluating the Logistics of Inbound Shipping/Manufacturing at Alternative Sites

UG Team: Hao He, Rob Till, Michael Yang, Ruoxing Zhao

Industry Sponsor: Ryan McGinnis, Quality Manager, Bulk Handling Systems, Eugene, OR

Faculty Adviser: Nagesh N. Murthy

DSC 477, Spring, 2013

Evaluating Sustainability of Plant Operations at Killingsworth Plant (Myers Container)

MBA Team: Matt Fanelli, Eric Ringer, Rob Woltil
Industry Sponsor: Cody Stavig, Plant Manager, Owner, Myers Container, Portland, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 577, Spring 2013

Technical Manuscript (research paper) titled, "Society or the Environment? Understanding How Consumers Perceive Corporate Sustainability Initiatives", By Sara Bahnson, Lan Jiang, Jun Ye, and Nagesh Murthy.

Abstract: This research examines how and why consumers evaluate a company's environmental and social practices differently. Using secondary data, a field experiment, and laboratory experiments, we show that the tangibility of a company's product offering and the process to develop the offering influence consumers' evaluations of environmental practices relative to social practices. Specifically, environmental practices generate greater impacts for goods companies, companies with tangible offerings, and companies with a tangible process. By contrast, social practices are more influential for services companies, companies with intangible offerings, and companies with an intangible process. Increased awareness rather than an obligation to compensate underlies the role of tangibility

Technical Manuscript (research paper) titled, "Making the Monopolist's Product Line Green: The Effects of Consumers' Opposing Perceptions of Recycled Content, Material Cost Savings, and the Diseconomies of Scope in Production", by Monir Jalili, Tolga Aydinliyim, and Nagesh Murthy

Abstract: In this study, we consider a two-stage "product line and pricing" problem for a monopolist firm who (potentially) offers two variants: Ordinary and Green. The first stage involves choosing the optimal recycled content percentage $\beta\%$ (i.e., the vertical differentiation gap between the two variants) of the green product, where a 0% recycled content decision implies offering *only* the ordinary product. Then, in the second stage the firm determines the optimal prices for the two variants to be included in its product line. Our analysis and findings contribute to the literature at the interface of operations, marketing and sustainability, and offer managerial insights for practitioners who must assess the trade-offs while introducing green variants with recycled/reused material in their product lines.

Technical Manuscript (research paper) titled, "Balancing Production and Distribution in Paper Manufacturing", by Neil Geismar and Nagesh Murthy. Due to the challenge posed by scale and complexity of the problem this problem was deemed important to expand the scope on the research started in OEI-DLA-DOD 2009 Northwest Manufacturing Initiative.

Abstract: A paper manufacturing plant minimizes its production cost by using long production runs that combine the demands from its various customers. As jobs are completed, they are released to distribution for delivery. Deliveries are made by railcars, each of which is dedicated to one customer. Long production runs imply that maximizing railcar utilization requires holding the cars over several days or holding completed jobs within the loading facility. Each of these methods imposes a cost onto the distribution function. We find how distribution can minimize its cost, given production's schedule. We then consider the problem of minimizing the company's overall cost of both production and distribution. A computational study using general data illustrates that the distribution cost is reduced by 25.80% through our proposed scheme, and that the overall cost is

reduced an additional 4.40% through our coordination mechanism. An optimal algorithm is derived for a specific plant's operations.

Technical Manuscript (research paper) titled, "Timing and Signaling Considerations for Recovery from Supply Chain Disruption", by Zhibin Yang and Nagesh Murthy. Due to the challenge posed by scale and complexity of the problem this problem was deemed important to expand the scope on the research started in OEI-DLA-DOD 2009 Northwest Manufacturing Initiative.

We study the interaction between a supplier's timing of recovery ex post a disruption in the face of a buyer that has a backup production option. After disruption, the supplier quotes a recovery due date and make recovery effort. We find that the supplier's quote of recovery time affects the buyer's use of the contingency option in two ways. First, when the supplier possesses the flexibility of quoting any recovery due date, the supplier may use the quote as a strategic subsidy to retain the buyer from invoking its backup option. As a result, the channel is pareto-improved. Second, when the supplier has private information about the severity of supply disruption, the supplier uses the quote of recovery due date to signal the disruption severity. The supplier may be unable to credibly convey the severity level of disruption to the buyer.

Technical Manuscript (research paper) titled, "Immediate versus Delayed Price Discounts", by Monir Jalili and Michael Pangburn

Sellers commonly offer an immediate discount percentage off the regular price. In contrast, some sellers apply a credit toward a future purchase, based on the customer's prior purchase. We contrast the efficacy of these two discounting strategies to better understand conditions under which prior-purchase based discounts may outperform immediate discounts.

Additional research is being undertaken in the following areas that are a direct result of the research initiatives completed under this grant. These are expected to be completed in the time range of 6 – 12 months.

- 1) When and why is it in the strategic interest of a seller to offer a menu of contracts, particularly a combination of fixed price (without returns) and a buyback contract (i.e., with ability to return)? (Nagesh Murthy, Ramin Shamsi, and Michael Pangburn)
- 2) How and why consumers perceive eco-labels that signal a firm's or industry's sustainability initiatives in various facets of the value chain? (Nagesh Murthy, Lan Jiang, Jun Ye)
- 3) How to gainfully integrate the decisions for loading trucks with loading rail cars at a paper mill to minimize distribution costs while improving customer responsiveness? (Nagesh Murthy and Neil Geismar)
- 4) How are supplier's recovery efforts when faced with disruption at a site influenced by a buyer's policy that adopts sourcing from multiple suppliers (each having multiple sites)? (Nagesh Murthy and Zhibin Yang)

Worksystems Inc. Executive Summary and Recommendations

The goal of the evaluation conducted by Pacific Research and Evaluation for Work Systems Inc. (WSI) was to identify whether three trainings funded by the Department of Defense are likely to have a lasting effect on the defense contractors, resulting in continued process improvement. Specifically, WSI was interested in an evaluation that assessed the application of training skills and demonstrates that the applied principles learned in the training result in a process or manufacturing change within the organization. Common themes emerged across the three trainings which included positive feedback from the trainings as well as areas for improvement. Positive feedback received across all training was related to the focus of training content on lean concepts. Results of the interviews showed that employees feel the content of the training and the six sigma principles are very relevant to the manufacturing industry. The instructors received positive feedback across all trainings as well, even when employees were unsure of how the training could be used on the job,. Finally, employees across all trainings responded positively to bringing multiple organizations together in the trainings. Suggestions for improvement were related to a lack of resources to facilitate transfer of training concepts back to the job. Specifically, results showed that a lack of supervisor buy-in or knowledge of lean concepts inhibited transfer. Additional time allocated to applying the concepts on the job and the availability of software programs used in the training are other resources that could improve training transfer. Finally, when train the trainer courses were included in the training suite, it was difficult for interviewees to make the connection between this training and process improvement outcomes. Overall recommendations for funding future trainings are provided below:

Recommendation #1:

Future training efforts for manufacturing companies should continue to focus on lean principles. Interviewees consistently shared positive feedback about how lean manufacturing is leading to efficiency outcomes within their organization.

Recommendation #2:

We recommend that trainings continue to bring together multiple organizations in the same industry. Feedback from this evaluation showed that employees valued the opinions and experiences of fellow trainees from different organizations.

Recommendation #3:

It is recommended that future training efforts that are focused on lean manufacturing require a supervisor's attendance with his/her employees. In order for employees to feel supported in the application of lean concepts, supervisors and managers need to have an understanding of the concepts and the potential impact on the organization as well. These trainings often encourage employees to completely re-work processes within the organization

and if the supervisor does not understand lean, it is less likely they will support these change efforts.

Recommendation #4:

If training efforts are going to focus on specific software programs, we recommend that the organizations receive support to purchase these programs for the employees. The transfer of training is less likely to occur if employees do not have access to the software they were using during the training. Pacific Research and Evaluation, LLC 5

Recommendation #5:

We suggest including time built into the trainings for application of training content. One of the three training programs included in this evaluation incorporated built in time to apply the knowledge and skills learned in the classroom to a real world project. This portion of the program received the most positive feedback and led to noticeable outcomes related to productivity and efficiency. Those trainings that assigned an application project but did not set aside actual course time to complete it saw less transfer of training to the organization.

Appendix A – Pacific Northwest Defense Coalition

PNDC FINAL REPORT FOR DLA 2011

CONTRACT # SP4701-11-C-0002

CONTACT INFORMATION:

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Project Name: Northwest Manufacturing Initiative (Contract # SP4701-11-C-0002)

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Name of another signing authority (Executive Director/Board Chair) who acknowledges approval of this report:

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FINANCIAL SUMMARY

Total value of contract \$ 355,000

Amount spent to date: \$ \$347,259.87

EXECUTIVE SUMMARY

The Northwest Connector is an online database containing detailed profiles of Pacific Northwest companies across all industries at every level of the supply chain. The purpose of the NWConnector is to create a regional buyer-supplier network that will connect businesses to each other and enable them to strengthen their supply chain within the region. The NWConnector also provides information about the industrial and technology base of the Pacific Northwest economy, and includes profiles of other critical assets including federal labs, university and private research centers. The Pacific Northwest Defense Coalition (PNDC) has been working since 2007 to create, launch and maintain the NWConnector. The PNDC staff is currently composed of an Executive Director, Program Director, Procurement Counselor, and Program Coordinator; who are all dedicated to the maintenance and outreach of the NWConnector. As of today, PNDC still plans on maintaining the NWConnector till the end of 2014. There are several plans in place to secure additional funding to maintain the NWConnector past the 2014 mark.

ABOUT THE PROGRAM

The Pacific Northwest Defense Coalition (PNDC) has been working since 2007 to create, launch and maintain the NWConnector, an online buyer-supplier network for the Pacific Northwest industrial and technology companies across all industries at every level of the supply chain. What began as an earmark in the 2007 Defense Appropriations Bill has grown to become a regional economic development tool that gives economic development professionals unprecedented access to near real-time information on the businesses that are operating in their region.

Products and Services

The NWConnector Network is a regional, Web-Based Buyer-Supplier Network that provides:

- A unique way to connect with companies and other assets by understanding their capabilities
- Powerful means for government, large company, and institutional buyers to identify sources of products, services, technologies, capabilities, and capacities
- Detailed capabilities and capacities for companies at every level of the supply chain
- Focus on manufacturing/technology companies and their supplier chain including wholesalers/logistics, technical services, construction, agribusiness, and mining

- A showcase for tens of thousands of Pacific NW companies at NO COST to them
- Internet speed/powerful search engine combined with in-depth company database
- Commitment to usability, coverage, quality, and continual updating distinguishes it from any other available database.

PROJECT SUMMARY

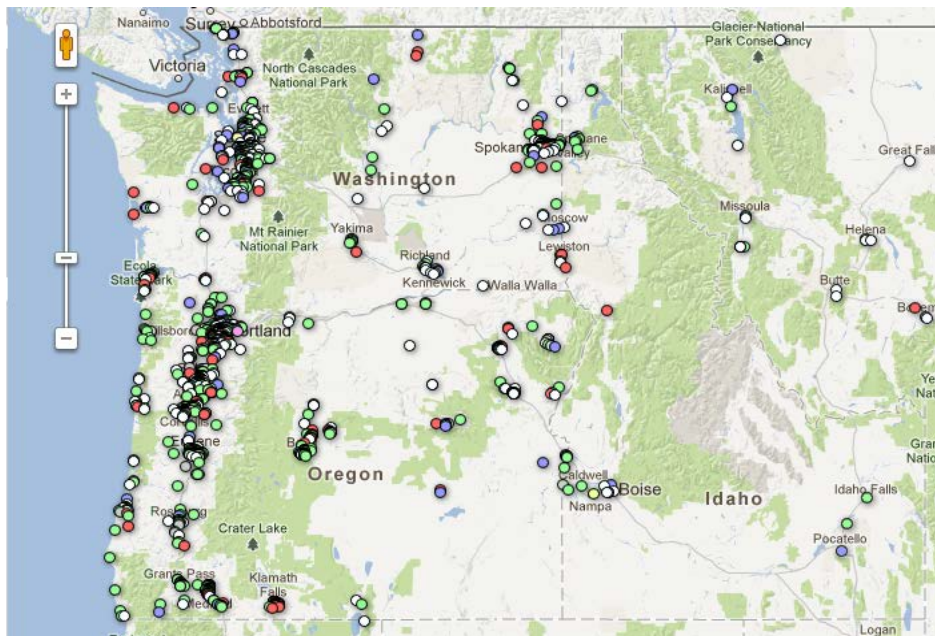
Since going live in August of 2011, the Northwest Connectory has grown to include nearly 4,497 companies in 6 states.

Breakdown by State:

- Alaska = 16
- Hawaii = 16
- Idaho = 23
- Montana = 25
- Oregon = 1904
- Washington = 2,513

Profiling was done by Molly Hefeneider. In addition to directly creating profiles, Molly focused on obtaining lists of companies from partners, and then worked with ECEDC staff to have those lists profiled.

Geographic Area Map



Partners who help promote the NW Connectory

- Oregon Business Development Department
- Portland Development Commission
- Pacific NW Aerospace Alliance
- Oregon Manufacturing Extension Partnership
- Columbia River Economic Development Council

- Drive Oregon
- AUVSI – Cascade Chapter (Association for Unmanned Vehicles International)
- AUSA – Columbia River Chapter (Association of the United States Army)
- Navy League - Bremerton
- Techlink – University of Montana
- Western Washington University

NWConnectory targets industrial and technological companies in the Pacific Northwest with a focus on Oregon and Washington. There are currently 4,497 companies profiled in the NWConnectory.

Testimonials

Technical Procurement Centers and Congressional Offices also use the NWConnectory to pull industry data for research and grant needs.

Under a very tight deadline, a business called me looking for packaging support that would have allowed them to bid on a federal solicitation. One quick search in NW Connectory led me to a few options for this firm. They were able to bid the job, win, and appropriately package their product for shipment to DoD. Thank you NW Connectory!

-Tiffany Scroggs, Statewide Program Director, WA Procurement Technical Assistance Center

The NW Connectory has been useful in marketing our services. I routinely provide the web link so prospective clients can see our profile. I have used the NW Connectory to locate suppliers and prospective team members. We recently competed for and received a grant for an engineering study with a team member from NW Connectory.

-Rick Williams, Director, Columbia Region, SAIC Ocean Technologies at SAIC

Outreach

All PNDC staff members are involved with the outreach of the NWConnectory. Since August 2011, PNDC has promoted the NW Connectory at the following events:

- Masterpiece Models – Member Meeting – September 20, 2011
 - Vancouver, WA
 - Attendance : Approximately 50 companies
- PNDC Networking Event – Oct 5, 2011
 - Location: The University Club, downtown Portland
 - Attendance : Approximately 50 companies

- Red Arrow Logistics – Member Meeting – October 19, 2011
 - Location: Seattle, WA
 - Attendance : Approximately 50 companies
- PNDC Annual Meeting & Social – October 27th , 2011
 - Location: Governor Hotel, downtown Portland
 - Attendance : Approximately 150 companies
 - NWConnectory booth and display
- Manufacturing Career Workforce Summit-Nov 15, 2011
 - In partnership with PDC and Worksystems
 - Attendance : Approximately 40 companies
- PNDC networking Event with Oregon National Guard Association - 12/14/11
 - Location: Camp Withycombe, Clackamas, OR
 - Attendance : Approximately 175 companies
- ITAR Training – USDOC/ITA Partnership - Jan. 25, 2012
 - Location: Portland, OR
 - Attendance : Approximately 75 companies
- PNDC networking Event at Omega Morgan -2/23/12
 - Location: Omega Morgan, Hillsboro, OR
 - Attendance : Approximately 40 companies
- Portland Networking Breakfast -2/29/12
 - Partnership with the Portland Development Commission
 - Location: Governor Hotel, Portland, OR
 - Attendance : Approximately 60 companies
- Aerospace & Defense supplier Summit -2/29/2
 - PDNC had a NWConnectory Display Booth
 - Location: Seattle, WA
- Alliance NW Conference - 3/14/12
 - Hosted Washington PTAC
 - Outreach: NW Connectory had a display booth
 - Attendance : Approximately 500 companies
 - Location: Puyallup, WA
- Clean Tech Defense Symposium - 4/26/12
 - PNDC hosted a Clean Tech Defense Symposium
 - Outreach: NW Connectory had a display booth
 - Attendance : Approximately 100 companies
 - Location: Tacoma, WA

- PNDC networking Event – 5/9/12
 - Location: Camp Withycombe, Clackamas, OR
 - Attendance : Approximately 40 companies
- PNDC Lean Leadership Workshop – 6/20/12
 - Location: Portland, OR
 - Attendance : Approximately 20 companies
- PNDC Networking Event – 7/10/12
 - Location: Woodinville, WA 98072
 - Attendance : Approximately 20 companies

- PNDC Networking Event – 7/17/12
 - Location: Portland, OR
 - Attendance : Approximately 30 companies

- Pacific NW Defense Symposium – August 20-21, 2012
 - PNDC hosted tradeshow
 - NWConnectory booth and display
 - Location: Bremerton, WA
 - Attendance : Approximately 100 companies

- PNDC Networking Event – 9/18/12
 - Location: Portland, OR
 - Attendance : Approximately 30 companies

- Defense Roundtable with Congressman Kurt Schrader – October 29, 2012
 - Location: Hillsboro, OR
 - Attendance : Approximately 20 companies

- PNDC Annual Meeting & Social – November 7, 2012
 - Location: Governor Hotel, downtown Portland
 - Attendance : Approximately 120 companies
 - NWConnectory booth and display

- PNDC networking Event with Oregon National Guard Association - 12/14/11
 - Location: Army Aviation Hangar, Portland Air National (Portland, OR)
 - Attendance : Approximately 200 companies

- PNDC Networking Event – 1/10/13
 - Location: Portland, OR
 - Attendance : Approximately 40 companies

- PNDC Networking Event – 1/10/13
 - Location: Portland, OR
 - Attendance : Approximately 40 companies

- ITAR Summit – USDOC/ITA Partnership - Jan. 23, 2013

- Location: Portland, OR
 - Attendance : Approximately 75 companies
- Defense Roundtable with Assistant Secretary of Defense Sharon Burke – 1/29/13
 - Location: Hillsboro, OR
 - Attendance : Approximately 30 companies
- PNDC Networking Event – 2/13/13
 - Location: Portland, OR
 - Attendance : Approximately 40 companies
- PNDC Networking Event –3/24/13
 - Location: Seattle, WA
 - Attendance : Approximately 40 companies
- PNDC Networking Event at SAM Medical–4/27/13
 - Location: Wilsonville, WA
 - Attendance : Approximately 50 companies
- PNDC & Association of the United States Army –Columbia Chapter Networking Event at Oregon Ballistics Labs - 5/15/13
 - Location: Salem, OR
 - Attendance : Approximately 50 companies

Newsletter

The PNDC newsletter has a dedicated section for the NW Connectory where companies can learn more about the NW Connectory and sign up for a profile. Company profiles are highlighted in the newsletter to promote the NW Connectory and encourage usage.

OPERATIONS

Management & Organization

Dave Hunt, PNDC Executive Director

Dave Hunt was named PNDC Executive Director on March 27th, 2013. He has served nearly eight years as executive director of the Association of Pacific Ports, working to strengthen trade and effectiveness for ports throughout the Pacific. He recently completed 10 years representing Clackamas County in the Oregon House of Representatives, including service as majority leader and as speaker of the house. Dave previously served as executive director of the Columbia River Channel Coalition, as an elected member of the Oregon City School Board, and as national president of American Baptist Churches USA.

Dave will be managing the staff and the outreach of the NWConnectory.

Weekly staff meetings have been scheduled to train the staff on the NWConnectory outreach and mission.

Suzanne Lam, Director of Programs & Events

Suzanne Lam has been with PNDC since 2008 and has played a key role in PNDC's growth during that time. As a Director, Suzanne is primarily responsible for managing PNDC's revenue to carry out goals set by the Board of Directors. Suzanne's budgeting and forecasting expertise have allowed PNDC to dramatically increase the scope of its program offerings to facilitate increased opportunities for education and interaction among its members. Suzanne also manages PNDC's marketing campaign and assists the Executive Director with the daily management of the association.

Suzanne is responsible for the daily management of NWConnectory and the implementation of its marketing plan. Suzanne is the main point of contact for the NWConnectory with oversight from Dave Hunt and support from staff.

Molly Hefeneider, Project Coordinator

Molly graduated from the University of Montana in 2012 with an undergraduate degree in business. Molly is responsible for the NWConnectory data and profile management. Molly is also the point person for companies with questions on their company profile. Molly also assists in the NWConnectory outreaching efforts.

NWConnectory® Committee

This volunteer committee meets quarterly to discuss the marketing efforts and funding of the NWConnectory®. This committee also helps reviews the NWConnectory® mission statement and provides guidance to staff on how to best fulfill the NWConnectory® strategic goals.

Members include:

Karen Goddin, Business Oregon

Chad Harder, LaunchPad

Kevin Johnson, PDC

Will Macia, The Last US Bag

Mike Matthews, Axiom Electronics

Pam Neal, PDC

Richard Williams, SAIC3

PNDC Board

The PNDC Board of Directors meets monthly to discuss the strategic objectives of the

NWConnectory®

- CHAIR: Will Macia, President, Last US Bag Company
- VICE-CHAIR: Tim Lachenmeier, President, Near Space Corporation
- SECRETARY: Katherine Cowan, General Counsel, Eid Passport
- TREASURER: Eric Meslow, President, Timbercon
- Casey Ingels, CEO, Tactical Tailor
- Liz Lasater, President, Red Arrow Logistics
- Dallas Meggitt, President, Sound & Sea Technology
- Dr. Adrian Polliack, President, SAM Medical
- Mike Reightley, President, Kawak Aviation Technologies
- Andrew Spiering, Operations Manager, Valley Machine
- Kevin Tropa, VP of Tactical Division, Leupold & Stevens
- Robert Toppel, President, Axiom Electronics

Board of Advisors:

- Col. Mike Bieniewicz, Oregon National Guard
- Chandra Brown, U.S. Department of Commerce
- Barry Hendrix, HBG Consulting
- Kevin Johnson, Portland Development Commission
- Bonnie L. Moore, Columbia River Economic Dev. Council
- Chris Scherer, OMEP
- Will Swearingen, TechLink

LESSONS LEARNED & RECOMMENDATIONS

We summarize a few key lessons that we have learned along the way in managing the NW Connector.

1. Tracking Success Stories

In the past, it has been a challenge to track success stories in the NW Connector. To rectify this we have set our staff has been trained to track success stories and look for success stories. Companies are also encouraged to send success stories to the Pacific NW Defense Coalition.

2. Leveraging Partnerships

Outreach through partnering organizations like Business Oregon, Portland Development Commission, WA PTAC, Columbia River Economic Development Council, Oregon Government Contracts Assistance Program, Washington Department of Commerce, and Oregon Manufacturing Extension Partnership will help promote and increase usage of the NWConnector.

Business Oregon - Business Oregon will require companies who register under their state certification program to also fill out a profile in the NWConnector.

Portland Development Commission – Will ask companies who register for the PDC Supply Chain Program Event to fill out a NWConnector profile.

Oregon Government Contracts Assistance Program – Lisa Brookshier, PNDC’s Procurement Counselor will profile all relevant companies she meets in the NWConnector.

3. Training Staff

We have found that is important to consistently train and update our staff on the NW Connector business plan and goals. In the past, employee turnover has complicated the development and promotion of the NW Connector. Updating, informing and streamlining this data will help to inform new and old employees on the strategic plans

4. Promotion & Outreach

➤ **Tradeshows and Symposia**

Having a booth or display at tradeshows and symposia has been a great way to promote the NWConnectory. In March 2013 PNDC had a booth at the NW Alliance Tradeshow in Puyallup, WA. After the tradeshow, we were able to add 40 new company profiles to the network. Attending tradeshows and symposiums is a very cost effective way to promote the NWConnectory.

Here are some purposed tradeshows and symposiums that the PNDC staff will attend to promote the NWConnectory:

- ✓ NW Aerospace & Defense Symposium – May 21-22 (Tacoma, WA)
- ✓ AUVSI Conference – August 2013 (Pendleton, OR)
- ✓ Pacific NW Defense Symposium – Sept 24-25 (Bremerton, WA)
- ✓ The Northwest Supply Chain Opportunities Conference – Sept 2013 (Portland, OR)
- ✓ Aerospace & Defense Supplier Summit – March 2014 (Seattle, WA)

➤ **One-on-one Outreach with Manufacturing Firms**

When meeting with manufacturing firms in the area, the staff has been trained to promote the NWConnectory and profile each manufacturing firm in the NWConnectory.

➤ **Google Ad-Words**

PNDC will work with the **NWConnectory®** committee to hone in on specific Google Ad word searches. These searches will help further the reach and usage of the **NWConnectory®**.

➤ **Edelman**

5. PNDC will use its partnership with Edelman (a public relations firm) to help promote the **NWConnectory®**.

THE FUTURE OF NW CONNECTORY

PNDC will manage the NW Connectory through 2014. PNDC hopes to accomplish the following strategic goals for 2013-2014

- ✓ To add 250 new profiles over the next 12 months, bringing the profile total to over 4,750 companies

- ✓ To have additional prime contractors using the NWConnectory for their buyer/supplier needs
- ✓ To see improvements in the Google Analytics usage results
- ✓ To continue outreach of the NW Connectory to Pacific NW manufacturers

Website Interface Project

A website interface will be developed for the NWConnectory to create a more user friendly website. The interface will have the following:

- ✓ Instructions on how to use the NWConnectory
- ✓ Success Stories
- ✓ Grant and Job Opportunities
- ✓ Contact Information
- ✓ Testimonials

Appendix B: University of Oregon

Final Report for OEI-DLA-DOD 2010: Northwest Manufacturing Initiative,

Executive Summary, June 9, 2014

Principal Investigator: Nagesh N. Murthy, Lundquist College of Business, University of Oregon

UO Grant # 271251

This funding is a major part of building the research and teaching capacity of the faculty at the Lundquist College of Business to engage with the Industry in the Pacific Northwest (in particular with firms in the manufacturing eco-system of defense supply chains). Special emphasis was placed to increase the manufacturing competitiveness in the region by engaging in problem solving projects with firms, offering experiential education that can train and excite students to pursue thriving careers in operations and supply chain management, and undertake research to address the problems of import to the industry. A major emphasis was also placed on engaging in interdisciplinary and multi-disciplinary endeavors when possible. A special effort was made to build gainful collaboration between faculty in the areas of operations and marketing to study problems at the operations-marketing interface and also in areas such as sustainability.

Six major deliverables have been submitted as part of the final report for OEI-DLA-DoD 2009 initiative. These include:

- 1) Summary of 17 Field-Based Experiential Learning Projects
- 2) Technical Manuscript (research paper) titled, "Society or the Environment? Understanding How Consumers Perceive Corporate Sustainability Initiatives"
- 3) Technical Manuscript (research paper) titled, "Making the Monopolist's Product Line Green: The Effects of Consumers' Opposing Perceptions of Recycled Content, Material Cost Savings, and the Diseconomies of Scope in Production"
- 4) Technical Manuscript (research paper) titled, "Balancing Production and Distribution in Paper Manufacturing"
- 5) Technical Manuscript (research paper) titled, "Timing and Signaling Considerations for Recovery from Supply Chain Disruption"
- 6) Technical Manuscript (research paper) titled, "Immediate versus Delayed Price Discounts"

Four additional projects have been initiated as a direct result of the research supported by this funding and are outlined at the end. We next provide a brief summary on each of the six deliverables. The principal investigator, collaborating faculty, and doctoral students funded via this grant have been listed in the reports.

Field projects dealt with problem solving and analysis on issues such as forecasting, process layout analysis and design, bottleneck analysis, quality control, inventory management, sourcing and procurement, capacity planning, justifying capital investments related to manufacturing, production planning and control, warehouse location or layout, and transportation logistics. A special effort was made to seek problems that address environmental issues in supply chain management. These sponsored projects were undertaken in Spring, 2011, Winter/Spring 2012, and Spring, 2013 as part of the course in Supply Chain Management or Operations Management Practicum.

Demand Forecasting at Shady Peeps

MBA Team: Geo Lee, Rusten Gomez, Nandini Mitra, Jaren May
Industry Sponsor: Caleb Org, CFO, Shady Peeps, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 577, Spring 2011

Freight as a Profit Center: A Feasibility Study for Myers Container
UG Team: Adam Walp, Grant Small, Wade Jelinek, Milaine Dickinson
Industry Sponsor: Cody Stavig, Plant Manager, Owner; and Dustin Ma, Accounting Associate, Myers Container, Portland, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2011

Supply Chain Analysis for gDiapers
UG Team: Lance Keith, Stacie Dillingham, Sean Evert, and Bryon Abblitt
Industry Sponsor: Jeff Harvey, Director of Operations; Jolynn Mitchell, VP Merchandizing, gDiapers, Portland, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 477, Spring 2011

Evaluating Procurement: Material Sourcing, Use, and Disposal at Monaco RV
MBA Team: Lauren Schwartz, Amanda Rhodes, Gaby Zhu, Cassidy Williams, Andy Fenstermacher
Industry Sponsor: Dennis Girod, Plant Manager, Coburg, OR
Faculty Adviser: Nagesh N. Murthy
Field Project: DSC 577, Spring 2011

Optimizing Shipping and Inventory Management at Visionary Lenses
UG Team: Emmanuel Luvert, Andrew Marshall, Tyler DeMuth, Yan Gao
Industry Sponsor: Caleb Org, CFO, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 477, Spring 2011

Analysis of Warehouse Expansion Options
MBA Team: Brian Oehler, Brad Puglio, Neil Vance, Claire Williams, Tiffany Yep
Industry Sponsor: Joe Iaigulli, VP Supply Chain Management, Kettle Foods
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 477, Spring 2011

Analyzing Dismantling and Testing Processes at Next Step Recycling
UG Team: Katarina Ivezic, Yunru Wu, Ge Song, Yujie Tang, Blake Sedgley, Ty Kouri
Industry Sponsor: Lorraine Kerwood, Executive Director, Next Step Recycling, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 477, Spring 2012

Warehouse Layout Design at Shady Peeps
MBA Team: Jennifer Adams, Troy Beck, Andy Behl, Peter Kaupert
Industry Sponsor: Caleb Iorg, CFO, Shady Peeps, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 577, Spring 2012

Effects of Hard-to-Recondition Containers on Efficiency at Myers Container
UG Team: Rodd Danpour, Mitchell Eckberg, Kerin Green, Amber Liu, Hogan Scholten
Industry Sponsor: Cody Stavig, Plant Manager, Owner, Myers Container, Portland, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 477, Spring 2012

Order Process Fulfillment Analysis for Visionary Lenses
UG Team: Dominic De Martini, Arunava Chaterjee, Stephen Witbeck, Taylor Hughes, Elizabeth May
Industry Sponsor: Caleb Iorg, CFO, Visionary Lenses, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 477, Spring 2012

Paint Room Materials Flow at Ulven Companies: Analysis and Recommendations
UG Team: Christopher McClellan, Cody Kuntz, Sam Schwab, Ben Goodman, Lane Seals
Industry Sponsor: Mike Ulven, C.O.O., Rick Russ, Sales, Tom Wright-Hay, Lean Consultant, OMEP
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 477, Spring 2012

NextStep Recycling: Supply Chain and Operational Analysis and Recommendations
MBA Team: Kevin Klein, Blake Scott, Andrew White, Ahmed Alhaddad, Jeff Mathews
Industry Sponsor: Lorraine Kerwood, Executive Director, Next Step Recycling, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 577, Spring 2012

Process Capacity Analysis at Ninkasi Brewing Company
MBA Team: Bryan Schoen, Monir Jalili, Jake Heckathorn, Thomas Schwenger
Industry Sponsor: Jessica Jones, Director of Business Process Improvement
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 577, Spring 2012

Paint Process Analysis at Bulk Handling Systems
UG Team: Kerin Green, Ty Kouri, Mitchell Eckberg
Industry Sponsor: Ryan McGinnis, Quality Manager, Bulk Handling Systems, Eugene, OR
Faculty Adviser: Nagesh N, Murthy
DSC Practicum, Winter/Spring, 2012

Reducing Overlap in Product Lines at Skookum
UG Team: Jordan Anzaldo, Ana Ibanez, Ian Needham, Jake Thomas, Eddie Zhu
Industry Sponsor: Chris Reddy, General Manager, Ulven Companies; Rick Russ, Operations Manager, Ulven Companies
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 477, Spring 2013

Evaluating the Logistics of Inbound Shipping/Manufacturing at Alternative Sites
UG Team: Hao He, Rob Till, Michael Yang, Ruoxing Zhao
Industry Sponsor: Ryan McGinnis, Quality Manager, Bulk Handling Systems, Eugene, OR

Faculty Adviser: Nagesh N. Murthy
DSC 477, Spring, 2013

Evaluating Sustainability of Plant Operations at Killingsworth Plant (Myers Container)
MBA Team: Matt Fanelli, Eric Ringer, Rob Woltil
Industry Sponsor: Cody Stavig, Plant Manager, Owner, Myers Container, Portland, OR
Faculty Adviser: Nagesh N, Murthy
Field Project: DSC 577, Spring 2013

Technical Manuscript (research paper) titled, "Society or the Environment? Understanding How Consumers Perceive Corporate Sustainability Initiatives", By Sara Bahnson, Lan Jiang, Jun Ye, and Nagesh Murthy.

Abstract: This research examines how and why consumers evaluate a company's environmental and social practices differently. Using secondary data, a field experiment, and laboratory experiments, we show that the tangibility of a company's product offering and the process to develop the offering influence consumers' evaluations of environmental practices relative to social practices. Specifically, environmental practices generate greater impacts for goods companies, companies with tangible offerings, and companies with a tangible process. By contrast, social practices are more influential for services companies, companies with intangible offerings, and companies with an intangible process. Increased awareness rather than an obligation to compensate underlies the role of tangibility

Technical Manuscript (research paper) titled, "Making the Monopolist's Product Line Green: The Effects of Consumers' Opposing Perceptions of Recycled Content, Material Cost Savings, and the Diseconomies of Scope in Production", by Monir Jalili, Tolga Aydinliyim, and Nagesh Murthy

Abstract: In this study, we consider a two-stage "product line and pricing" problem for a monopolist firm who (potentially) offers two variants: Ordinary and Green. The first stage involves choosing the optimal recycled content percentage $\beta\%$ (i.e., the vertical differentiation gap between the two variants) of the green product, where a 0% recycled content decision implies offering *only* the ordinary product. Then, in the second stage the firm determines the optimal prices for the two variants to be included in its product line. Our analysis and findings contribute to the literature at the interface of operations, marketing and sustainability, and offer managerial insights for practitioners who must assess the trade-offs while introducing green variants with recycled/reused material in their product lines.

Technical Manuscript (research paper) titled, "Balancing Production and Distribution in Paper Manufacturing", by Neil Geismar and Nagesh Murthy. Due to the challenge posed by scale and complexity of the problem this problem was deemed important to expand the scope on the research started in OEI-DLA-DOD 2009 Northwest Manufacturing Initiative.

Abstract: A paper manufacturing plant minimizes its production cost by using long production runs that combine the demands from its various customers. As jobs are completed, they are released to distribution for delivery. Deliveries are made by railcars, each of which is dedicated to one customer. Long production runs imply that maximizing railcar utilization requires holding the cars over several days or holding completed jobs within the loading facility. Each of these methods imposes a cost onto the distribution function. We find how distribution can minimize its cost, given production's schedule. We

then consider the problem of minimizing the company's overall cost of both production and distribution. A computational study using general data illustrates that the distribution cost is reduced by 25.80% through our proposed scheme, and that the overall cost is reduced an additional 4.40% through our coordination mechanism. An optimal algorithm is derived for a specific plant's operations.

Technical Manuscript (research paper) titled, "Timing and Signaling Considerations for Recovery from Supply Chain Disruption", by Zhibin Yang and Nagesh Murthy. Due to the challenge posed by scale and complexity of the problem this project was deemed important to expand the scope on the research started in OEI-DLA-DOD 2009 Northwest Manufacturing Initiative.

We study the interaction between a supplier's timing of recovery ex post a disruption in the face of a buyer that has a backup production option. After disruption, the supplier quotes a recovery due date and make recovery effort. We find that the supplier's quote of recovery time affects the buyer's use of the contingency option in two ways. First, when the supplier possesses the flexibility of quoting any recovery due date, the supplier may use the quote as a strategic subsidy to retain the buyer from invoking its backup option. As a result, the channel is pareto-improved. Second, when the supplier has private information about the severity of supply disruption, the supplier uses the quote of recovery due date to signal the disruption severity. The supplier may be unable to credibly convey the severity level of disruption to the buyer.

Technical Manuscript (research paper) titled, "Immediate versus Delayed Price Discounts", by Monir Jalili and Michael Pangburn

Sellers commonly offer an immediate discount percentage off the regular price. In contrast, some sellers apply a credit toward a future purchase, based on the customer's prior purchase. We contrast the efficacy of these two discounting strategies to better understand conditions under which prior-purchase based discounts may outperform immediate discounts.

Additional research is being undertaken in the following areas that are a direct result of the research initiatives completed under this grant. These are expected to be completed in the time range of 6 – 12 months.

- 1) When and why is it in the strategic interest of a seller to offer a menu of contracts, particularly a combination of fixed price (without returns) and a buyback contract (i.e., with ability to return)? (Nagesh Murthy, Ramin Shamsi, and Michael Pangburn)
- 2) How and why consumers perceive eco-labels that signal a firm's or industry's sustainability initiatives in various facets of the value chain? (Nagesh Murthy, Lan Jiang, Jun Ye)
- 3) How to gainfully integrate the decisions for loading trucks with loading rail cars at a paper mill to minimize distribution costs while improving customer responsiveness? (Nagesh Murthy and Neil Geismar)
- 4) How are supplier's recovery efforts when faced with disruption at a site influenced by a buyer's policy that adopts sourcing from multiple suppliers (each having multiple sites)? (Nagesh Murthy and Zhibin Yang).

17 Field-Based Experiential Learning Projects
2011 - 2013

Demand Forecasting at Shady Peeps

MBA Team: Geo Lee, Rusten Gomez, Nandini Mitra, Jaren May

Industry Sponsor: Caleb Org, CFO, Eugene, OR

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 577, Spring 2011

EXECUTIVE SUMMARY

Problem Description

Shady Peeps operates in an extremely volatile and seasonal market with rapid and unpredictable changes in demand. Forecasting sales in each expansion market for the company under these circumstances is extremely difficult but is crucial to making inventory purchasing decisions and monitoring cash flow. Additionally, the company is currently operating with only six months of past sales data from one market and no point of sale data from its retailers. The company must weigh the costs and benefits of overstocking, stock-out, holding costs, and all the variables affecting the flow of product from manufacture to delivery.

Scope and Objectives

Our team operated within the scope of demand forecasting and inventory purchase decisions for 2011 for Shady Peeps. We also considered the cash flow impacts of these decisions and attempted to create a solution that is scalable beyond 2011. The primary focus of our model, however, was on each expansion market in 2011. We began this project with the following set of objectives.

1. Define a set of variables that impact demand for the product and supply of the product and research values and relevance of these variables.

2. Create a comprehensive, scalable forecasting tool based on these demand and supply variable factors and the appropriate input values from a given expansion market.
3. Use this forecasting tool and the data collected from Shady Peeps actual 12 expansion markets to predict 5 different demand scenario ranges.
4. Analyze inventory purchasing decisions (EOQ, safety stock, etc.) under each demand scenario to plan for various contingencies in 2011.

Objective 1 – Define and Categorize Relevant Variables to Demand and for the Supply Chain

The first task for our team in accomplishing the overall project goal was to define the relevant variables for forecasting demand and understand the significance of each variable. In addition, we identified each of the supply chain variables that would impact purchasing, inventory, and distribution decisions. The following list represents the variables we identified that impact demand forecasts.

- Fan Passion and Loyalty
- Student Enrollment
- Home vs. Away Games
- Team Success
- Sunny Weather
- Stadium Size
- Marketing Resources Allocated
- Commuter vs. Residential School
- Disposable Income Demographics
- School Start Date

We determined the relative impact of each variable on sales based on multiple conversations with executive management and retail partners. In addition to these demand variables, there

were a number of variables with necessary information for analyzing our remaining objectives on the supply side. These supply variables were identified as follows:

- Manufacturing time
- Shipping time and cost (air versus ocean)
- Available storage and cost of warehousing
- Direct labor costs
- Quality check time
- Interest rate
- Shipping time and cost (ground versus air) to customers

These supply variables were necessary to determine the optimal and efficient inventory order points and order quantities for Shady Peeps. The data for each of these variables were provided by the executive management team for our review.

Objective 2 – Comprehensive and Scalable Forecasting Model

Our goal was to create a dynamic demand forecasting tool in Excel that forecasts demand scaled by individual school characteristics based on historic sales of Shady Peeps at the University of Oregon at the UO Duck Store. Through data and statistical linear regression analysis, our team attempted to model the effect of seven of these previously defined demand variables to forecast future sales for the upcoming 2011 season. From this baseline sales forecast for the University of Oregon, the following variables were used to scale and predict demand for the other expansion schools: fan passion and loyalty, student enrollment, sunny weather, stadium size, marketing resources allocated, disposable income and commuter vs. residential campus.

The first step was to use sales data provided by the Duck Store to develop a statistically sound model to forecast demand using the previously mentioned demand variables. After many regression iterations using many variants of the demand variables, the model our team deemed most technically and reasonably sound was a simple linear intercept model with two binary

variables which determined a home game or away game (Figure 1). This was the only consistently reliable variable, and yielded a model that matched up best with Shady Peeps management. From this model, weekly demand was forecasted from June 2011 – Dec 2011.

Figure 1: Final Model Regression Output

Regression Statistics								
Multiple R	0.64479285							
R Square	0.41575782							
Adjusted R Sq	0.38329992							
Standard Error	101.79255							
Observations	39							
ANOVA								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	2	265449.553	132724.777	12.8091412	6.2903E-05			
Residual	36	373022.037	10361.7232					
Total	38	638471.59						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	59.0769231	19.9631615	2.95929696	0.00542367	18.5897553	99.5640909	18.5897553	99.5640909
Home Dummy	232.25641	46.1029467	5.037778	1.3385E-05	138.755301	325.757519	138.755301	325.757519
Away Dummy	22.7802198	43.3448266	0.52555799	0.6024178	-65.127162	110.687602	-65.127162	110.687602

Once the baseline forecast for the University of Oregon was complete, we began to compile demographic data related to the demand variables from each of the expansion schools, to determine scalable relationships from the Oregon forecast. The metric and methodology for each of these demand variables are described below:

1. *Current Enrollment*: This is a simple count of the undergraduate population from each school.
2. *Fan Base Fervor Index*: This is a subjective grading index that assesses the quality of the student fan base. This index is a relative scale based on the University of Oregon's fan base score of 5, and ranges from a score of 1 to 10.
3. *Stadium Size*: This is measured by the total capacity at each school's home stadium.
4. *Marketing Resources Allocated*: This metric is the number of dollars allocated to each school for marketing purposes, and is supplied by Shady Peeps management.

5. *Sunny Weather*: This metric is based on the percent of possible sunshine statistic supplied by the National Climate Data Center. This index is a relative scale based on the University of Oregon's sunshine score of 5, and ranges from a score of 1 to 10.
6. *Disposable Income Demographics*: This metric is based on personal income statistics by local area supplied by the Bureau of Economic Analysis (BEA). Again, this index is a relative scale based on the University of Oregon's score of 5, and ranges from a score of 1 to 10.
7. *Commuter vs. Residential School*: This metric is based on the extent to which each expansion school is a commuter or residential school, and is thus based on the percentage of undergraduate students residing in dorms or in close proximity to the University. Again, this index is a relative scale based on the University of Oregon's score of 5, and ranges from a score of 1 to 10.

In the interest of preserving the flexibility of this model, the tool was built to allow for adjustments to the weights of each of these variables on the forecasts of each school. This was a specific request by management, who wished to place some of their own intuition into the model due to a lack of statistical bases. The intuition here is that once time allows for more data to be collected, these weights could be statistically derived.

The final output sheet displays monthly demand forecasts for each school from June 2011 to December 2011 since the current ordering policy is to fulfill two months at a time. In addition to this forecast, regression standard errors were extracted to produce high and low estimates described further in the next section.

Objective 3 – Use Tool to Create 5 Different Demand Scenarios

Our team had initially envisioned to forecast 5 arbitrary demand scenarios to provide a range of possible outcomes. After some deliberation with management, it was deemed more pertinent to use the statistical standard errors provided by the regression results to estimate high, low, and

average forecast values. These estimates would at least have statistical support, as opposed to random growth expectations, and would facilitate an ordering policy that could incorporate stock out risks and minimum inventory levels.

The result is shown in the final output tab in the Excel worksheet, which displays average forecast demand, low demand, and high demand based on subtracting and adding the standard error to the baseline Oregon forecast and the scaled expansion school forecasts. Based on the limited amount of data and expected “noise”, standard errors were predictably high, ranging from approximately 30% - 60%. Due to the nature of the product and its infant expansion stage, we believe these errors to appropriately quantify demand volatility.

Objective 4 – Analyze the Optimal Inventory Purchasing Decisions in Each Demand Scenario

We calculated Shady Peeps total lead time from purchase to point-of-sale to be 80 days. This includes 40 days production time, 20 days for ocean freight, 10 days quality checking in the SP warehouse, 5 days average shipping time to customer, and an additional 5 day buffer for the retailers receiving the sunglasses and setting up the displays. The primary selling season for Shady Peeps is from September through December, mirroring the college football season. Because the total selling season is 160 days, it would be very difficult to wait to receive real time demand before making purchasing decisions. For this reason, Shady Peeps must make all of its purchasing decisions for its fall 2011 expansion in the speculative order phase. However, we still recommend making these orders in two installments to spread out cash outflows over the summer.

Additionally, we analyzed the costs and benefits of stocking out vs. oversupply. We recommend Shady Peeps lean towards oversupply when making its purchasing decision off of the demand forecast created. As a start-up, cash flow is limited but the company cannot sustain stock-out in its key markets. The brand is not well known and will quickly fade if products cannot be supplied to meet demand. Shady Peeps has one chance to penetrate the market and cannot

afford to run out of products. Furthermore, the company is currently operating out of subsidized warehouse and office space due to its relationship with the UO entrepreneurship program. The company has plenty of space to store products and so incremental holding costs are very low. The product also has a long shelf life as products not sold during football season can be stored and sold through winter and spring seasons and even on into the summer.

Conclusion

This project proved difficult as the amount of data available for analysis limited the statistical significance and accuracy of the forecasts. However, by building a comprehensively simple but scalable model, management will now be able to use statistical analysis and standard error in addition to their intuition when making purchasing decisions. This will allow management to better understand the cash flow impacts of the purchasing decision and provides a baseline forecast to compare actual demand to improve upon in the future.

The project provided some key lessons to our group. We could not help but feel slightly disappointed in our final product considering all the resources spent on exploring different options, including expanding the explanatory powers of the demand forecasting tool and attempting to improve inventory management. We believe these issues to be unique to the nature of a start-up business and the challenges that it faces in a competitive environment. With relatively limited resources and undeveloped systems and processes, it was very difficult to analyze performance and in turn recommend changes in an ever-changing dynamic environment. With this in mind, the project provided valuable insight to the nuance and delicate balance between an optimally planned inventory system and the necessity for flexibility.

Please see 'Shady Peeps Demand Forecast Tool_Presentation.xls' for the forecasting tool and supporting analysis.

Freight as a Profit Center: A Feasibility Study for Myers Container

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Faculty Adviser: Nagesh N. Murthy

Field Project: DSC 477, Spring 2011

Executive Summary

Problem

Myers Container would like to turn their freight operations into a profit center in order to determine appropriate pricing for freight as well as use this information to assist in the negotiation of contracts. Myers Container has not specifically tracked profit associated with freight in the past.

Situation

Myers Container operates from three different areas; The Portland area, Northern California and Southern California. Each of the three areas uses a different model for their freight operations. The Portland center uses a 3PL, Pathfinder Logistics, the Northern California center uses trucking owner/ operators and the Southern California center uses fleet vehicles and contract drivers.

Each of the three centers uses a slightly different method for invoicing customers and each customer invoice is somewhat unique to that specific customer. That is to say, the level of detail on each invoice is specific to that customer.

Solution

The biggest obstacle to calculating profit from freight is the lack of completeness of the available data. As such, steps need to be taken at the invoicing/ billing stage to collect relevant data and

enter this data in a retrievable manner in the existing database structure. This should include separating charges for freight and product on all invoices at least on the Myers Container side. Because each of the three centers operates on different models, the information that will need to be tracked will be slightly different at each location. Also, the intended use of the data will dictate the specificity of data collected. If the intended use is to determine the profitability of the centers freight operations, this data can be much more general. If the data is to be used to renegotiate contracts with customers, the data will have to be collected down to the customer level.

Initial Meeting, Preliminary Objectives/ Scope of Work

Problem Description: Myers Container would like to turn their freight operations into a profit center. In the past, they have not tracked profit specifically associated with their freight operations, in part due to structural resistance to change and the influence associated with multiple owners/ partners. Recently, the ownership structure has changed and there is an effort to modernize and optimize operations. By calculating profit from freight, Myers hopes to be able to adjust their freight pricing to appropriate levels, and use this information to better negotiate shipping contracts.

Initial Objectives:

- Help Myers develop a method to calculate and analyze profit from freight operations
- Provide Myers container with a template and instructions for the analysis in order to facilitate their being able to do this in the future

Initial Proposed Solution: Prepare an Excel workbook that Myers Container can import data into that will calculate profit from freight operations. Features should include a means to estimate unknown or incomplete data, distinguish estimated from calculated profit, the ability to handle a variety of data points in the areas of revenue and expenses and be clearly annotated for ease of use/ reuse.

Situational Description and Analysis

Portland Operations (Pathfinder Logistics)

Myers Container utilizes a 3PL, Pathfinder Logistics for operations served by the Portland area facilities. The delivery charge to each customer is fixed by contract and is determined by a freight lane schedule. On occasion there are additional charges incurred do to demurrage, driver assist, dock fees or other incidentals. These are not known in advance, and Pathfinder passes these charges on to Myers at the time of billing. Myers issues its own invoice to the customers. Customer invoices may or may not have freight charges as a separate item.

Northern California (Owner/ Operators)

For operations served by the Northern California area facilities, Myers Container utilizes truck owner/ operators. For the most part drivers are paid an hourly rate, but this can vary. Also, the amount paid to drivers varies. As in the Portland area, there can be additional fees incurred at the destinations. After delivery, an invoice is submitted to Myers, and Myers bills the customer. Customer invoices may or may not have freight charges as a separate item.

Southern California (Fleet vehicles, Contract Drivers)

For operations served by the Southern California area facilities, Myers Container utilizes fleet vehicles and contract drivers. Drivers are paid an hourly rate. As in the other areas, there can be additional fees incurred at the destinations. After delivery, an invoice is submitted to Myers, and Myers bills the customer. Customer invoices may or may not have freight charges as a separate item.

Invoicing, Accounting and Data

After the initial and subsequent offerings of data from Meyers Container, it became clear that complete data was going to be difficult or impossible to get. In addition, much of the data provided were estimates. After coming to a better understanding of Myers operations, the reasons for this became clearer.

Not only do the differing methods of shipping complicate the retrieval of relevant and complete data, but it makes the calculation of profit for each center, in fact each customer, a separate and distinctly different task. Additionally, customers are invoiced with varying degrees of detail and each shipping center accounts for these in slightly different ways. Because of these inconsistencies, much of the data required to calculate profit is not readily available, difficult to extract or not specifically tracked. Another significant difficulty is the physical distance between the centers, and the large amount of labor needed to extract and compile data over and above normal daily duties.

Recommendations

General Recommendations

The biggest obstacle to calculating profit from freight is the lack of completeness of the available data. As such, steps need to be taken at the invoicing/ billing stage to collect relevant data and enter this data in a retrievable manner in the existing database structure. This should include separating charges for freight and product on all invoices at least on the Myers Container side. Because each of the three centers operates on different models, the information that will need to be tracked will be slightly different at each location. Also, the intended use of the data will dictate the specificity of data collected. If the intended use is to determine the profitability of the centers freight operations, this data can be much more general. If the data is to be used to renegotiate contracts with customers, the data will have to be collected down to the customer level. It is recommended that the following data be collected from the centers:

Portland Operations (Pathfinder Logistics)

Expenses

- Amount charged by Pathfinder for freight.
- Additional fees such as demurrage, driver assist, dock fees etc.
- An estimate of overhead attributable to freight operations such as facilities, wages, etc.
- Revenues

- Amount invoiced to customers for freight.
- Fuel surcharges.

Northern California (Owner/ Operators)

Expenses

- Amount charged for driver labor.
- Destination fees.
- Additional fees such as demurrage, driver assist, dock fees etc.
- Labor for the dispatcher.
- An estimate of overhead attributable to freight operations such as internal trailer maintenance, facilities, wages, etc.

Revenues

- Amount invoiced to customers for freight.
- Fuel surcharges.

Southern California (Fleet vehicles, Contract Drivers)

- Amount charged for driver labor.
- Additional fees such as demurrage, driver assist, dock fees etc.
- Labor for the dispatcher.
- Fleet maintenance.
- Fuel.
- An estimate of overhead attributable to freight operations such as internal trailer maintenance, facilities, wages, etc.

Revenues

- Amount invoiced to customers for freight.
- Fuel surcharges.

Obstacles

There are several obstacles to implementing any procedural changes in tracking specific expenses and revenues, mostly associated with institutional inertia. Any changes in an organization that require more complexity and more work will be met with resistance. This might be particularly true in an instance like this where the people performing the actions will not be directly benefited by their efforts. An employee's natural resistance to change is difficult to overcome in the best instance.

That Myers Container is a mature company with somewhat disassociated operations will also be a difficult challenge to overcome. The diversity of freight methods and the great physical distance between centers will compound this. Further difficulties will be caused by the fact that each center will have to implement a unique solution for accurate data gathering.

All of these challenges are surmountable however. The value of gaining a better understanding of the profitability of freight operations and the associated benefits is worth the effort to implement change.

Supply Chain Analysis for gDiapers

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Faculty Adviser: Nagesh N. Murthy

Field Project: DSC 477, Spring 2011

Background:

Founded in 2004 by Jason and Kim Graham-Nye, gDiapers is a growing business that sells baby products, primarily alternatives to disposable diapers. Conventional disposable diapers are the third largest contributors to landfills in the world, despite the fact that only five percent of the world uses them. Upon learning this fact, the founders began researching an alternative. Unable to find a good product already in the marketplace, they started gDiapers upon the principle of "FairDinkum," an Australian expression which means being genuine and real with everyone you encounter. gDiapers lives this philosophy through its relationships with its partners, customers, and the planet.

gDiaper's primary product line is gPants, though they carry other related items and are expanding into infant clothing. The gPants line consists of: diaper covers, cloth liners, disposable liners, biodegradable wipes, and bags. The gStyle clothing line consists of various types of stylish clothes for babies. All gDiapers are plastic free, elemental chlorine free, latex free, and perfume free. Its gRefill is also biodegradable; it can be flushed, composted, or just thrown away, where it will biodegrade within 50-150 days rather than up to 500 years for other disposable diapers.

The gPants product line accounts for a little more than 55% of all of gDiapers sales. This, combined with the long lead time for factory orders has led us to focus our efforts here. Over the past 12 months, the number of gPants units sold has ranged from a low of 10,750 to a high of 25,250, with the average being about 17,560. The bulk of gPants sales are concentrated among three large customers, Quidsi, Inc (fka Diapers.com), Babies R Us, and UNFI, who combined account for 85% of all gPants sales.

The original problem was presented to our group as:

Production Analysis – determine reorder point and order quantity to optimize inventory related costs while accounting for uncertainty in demand and desired service levels; find ways to mitigate risk on both demand and supply side; find ways to reduce supplier lead time.

However following our initial meeting with gDiapers at their Portland office, we refined the problem as follows:

Improve gDiapers ordering process to place larger, less frequent, orders. This will enable the factory to optimize workflow and labor allocation across longer time periods, reducing employee turnover and overtime.

One of the first things we learned from gDiapers, which was a critical factor affecting their business, is that gDiapers is a textile business operating in the consumer package goods market. gDiaper's customers expect order-to-delivery times of about 3 days, while gDiapers has a total product lead time of about 6 months, and an order-to-delivery time of about two weeks. With this problem in mind we began by trying to understand and document the entire supply chain. During the following weeks we held three additional conference calls and some email communication. We analyzed sales and purchase order data; created supply chain diagrams, and finally felt like we had a fair understanding of the supply chain. However we also felt like the problem we were attacking was beyond our ability to provide any workable solution. We reached this conclusion primarily based on the information that there was no impact on price if larger orders were placed less frequently. Given this information, and gDiapers cash constraints, there seems to be no measurable incentive for gDiapers to place larger orders.

Through this process we also learned that gDiapers was currently working to begin packaging some products in China. This effort was primarily driven by their current and future international expansion plans. However given the potential cost savings (primarily from reduced labor cost) there are definite advantages to packaging some percentage of U.S. bound products in China as well. In addition to the cost savings, there is the additional benefit of reducing customer order-to-delivery time since most of the product would already be complete, compared to shipping all product in bulk packages from China and postponing packaging to the Ohio warehouse.

Finally here was a problem we felt like we could help with. Our new goal was to build a simple model to help gDiapers to identify what percentage of certain package types could safely be shipped complete from China. Before presenting our model, we will review our supply chain analysis.

Supply Chain

gDiapers outsources manufacturing of all gPants to Fountain Set in China. They are a company located in the Guandong province of Dongguang, a mere two hours away from Hong Kong by vehicle. Fountain Set is a vertically integrated company that performs every step in the manufacturing process, including weaving, dyeing, and finishing. Total manufacturing lead time is 130 days and breaks down as follows:

Process	Time	Description
Fabric	45 days	Dyeing and Finishing
	10 days	Transit to/from Hong Kong for duty purposes
	5 days	Dyeing elastic to match
Production	60 days	Not dependent on order size. The number of workers is adjusted as necessary to maintain constant production time
Transit	10 days	Time to get product to port and loaded on a ship

The factory has an area dedicated to manufacturing the gDiapers product. On a recent visit Jolynn observed that two lines were in operation, with each producing 1,600 units per day. The biggest constraint in the manufacturing process is dyeing. For minimum efficient scale the fabric needs to be dyed in 1,000 lb lots. This amount of fabric will make approximately 12,000 pants. A smaller lot size of 550 lbs is available, but should be considered an exception only.

The factory prefers large orders approximately every six months, so that production can be effectively spread out to best utilize the facility. If a line sits idle, trained workers may be lost to competitors, or the factory space may be lost to another customer.

Despite their wish for larger orders, Fountan LEV does not currently levy any financial penalty to gDiapers for placing smaller, more frequent orders. As a relatively young company gDiapers does not have the financial resources to accommodate the factory's requests for larger, less frequent, orders. They simply do not have that kind of cash available to tie up in holding inventory. When gDiapers issues a PO to the factory it must specify quantity by color and size. Within 60 days after this date gDiapers must provide a delivery breakdown to the factory. Any changes to the delivery breakdown after this point results in additional cost as paperwork must be re-submitted to the Chinese government.

Before the finished product can leave the Chinese port, it is transported by truck to Hong Kong and then back into China in order to save the factory an additional 17% tariff. This is a non-negotiable step in the supply chain, which tacks on an extra 10 days to the lead-time. We do not know exactly why this process saves them a 17% tariff tax, but since it is a non-negotiable topic gDiapers will have to accept the additional 10 days it adds to the lead-time.

The factory representatives are worried that they will not have enough orders placed to keep the products flowing through at a steady rate. They would like to be able to take these larger orders less frequently and are willing to roll out the deliveries as needed. The factory explains that if a PO is placed in August but gDiapers doesn't want to take delivery of that order until February, the factory will hold the completed product in their warehouse until it needs to be shipped to arrive in February. gDiapers also doesn't have to pay for the goods until they are verified as received by the factory in Ohio.

After the product leaves the Chinese port, the time on the water is 20 days to arrive in Los Angeles. From there it is about another week in transit from Los Angeles to Ohio. If the product is shipped in less than container load (LCL) quantities, then it adds an additional week in transit from Los Angeles to Ohio, as the container has to stop en route and be broken down into individual shipments. We have been provided an unconfirmed estimate of 24,000 pants required to fill up one 20-foot shipping container. Shipping LCL also increases the per unit freight cost by to .03 cents per piece.

Total manufacturing lead-time from the PO issue date to product arriving in Ohio is approximately 150 days.

Currently all product is shipped from China in bulk packaging, 20 pants per bag, and 8 bags per case. Final packaging and labeling is postponed until the product reaches Ohio. gDiapers is currently working to implement final packaging and labeling in Asia for some percentage of the product. At this time they do not know what percentage will be shipped complete versus in bulk, nor have they determined what the cost savings will be. This effort is being driven by the need to ship product directly from China to other countries in Europe and South America as gDiapers expands into those areas. It is simply not feasible to continue importing all products to the U.S. only to package it and send it back overseas.

Total land/sea transport time is approximately 5 weeks. gDiapers has, in the past, utilized air freight when stockouts occurred. However this has not been necessary during the past 4-5 months.

Warehousing:

As recently as last year, the product would sit at the warehouse in bulk packaging until the customer orders were placed. However it seemed as if the current warehouse supervisor was packaging some goods ahead of time based on some forecasting method. This effort has led to a reduction in order-to-delivery times to about one week in many cases.

Currently all products are shipped from Asia to the U.S. for final packaging. Product destined for international markets in Canada, UK, and South America are then shipped back out of the U.S. This increases both freight and tariff expenses and is the primary driver behind gDiaper's efforts to begin packaging in China.

Packaging

gDiapers has a variety of packaging types for various market segments. 2 packs are primarily for retail point of sale, with the largest customer as Babies 'r Us. These are sold in 4 count cases and contain an assortment of colors by size. The other significant package type is the 12 pack which is primarily used for web fulfillment. A 12-pack consists of 12 identical SKUs, one size and one color. In addition to these two packages, there are also singles, 6 packs, 24 packs, and various kits. At this time the single units are only sold through Canadian web orders, which are still fulfilled by gDiapers. There is not enough volume of any of these additional package sizes to justify moving the packaging to China at this time.

Labeling is an entirely separate problem which was beyond the scope of our project. However it was interesting to learn about the difficulties involved with labeling that we take for granted.

Most countries or regions have very specific labeling requirements, both content and language.

Canada, for example, requires all packaging to be printed in both English and French, with each given equal billing.

Customers

As previously stated, gDiapers operates in the Consumer Package Goods market, where there largest customers are accustomed to very short (2-3 days) order-to-delivery times from some mega brands as Huggies and Pampers. While these customers have been accepting of the longer (up to two weeks) order-to-delivery time previously provided by gDiapers, they continue to ask for shorter lead times.

gDiaper's three largest customers account for 85% of all gPants sales. This has caused some huge variability in orders placed (see Attachment 2), which has made accurate forecasting difficult prospect. However, as these customers build history with gDiapers, we can see a trend towards steadier growth. The other 15% of the sales are to a variety of customers, including Wal-Mart, Target, and hundreds of small boutiques. None of these companies are currently providing any forecasts, however all three of the biggest are now providing consumption data to gDiapers.

Prediction Model

Now that we have a better understanding of the entire supply chain, we will describe the model we have created and provided to gDiapers.

With the sales data we were provided we were able to dis-aggregate that data into single units of sales by size for each of the previous 27 months. This data was organized into one tab of the spreadsheet with additional columns prepared to facilitate entry of future sales data through the end of 2013.

From the sales data we extracted the percentage of each of the two package types as a percent of the total sales within that size. For example in February of 2011 we calculated that 49% of all medium gPants sales were in 12 count packages, while 44% were in 4x2 count packages. From these monthly percentages we created a rolling 6 month average for each package type and product

size. Our predictions are based on these rolling averages.

The final tab of the worksheet is where the forecasts are entered. Predictions can be made for any future month, but will always be based on the most recent 6 months for which sales data has been entered on the first tab. For any given month the forecast sales should be entered by product size in single unit quantities. The model will multiply this forecast by the most recent 6 month average for each package type to provide a prediction based on the 6 month mean.

We believe that the mean is a suitable estimate based on the information provided. Because of the variability in demand, the minimums over the previous six months provided predictions that were considered too small to be of real value. Much of this variability will fade away as new sales data is entered, as much of it is from the last 3 months of 2010, when gDiapers was still fulfilling the majority of web orders with single unit packages.

We have enjoyed working with your company. It has given us an opportunity to see firsthand the challenges associated with what is a relatively simple product lineup. We hope that our work on this project will provide some benefit to your company.

Evaluating Procurement: Material Sourcing, Use, and Disposal at Monaco RV

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Field Project: DSC 577, Spring 2011

Executive Summary

Monaco RV uses a wide variety of materials in its vehicle manufacturing process, including expanded polystyrene foam (a.k.a. bead board), wood, and various metals. The purpose of this project is two-fold: (1) to provide Monaco an evaluation framework for the sourcing, use, and disposal stages of a material, and (2) to apply that general framework to a specific material. For this project, the material in focus was bead board, a relatively low-cost component of the RV manufacturing process that has not been subject to the significant managerial and operational scrutiny applied to higher value materials.

The goal of the project is to provide Monaco RV with a reflective and comprehensive tool that can allow the company to identify and address any number of over-arching objectives for its materials, such as cost reduction or environmental performance. The result is an evaluation template that lays out a set of questions related to sourcing, use, and disposal.

Using plant tours, interviews, correspondence with Monaco's Materials Manager, and analysis of historical ordering data, the project team performed a sample application of the evaluation framework to bead board/polystyrene foam.

Purpose & Key Objectives

The general issue Monaco RV asked the project team to address was the sourcing, use and disposal of various materials, and in particular EPS (expanded polystyrene) foam, also known as bead board. In order to address the 600 to 800 materials used in its manufacturing process Monaco needed some type of general evaluation framework. The project team performed preliminary evaluations of procurement and use, but due to various project constraints, the team chose to narrow its most in-depth evaluation of the bead board material to the disposal stage.

Methodology

Factory visits and direct observation of the manufacturing process: The project team visited the Monaco RV plant in Cobourg on two occasions. The first visit focused on a general introduction to the facility, the manufacturing process, and the RVs produced by the company. It also included an interview with Dennis Gird, the Materials Manager at Monaco RV, to discuss the opportunities and challenges for the company in terms of materials. After clarifying the focus of the project, the team returned to the facility for more specific observation pertaining to Monaco's use of EPS foam.

Analysis of historical ordering information: Monaco provided the project team with a spreadsheet detailing its orders for EPS foam over the previous 12 months. This information was used to get a sense of the material's overall scale and significance in the manufacturing process, and to determine feasibility of potential recommendations.

Background & Context

Monaco RV manufactures a range of motorized and towable vehicles across a broad spectrum of customer price points. The value of the materials that the company uses in its manufacturing process varies widely, especially when considering those used for interior finishes – for example, laminate counters in an entry-level product compared to granite in a high-end coach. Other materials are relatively common across the entire product range,

especially those that are used as structural components not readily visible to the end consumer. After visiting the Monaco plant and speaking with Dennis Girod, Materials Manager, the project team identified a number of materials that seemed most appropriate for evaluation, including wood, plastic, metal, wire, and polystyrene foam (i.e. bead board). These materials were considered priorities because they are used in relatively large quantities, they can be sorted in the waste stream, and they have the potential to provide salvage/scrap value.

Material Evaluation Framework: The Template

After speaking with Mr. Girod, visiting the Monaco plant and observing the manufacturing process, the project team devised an evaluation template to help bring to light the types of opportunities and challenges that had been identified. The complete evaluation template is located in the appendix at the end of this document. It contains a broad range of questions that can help Monaco RV dig deeply into its sourcing, use and disposal practices. When using the template, Monaco should identify the key objectives for the material in question, such as improving environmental performance, reducing cost, or increasing efficiency. With those objectives in mind, the template questions “help get the ball rolling” and encourage critical thinking about the material. While relevance of the questions may vary depending on the material and the identified objectives, it is important that Monaco attempt to answer each one as completely as possible. The sourcing, use and disposal stages for any given material are so intertwined that there is the potential to overlook opportunities if the template is not completed in its entirety.

In order to successfully use the template, Monaco should be cognizant of related management issues. To arrive at a level of effective implementation throughout the plant, use of the template needs to begin from the top down. Upper management must express full support of the template and mandate its use. In addition, there are a few additional points of focus for management:

- Clear policies for recycling and other disposal practices
- Employees are incentivized to act in accordance with policies

- Enforcement of policies is consistent among upper management

In addition to the management implications discussed above, it is also worthwhile to consider how the template can be used to support the company's marketing efforts, especially its brand image. For example, the template can be used to improve the environmental performance of a material, which can then be used in communications focused on sustainability. Likewise, the template can help Monaco identify opportunities for increased use of domestically produced materials, allowing Monaco to communicate to potential customers that the companies "buys American."

Bead Board Evaluation

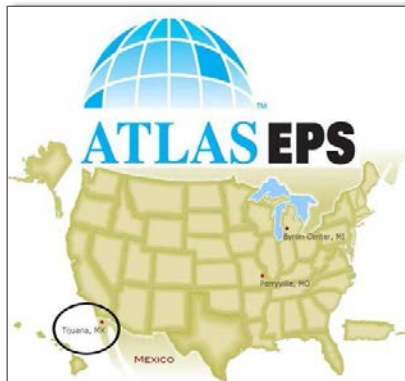
Background Information

Monaco RV uses EPS foam (also known as bead board) in a variety of applications in its manufacturing process. It is primarily used as a structural material in ceilings, floors, and walls, but it is also placed around water tanks. In addition to support, the bead board also provides a degree of insulation – one of Monaco's commonly used foams (1# density and 1 inch thick) yields a per square-inch R-value similar to common insulation materials such as fiberglass batting.

Outline of bead board procurement:

Step 1) Monaco forecasts its bead board needs based on sales and production forecasts.

Step 2) Monaco places an order with its manufacturer Atlas EPS (formerly Falcon Foam) for one of 15 different product SKUs – Monaco orders a variety of sizes, as well as tapered pieces.



Step 2) The material is produced at the Atlas facility in Tijuana, Mexico.

Step 3) When production is complete, an owner/operator truck driver is dispatched to make the delivery from Mexico to the Cobourg facility.

B1-FB4-4

Step 4) Material arrives at Monaco approximately 4 weeks after the order was originally placed. Approximately one truck-load of foam arrives per week.

Outline of bead board use:



fitted into walls and flooring by perform the free-hand cutting in

Step 4) The bead board is laminated for the walls of the vehicle.

Step 1) The bead board inventory is stocked in piles outdoors. Workers bring in sheets of the material as needed for use in Monaco's coaches and towable RVs.

Step 2) The material is cut, either by hand or with a hot wire.



Step 3) The material is the same workers that the previous step. either glued for flooring or

Step 5) Scrap pieces of bead board are placed in 4x4 white bags.

Outline of disposal:



Step 1) Bags of scrap bead board are delivered to St. Vincent de Paul Industrial Services for recycling at a cost of \$5 per bag. Approximately 15 bags are sent per week, spread across 3 deliveries.

Step 2) St. Vincent de Paul uses an EPS foam compactor to condense the scrap pieces into extruded blocks of recycled material.

Step 3) The recycled foam blocks are sold using a bid process, which usually generates about \$0.25 per pound. Super Link Inc. is one of the main purchasers.

Evaluation of Procurement, Use and Disposal

The questions in the template were used to evaluate how Monaco sources, uses, and disposes of bead board. Due to scope and time constraints of the project team it was not possible to fully evaluate all three stages of the material. Instead, the sections below provide cursory evaluations

of the sourcing and use stages, followed by a more thorough discussion of the material's disposal/end of life.

Procurement

Potential Considerations: Given the long distance that the bead board currently travels from Tijuana there is some concern about the environmental impact of its transportation. Monaco should seriously consider identifying a domestic supply. This could increase reliability and mitigate potential risk related to rising fuel costs. Monaco's current bead board supplier, Falcon Foam (recently changed to *Atlas EPS*), operates a total of three manufacturing facilities in Michigan, Missouri, and Tijuana, Mexico. It is currently unknown whether the domestic facilities are able to provide the material at a comparable cost.

The decision to source materials from international suppliers may have other environmental implications that Monaco could choose to consider. For example, in 2005, Monaco's current foam supplier was fined \$369,000 for air pollution violations at its California foam plant and ordered to comply with regulations. After paying the fine, Atlas EPS shut the facility and shifted its foam production to Tijuana, where Monaco's foam supply is currently produced. As sustainability becomes more important for all companies, issues like these may need to be addressed. International material sourcing may help reduce costs, but it could create other complications as companies like Monaco face increasing scrutiny with regard the environmental performance of their supply chains.

Use

Potential Considerations: After visiting the Monaco facility and viewing the production process, the project team considered areas for improvement. As the foam is being used in production, the steps that showed the most opportunity for change or refinement were those involving hand cutting. The workers did not appear to have a structured process for measuring and cutting. Further research is necessary but Monaco could potentially eliminate considerable waste by creating a more precise and structured cutting process.

Disposal

In its current system, Monaco collects bead board scraps and then transfers them to local charity St. Vincent de Paul. The project team reviewed the disposal process and made the



following observations:

- Monaco pays St. Vincent de Paul (SVP) a \$5 per bag disposal fee.
- SVP receives roughly 15 bags from Monaco weekly, which currently constitutes the charity's single largest scrap foam supply.
- SVP uses a foam compression machine that it recently purchased to recycle and compress the scrap

bead board.

- The final product is a log of compressed recycled foam (shown in the image above) that SVP collects in large quantities and then sells through a bidding process (usually at around \$0.25/pound). Super *Link, Inc.* is one of St. Vincent's main purchasers.

Going forward, Monaco has the option of maintaining its current arrangement with St. Vincent de Paul, or it can bring the process in-house. In order to provide an objective basis for making this decision, the project team completed a quantitative analysis exploring the potential purchase and deployment of a foam compressor. The full analysis is shown in the appendix of the document. It takes into account a small number of factors, including the machine cost, labor cost, the quantity of foam purchased, and the money saved by not paying SVP to take the scrap foam. An additional variable that is key to the analysis is the percentage of bead board that Monaco actually wastes. The project team was unable to identify a definitive value for the amount of foam that ends up as waste, so the analysis includes a sensitivity factor ranging from a low of 10% to a high of 40%. The analysis shows that even with a relatively conservative

assumption for waste (i.e. 10%) that Monaco would break even on a foam compressor purchase in around 3 years.

Beyond cost, there are certainly other factors for Monaco to consider, such as the space required to process and store the scrap foam. SVP's compression machine, after reducing the volume of scrap material up 50-to-1, produces a 10-inch by 10-inch log of densities up to 25 lbs per cubic foot (similar to a low density wood). Even with less than optimal performance from the compression machine, Monaco would be able to recycle its annual scrap foam (assuming a 10% waste rate) into around 1600 linear feet of compressed material, which would occupy approximately 11 pallets stacked 4 feet high. This compares to the hundreds of bags of scrap material that Monaco transports to St. Vincent de Paul over the time span of an entire year.

Implementation Considerations: In order to successfully implement the use of the foam compression machine there are a series of steps management would need to take to ensure a smooth transition.

1. Train and assign a small number of employees who will be responsible for operating the machine
2. Find a space within the plant that makes sense to operate the compression machine—minimizing the distance from the bead board processes
3. Reinforce the importance of continuing to be as efficient as possible with the bead board, despite the new potential for revenue
4. Intermittently monitor the compressing process during the first few months of implementation to ensure procedures are carrying forward as desired
5. Internally communicate the value of adding the new machine to the current operations to gain employee buy-in
6. Maintain good relationships with potential buyers

These steps will help to ensure that the proper measures are taken to prepare for the machine, maintain the machine, and sustain its usefulness to the company.

The purchase of the compression machine provides a number of opportunities for Monaco. Not only does it provide a potentially easier and more economical way to dispose of its bead board, it creates an opportunity to improve Monaco's brand image. Through its external communications, Monaco can send a message about the value it sees in aggressively addressing the environmental performance of its materials. At the same time, Monaco should be cautious about purchasing the machine simply because it "pencils out" in the analysis. If foam processing is brought in-house, then Monaco would be discontinuing its support of a local charity. The good will garnered by supporting St. Vincent de Paul may simply be worth more than the money it can save by processing scrap foam in-house. This type of subjective decision-making will be necessary for any other material that Monaco chooses to evaluate. It is the project team's hope that the template provides at least a solid foundation from which to make those decision.

Optimizing Shipping and Inventory Management at Visionary Lenses

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Industry Sponsor: Caleb Org, CFO, Eugene, OR

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 477, Spring 2011

Shipping Analysis

This sections aims to determine which shipping company would be best for use in shipping both domestic and international package. The main considerations involve the following:

- Cost
- Reliability
- On-site pick up
- International order tracking

Current Method

Currently, Visionary Lenses uses the United States Postal Service (USPS) for all domestic and international packages. The cost for domestic packages ranges from \$1.75 for First Class up to \$22 for Express, while international packages range from \$9 up to \$35. The problem with USPS is that they do not offer international package tracking nor do they provide on-site pick up of packages. These two things make it so Visionary Lenses doesn't know if or when a package reaches an international customer, which results in sending additional lenses to some customers if they say they didn't receive them. And with no on-site pick up of packages employees of Visionary Lenses have to take additional time out of their day and drive down to the post office to drop off each day's packages.

	Domestic	International
1 st Class	\$1.75	\$9
Priority	\$8	\$14
Express	\$22	\$35

Potential Alternatives

We looked into two alternative methods of shipping besides USPS to try to address the issue of no international order tracking and no on-site package pick up. The two alternatives that addressed these issues while still being extremely reliable are UPS and FedEx. UPS offers an additional 10% discount on total monthly shipping costs while FedEx eliminates residential surcharges and has bulk prices on items over three pounds (which VL will not be able to take advantage of).

Both alternatives cost substantially more than Visionary Lenses' current method of the USPS, however both UPS and FedEx try to justify their higher prices by providing additional services, like the on-site pick up and international order tracking. This being said, it is not worth switching over to one of the alternatives and incurring the much higher shipping costs for domestic or international orders. As Visionary Lenses continues to expand they should consider looking into a company that will provide all these services.

Recommendation:

After analyzing the alternative shipping methods and Visionary Lenses current shipping method,

USPS remains the best method for shipping both domestic and international packages. To

	UPS	FedEx
Domestic	\$7	\$7-8
International	\$50	\$50

better utilize USPS and to address some of the problems created from solely using USPS we recommend the following:

1. Fully integrate with USPS using their Endicia program which provides additional discounts and service options not available with their current level of integration
2. Implement USPS's Click & Ship labeling program that is specially designed for EBay listings and will reduce the domestic shipping cost from \$1.75 to \$1.71
3. Provide an alternative shipping method for international customers through UPS or FedEx, at an additional cost that will allow them to track their package to their door.

Overseas Distribution Considerations

The objective of this section is to determine if Visionary Lenses should use an overseas distributor to get packages to international customers given Visionary Lenses current size and that approximately 30% of their orders are shipped internationally.

International Demand:

In the past 16 months, from January 2010 through April 2011, Visionary Lenses sold 4,079 units internationally in 79 different countries. The top three countries make up 52% of international sales and the top five countries make up 70% of international sales. Out of the 79 countries, 74 of the countries each make up less than 4% of international sales. The following is a list of the top countries and their respective percentage of international sales:

1. United Kingdom – 23%
2. Australia – 15%
3. Canada – 14%
4. Brazil – 10%
5. Malaysia – 8%
6. Other – 30%

Distributor Benefits:

An international distributor provides numerous benefits especially as international demand for Visionary Lenses' products continues to increase. A distributor would:

1. Reduces the shipping costs customers have to pay
2. Reduce the time it takes to get products to customers, which reinforces Visionary Lenses domestic practices of getting products to customers very quickly
3. Opens up new markets and channels for customers to get their products, further increasing international awareness and demand
4. Handles the majority of the paperwork involved in international shipments. This will allow Visionary Lenses to focus on their product offerings and points of differentiation rather than focusing on the logistics of getting products to consumers (which distributors specialize in).

Considerations

There are a couple of main considerations that need to be accounted for when picking a distributor and building a relationship with the distributor in order to ensure a successful long- term relationship. The considerations include the following:

- Cost
- Proximity to consumer and manufacturer
- Operating industry and industry experience
- Transparency, reliability, trustworthiness, and honesty

Cost

The cost to secure a distributor varies greatly depending on three factors

1. The relationship built with the distributor
2. The quantity of products sold internationally
3. The projected international growth.

This being said, the cost ranges anywhere between 5% and 20% of the sales price.

The given percentage that the distributor will take will change as the relationship progresses and international sales increase, so the relationship should be reevaluated on a quarterly bases and the percentage should change accordingly.

Location: Proximity to Consumer and Manufacture

After analyzing demand by region and taking into account the manufacturer's location, two regions are of interest:

1. Shanghai, China
2. Malaysia

These regions are the most viable to locate a distributor in because of their proximity to consumers, the proximity to the manufacturer, and the low labor costs. These regions minimize shipping costs and operating costs, which means better and more profitable margins. However, it is important to note that for some international demand, like Canada or Mexico, it may be cheaper to distribute products from the Eugene, OR warehouse depending on the relationship built and the respective percentage that is decided on with the distributor.

Operating Industry & Industry Experience:

There are three main industries that a distributor should be picked from depending on how Visionary Lenses wants to position itself in the market. The three different industries operate in a similar manner to Visionary Lenses and therefore Visionary Lenses' product line could be easily incorporated into the distributor's current product offerings. The three industries are the following:

1. Eyewear (traditional)
2. Jewelry, fashion, apparel
3. Sporting goods

By targeting distributors in these industries Visionary Lenses can align itself traditionally with other eyewear providers or they can position themselves in a less conventional manner. The different colored lenses can be seen as fashion wear where the consumer interchanges the different colored lenses depending on the color of clothing they are wearing or they can be positioned as a tool used in different sports (i.e. golf, skiing, running, etc.) and be distributed alongside other sporting equipment.

Potential Distributors

The following list contains potential distributors in the three industries that should be looked into further:

- Beijing Chuangren Imp. & Exp. Co., Ltd – Jewelry, toys, & games
- A yong culture CO., Ltd – Jewelry
- Beijing onlinknike International trade CO., Ltd – Sporting goods
- Classic Handbags & Purse Co., Ltd – Apparel & sporting goods

Building the Relationship

Building a strong long-term relationship is paramount in creating a successful long-term international distributor relationship. A solid distributor relationship is necessary to ensure that any trade secrets or company information is protected throughout the life of the relationship. The following is a list of ways to help build a strong relationship with the distributor:

- Demonstrate a strong track record and consumer appeal
- Provide a marketing campaign that supports that products that the distributor carries
- Provide proof of any already secured retail contracts (VL doesn't currently have any international retail contracts)
- Increase the percent of sales the distributor handles (5-20%)
- Offer product perks based on the distributor order size

The last two methods are ways in which Visionary Lenses can buy itself into the distributor network. Although effective in some cases, they are not as effective or as profitable in the long-term because of the reduced margins.

Distributor Recommendation

Given Visionary Lenses current size and the level of international demand, it is not a good idea to use an international distributor. By involving a distributor at this point it would mean sizable erosion of profits as well as a decline in Visionary Lenses level of control over the supply chain.

Visionary Lenses is not large enough to make the benefits of having an international distributor outweigh the costs having an international distributor. However, keeping in mind everything stated above, as Visionary Lenses continues to grow their international demand it could be a good idea to start looking into building a distributor relationship for the future. When that time comes, finding a distributor based off of a word-of-mouth referral or endorsement from a trusted source will be the best way to narrow down potential candidates and end up with the best results.

Determining Reorder Points

The next key objective is to determine reorder quantities and reorder points by forecasting demand. This is to minimize the probability of stock outs and while keeping as much cash available for other investments as possible.

Early Work: Data collection & Quantitative Model

In order to predict future demand and then to determine reorder point and reorder quantity, sales data was collected from the last 16 months (16,198 records) using PayPal. The data shows both a growth trend and seasonality. Based on this information both *Winter's model* and *Holt's Model* were tested to forecast demand. These models are adaptive forecasting models that balance the historical data with the most recent sales data each period. For this analysis, the time interval for each data point is one month.

The following is the table of relevant forecasting data of both forecasting modes looking more closely at one of Visionary Lenses' most popular products, *Green Juliet Lenses*, as an example. There is a great deal of fluctuation and prediction errors are roughly 20%. Since the error percentage is large, the quantitative model will not be the best way to predict demand in the end. Moving forward, a new prediction method needed to be developed using qualitative business knowledge to fit Visionary Lenses.

Total		157	283	430	351	566	494	472	877	998	845	798	817	914	800	1425	1720
Linear Regression demand		174	250	327	403	479	556	632	709	785	861	938	1014	1091	1167	1243	1320
Level(L)	97.4	169	255	363	420	519	570	593	719	858	922	946	955	978	954	1111	1338
Trend(T)	76.4	75	78	87	78	84	74	59	79	97	87	68	50	42	22	63	112
Winter's model		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Forecast(F)		174	244	334	450	498	603	645	652	799	956	1010	1014	1067	1142	1217	1292
Error		17	-39	-96	99	-68	109	173	-225	-199	111	212	197	153	342	-208	-428
ABS Error		17	39	96	99	68	109	173	225	199	111	212	197	153	342	208	428
MAD		17	28	51	63	64	71	86	103	114	114	122	129	131	146	150	167
%ErrorForecast		11%	14%	22%	28%	12%	22%	37%	26%	20%	13%	27%	24%	17%	43%	15%	25%
Average % Error		11%	12%	16%	19%	17%	18%	21%	21%	21%	20%	21%	21%	21%	22%	22%	22%
Holt's model		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Error Linear		17	-33	-103	52	-87	62	160	-168	-213	16	140	197	177	367	-182	-400
ABS Error Linear		17	33	103	52	87	62	160	168	213	16	140	197	177	367	182	400
MAD		17	25	51	51	58	59	73	85	99	91	96	104	110	128	132	148
%ErrorLinear		10%	13%	32%	13%	18%	11%	25%	24%	27%	2%	15%	19%	16%	31%	15%	30%
Average % Error		10%	11%	18%	17%	17%	16%	17%	18%	19%	17%	17%	17%	17%	18%	18%	19%

Table 1: Quantitative models

Inconsistent Growth

The primary reason that the errors were so large and that the quantitative models did not work was due to inconsistent growth trends over the last 16 months. For the models to work properly with minimal error, some amount of predictable growth and seasonality are required. The inconsistent growth in overall data can be attributed to several factors:

- Changes in EBay posting titles. The item titles influence search optimization and by extension final sales.
- Different trends were observed for each product. We know that business has consistently grown on an aggregate level, but on a product level, the trends vary greatly.
- The number of products available for sale is consistently increasing.

Forecasting Demand based on Business Knowledge

Based on further analysis, the following process outlines one reasonable way to forecast demand and determine reorder points and quantities.

1. Sort Products by aggregate sales over the last 4 months

VL is growing rapidly; therefore it is necessary to use the most recent date to capture the most recent trends to aid more accurate prediction. Using this year's sales data (01/2011-04/2011), generated from QuickBooks, there is large amount of observed variation in the sales quantities. Organization the products by aggregate sales allows for the most effective analysis of different trends.

2. Separate into 4 key groups

Four logical sales groups were identified based on the total sales for the past 4 months and the products were separated accordingly:

1. ***Top Sales group (100 units or above),***
2. ***Strong Sales group (50-100 units),***
3. ***Low Sales group (20-50 units)*** and
4. ***Bottom Sales group (0-20 units).***

Each group was then further analyzed to determine reorder quantity and reorder points.

3. Calculate Safety Stock & Reorder Point

Reorder Points are determined based on two factors: safety stock and demand during lead time. Safety stock quantities are estimates used to capture any unexpected increases in demand that may occur between when products are reordered and when they arrive. Expected demand during lead time is added to safety stock to determine reorder points.

Key factors taken into consideration to generate reorder points:

- Relative to lost sales, VL' s inventory cost is low, thus a low risk of stock out is preferred
- It is necessary to keep as much cash available as possible
- Lead time ranges from 35 days to 45 days
- The growth rate from month to month for products in each of the four categories.

Based on these considerations one potentially good way to calculate safety stock is to multiply largest sales amount in the last four month by a growth factor that is slightly above the observed growth rate in the each of the four groups. For example, the top sales group's month to month growth rate was normally between 100-150% so we choose to use 150% as the growth rate factor. The safety stock can be calculated as follows:

- Top Sales Group: SS= Largest sales quantity in the last 4 month * 150%
- Strong Sales Group: SS= Largest sales quantity in the last 4 month * 100%
- Low Sales Group: SS= Largest sales quantity in the last 4 month * 50%
- Bottom Sales Group: SS= 0

Reorder Points for each product are then determined based on the following calculations:

$$\text{Reorder Point} = \text{SS} +$$

1.5 MaxD The following

notations are used:

SS = safety stock

1.5 = approximately 45 days' time expressed in months

MaxD = the maximum sales quantity observed in the past four months

4. Order Quantity

Historically, all shipping costs for freight, customs fees, etc. have been variable using air freight. Assuming this order method continues to be used, the following suggestions were determined for calculating reorder quantity.

In order to determine Order Quantity, we considered the following factors:

- Observed and expected seasonality: the order quantity should aim to ensure that products will be available through the peak seasons of demand and lowered when demand is expected to decrease due to seasonal factors.

- Our minimum order quantity is 100 pairs of lenses for each unique product.
- The most recent growth trends for each product will affect the most advantageous quantity to order.

Taking the above considerations into account, one way VL could potentially calculate reorder quantities for the products in the **top sales and strong sales groups** going into the peak summer season is as follows:

$$\text{Order Quantity} = \text{MaxD} * 2$$

This would suggest that products in the top sales group could be expected to be reordered approximately every two month if not more frequently. Two months is just above the lead time for products which makes sense in order to keep cash on hand longer. Ordering more frequently allows cash to be held longer. For products in the strong sales group, the minimum order quantity will overtake the suggested order quantity above for most products.

For those products in the **low sales and bottoms sales groups** it would be best to reorder at the minimum order quantity. Most likely, there will be six months' of potential sales on hand when orders arrive leaving a large margin of error and minimal losses if stock outs occur.

Because we have run into minimum order quantity constraints, the key decision factor is the reorder point suggested above.

The items in the **bottom Group** will consistently require further analysis on a product by product basis and could be analyzed based on the following possibilities:

- Some items in this group potentially should not be reordered because their sales are too low to merit the capital required to keep them on hand.
- Some of these items are new, so there is not yet a good way to predict sales or establish reasonable measures for ordering and reordering (E.g. Sideways).

It is recommended that the estimates explained above should be reevaluated each month. This allows for the following:

Incorporation of the most recent trends in sales growth

- Qualitative analysis of seasonal factors for the coming months
- Changes in assumptions based on new and changing business constraints and opportunities.

Maintaining Data Reliability and Availability

Moving forward, accurately tracking data to provide useful information for business decisions will be crucial. To this point, Visionary Lenses has been dependent on third parties to provide sales information such as PayPal and EBay. Visionary Lenses has also been running their warehouse and reordering products without any system in place to accurately keep track of the inventory on hand. VL recognized the need for an investment in considerable information gather resources and has begun to implement new systems to track key information. For example, beginning in 2011 VL uses QuickBooks to track financial information and sales.

Inventory Information Tracking

To further address this need for information, an Excel based tracking system was put together to improve inventory management, supplier ordering efficiency, information gathering and additional product analysis by Visionary Lenses' owner and CFO.

Upon management approval, the suggested process above for calculating reorder points and quantities can be now be implemented and integrated into this Excel based inventory tracking system.

The initial version of an Excel based inventory tracking system is currently in use in the VL warehouse to keep track of up to date inventory levels of all products. These levels include:

- The quantity of inventory received,
- The quantity quality checked—both passing and failing
- The quantity shipped.

The workbook tracking system includes five worksheets with three purposes.

Master list of barcodes and item descriptions

When new products become available for sale, their information will be added to this sheet. The barcodes used in the other four sheets are directly linked to this sheet.

Sheets to Receive data

The next three sheets were created to receive the data from each of the three respective programs in the barcode scanner:

- Items received,
- Items quality checked—good and bad,
- Items shipped.

Aggregation Sheet

This sheet aggregates the information added from the barcode scanner. This sheet dynamically updates the total quantity available for shipping and in the warehouse using the data received in the other worksheets.

Implementing Reorder Points into the System

The next modifications and worksheets that will need to be added to the inventory tracking system will be designed to integrate the reorder mentioned above.

First, a new worksheet will need to be added to the inventory tracking workbook called *Reorder Point Calculations*. This page will be populated with the most recent 4 months of sales data from QuickBooks that will be used for reorder point calculations and then calculate the reorder points.

This page will be updated monthly.

Next, two columns can be added to the *Aggregation Sheet*:

- A column to lookup up the reorder points as calculated in the newly add *Reorder Point Calculations* worksheet by barcode
- A column that generates flags based on the difference between the reorder point and the total quantity on hand.

The flagging column will include conditional formatting to color the cells corresponding to products that need to be reordered, are close to needing to be reordered and products that are out of stock. The words in the cells will all change accordingly and match the levels indicated by the conditional formatting.



— BRAND —

POTATO CHIPS

Analysis of Warehouse Expansion Options

**Brian Oehler
Brad Puglio
Neil Vance
Claire Williams
Tiffany Yep**



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I. Executive Summary

Problem

Kettle Foods, Inc. (Kettle Foods) plans to increase production by 25% in the near future, but the company's main distribution center (which is currently operating at near maximum capacity) cannot feasibly handle an increase in output. To facilitate a smooth ramp-up in production levels, Kettle Foods will need to expand its warehouse capacity from 170,000 ft² to 250,000 ft².

Kettle Foods has identified six options for expansion that will bring its total warehouse capacity to 250,000 ft². These options differ in terms of cost, ownership model, location, physical condition, suitability and other qualitative factors. Our task is to perform an analysis on each of these options and make a recommendation on which option Kettle Foods should pursue.

Solution Methodology

A DCF analysis was performed to determine the net present value (NPV) of each option, as seen in the table below:

Option	Description	NPV
1	Negotiate lease extensions on two current warehouses	\$7,117,395
2	Purchase and expand Stayton warehouse	\$9,421,675
3	Lease and expand Stayton warehouse	\$7,892,924
4a	Build new warehouse with Company A	\$10,999,434
4b	Build new warehouse with Company B	\$11,261,046
4c	Build new warehouse with Company C	\$13,939,102
5	Build new warehouse with Company D	\$20,273,467
6	Lease and expand Oxford warehouse	\$5,548,472

Although options 1 and 6 have the lowest NPVs, a careful analysis determined that these options do not meet all of the requisite criteria for expansion, and were thus removed from consideration. We narrowed our choices to the three with the next lowest NPVs and used qualitative factors to determine which option was right for Kettle Foods.

Recommendation

We recommend that Kettle Foods pursues option 3: lease and expand the Stayton warehouse. This option presents the best combination of relevant factors, including minimal capital outlay, low annual costs, room for future expansion and flexibility. To maintain its image as an earth-friendly food manufacturer, Kettle Foods should also consider expanding the warehouse to meet the criteria for LEED certification.



II. Overview

Kettle Foods currently operates two distribution centers in Salem, Oregon located on Fairview Avenue and Oxford Street respectively. In order to allow for a 25% increase in production, the company needs to increase its current warehouse capacity for storage of chip production to a total of 250,000 ft². Kettle Foods identified several lease and build options to achieve this strategic objective, and our group was asked to determine which option has the best value (minimize cost while maximizing non-financial benefits).

The following two distribution centers are currently in operation:

Fairview

Fairview DC	
Capacity	120,000 ft ²
Available Capacity	120,000 ft ²
SKUs	Approximately 130
Primary customers	US and Canadian grocery markets
Pallet description	Mixed SKUs in a single pallet
Number of staff	14
Layout	Product organized by aisle, bay and section
Inventory system	Paper-based (Excel)

Summary

The Fairview Distribution Center is in good operating condition, and currently suffices as a distribution facility. Due to height limitations and lack of additional capacity for expansion, the Fairview DC is less than ideal for continued use.

Pros and Cons

Pros

- Meets our current needs for current production levels
- Has 8 dock doors, which is “workable”
- Has a 1,000 ft² space for marketing to hand-pick small orders
- Monthly rates for lease could be reduced through negotiations
- Has room for staging out-bound loads
- Accommodates ideal stacking height of 4 pallets

Cons

- Irregular shape makes inventory management less than ideal
- Variance in height of ceiling limits efficiencies
- Cannot serve as single DC because of capacity constraints
- Office location within facility is less than ideal

Oxford

Oxford DC	
Capacity	60,000 ft ²
Available Capacity	415,000 ft ²
SKUs	Exactly 4
Primary customers	Trader Joe's and CostCo
Pallet description	Whole pallets of single SKUs
Number of staff	2
Layout	Unknown
Inventory system	Some RFID provided, but not utilized

Summary

The Oxford Distribution Center presumably was adopted as a short term solution, where expansion was not a foreseeable option. The building is a piecemeal of four different buildings built in four different decades. For this reason alone, the renovation costs to make the building suitable for expansion would be significant. In addition, this option becomes more risky considering that the condition of the unused capacity is currently unknown. The lighting in this building is a representation of the building itself: it works for what's needed, and could possibly be renovated to meet our needs, but the cost would no doubt be significant.

Pros and Cons

Pros

- Currently operating dock doors prove that the current facility can accommodate forklift equipment
- Available capacity well exceeds requirement, indicating room for future expansion
- The additional structures may be in good condition such that remodeling costs would be minimal
- Flexibility to add in certain designs due to the extent of renovations needed

Cons

- Likely variances in ceiling height among buildings
- Existing facility will likely need extensive work
- None of the existing features are currently built into the structure



III. Decision Variables

We met with various employees of Kettle Foods to determine what criteria should be used when evaluating potential warehouse expansion options. Our analysis should reveal which option is the best fit when measured against the following quantitative and qualitative factors:

Quantitative

- NPV/DCF
- Discount factor
- Expansion costs for each option
- Time and fuel costs of travel time/distance
- Reduction factor for negotiating new leases
- Need to account for taxes, depreciation, etc
- Opportunity cost of cash investment

Qualitative

- Number of dock doors (ideally 24 total)
- Number of ground level doors (minimum of 2)
- Flexibility in organizing inventory management system (in case of additional SKUs/non-chip products)
- Ability to add-in RFID or other IMS in future (Europe already moving to IGPS)
- 1000 ft² of Marketing space for hand-picked pickups
- Floorplan of facility (simple rectangle ideal)
- Sustainability
- Variances in height of ceiling (ex: Fairview back area limited by ramp, 8 ft ceiling)
- Option for continued expansion (ex: Stayton option has land to continue add-ons in the future if needed)
- Room for staging outbound loads (primarily for big box, mixing displays and shippers)
- Mailing access (UPS/FedEx)
- Truck yard capacity
- Employee parking spaces (ideally 20+)
- Communications solutions (phone lines, etc)
- Preference for consolidation to one DC
- Productivity as it relates to DC's proximity to office (closer means more visits, but also added flexibility)
- Location of offices (preferably stacked, employees below, managers above)
- Break area to accommodate 40 people
- Height: ideally 4-high (need to account for stacking, lighting and sprinkler clearance)
- Conference room
- One central driver check-in area
- Ability to separate product for domestic, export and big box customers within one DC
- Food regulation costs (might be disproportionate for lease vs. build)
- Changes needed in streets, neighborhood, route planning, etc.
- Support of local government/authorities



IV. Potential Solutions

The following alternatives were provided as options to increase Kettle Foods' total warehouse capacity to 250,000 ft²:

Option 1	Negotiate an extension of the Fairview and Oxford leases with sufficient space
Option 2	Buy the Stayton building and expand
Option 3	Lease the Stayton building and expand
Option 4a	Build with CBRE: Dermody Properties
Option 4b	Build with CBRE: Trammell Crow Company
Option 4c	Build through CBR
Option 5	Build with White Oak
Option 6	Lease with Oxford after expansion



V. Analysis

Through analysis and consultation, we created the following list of pros and cons for each of the identified options.

Option 1

Option 1: NPV of \$7,117,395

<p>Pros</p> <ul style="list-style-type: none"> • No need to move facilities, save time and money • Both warehouses are in close proximity to the production facility <p>Minimize damages caused by fire or natural disaster by having two separate facilities</p>	<p>Cons</p> <ul style="list-style-type: none"> • Only works for now, if space is added it will be at Oxford and the variances in ceiling height among the existing buildings and the shape of the warehouse are not ideal • City permits, regulations, possible street construction needed to accommodate higher traffic level at Oxford • Two separate facilities is not the best set up for maximum efficiency • Limited office space at Fairview <p>Less room for flexibility in utilizing the spaces</p>
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Overall Rating:



Option 2

Option 2: NPV of \$9,527,407

Pros

- Own facility, possibility of appreciating in future
- A lot of land for expansion to accommodate flexibility in utilizing warehouse floor space for products (includes space to expand beyond 250K if needed in the future)
- Large amount of office space, parking space, trailer stalls and trailer yard
- Ideal ceiling height and the ability to add more dock doors where necessary
- One central warehouse will increase efficiency
- Not located in a residential or heavy traffic area
- Minimal amount of conversion is needed in the space since it was previously used as a warehouse

Cons

- Owned facility constrains flexibility of pursuing other options in the future
- Further distance away from production facility (but possibly negligible)
- Huge capital investment
- Possible construction delays

Overall Rating:



Option 3

Option 3: NPV of \$7,892,924

Pros

- A lot of land for expansion to accommodate flexibility in utilizing warehouse floor space for products (includes space to expand beyond 250K ft² if needed in the future)
- Large amount of office space, parking space, trailer stalls and trailer yard
- Ideal ceiling height and the ability to add more dock doors where necessary
- One central warehouse will increase efficiency
- Not located in a residential or heavy traffic area
- Minimal amount of conversion is needed in the space since it was previously used as a warehouse
- Less amount of capital investment needed

Cons

- Further distance away from production facility (but possibly negligible)
- Possible construction delays

Overall Rating:



Note: the following build options are assumed to be build-to-lease.

Option 4a

Option 4a: NPV of \$10,999,434

Pros

- Ability to build a warehouse that is customized to meet the company's needs
- Close proximity to production facility
- One central warehouse will increase efficiency

Cons

- Huge capital investment
- Possible construction delays
- No room for expansion in future if more than 250K ft² of space is needed

Overall Rating:



Option 4b

Option 4b: NPV of \$11,261,046

Pros

- Ability to build a warehouse that is customized to meet the company's needs
- Close proximity to production facility
- One central warehouse will increase efficiency

Cons

- Huge capital investment
- Possible construction delays
- No room for expansion in future if more than 250K ft² of space is needed

Overall Rating:



Option 4c

Option 4c: NPV of \$13,939,102

Pros

- Ability to build a warehouse that is customized to meet the company's needs
- Close proximity to production facility
- One central warehouse will increase efficiency

Cons

- Huge capital investment
- Possible construction delays
- No room for expansion in future if more than 250K ft² of space is needed

Overall Rating:



Option 5

Option 5: NPV of \$20,273,467

Pros

- Ability to build a warehouse that is customized to meet the company's needs
- Close proximity to production facility
- One central warehouse will increase efficiency

Cons

- Huge capital investment
- Possible construction delays
- No room for expansion in future if more than 250K ft² of space is needed

Overall Rating:



Option 6

Option 6: NPV of \$5,548,472

Pros

- Close proximity to production facility
- Familiar with facility
- One central warehouse will increase efficiency

Cons

- Huge capital investment
- Require current operations in facility to be moved temporarily for construction
- Structural issues still present (variance in ceiling height, poles taking up floor space, floor not level)
- City permits, regulations, possible street construction needed to accommodate higher traffic level at Oxford

Overall Rating:





VI. Recommendation

Looking at both quantitative and qualitative factors for each option, we narrowed our choices down to three. Our top three choices were:

- Build new warehouse with CBRE: Dermody Properties (Option 4a)
- Purchase and expand warehouse in Stayton (Option 2)
- Lease and expand warehouse in Stayton (Option 3)

The build options are all very similar so we took the one with the lowest NPV as our best build-to-lease option. However, we eliminated the build-to-own option because of the high capital investment needed, possible construction delays and the inflexibility that would exist should Kettle Foods need additional warehouse space to exceed 250,000 ft².

The second best option was to purchase and expand the warehouse in Stayton. Based on our discussions with Kettle Foods executives they were hesitant about owning real estate. Our group eliminated this option due to this factor as well as the inflexibility associated with this option if Kettle Foods were to continue to grow rapidly.

The top choice was to lease and expand the Stayton warehouse. This option was attractive when keeping the issues of flexibility, space, capital outlay and location in mind.

LEED Certification at Stayton

Kettle Foods already operates one LEED certified facility in Beloitte, WI. This certification reinforces Kettle's image as a company concerned with environmental sustainability. We recommend that the company pursue LEED certification for the Stayton facility to reinforce this image. While the requirements for different levels of certification vary, we are confident the costs to renovate to these requirements will be a negligible addition to the existing costs requirements for Kettle to adequately alter this facility as a predication for use. Furthermore, a case can be made that LEED certification costs pay for themselves over time in the form of energy efficiency savings. It should be noted, however, that these savings are generally captured from building HVAC savings. Since Kettle has minimal requirements for HVAC systems in its Oregon warehouses, the company will need to examine which level of LEED certification has the most potential for payback over time.



VII. Action Steps

To pursue this strategy, the following action steps need to be taken:

1. Meet with Stayton facility owner to finalize renovation plans and lease terms
2. Determine if current leases on warehouses need to be extended to accommodate construction
3. Begin planning space usage in new facility
4. Begin developing a plan for moving from current warehouses to new warehouse



VIII. Exhibits

Analyzing Dismantling and Testing Processes at Next Step Recycling

UGTeam: Katarina Ivezic, Yunru Wu, Ge Song, Yujie Tang, Blake Sedgley, Ty Kouri

Industry Sponsor: Lorraine Kerwood, Executive Director, Next Step Recycling, Eugene, OR

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 477, Spring 2012

EXECUTIVE SUMMARY

Organization: NextStep Recycling is a pioneer and nonprofit in the tech refurbishing and recycling community, making technology more accessible to individuals, and reducing the impact of E-waste on our environment.

Project: Our team of undergraduate students was charged with performing a value stream mapping of the entire NextStep operations and making recommendations for getting cheaper, faster, and better.

Objectives

1. Maintain opportunities for those considered unemployable, currently unemployed, and/or people new to the job market to develop social and technical skills
2. Prioritize access to technology
3. Create a more efficient work environment while maintaining safety

Problem Analysis: A large portion of NextStep's labor is volunteer-based. Labor constraints within the dismantling and tech departments are analyzed in-depth to understand and mitigate the scheduling, training, and quality assurance challenges a volunteer-based labor pool brings.

Recommendations: To better prepare volunteers for tech, a two-track system is recommended in dismantling. Within tech, NextStep can better utilize its labor by addressing training, product prioritization, and volunteer retention.

INTRODUCTION

NextStep recycling provides Oregonians with access to technology, and offers those with barriers to employment and education the opportunity to develop social and technological skill sets. As a group from the supply chain class at the University of Oregon, our goal is to help NextStep facilitate this mission by giving an outsider's overview of the entire operational process inside the facility. We aim to develop specific recommendations that consider NextStep's mission and goals.

Overview of Operations

Triage

Receiving and sorting is the first step in the NextStep process. Donations are separated into household and business as these have different tax filing procedures, though all products end up going through the remainder of processes together. Team Members determine if items will be refurbished or recycled for parts. Refurbished items go directly to the Tech Department while recycling goes to the "graveyard" to be dismantled.

Dismantle Line

Once in the graveyard, items are taken apart and individual components are separated by type; different plastics, different metals, RAM, daughter boards, etc. There is currently a multi-bin sorting procedure where a small bin of parts is filled, transferred to a circular bin, and then transferred again to large gaylords to be outsourced by recycling companies.

Tech Department

Staff and volunteers who have applied and interviewed within the tech department, test and build computers, laptops, routers, and other household electronics. They perform four main steps per box (computer) including, Initial PC Eval, PC Build, External Peripheral Device Testing, and Internal Component Testing. Additionally Tech is responsible for initiating any

Microsoft licenses before sending product to the store or grants. As expected with the nature of detailed refurbishment, Tech is currently NextStep's bottleneck.

Stores & Outgoing

Tech receives processing orders from store managers to determine what products are selling best or are running low in inventory. Stores track customer zip codes for those purchasing Microsoft licensed products.

To ensure specific and in-depth understanding, Tech and Dismantling were analyzed more in depth. Though expected, it is important to look at ways to reduce the effect of the bottleneck in Tech. Dismantling is another large department receiving many volunteers and with many different processes to track.

DISMANTLING PROCESS: INEFFICIENCIES OF RECYCLING

Sorting Materials

The dismantling process requires individual labor. Components are dismantled by hand, sorting components into silos. Sorted materials are then outsourced to various materials recyclers throughout Oregon and Washington.

Error in Sorting and Resorting Materials

The process of sorting is difficult because volunteers in the dismantle section do not have extensive training. This large volume of hand sorting is fast paced, and lack of training can lead to sorting errors, breaking and throwing away useful materials, keeping useless materials, mixing different types of metals etc. If error occurs, employees resort all of the individual bins.

DISMANTLING PROCESS: LABOR EVALUATION

After observing dismantling processes, it became clear that labor is a very important function within the department. As much of NextStep's labor force is volunteer based, and all volunteers

move through dismantling, the department is highly dependent upon the number of volunteers trained in the area. The largest labor challenges are:

- *Group training*—Training new volunteers often has to be done on an individual basis since the number of volunteers beginning at NextStep at a given time is inconsistent. This takes up time from staff members and is often limited by the number of staff available to train.
- *Consistency in volunteer hours*—Volunteer commitment varies widely. Some come in on a regular basis but don't keep a regular schedule week to week. Others have highly varied monthly hours. This puts pressure on NextStep because there is always an inflow of materials to be dismantled regardless of if there are volunteers in the department.
- *Retention*—Retaining volunteers at NextStep is important to an organization so widely dependent upon their contribution. Ensuring volunteers with the desire and ability to learn about NextStep processes are challenged can be difficult within dismantling.

DISMANTLE PROCESS: RECOMMENDATIONS

To mitigate sorting and labor challenges within dismantling, visual aids and a two-track training program could be utilized.

Visual Aids

Sorting errors sometimes occur if a volunteer cannot remember or does not understand their training. In analyzing this issue, we initially thought having a book of images containing each item would be helpful in identifying which parts should go in each bin. Though helpful in theory, this would take a lot of work to start and update because of the amount of items that can be recycled. Consulting a comprehensive book may also be too time consuming for volunteers to utilize in practice.

However, adding visual aids to bins could be helpful. This would give volunteers an example of what components need to go in different bins. The visuals could specify some key characteristics of the component that are often overlooked. This could decrease the number of times bins need to be resorted and help volunteers better understand the reasoning behind decisions. These visual aids would also serve more generally than a book would. Still though, it is important to account for the continuously changing technology and maintenance involved with any added visual.

Two Track Training Program

Another suggestion in dismantling, is that the training system be separated into two tracks. Volunteers could self-select into these tracks which would have different training processes.

Classic Track

Classic track is equivalent to the processes within dismantling. It is especially geared towards those who look forward to staying in the dismantling department or who do not anticipate becoming highly involved or long-term volunteers.

For a full description of the current training program (Current Classic Track Training Program Description) see Appendix #4.

Progressive Track

The proposed progressive track, aims to help expedite the time it takes for individuals to get into the tech department. The new track will be for those who have shown interest in moving into the Tech segment of the company and/or wish to become a highly invested volunteer.

The best way train new progressive track volunteers is to immediately teach them applicable skills that they will use in tech. This track will disassemble and sort the newest computers that have failed or been deemed unusable. This makes the most of volunteer training time by allowing new trainees to learn how to differentiate computer parts on boxes most relevant to tech. Learning about the latest components in dismantling will better prepare volunteers for

tech and increase their ability to pick up on tech training quickly. To better demonstrate how the progressive track will prepare volunteers, three stages of the process have been developed.

1. The first level is the simple dismantling of computers. Volunteers learn how to sort by component. Graduation from level one simply requires that a volunteer can demonstrate to staff supervisors that they have the component knowledge necessary to properly sort components.
2. The second level is a combination of learning about the different types of components within the computer and how to diagnose the type of components by year, brand, and type. Volunteers will utilize tutorial videos (discussed further on page 14) This portion will require NextStep to develop a catalog of known/commonly seen computer parts. To graduate from level two a trainee must view all completed tutorial videos.
3. The third level is the last required stage within the progressive track and is where the introduction of the newer, failed tech computers are introduced. Volunteers will continue with use of the catalog in this stage. The key goal of this stage is for volunteers to become proficient in identifying all commonly seen computers to prepare them for their tech training. To graduate from this level and become eligible for a tech department interview, volunteers must show proficiency in identifying and categorizing all the parts within a number of different types of computers.

There is no 10 hour time limit on the progressive training cycle. Once a trainee has completed all three levels, they can move on to the tech training program. This should help expedite the training progress and add additional trained volunteers to the Tech segment.

TECH DEPARTMENT: UNDERSTANDING THE PROCESS

To better understand the tech department and process improvement within the area, the following areas were analyzed:

Number of Touches

High numbers of touches per part was one of the initial sponsor concerns to be further investigated through the project. In most companies and organizations, reducing the number of touches is important for efficiency, however within tech at NextStep, touches do not appear to be a constraining factor. The development process of volunteers and highly technical skills required within the tech department actually indicate that high touch rates ensure greater accuracy and lessen fail rates. However, it is important to note that additional touches are typically coming from trained staff which therefore reduces the productivity and efficiency of tech process.

Space/Flow

All infrastructure within the tech department is mobile, and the department's work station layout and orientation has been consistently changing. The current set-up separates laptops, PCs, and household electronics into separate areas, with the PC layout moving from evaluation, to build/test stations, to final device and component testing. Worker space is not a pressing issue, as there are usually vacancies in the eight build/test stations. Products are worked on at an at-needed basis as labor is knowledgeable about the all steps of the flow and there is not enough labor to reach capacity of any one tech stage.

Labor

Most of the tech department time and output is spent on PC refurbishment. With three staff members working directly within this area, much of the tech output comes from volunteers. A lot of training is necessary within the department because it requires such skilled and technical labor. These volunteers vary significantly in technical and social backgrounds and receive training from the same three staff members working in the area. Currently, the number of volunteers fluctuates heavily, though typically, there are a large number of work stations going unused.

TECH DEPARTMENT: LABOR INEFFICIENCIES

Because skilled labor affects both touches and NextStep's work in progress, we took a closer look at how labor is affected. Below outlines key challenges for tech department labor.

The whole tech department has only 3 staffs who are actually working on numbers of unfinished products. Usually they can finish 10-15 products every day without any disturb; however, these 3 staffs are also responsible to train the people who want to get trained. It requires the staff to be able to stop their works on hand at any time, train and make sure the trainers or volunteers are clear about their questions or are able to work on their own with right approaches.

Staff needs to keep training new learners since there are always new people come in and want to learn something of computer. This creates the cycle that the staffs always need to stop their works and train the new people. At the same time, the 3 staffs in tech department need to test and build all the machines they got from donation no matter if the product will be sold in the store. The staffs know which product will be easily sold with good price but there is not priority rule among all the products for them to follow.

The volunteer aspect plays an important role here but there are some problems with them. First, since they are voluntarily to work in the organization, they come from different education and experience level; moreover, the ability of learning tech strategy for them varies a lot. Even more, some of these volunteers are here to fulfill school activity requirement and some of them are here to make some contributions to community, their attitudes varies a lot as well. Based on these factors, we further discovered some problems. One new volunteer needs as much as two hours to build a computer compares with one experienced volunteer only needs 20 minutes; one new volunteer typically need 60 hours to becomes expert in the working process but majority of them are leaving at the time they are expert because some of them do not feel they are doing meaningful things; one volunteer usually works 1-2 hours per time and 1-2 times per week which results in repeating training process since the volunteer will forget the training from last week with great possibility. We suggest having some new types of training process and providing more incentives for both volunteers and trainers.

TECH DEPARTMENT: RECOMMENDATIONS

After analyzing the process within the Tech department, training, product prioritization, and volunteer retention all appear to be important aspects of improving current labor constraints.

Training

Since Tech volunteers must have highly specialized skills in order to contribute in an efficient way, the training they receive is very important. Based on our observations, we see the following as feasible and beneficial to Tech Department training:

- *Video Tutorials*—Videos can serve as a beginning stage of training. They allow volunteers to receive a standardized training while training managers are able to perform other tasks. Quality videos already exist on YouTube, but NextStep could also make a short recording for information tailored to their needs for little or no cost. Videos would easily integrate with the progressive dismantling track, requiring these volunteers to begin video training while in dismantling. Videos would serve as informational but could also offer opportunity for hands-on learning with follow-along demonstrations. As many volunteers do not have current access to technology, NextStep would need to offer space to view tutorials.
- *Shift Minimums*—Increasing the minimum shift requirement from 1, 3-hour shift per week to 2, 3-hour shifts per week will improve the use of both employee and volunteer time. This requirement eliminates much of the retraining done with a 1-shift minimum.
- *Experienced Speeds*—With such extensive training within tech, it is important that volunteers understand one step of the training before moving on to another. By requiring volunteers to perform each step within that of an experienced worker, NextStep will ensure they have adequately mastered one stage before moving on to the next. For example, a beginning volunteer will take about 2 hours per box, but an expert can

perform a build in 20 minutes. Therefore a reasonable metric to move onto the next stage is performing a 30 minute build.

Product Prioritization

With limited labor that does not match the product volume, it is important that NextStep can accurately assess their highest (and lowest) priority work in process. Data collection will be important in the future, and made easier with the recommended centralized database for inventory tracking as outlined by another project team. Sales data, profit margin, and number of failed machines will be especially important metrics to track. Further analysis of work in process makes sense after a data collection mechanism is in place, as any recommendation at this point, is speculation.

Volunteer Retention

Since the training investment in tech department volunteers and trainees, skilled labor retention is a valuable consideration. Currently the Tech Grant Program is very successful in helping retain trainees in the short-term but not long-term. The program also does not apply to volunteers who cannot receive any form of compensation for their labor. However, the success of the program offers inspiration for other retention methods. The following suggestions aim to provide the same incentives of the Tech Grant Program for volunteers and for the long-term.

- *Store Discounts*—A store discount taps into the technologically driven incentives behind the Tech Grant Program, however applies to all in the labor force. We see this as a long-term incentive where unpaid labor is eligible after 60 hours of service and maintains 10 hours of service monthly. Specific restrictions (i.e. products, number of purchases, hour modifications, etc.) may need to be developed as above mentioned sales research is collected. Though this would reduce profit margins on discounted products, the increased output of skilled labor would outweigh this.

- *Opportunity for Increased Responsibility*—Emphasizing and adding to the availability for increased volunteer responsibility will provide them with something to work towards. For example, while not a requirement to move onto the next stage of training, mentors can be better utilized. Mentors can pose as a first resource when trained, but new volunteers have questions. Though a higher skill-level, a volunteer could eventually be trained in finishing table or new volunteer trainer roles.
- *Tech member of the month*—Explicit acknowledgements of outstanding achievement can demonstrate volunteer appreciation and provide them with resume material to further the NextStep mission

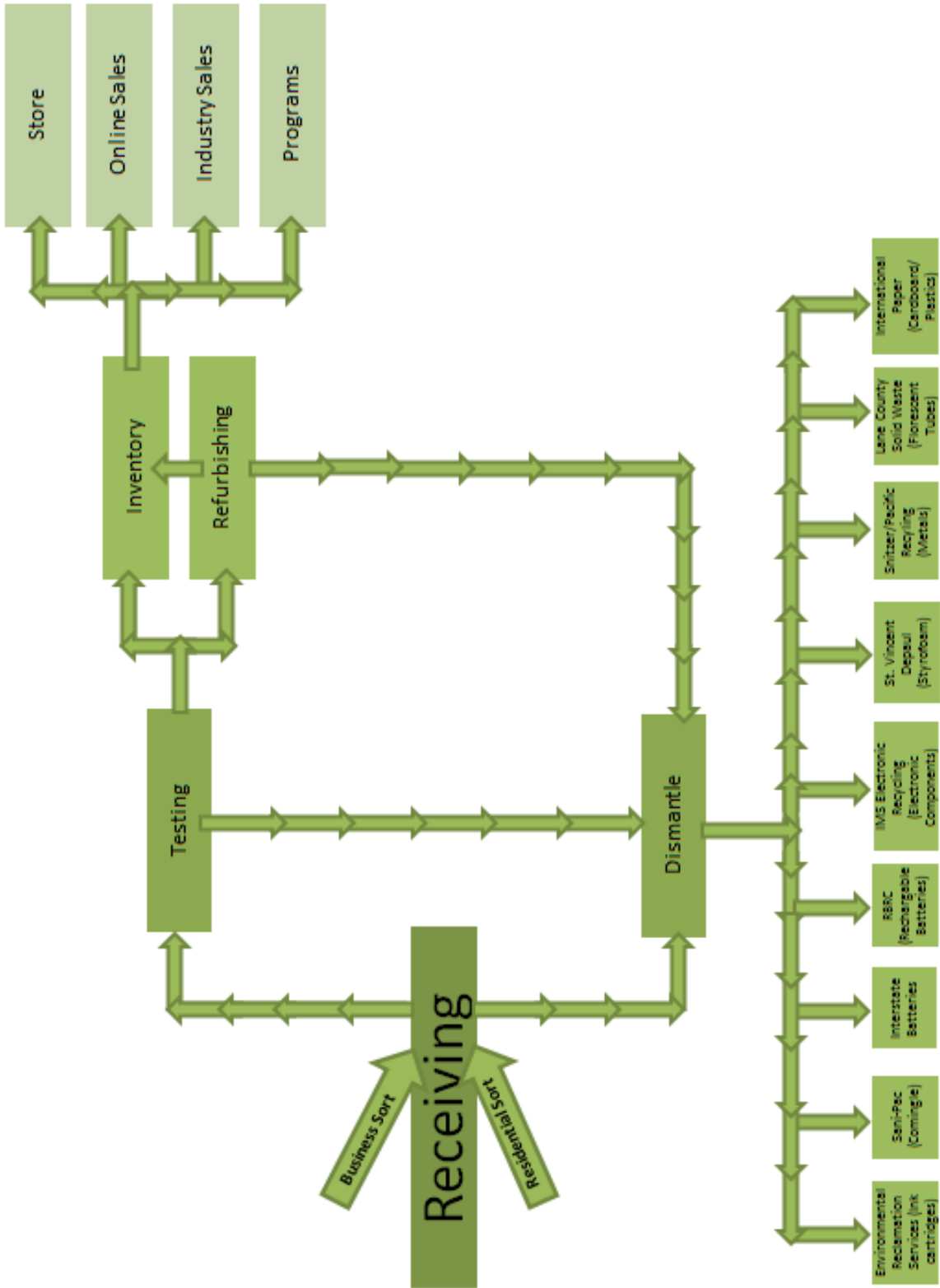
See Appendix #6 for further details on retention methods that were considered, but not recommended.

OPERATIONAL MODEL INTEGRATION

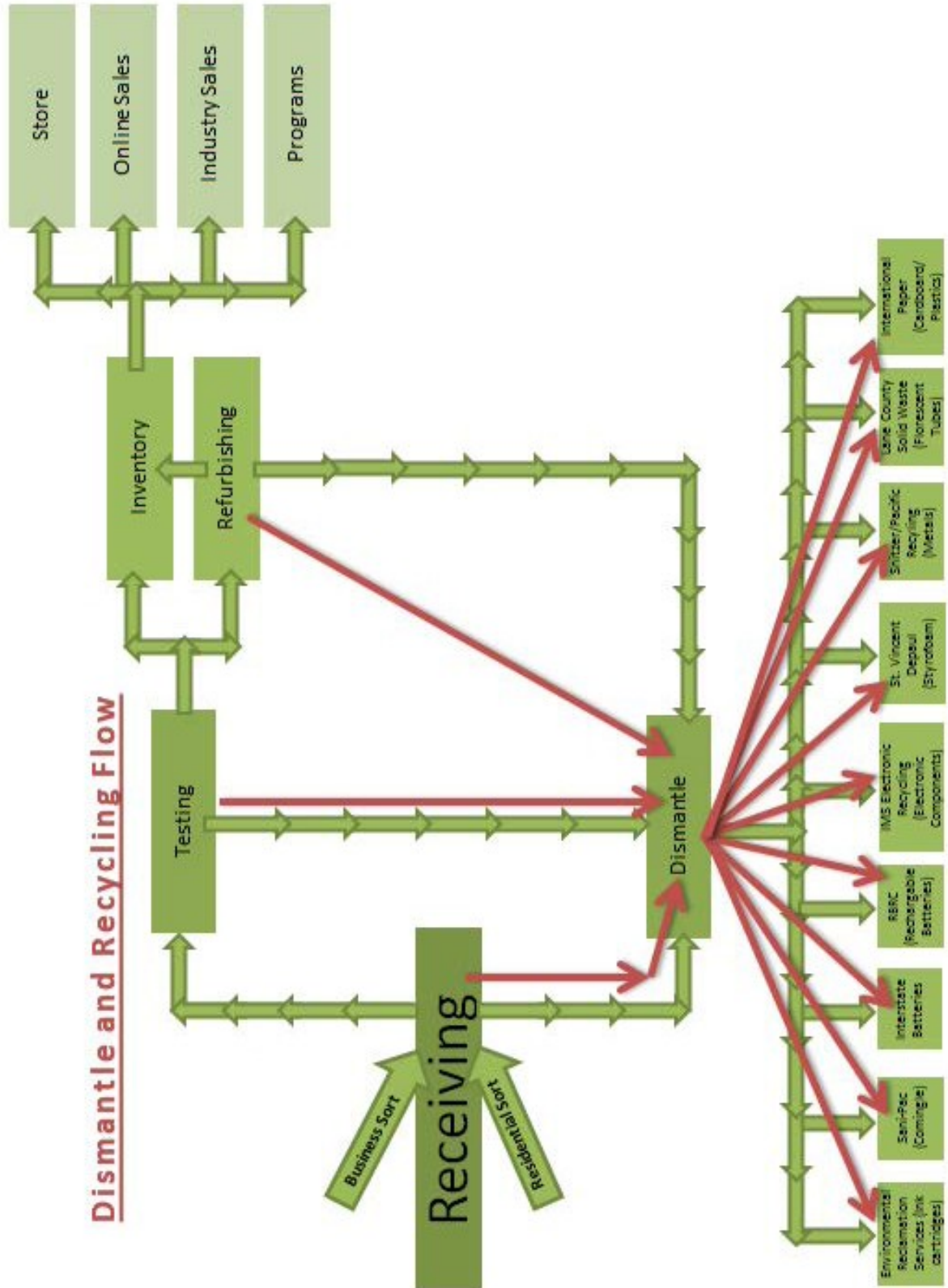
It is important to consider how the above Dismantling and Tech recommendations fit into the larger picture of NextStep Recycling. Recommendations aim to maintain the organization's mission, consider other areas of operation, and consider recommendations of other supply chain group projects. The two-track training program suggested within dismantling aims to help tech distinguish volunteers who are most committed to volunteering with NextStep long-term. With this system, tech training can then be integrated earlier and more gradually with minimal staff investment.

In addition to specific departmental retention efforts, projects also integrate to create possibility for overarching retention increases. Specifically the two-track training aims to better cater to volunteers seeking greater challenges upon first starting as a volunteer for NextStep and allows them to see the larger picture of advancement opportunities. Inventory tracking aids data collection allowing for volunteers to see the impact of their efforts, another overarching retention aid.

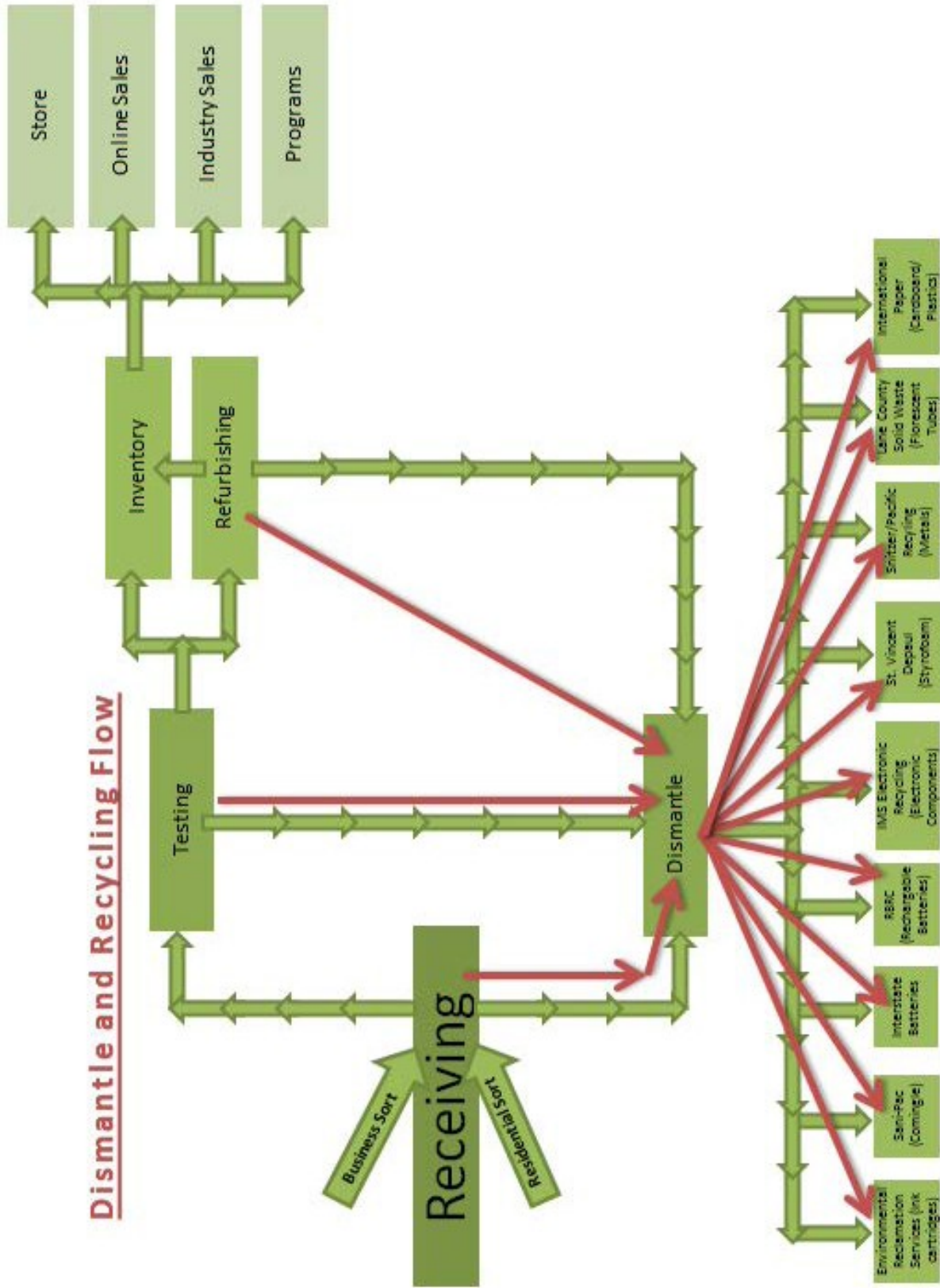
Appendix #1: Overall Flow Chart



Appendix #2: Dismantle Flow Chart



Appendix #3: Refurbish Flow Chart



Appendix #4: Current (Classic Track) Training Program Description

Process from dismantle to tech:

- Requirements: application and meet with Angel
- No hours logged requirement is necessary, as volunteers can fill out an application at any time. (from what I understand)
- Application: Standard for movement to any other department (includes check boxes for the departments of interest, and a few questions such as why you are interested in that role)
- Interview: Angel, the primary manager of volunteers within Tech meets with the applicant. She usually gives everyone a chance if they have sincerely filled out the application (as this goes with the mission). Sometimes she has to tell the applicant that they filled it out incorrectly, and they must fill it out correctly to move to tech.
- Typically the first step at tech is Harvest. ATM, I'm blanking on what that is exactly, but I know it is fairly simple and provides time to understand what the department does. 10 hours there in harvest is pretty typical, but I don't get the impression that it is a rigid number.

Appendix #5: Test & Build Output

Test and Build Weekly Output NextStep Recycling Tech Department (As based on estimates from Tech dept. Staff)		
Labor	Low-end estimate (Boxes)	High-end estimate (Boxes)
3 Staff	10	15
3 Staff & 2 inexperienced volunteers	8	10
3 Staff & 5 volunteers (some experienced)	20	45



Appendix #6: Retention Considerations

Many considerations were made in deciding upon training and retention recommendations within the tech department. The following chart displays why we ultimately did not suggest these ideas:

Method	Pro	Con
Opportunity to upgrade a Tech Grant Program (or personal) computer with continued service	Long-term retention: can always get something better, ability to work on own machine	Possibility this would appear that the Tech Grant Program is providing inadequate technology
Skill building workshops with continued service (resume, etc.)	Fulfills mission, incentives to continue service	Resources necessary to provide this type of service
Hire staff	Accountability, skill level, long-term	Not feasible financially, too much of this takes away from mission
Require mentoring before moving onto the next stage	Demonstrate comprehensive understanding and ability to trouble-shoot, increases responsibilities, reduces staff training time	Not all volunteers comfortable with this, may affect standardization of training

Appendix #7: Pictures

Graveyard:



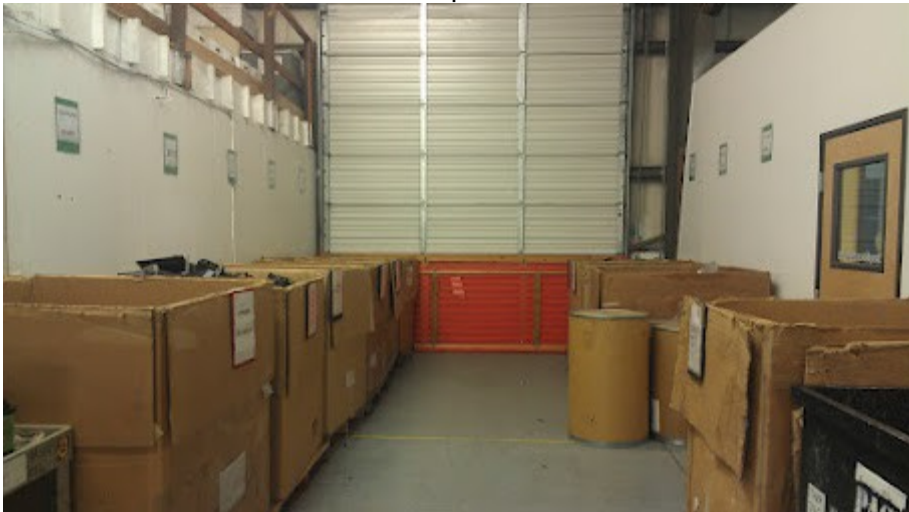
Work benches in the graveyard



Little bins on the work benches/desks



Barrels where the little bins are emptied into





(3 above) The large crates of recycling before it gets shipped out

Tech:



Space/flow issues in the tech department

Appendix #8: Team Members Notes

Kat's Notes for:

NextStep Recycling Tour:

Intake:

Two sides; Business and Residential

Residential Donation Side:

Electronics come in and go to 4 places:

- Recycling – covered electronic devices
- Queue for wholesale sales
 - They review and pick, then buy what they want. NextStep then has to re-handle the materials the wholesalers don't want
- Store – directly
- Tech – gets tested and reused

* a tone of hand sorting that is fast paced

* we want to handle materials less

- Things that are Queued up: software, house hold items, computers for IT, stereo equipment, etc. (vacuum tubes)

Business Donation Side:

- Large/industrial printers cost \$ to recycle
 - NextStep asks the businesses to pay the cost
- Everything gets a label (for tracking purposes)
- The majority of reusable materials comes from the business donation side
- Businesses are not qualified for the DEQ (which manages the Oregon _____ Program)
- All materials are melted and extruded in the US
- The Conex's (big storage containers) outside are full of Queued materials
- Stretch wrap is re-sold and goes to Seattle
- Metal recycling brings NextStep \$8-10,000 a month

Refurbishing (Hospital)

- Queued items: basic computer boxes are stripped down and a training program to teach people how to build a computer is how the boxes get rebuilt
- Takes the internal parts of computers and tests them before re-building
 - Tests: RAM, cards, etc.
- This allows for a higher quality control, because this way NextStep will not have the same material they reused back in their facilities
- Bill → locksmith genius (unlock computers)
 - LCD screen repairs
 - Repairs large screen TVs
- Gs and Ns
 - Mining: taking out the reusable parts in computers/electronics

Cycle: box → clean out → test → rebuild → software install → quality control

- Based on store and eBay needs/demands, uses pull not push method
- Could be once a week or per day to communicate orders
- Use a spreadsheet
- NextStep tests clocks, radios and other household items
- Laptops are the most stable/reliable revenue for NextStep

Ebay room: 3-4 people who put materials/recycled items on eBay

- 1 shipper
- NextStep used to put 1,500-2,000 items on eBay each month
- Now they put about 10,000 or so

Graveyard:

- Hand dismantle
- Then sorted into types: computer plastics and PC plastic
- This is where people enter the NextStep process because you don't have to train people very much and don't have to worry about them breaking potential revenue
- There are 2 types of volunteers:
 - People who are trying to work on their job/social skills, and
 - People who like to hang out around technology and take stuff apart
- Waste stream ← people need to know it

Training center:

- Working with Comcast

Testing:

- Mostly from business, but sometimes both sides
- Takes the longest ← bottleneck
 - 1 box = 2 ½ hours
 - 200 desktops in a month
 - 25 a week
 - All dependent on materials
- Revenue comes from the store /eBay
 - NextStep does not have a system to know when/how long something is on the shelf for

NextStep Notes 5/22/12

- Mike sorts/recycles all of the tech stuff
 - it would make it easier for Mike if there was a centralized recycling location within the plant. or if there was another person to help him
 - since Mike sometimes has to make multiple trips a day, if the bins/location of the recycling was in the same room it might make it easier
- bins → carts → boxes → ship out/conex/annex
- When a box is full it gets labeled, then taken out to a truck, the conex or the annex
- if it goes on a truck it is sent out to a different vendor to be recycled
- if it is stored, when it is ready to be shipped it is put on a pull list and then put on a truck
- the Graveyard → dismantling
 - they take apart everything that needs to be recycled
 - they have bins for:
 - RAM, batteries, daughter cards, screws, processors, wires, computer plastic, motors, etc.
 - Parts goes from the little bins on workbenches to larger barrels in the graveyard to the boxes(recycling crates) outside the graveyard
 - Pictures
 - joking culture, friendly
- Louis: facilitates/oversees everything in the graveyard
 - tools: having enough tools would make it easier to dismantle

- most tools are actually recycling people bring in and NextStep reuses
- Louis and Debbie do the resorting/dumping the barrels of recycling into the larger crates outside the graveyard
 - if there is one thing that is not supposed to be in that barrel then they resort the entire thing.
 - This takes extra time
- It takes about 10 hours to get out of the graveyard to the next stage of volunteering

Austin's notes:

Monitor/TV: 24 hours testing' setup every morning; visual inspection.
 Hard drive: locked for safety; distinguished by size.
 Eval step: slightly higher level than Basic boxing; requires more knowledge.
 Regular staffs are focusing on coordinating volunteers.
 Productivity: 100 units per month.
 Reclaim rate: 7%.
 Current demand data are from two months ago.

Carol's notes:

Testing: Target on process 12 boxes per day with the minimum of 10 boxes
 Build Process: The more uniform the machines came, the more easier for volunteer to process.
 The more touches, the better quality.
 623 days without a lost - time accident.
 Finishing table: install/add the license to finished product and scan the license to their spare sheet and record the pin number back to Microsoft.
 Eval, Basic boxing: peaking time is every school year(July.)
 Saturday-Orientation: take apart-computer(Eval, Basic boxing)-component testing-hands on build training.

Ty's Notes

NextStep Recycling
 DSC 477 Project
 Site Visit Notes

INITIAL MEETING

Contacts

Name	Position	Responsibilities	Phone	Email
Roy Nelson	Facilities Manager	Oversees all material that comes in through the time to the store	Desk: 541.686.2366 ext. 116 Cell: 541.731.9352	Roy.Nelson@nextsteprecycling.org
Josh	Shipping and Receiving	Movement of material in process	Cell: 541.525.6270	

Laurie McVicar	Store Manager		541.686.2366 ext. 124 Cell: 541.337.1089	
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Initial site visit

- Come during operations: Tu-Sa, 10-5
- W, R, Sa w/ Lorraine

Key Areas to Address

- How to better supply store with reusable materials
- Better revenue streams
- Reduce touches
- Improve flow through building
- Streamline
- Keep employee safety in mind at all times

Typical Volunteer Pools

- Interns
- International students
- Community service (required)
- Volunteers (ambassadors-bringing skill to NextStep)

Other

- ~6-8 months move special locations of the warehouse
- ~5-10 years move towards software training
- Potential interviews:
 - Julie Daniel—Bring Recycling (used construction)
 - Terry McDonald—ED at St. Vincent DePaul
 - Habitat for humanity
 - Main differences = training program and giving products away at NextStep

Distribution of sales/product

- Charitable goals are predetermined
 - Goes up depending on sponsor
- Designated employees to decide if online or physical store
 - eBay staff cherry-pick, the rest go to the store
- 2-3 times/week: Business sort (queued pallets of material to go through quickly all at once)

SITE VISIT 1—overview & tour of entire facility (Lorraine)

- Truck loads into the back area

Step 1: Triage

- Main idea: Figure out where to go in the building (1 of 3 places)

1. Recycling (direct and least touches)
2. Q4 wholesale sales – queued bulk items for wholesalers and redistribute unwanted
3. Tech – tested, refurbished, or direct to store
 - Triage: sort to bin there then move bin
 - Majority comes from businesses
 - Separates between business sort and residential
 - Businesses not allowed to get donated product
 - Pick up shrink wrap from business and sell
 - Sell metals: generate \$8-10,000/month

Tech Room—Refurbishing

- Base boxes: queued, stripped down computers (just have a motherboard)
- Then tested
 - Ex. Data protection- wipe and reset
 - Ex. LCD test for 24 hours
- Everything has threshold for what's acceptable
- Inventory specialist communicates to shop about what needs are 1st priority; queue created by need
 - Could be 1 time per week or every other day
 - Coming up with web based or spreadsheet communication for “pick-order”
- Testing is the bottleneck
 - 1 box = 2.5 hours not including queue time
 - Queuing may take a week (depends on material flow)
- 1 electric forklift in test area & propane outside

eBay Store

- \$10,000/month
- Technicians and Jerry queue/pick things for eBay

Front

- Already know units will not be reused
- Sort materials into bins to get salvageable material

Stores (General)

- No system for how long something stays on shelf
- Sometimes (depending on trainees) have more materials ready than store can handle

*Their concern with touches primarily comes from efficiency perspective, not immediate safety concern

SITE VISIT 2—Testing and Building Area (Drew)

- Step 1: count record of monitors on paper
 - Test monitors for 72 hours
- Mike—1st sorting (central location)

Building tables

- 2-4 volunteers
- Later half of the week is usually build
- 1st half: @ least 4 benches on test
- With 1 build coordinator, can't do both (bouncing back and forth)
- Scan & wipe: 1 hour to 5 hours

Sort/Cabinets in sort

- Hard drives – 80 GB
 - Or greater than 80
- Laptops
- Video cards (2 different boxes)
- Data security a main focus of the sort stage
- Can do 12 drives at once
- E-cycles recorded on paper then put into excel monthly

Computers

- 2 step process done by same person
 - Evaluation—higher level of knowledge
 - Baseboxing
- 32 bit machines
 - 4 pallets per month
 - $\frac{3}{4}$ go to stores
 - $\frac{1}{4}$ placement in EPOC and gifting
- 90% of machines = 32 bit
- Sort, eval, baseboxing happens faster than the production rate
 - Sort, eval, baseboxing = 150-200 per month
 - Production rate = 100 per month
- Build cycle
 - 2 computers per station (~16 computers at once if the tables are fully staffed)
 - Then put computers on black pallets at end of tables for the finishing
- Estimated 80% keep rate of boxes that come to testing

Other

- Peak times are beginning of fiscal year and July (school fiscal year)
- Grant placements storage in flux
 - Now being stored on the back side of the finishing table for quality assurance to sign off and finish installations
 - Packaging needed with these (mouse, keyboard, etc.)
 - Now these have started to get queued up together as they move through the process
- Bar Codes & licensures
 - Licensing scanned in for accuracy more than speed
 - Barcode put on at finishing to track through sale (zip code, etc.)

Volunteers & People to get job done

- Biggest limitation from volunteer pool
- Since many just learning, more touches helps to ensure quality assurance
 - < 3% fail rate once through process

- Theoretically: 160-200 units/month if added another staff (but would need volunteers)
- 20 minute start-up and clean-up time
- Build times
 - Experienced volunteer = 20 minutes/box
 - New volunteer = 2 hours/box
- Failed box? Pull out components (sometimes retest)
- Finishing—depends on processer speed
 - Target = 12 boxes per day
 - 10 = minimum
- Failure Rate: 1 in 5 (based on a guess)

Most helpful to look into

- Cleaner streams of products so things are better and faster in this process
- Volunteer handling

SITE VISIT 3—staff meeting and questions with Drew & rest of Team

- Meeting attendance: 7 staff & 2 mentors
 - Discussion broken into categories
 - Cell phone
 - Household
 - Eval
 - Build/production
 - Testing
 - Outbins

Laptops

- Don't typically take volunteers besides the set Team (higher skill level, less availability of replacement parts)
- Useful with 80 hours of training
- Models not to sell are stored in area for if get another of the same model in
 - There are further categories/determinants of keeping these units based on the expectation of further units coming in

Tech Area Volunteer Process

- 10 hours dismantling before coming to Testing
- Work through training in tech area over a few weeks (60 hours total on a regular basis)
 - 1st Harvest- take apart computers
 - 2nd Eval/Baseboxing
 - 3rd Hands-on build training or component testing
- Use plain language training
- Accept any 3 hour chunk of time a week (prefer more & may get pigeon-holed if volunteering minimum)
- There is an emphasis on production in picking the task that volunteers will perform
- LCD monitors, keyboards are always on the list of what volunteers can do
- Production does take priority

Macs

- Macs are a challenge

- Lamp-style priced too high to sell. (Sell when 25% off of \$99, but production for these is half a day's labor)
 - Not profitable
 - Can sell to refurbisher once queued
 - Ex. \$.55 per pound or \$3-8/unit

SITE VISIT 4—Final Questions with Drew & Angel

Products

- Top priority: lies in duration of the test
 - Larger the hard drive, the longer it takes to test
 - Also depends on age
- TVs another priority
 - 50% + fail out
 - Take up space
- Most regular are laptops (highest \$) and computers in general (~50-66% of store income)

*what should not be tested is more important than the priority tests

- Ideal: build all the time, and test all the time
- Store requests 60-70 desktops per month
- \$175 or \$120 cost per computer
 - This is an estimate. Lorraine has exact figure, however the figures are quite old

Standardized Priorities

1. Initial PC Eval
 2. PC Build
 3. External Peripheral Device Testing
 4. Internal Component Testing
- Likely spend about a month on each of the areas to gain an expert understanding (assuming they come in 2 days a week for 3 hours)
 - Steps 2 & 3 can be swapped depending on the time of the week
 - If just minimum (1 3-hour shift per week), knowledge retention is low (80% of next training must be repeated from previous week, 20% new material)
 - Also can be retasked
 - Option to be a “mentor” (train others) but can move on without it
 - I get the impression that most do not become mentors
 - Angel and Michael do training
 - Volunteers are asked to consider committing to a minimum of 90 hours if they want to join the testing/building
 - Try for 2 new volunteers at once to make the most of the trainer's time

Estimated Production Levels (weekly)

- 3 people (experts) – 10-15 units
- 3 beginning volunteers + 3 expert staff (Angel, Michael, Yadira) – 8-10 units
- 3 expert staff + 5 volunteers – double/triple production

- Generally doesn't help volunteer, staff, or production levels to just do one task (pigeon- hole)
 - Same with one-time events (ex. business ABC is volunteering for the day)

What would help Angel most?

- Volunteer retention
- Many volunteers leave after they have completed 60 hours and are eligible for tech grants
 - This is the time when they are becoming skilled enough to impact production levels in a positive way

What would help Drew most?

- More quality material

Warehouse Layout Design at Shady Peeps

MBA Team: Jennifer Adams, Troy Beck, Andy Behl, Peter Kaupert

Industry Sponsor: Caleb Iorg, CFO, Eugene, OR

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 577, Spring 2012

Executive Summary

This paper addresses considerations with respect to Shady Peeps' new warehouse space and the resulting process flow, inventory storage, and workstation layout. As referred to in our previous paper, the goal of the design has two main objectives. One is to create a layout conducive to Shady Peeps and Visionary Lenses' shared use of the shipping and receiving area and the other objective is to design the layout so it also allows for easy expansion as the business grows. The plan that we have developed maximizes the floor space so that the majority of their inventories can be organized on the ground floor and do not have to be stored above the offices, minimizing the amount of stairs employees need to climb. Additionally, our proposed process flow minimizes the distance employees must move to prepare, assemble, and ship orders. Finally, our recommended solution aligns with Shady Peeps' desire to keep wholesale and custom order assembly stations separate.

Background

Shady Peeps LLC was launched in 2010 after its founder Jason Bolt recognized a market opportunity to sell university licensed polarized sunglasses to sports fans. The sunglasses provide ultraviolet solar protection at sporting events while providing fans with one more way to

show their team enthusiasm. The first sunglasses were sold at the University of Oregon and with over 25% of the student population purchasing a pair, they were an instant success.

Shady Peeps has grown rapidly in the last three years. Last year, Shady Peeps was licensed to sell sunglasses with logos of each of the universities in the PAC 12 and this year it has increased its licensed offering to 54 different universities. A typical retail shop order ranges between 40 and 300 pairs of sunglasses and 85% of Shady Peeps sales are from these bulk orders.¹

In addition, Shady Peeps also takes custom orders. Custom orders are made through Shady Peeps' website and may be for one pair or for any small quantity. Through custom orders, customers may purchase personalized sunglasses for themselves or for a group of friends or associates. Between 10 different color temples, 10 different color frames, and 6 different color lenses, Shady Peeps offers 600 color combinations for custom orders. In the next couple of years, Shady Peeps plans to increase the percent of custom orders it sells. Because the requirements for processing custom orders differ from processing bulk orders, these two processes are kept physically separate in the warehouse.

All of Shady Peeps products are manufactured in China, which requires a sixty day ordering lead-time. Because of this large lead-time, Shady Peeps attempts to order a sufficient amount of inventory to avoid ordering more than a few times per year. This means that Shady Peeps needs sufficient storage capacity to store and meet the challenges of dealing with large product quantities.

¹ *Shady Peeps Website*. 2012. Web. June 8, 2012. <http://www.shadypeeps.com/aboutus.asp>

To accommodate its rapid expansion, Shady Peeps recently relocated to a new warehouse. In this report, we share our recommendation for a new warehouse layout that will allow Shady to maximize its operational efficiency and capacity.

Process

We initially met with Caleb Iorg, CFO of Shady Peeps, in mid-April and were able to see their new facilities first-hand. We found a considerable amount of space with which to work, including the possibility of utilizing inventory storage above their current office space. To begin our analysis, we first wanted to understand exactly how the process flows for placing, accepting, fulfilling, and shipping orders worked. Figure 4 in the appendix shows a graphical representation of the following steps in the overall process flow.

Web Orders: There are currently two ways that orders enter the system. For the first one, the customer places an order online and it is sent to a central server, which prepares and delivers a daily report to the sales team for review (which is currently comprised of just Caleb).

Wholesale Orders: Larger customers who order wholesale work with the sales team directly to help determine their specific needs and place appropriate orders according to product mix and quantity. After review, the order is submitted for processing much like the web orders.

Purchasing: Once the sales department has confirmed that the orders are legitimate and valid (regardless of web orders or wholesale), the order is approved and submitted for fulfillment. The purchasing department reviews the order to ensure that there are enough items in stock to fulfill the order. If not, it makes the appropriate adjustment to its supplier's order to meet demand.

Q/A: Once new items are received from the supplier, it is one of Shady Peeps' priorities to review the quality of the shipment to verify that there aren't any scratched lenses, broken frames or temples, and that the colors and logos are consistent. It is at this point that any disputes in

quality must be declared so that product can be returned or replaced, depending on the terms and conditions of the order.

Inventory: Having verified that the shipment meets specifications, its contents can be allocated to inventory and entered into the tracking system. Product will be arranged alphabetically, according to SKU so that workers are able to easily locate each item necessary to fulfill an order. It is also at this point that Shady Peeps has the option to send items to a “reprinter” to help alleviate excess stock by changing logos or converting licensed items to items without a logo.

Assembly: Once a worker has order instructions and the items are located in the inventory shelving system, the process for customs and wholesale orders are generally very similar. The items are brought back to a workstation where they will be assembled accordingly, packaged, and prepared for shipment. For the customs orders and lower-volume web-orders, this is in the designated area in the top right-hand corner of the diagram and for wholesale orders; these workstations are centrally located with ease of access to inventory prioritized. (See Figure 3)

Layout Options & Decision

The current ad hoc layout that Shady Peeps utilizes was left intentionally flexible for the MBA group to analyze and adjust. Figure 1 most resembles the existing layout and focuses on providing maximum floor space for production and space for workers. However, once this model was put to scale and analyzed, it was determined that the storage capacity

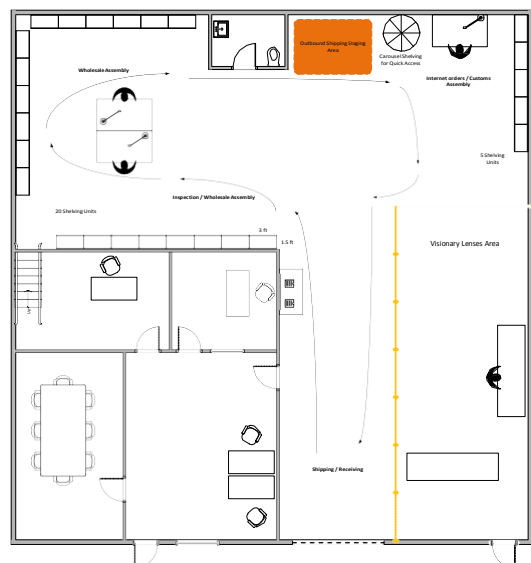


Figure 1

of this simple layout was approximately 57,600 shades.

A simple reversal of inventory as seen in Figure 2, from the wall to the middle and a shift of workers' stations to the wall also yields a similar capacity of 57,600 units from a layout of 20 shelving units.

This model yielded a storage capacity that may address current needs; however through some reconfiguration, there is an even greater potential to grow this capacity. In addition, when considering process flows and the need for workers to

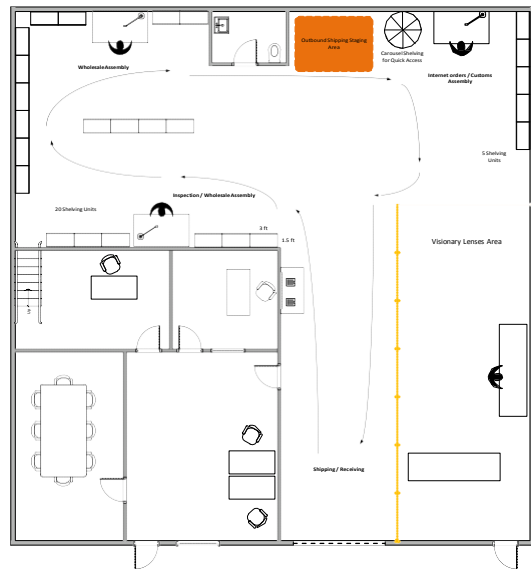


Figure 2

communicate with each other and create potential production synergies in the future, a third basic model was developed as illustrated in Figure 3.

This model features workers together in the middle with ample shelving along the walls and in bays that were created. Shelving unit capacity was increased from 20 units to 34 units from prior models. Capacity of individual units was increased from 57,600 to 97,200. With this set-up, there is room to

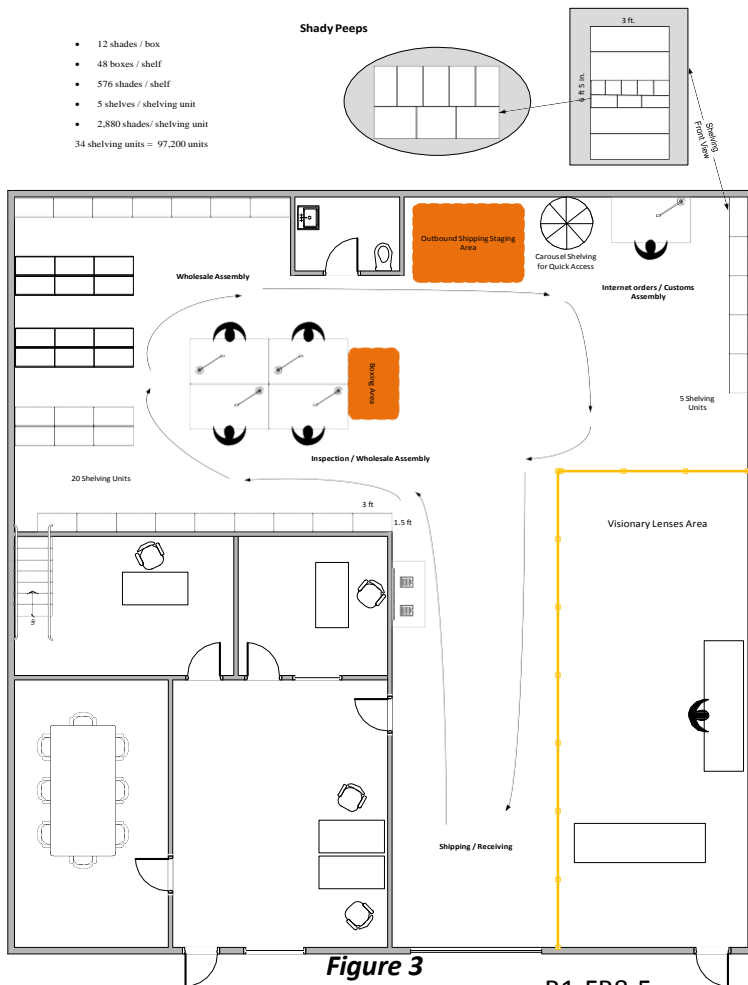


Figure 3

B1-FB8-5

easily add increased capacity at both ends of the bays and along the bathroom for a higher capacity of 123,840 units. Based on future needs for inventory capacity and space for workers, packaging, and staging, this model can be easily adapted in a way that meets all of these needs while still supporting the process flow of the overall operation.

Capacity Calculation Assumptions & Implications

- 12 shades / box
- 48 boxes / shelf
- 576 shades / shelf
- 5 shelves / shelving unit
- 2,880 shades/ shelving unit

Given these assumptions, one key to increasing capacity is to maximize the number of shelving units placed on the warehouse floor without impeding the workspace. These assumptions also have implications for stock keeping practices. Currently, orders for each school are between 1,200 and 4000 units. This means that for each school that Shady Peeps adds to their product line, they will need at least half of a shelf available. If the organization adds 20 more school licenses between 2012 and 2013, the organization can roughly predict a needed increase and space allocation of 10 more shelving units. These models, assumptions, and implications are estimates which are brought forth for the management of Shady Peeps to use as a reference in their future layout planning based on expected inventories, new school licenses obtained, and future inventory policies.

Logistics

As previously mentioned, the wholesale orders come in directly via email or phone call. The custom and web orders are batched and printed at 8:30/9:00 a.m. each morning and ship to the

customer on that same day. We recommend placing a small table just outside the main office door with two inboxes where orders are placed as they come in. From there, the worker fulfilling the order picks up the order and walks to the area where inventory is held. In the inventory bays we recommend organizing the product alphabetically by school, so that it is easy to know where product should go as it comes in. How much shelving space should be taken up by each school can be determined based on forecasted order sizes and supply levels.

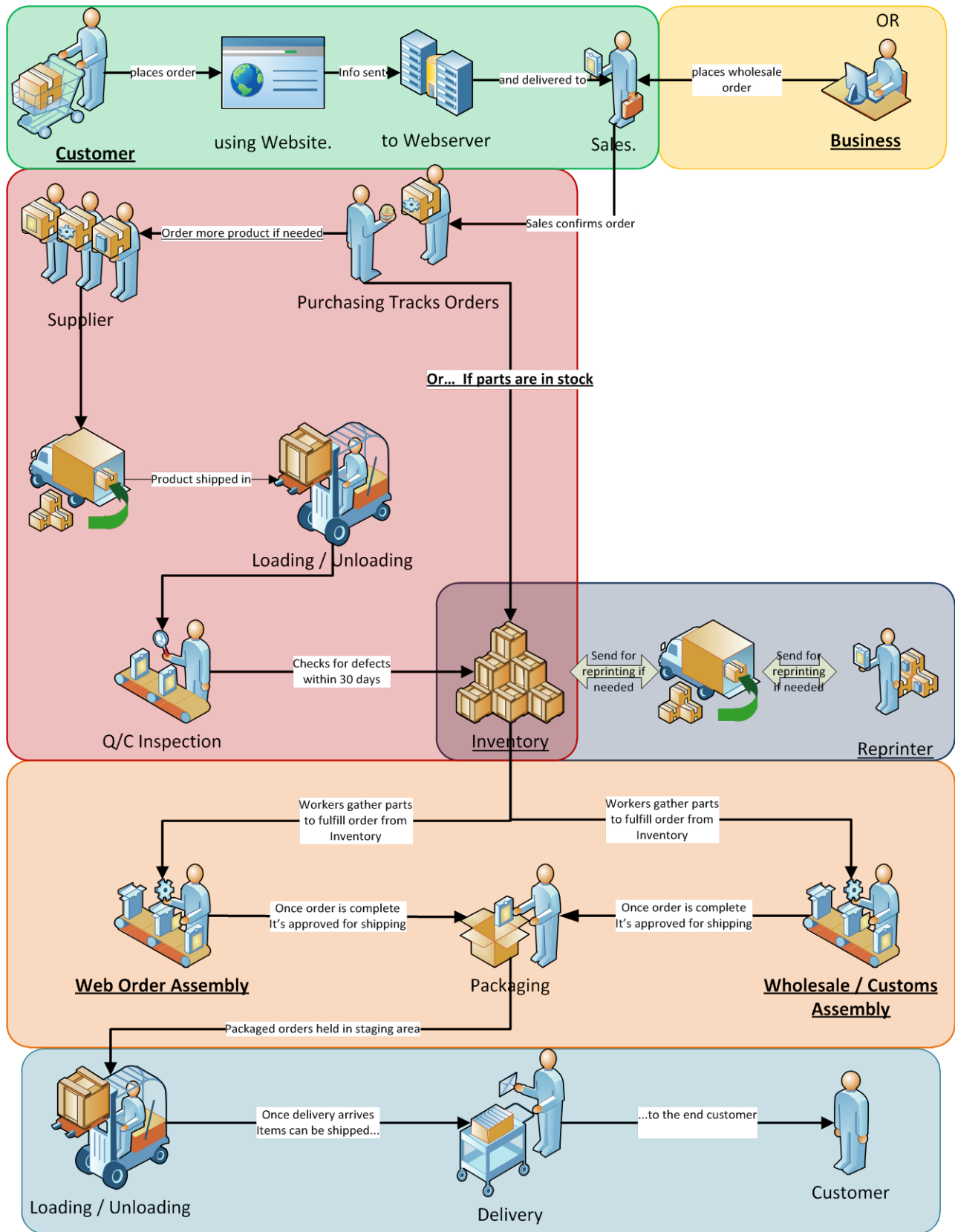
At the end of each of the 3 bays on the left side of the stock room we recommend placing a sheet protector that is zip-tied to the end of the rack with a sheet of paper inside that lists what product can be found in that row. From prior experience in retail, some of our team members found this to be a very useful tool to speed the process along as orders are being processed, especially if you have a new employee. Once the product for the order is pulled, the employee returns to the table in the center of the area, assembles the order, completes the quality control check, and boxes the order for shipping after verifying that everything in the order is accurate. The order is then placed in the Box Staging Area until the next delivery truck comes to pick up the order.

We anticipate a similar system for the custom and web orders. The orders are placed in the inbox and once the employee collects the orders, he or she walks to the custom/web orders station in the right back corner of the warehouse. Here, we recommend five shelving units, two of which are fully stocked with the complete selection of custom colors, and contain two rows at the bottom of the racks for spare parts in bins. The other three shelving units hold a smaller inventory of the different school licensed product for web orders. Here we recommend a table where the employee would put the order together, box it up, and prepare it for shipping by placing it in the Box Staging Area. We also recommend keeping a sunglass carousel at this station so as the licensed products are taken apart and the opposites are re-assembled for later use, they can be stored here to prevent any damage or scratching.

Conclusion

Due to the new layout, which allows all inventory to be stored at the ground level, Shady Peeps will see improved access to inventory, which lowers the amount of time spent locating the correct pieces to fill an order. By decreasing seek-time, each workstation will experience an increase in its flow rate and a general increase in worker productivity. This increase in productivity has the effect of providing lower labor costs per pair of sunglasses, while simultaneously decreasing holding costs.

In addition to our current recommendations, as the business grows, the floor space will eventually be insufficient to contain the entire inventory, and so one option is to allocate storage above the current offices. Moving forward, it is advised to examine the feasibility and cost of relocating the offices to the area above their current location. This will make the current office space available for additional workstations and/or inventory storage and possibly even accommodate a new loading bay, which could in turn lead to an even more improved work flow and increased flow rate.



Effects of Hard-to-Recondition Containers on Efficiency at Myers Container

UGTeam: Rodd Danpour, Mitchell Eckberg, Kerin Green, Amber Liu, Hogan Scholten

Industry Sponsor: Cody Stavig, Plant Manager, Owner, Myers Container

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 477, Spring 2012

Executive Summary

Myers Container reconditions steel drums, intermediate bulk containers, and high density polyethylene drums. These products are picked up from various companies and brought back to Myers Container to be reconditioned and resold to either the previous customer or a new customer.

The issue with reconditioning these units is that some require extra processes to be resalable. They may need to be de-dented, chained, or hard-washed depending on the degree of damage or previous use. These procedures require extra labor hours to run the machines and equipment in order to ensure products that would otherwise be scrapped still remain resalable.

Through our research and analysis we wanted to find the affect these-hard-to-recondition units had on the overall efficiency of labor. We claimed the efficiency variable to be units completed per man hour. We also wanted to find out at what amount of units does the units per man hour start to decrease rapidly. From this information we would be able to decide how much money could be potentially made or lost from scrapping extra units in return for more efficiency.

Our solution methodology included the use of SPSS, which is statistical analysis software. We wanted to run regressions through the data we had received in order to find out what caused the

largest variations in units per man hour. The data we had included units per man hour, the number of units cleaned, and the number of units that required extra cleaning processes. The data was tracked on a daily basis. Our analysis revealed that we didn't have the correct information to accurately correlate units per man hour with the hard-to-recondition units, so the rationale behind our solution is based on some underlying assumptions

Business Overview

Brief History

Meyers container is a fourth generation, family-owned business that dates back to 1917. In 2007 the Stavig brothers acquired Meyers Container and its subsidiary, Container Management Services. In 2011 the Stavig brothers added General Steel Drum in North Carolina to the Meyers family.

Meyers Container is managed and operated using the Meyers Container/Container Management Services business system. By utilizing industry-leading technology and human resource development, Meyers Container is able to deliver quality products in a timely manner and with excellent customer service.

Meyers Container believes in minimizing its environmental impact and is continually developing a company culture that strives to eliminate waste. By focusing on sustainability and lean manufacturing, Meyers Container aims to be a zero discharge community participant.

Business Scope

With operations in California, Oregon and North Carolina, Meyers Container deals in the manufacturing, collection, reconditioning and recycling of various containers.

New Containers

- Meyers Container manufactures a complete line of steel drums in various 10-85 gallon capacities and configurations.
- Most common variation is tight-head versus open-head, see Appendix A.

Steel Drums



- Intended for use as ship and storage containers for radioactive materials.

7A Type A Steel Drums



- 55 gallon steel drum with a "W" swedge configuration designed to optimize transportation for drums being shipped overseas.

ISO Export Steel Drums



- Salvage drums are designed to hold damaged or leaking drums to ensure safe transportation.
- Overpack drums are used as additional protection for the shipment of drums and other packages.

Salvage/Overpack Drums



- 55 gallon steel drum with a 40 mil rigid polyethylene bottle insert designed for hard-to-hold corrosive materials.

Composite Drums



- Offered in 55 gallon capacity and includes welded bodies, bottoms and covers for both open-head and tight-head drums.
- These are great for stacking and shipping when being assembled at a later time is convenient.

Knock-Down Drums



Reconditioned Containers



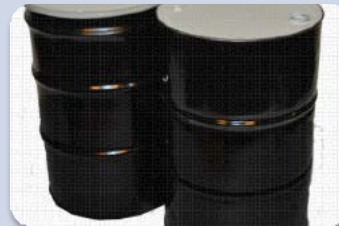
Intermediate Bulk Containers (IBCs)

- Used for the storage of fluids and bulk materials.
- Composed of stainless steel cage that surrounds a polyethylene bladder, available in 275 and 330 gallon capacities.



High Density Polyethylene (HDPE) drums

- Used for a variety of industrial processes and are available in 15, 30, 55 and 95 gallon capacities.



55 Gallon Steel Drums

- Offer quality comparable to new steel drums while reducing demand for raw materials..
- Most common variation is tight-head versus open-head, see Appendix A.

Container Collection

In-order-to recondition the listed containers, Meyers offers collection services to recover used containers for reconditioning. These services require a minimum number of containers to be picked up at once and that all containers be drip dry, have labels in place and all closures/openings must be secured/sealed.

Recycling Services

Meyers Containers also offers recycling services for industrial plastics and non-serviceable containers. Industrial plastics include pails, buckets, pallets, plastic film, and super saks. Non-serviceable containers are recovered containers found to be unfit for reconditioning and are scrapped for the materials to be recycled. These materials are ground into pellets and resold as raw materials.

Business Processes

Although Meyers Container provides services that encompass the manufacturing of new drums, the collection and reconditioning of old containers, and the recycling of non-salvageable products; **this report we will only focus specifically on the reconditioning of tight-head drums, open-head drums, and IBCs.**

Reconditioning

Once it is decided that a container is eligible for reconditioning it begins the reconditioning procedure. During this procedure the container undergoes various processes to return it to resalable condition. Some processes are fairly standardized and simple; rinsing, shot blasting, painting, and labeling; but others are much more complex and cost valuable time and money to be undertaken on harder to recondition containers. These processes are referred to as labor intensive reconditioning process or LIRPs; **this report will only focus specifically on the LIRPs of previously stated containers (tight-head drums, open-head drums, and IBCs).**

Labor Intensive Reconditioning Processes (LIRPs)

Washing

Containers with residual contents undergo a washing process. This process uses a caustic solution to remove any remnants within the container. Washes are classified by regular, hard and extreme, and differ by the amount of time needed to complete each. Regular washing requires a standardized period of time, hard washing requires an additional period, and extreme washing requires an additional period yet.

Dedenting

Containers with superficial dents undergo a de-denting process. This process uses a unique machine that applies force to the inside of a container to pop out any dents that may have resulted from the containers previous use. It is not always the case that containers look like new, but they are sufficiently refurbished for resale. The de-denting process is exclusive to steel tight-head drums.

Chaining

Containers with internal rust buildup must undergo a chaining process. This process uses sharpened chains and a rotating machine to dislodge any rust. Chains are placed into the containers, the containers then placed on the rotating machine and as the container is rotated the abrasion of the chains removes rust, leaving a bare metal surface. The chaining process is exclusive to steel tight-head drums.

Re-bottling

IBC with irreparable damage to the polyethylene bladder must undergo a re-bottling process. This process requires the opening of the stainless steel cage and the removal and replacement of the internal bladder. This salvages the stainless steel cage, which would have otherwise become scrap. The re-bottling process is exclusive to IBCs.

These exact processes vary between plants and containers and are only applied to containers as needed.

LIRPs Required by Container Type

IBCs	Tigh-Head Drums	Open-Head Drums
<ul style="list-style-type: none">•re-bottling•washing	<ul style="list-style-type: none">•washing•dedenting•chaining	<ul style="list-style-type: none">•washing

Plant Operations

Although Meyers Container owns and operates facilities in Portland, Oregon; City of Industry, California; Hayward, California; and Charlotte, North Carolina; **this report will only focus specifically on two Portland facilities, Saint Helens and Marx Crossing, and one California facility, Hayward.**

Saint Helens

Saint Helens houses operations to recondition both open-head and tight-head steel drums but only tight-head LIRPs are document. See Appendix B for a flow chart of the reconditioning process for tight-head drums at Saint Helens.

Marx Crossing

Marx Crossing houses operations to recondition both HDPE drums and IBCs but only IBC LIRPs are document. See Appendix C for a flow chart of the reconditioning process for IBCs at Marx Crossing.

Hayward houses operations to recondition both open-head and tight-head steel drums and documents LIRPs for both. See Appendix D for a flow chart of the reconditioning process for open-head and tight-head drums at Hayward.

Project Overview

As stated, our project scope is limited to the analysis of the LIRPs applied to tight-head drums, open-head drums, and IBCs at Saint Helens, Marx Crossing and Hayward plants. We have been provided metrics from each plant that include information such as; number of units produced, labor hours used, number of units processed at each LIRP, and an efficiency metric (UPMH=total number of units produced / total labor hours).

The goal of our analysis was to discover what affect each LIRP had on efficiency at each plant. As the LIRPs are inherently more time consuming, it is obvious that they should negatively affect efficiency (UPMH), but we would like to know the exact affect each individual LIRP has on UPMH, and what affect do hard to recondition containers have on UPMH as a whole.

Objectives

Some of the questions we hoped to answer were:

When the Saint Helens plant runs X amount of chainers, UPMH can be expected to decrease by Y units.

When the Hayward plant runs X amount of open-head hard washes, UPMH can be expected to decrease by Y units.

When there are no hard-to-recondition units, UPMH can be expected to increase by Y units.

Methodology

To attempt to predict UPMH by the number of units undergoing LIRPs we ran linear regressions with UPMH as the dependent variable as well as the number of units run through each LIRP on a certain day and created a new variable for products which were produced but not run through

any of the hard to recondition processes as the independent variables. We applied the four principle assumptions of linear regression:

1. Linearity of the relationship between the dependent and the independent variables
2. Independence of the errors or, no serial correlation
3. Homoscedasticity (constant variance) of the errors
4. Normal distribution

However, we quickly began running into problems with our datasets. The first problem was with the variable UPMH. UPMH is determined by taking the total output in units and dividing it by the total number of labor hours (regular and overtime). We want to predict UPMH based on the amount of units that are run through each or no LIRPs. From the production function we know that output of a firm is a function of all combinations of inputs. The problem is that labor hours are an input, so we are building our dependent variable by dividing an output by an input and we are then trying to predict the dependent variable with inputs. The result is not a linear equation and therefore problematic to attempt to use in a linear regression.

To deal with the flawed UPMH variable we decided to run two different linear regressions. One was to attempt to predict total hours using LIRPs and output as the independent variables. The second was to attempt to predict total output using the LIRPs as an input. Based on the information we had, total hours and total output were the best potential measures of labor efficiency.

The second problem was potential redundancy within the data. As we looked through the daily results we noticed a few glaring inconsistencies. On some days, no labor hours were worked yet there was output. On other days the amount of output for a type of product was less than the amount of products run through one or more of the LIRPs. We deduced that it was an issue of faulty data entry or a number of the products went through one, some or all of the production processes on a different day than the day they were counted as output. Furthermore, we have

no way of knowing if the same unit went through multiple of the hard to recondition processes.

This potential redundancy could dramatically skew the results we saw.

To try and correct the data redundancy problem, we ran a couple of different regressions experimenting with lag and logarithmic smoothing to see how large the variance was of the errors. Based on the error distribution we were able to determine the best fitting model from the data.

Finally we ran into trouble due to the size of our datasets. While St. Helens and Hayward had enough data points to run a regression, more data could have given us a better understanding of the trends and allowed us to derive better models from the data. We only had 13 data points to work with from the Marx St. plant, which was not enough to run any kind of analysis. The problem with the Marx St. plant will be discussed in further detail below.

Analysis

Saint Helens

SPSS Models (see Appendix E for detailed data)

Total Output

Model 1: Total Tight-Head Drums Produced= $B_0 + B_1(\text{Dedented}) + B_2(\text{Hard Wash}) + B_3(\text{Chainers})$

Adj. $R^2 = .81$

F-stat= 175.46 Sig=.00

$B_0 = 46.2$ Sig= .00

$B_1 = .92$ Sig= .00

$B_2 = -.06$ Sig= .17 (Statistically Insignificant)

$B_3 = -.07$ Sig= .09

Total Hours

Model 2: Total Hours = $B_0 + B_1(\text{Dedenters}) + B_2(\text{Chainers}) + B_3(\text{Hard Wash}) + B_4(\text{Total Open-Heads Produced}) + B_5(\text{Tight-Head Produced Without LIRPs})$

Adj. $R^2 = .69$

F-stat = 56.77 Sig = .00

$B_0 = 71.75$ Sig = .00

$B_1 = .30$ Sig = .00

$B_2 = .05$ Sig = .33 (Statistically Insignificant)

$B_3 = .04$ Sig = .48 (Statistically Insignificant)

$B_4 = .82$ Sig = .00

$B_5 = .39$ Sig = .00

Explanation

From our regression models we get a plethora of information. To begin we can see that Model 1 would provide us with the best prediction of LIRPs on production but because of the limitations in our provided data set, this model only explains variation in the production of tight-head drums. Our Adjusted R^2 from Model 1 tells us that over 80% of the variation in tight-head production (dependent variable) is explained by variation in the dedenting, wash, and chaining processes (our independent variables). With a large F-statistic that is statistically significant (.00), we can conclude that this model is useful in predicting the marginal effects of LIRPs on Tight-Head Production.

These Marginal effects are represented by the coefficients (B_1, B_2, B_3). So, from B_1 we can expect a .08 (.08 = 1 - .92) decrease in production of tight-head drums, for every additional drum that is dedented, holding all else constant. Similar inferences may be drawn from B_2 and B_3 . B_0 however, is a constant and tells us that given no LIRPs (dedenters, chainers, washes = 0) we can expect a baseline production of 46.2 tight-head drums.

Although Model 2 does not have as strong of an R-Squared and F-Statistic values, it is more likely to give us a better gauge of LIRPs effect on efficiency since it predicts total hours as a function of number of units undergoing LARP problems. Similarly to Model 1, the coefficients (B_1 , B_4 , B_5) can also be analyzed as the marginal effect of a given LIRP on total labor hours, but we cannot draw these inferences from B_2 or B_3 since they are not statistically Significant (sig. > .1).

Marx Crossing

From the data we received there were only 4 weekly observations and 13 daily observations. This not sufficient to provide statistically significant models using SPSS and we were therefore unable to analyze the effects of LIRPs on the efficiency at Marx Crossing.

Hayward

SPSS Models (see Appendix F for detailed data)

Total Output

Model 1: Total Tight-Head Drums Produced= $B_0 + B_1(\text{Tight-Head Hard Wash}) + B_2(\text{Chainer})$

Adj. $R^2 = .21$

F-stat= 11.12 Sig=.00

$B_0 = 332.57$ Sig= .00

$B_1 = .18$ Sig= .01

$B_2 = .41$ Sig= .00

Model 2: Total Open-Head Drums Produced= $B_0 + B_1(\text{Open-Head Hard Wash}) + B_2(\text{Open-Head Extreme Hard Wash})$

Adj. $R^2 = .66$

F-stat= 76.748 Sig=.00

$B_0 = 134.22$ $\text{Sig} = .00$

$B_1 = .73$ $\text{Sig} = .00$

$B_2 = .13$ $\text{Sig} = .18$ (Statistically Insignificant)

Total Hours

Model 3: Total Hours = $B_0 + B_1(\text{Open-Head Hard Wash}) + B_2(\text{Open-Head Extreme Hard Wash})$

* $B_3(\text{Tight-Head Hard Wash}) + B_4(\text{Chainer})$

Adj. $R^2 = .51$

F-stat = 20.65 $\text{Sig} = .00$

$B_0 = 107.7$ $\text{Sig} = .00$

$B_1 = .66$ $\text{Sig} = .00$

$B_2 = .00$ $\text{Sig} = .99$ (Statistically Insignificant)

$B_3 = .17$ $\text{Sig} = .42$ (Statistically Insignificant)

$B_4 = .07$ $\text{Sig} = .04$

Explanation

After analyzing our Hayward regressions we can see that our strongest model was the prediction of open-head drums produced as a function of open-head LIRPs (Model 2). Although this model is useful in predicting open-head production, it tells us very little about overall efficiency. For a better grasp on overall efficiency we can look to Model 3, which predicts total hours as a function of LIRPs. In Model 3, about half of the variation in total hours explained by variation in number of units that undergo LIRPs. Looking at the predicted coefficients we can also see that the open-head hard wash LIRP process had the largest effect on total hours.

Recommendations

Data Collection

Processes per Unit

Currently, the given data does not track what is specifically happening to each unit. Therefore, we cannot connect drums to processes to see how much time is spent on each individual unit. There is also no tracking on what processes have been completed on unfinished units. Because the overall reconditioning time varies widely per unit, tracking what happens to each unit is essential in developing and applying statistical analysis or regression to gain further insight on the plants current inefficiencies. Our recommendation is to implement a way to track these processes to improve overall data quality that offers a better opportunity for valuable analysis.

Labor per Process

By tracking what processes are completed on each unit, we can properly analyze the utilization of the reconditioning machines. With this procedure, we can better predict the most efficient order of the daily operations. Once an efficient order is identified, staging procedures for each operation will help improve the throughput rate of the plant. Staging parts before they enter a chainer, dedenter, or hard wash in a queue will cut down on the time required to move a batch or number of units through the process.

Labor per Unit

Labor is an important cost to the daily operations at Myers Container. Currently, the given data only tracks labor hours in terms of regular hours, overtime hours, and total hours. Tracking the labor hours per process will allow for a more in depth and significant analysis of UPMH. If each individual process completed per unit can be linked to labor time per unit, the most efficient and

inexpensive daily operation can be achieved through the application of similar analytical techniques used in this project.

Conclusions

Project Take-Aways

Upon receipt of the given data and spreadsheets, it was difficult to identify a proper place to begin our analysis. It was necessary to conduct a site visit and multiple conference calls in order to develop an understanding of the problem at hand. Data collection and analysis is very complex with companies like Myers container that have live processes running many hours of the day. Therefore, identifying the problem is essential to then finding a solution. This requires a proper understanding of operations on the floor of the factory. Without site visits and observation of these processes, the data has no meaning. Understanding the context is essential developing the best technique for approaching the identification of plant inefficiencies. With the problem defined, and the processes properly tracked, the same analytical techniques used in this project will prove to be beneficial in utilizing UPMH as a metric of efficiency at Myers Container.

Appendices

Appendix A

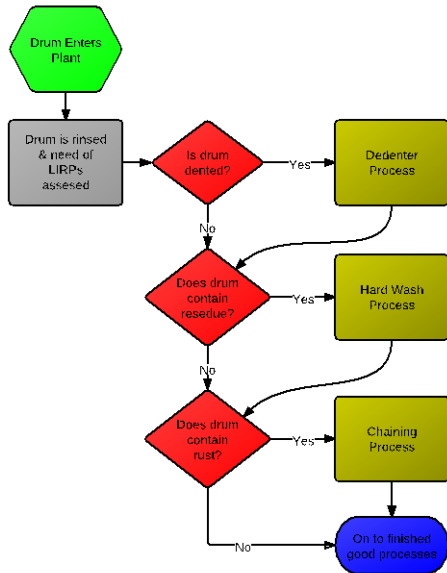
Tight-Head Drums versus Open-Head Drums

Tight-head drums are completely sealed with a chime at both ends (left). Open-heads have a removable cover that is fastened with a bolt-tightened ring (right).



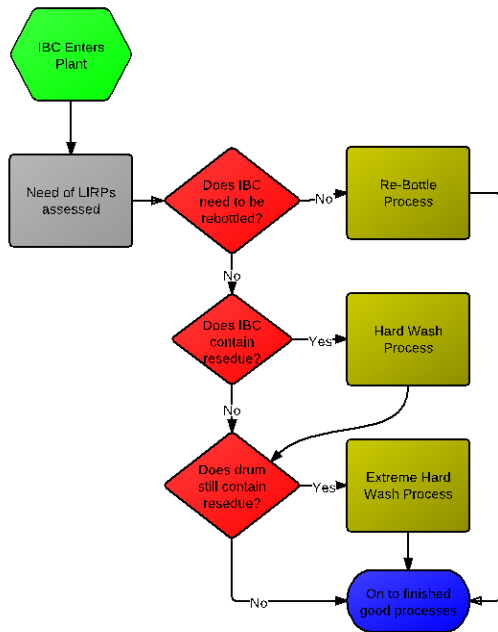
Appendix B

Flow Chart: Saint Helens Tight-Head Drum Reconditioning



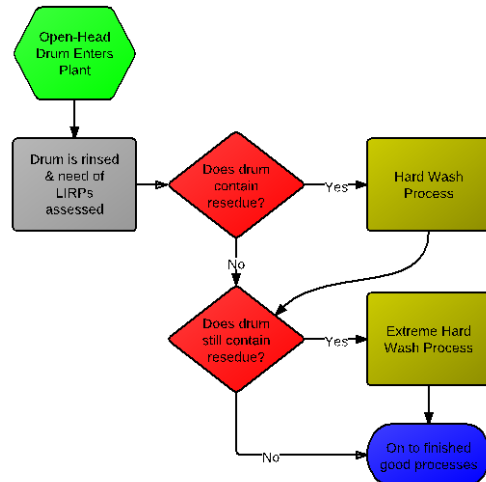
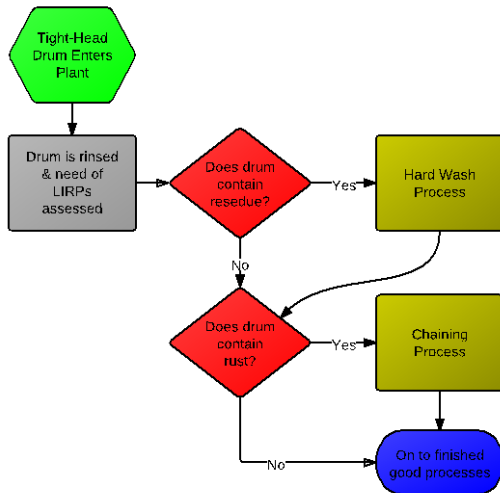
Appendix C

Flow Chart: Marx Crossing IBC Reconditioning



Appendix D

Flow Chart: Hayward Tight-Head Drum (left) & Open-Head Drum (right) Reconditioning



Appendix E

Saint Helens SPSS Model Data

Model 1

Variables Entered/Removed^b

Model	Variables Entered	Variables Removed	Method
1	TH Hard Wash Processed, Chainers Processed, Dedenters Processed	.	Enter

a. All requested variables entered.
b. Dependent Variable: TH Drums Produced

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.901 ^a	.812	.807	124.7951

a. Predictors: (Constant), TH Hard Wash Processed, Chainers Processed, Dedenters Processed

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8197854.162	3	2732618.054	175.462	.000 ^a
	Residual	1900006.544	122	15573.824		
	Total	10097860.70	125			

a. Predictors: (Constant), TH Hard Wash Processed, Chainers Processed, Dedenters Processed
b. Dependent Variable: TH Drums Produced

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	46.200	12.729		3.630	.000
	Dedenters Processed	2.851	.127	.922	22.466	.000
	Chainers Processed	-.693	.502	-.055	-1.381	.170
	TH Hard Wash Processed	-3.552	2.079	-.070	-1.709	.090

a. Dependent Variable: TH Drums Produced

Model 2

Variables Entered/Removed^b

Model	Variables Entered	Variables Removed	Method
1	OH Drums Produced, Chainers Processed, TH Hard Wash Processed, TightHead_ProducedNotProcessed, Dedenters Processed	.	Enter

a. All requested variables entered.
b. Dependent Variable: TotalHours

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.838 ^a	.703	.690	30.68971

a. Predictors: (Constant), OH Drums Produced, Chainers Processed, TH Hard Wash Processed, TightHead_ProducedNotProcessed, Dedenters Processed

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	267353.517	5	53470.703	56.772	.000 ^a
	Residual	113022.979	120	941.858		
	Total	380376.496	125			

a. Predictors: (Constant), OH Drums Produced, Chainers Processed, TH Hard Wash Processed, TightHead_ProducedNotProcessed, Dedenters Processed
 b. Dependent Variable: TotalHours

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	71.752	4.884		14.692	.000
	Dedenters Processed	.181	.052	.301	3.455	.001
	Chainers Processed	.121	.125	.049	.971	.334
	TH Hard Wash Processed	.374	.522	.038	.717	.475
	TightHead_ProducedNotProcessed	.106	.023	.391	4.702	.000
	OH Drums Produced	.135	.009	.815	15.138	.000

a. Dependent Variable: TotalHours

Appendix F

Hayward SPSS Model Data

Model 1

Variables Entered/Removed^b

Model	Variables Entered	Variables Removed	Method
1	TightHead_Chain, TH Hard Wash Processed	.	Enter

a. All requested variables entered.
 b. Dependent Variable: TH Drums Produced

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.476 ^a	.226	.206	213.1985

a. Predictors: (Constant), TightHead_Chain, TH Hard Wash Processed

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1010842.044	2	505421.022	11.119	.000 ^a
	Residual	3454473.045	76	45453.593		
	Total	4465315.089	78			

a. Predictors: (Constant), TightHead_Chain, TH Hard Wash Processed
 b. Dependent Variable: TH Drums Produced

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	332.574	29.259		11.367	.000
	TH Hard Wash Processed	1.690	.976	.178	1.731	.088
	TightHead_Chain	2.776	.699	.408	3.973	.000

a. Dependent Variable: TH Drums Produced

Model 2

Variables Entered/Removed^b

Model	Variables Entered	Variables Removed	Method
1	OH Extreme Hard Wash Processed, OH Regular Hard Wash Processed	.	Enter

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.819 ^a	.671	.662	160.2102

a. All requested variables entered.

b. Dependent Variable: OH Drums Produced

a. Predictors: (Constant), OH Extreme Hard Wash Processed, OH Regular Hard Wash Processed

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3926203.635	2	1963101.818	76.483	.000 ^a
	Residual	1925047.813	75	25667.304		
	Total	5851251.449	77			

a. Predictors: (Constant), OH Extreme Hard Wash Processed, OH Regular Hard Wash Processed

b. Dependent Variable: OH Drums Produced

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	134.218	28.719		4.673	.000
	OH Regular Hard Wash Processed	.945	.121	.725	7.784	.000
	OH Extreme Hard Wash Processed	1.921	1.407	.127	1.365	.176

a. Dependent Variable: OH Drums Produced

Model 3

Variables Entered/Removed^b

Model	Variables Entered	Variables Removed	Method
1	TH Hard Wash Processed, OH Regular Hard Wash Processed, Chainers Processed, OH Extreme Hard Wash Processed	.	Enter

a. All requested variables entered.
b. Dependent Variable: TotalHours

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.731 ^a	.534	.508	48.59773

a. Predictors: (Constant), TH Hard Wash Processed, OH Regular Hard Wash Processed, Chainers Processed, OH Extreme Hard Wash Processed

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	195090.912	4	48772.728	20.651	.000 ^a
	Residual	170045.263	72	2361.740		
	Total	365136.175	76			

a. Predictors: (Constant), TH Hard Wash Processed, OH Regular Hard Wash Processed, Chainers Processed, OH Extreme Hard Wash Processed
b. Dependent Variable: TotalHours

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	107.701	9.156		11.763	.000
	OH Regular Hard Wash Processed	.219	.037	.664	5.889	.000
	OH Extreme Hard Wash Processed	.006	.444	.002	.014	.989
	Chainers Processed	.137	.170	.073	.810	.421
	TH Hard Wash Processed	.475	.222	.174	2.139	.036

a. Dependent Variable: TotalHours

Appendix F References

meyscontainer.com (website)

Regression Analysis 7th Edition, Mendenhall & Sinichich (DSC330 text)

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Order Process Fulfillment Analysis for Visionary Lenses

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Field Project: DSC 477, Spring 2012

Executive Summary

Visionary Lenses opened in Eugene, Oregon in 2009. Their business revolves around selling replacement lenses for Oakley sunglasses on Ebay, Amazon and through their company website.

Supply Chain

Visionary Lenses uses 4 employees to ship their lenses. Once the lenses are checked for quality, they are placed in their appropriate bins. Each day, the employees fill the orders by grabbing the lenses from their bins and packing them into boxes. The issue being analyzed is how do we ensure that the lens bins are always full and how can we reduce the amount of time that quality checking takes.

Objectives

The objectives associated with the use of acceptance sampling are as follows:

- Reduce costs
- Reduce QC time
- Increase daily shipment capacity
- Find mean amount of defective lenses (in specific lot size)

We feel that we can use the process of “acceptance sampling” to achieve our objectives.

Acceptance Sampling

The methodology behind acceptance sampling is to build guidelines for determining acceptance or rejection of a lot of materials based on clearly defined sampling rules. If done correctly, Visionary Lenses will be able to determine specific acceptance guidelines that will enable them to either accept an entire lot of lenses or reject the whole lot.

This should enable Visionary Lenses to check lens quality more quickly and spend more time filling their orders.

Background

Visionary Lenses is a company that distributes advanced custom replacement lenses for sunglasses. The company was founded in 2009 and their warehouse is located in Eugene. After doing a survey of their company, we found that there were four workers that were also tasked with responsibilities from their affiliated company Shady Peeps. Both organizations are owned by one proprietor. Their distribution channels consist of the company website, Amazon and eBay listings. They have approximately 109 product listings, all of which are manufactured in China and priced from \$12 to \$100. Our recommendations for improving the system process are outlined in the proposal.

Supply Chain Issue

The issue that Visionary Lenses is currently facing revolves around the current construction of their supply chain. The lenses are shipped from China to Visionary Lenses with a lead time of 3-6 weeks. Once the lenses arrive, they are then stored in the warehouse until the workers have the time to make sure that each lens is of the necessary quality. There are seven (7) stages in the supply manufacturing process.

1. Print shipping labels
2. Take shipping labels from office
3. Retrieve appropriate lenses from bins
4. Assemble necessary boxes for shipping

5. Package necessary lenses into boxes
6. Attach label to box
7. Put in shipping bin

Print Shipping Labels

This step of the process involves printing the labels from the computer for the previous days order. This is done between 8 and 10AM by a designated crew member.

Retrieve Shipping Labels

Once the labels have been printed and the other crew members have arrived, they will take the shipping labels and bring them to their workbench so that they can efficiently fill all orders.

Retrieve Lenses

One of the workers will then look at the shipping label and see which lenses they need to retrieve to fill that order. They will then go to the appropriate bin (organized alphabetically) and retrieve the lenses. The issue that will be analyzed is what happens when there are no lenses in the bin. That will be discussed further later.

Assemble Boxes

Visionary Lenses uses two different boxes to ship their lenses. The first is a box to hold the actual pair of lenses and the other is a larger box which holds installation information, a screwdriver (if necessary) and the smaller box holding the lenses. These boxes are easy to assemble and that usually happens during down time in the warehouse.

Package lenses in boxes

Once the boxes have been assembled, the next step is to put the lenses into the small box and then put all the necessary contents into the larger box for shipping.

Attach label/Put in shipping bin

The last two steps are attaching the shipping label to the necessary box and then placing the sealed box into the bin that is taken to the U.S. Post Office. Shipments go out each day at 4PM

to ensure that they are included in that day's mail.

This is the process that Visionary Lenses would like to run through every day. The issue is that sometimes when they go to the bins to retrieve the necessary lenses there are not any lenses in there. This happens when the workers are too busy to spend time quality checking the new lenses that have arrived. The process as described would take 2-3 minutes but when there are no lenses in the bins the process can take 4.5-5.5 minutes. The issue that Visionary Lenses is facing is that they are not able to quality check enough lenses to keep the bins full.

Quality Checking

The quality checking process involves taking the newly arrived lenses and analyzing each lens individually to ensure that they are in perfect condition. This process includes looking to make sure that the color is right, that there are no scratches on the lenses and that there are no chips on the edges of the lenses. This process can take more than 2 minutes to complete and is the bottleneck of the supply chain.

Future Outlook

What Visionary Lenses is looking for is a solution that is going to help them reduce this bottleneck. There is a way to make sure that the bins are always full of lenses and finding that solution would help Visionary Lenses reduce costs, reduce time spent quality checking, increase their daily shipment capacity and would help them find a mean amount of defective lenses.

Key objectives

The objectives associated with the use of acceptance sampling are as follows:

- Reduce costs
- Reduce QC time
- Increase daily shipment capacity
- Find mean amount of defective lenses (in specific lot size)

Acceptance sampling will reduce costs for Visionary Lenses. Employees do not have to spend

the extra time associated with quality checking each and every lens, meaning their labor can be used elsewhere. Along with the reduction in costs, the quality check time will be reduced significantly. Instead of checking 200 lenses, only a sample is taken. This reduced quality check time allows for an increase in the daily shipment capacity. Right now, the total packaging process takes around 4.5 minutes. Quality checking alone accounts for 2-3 of the entire process. If acceptance sampling is implemented, the entire shipping process is cut in half and the capacity will increase significantly.

In order for this all to work, Visionary Lenses needs to pay attention to the mean amount of defective lenses in each specific batch size.

Supply Chain Solution (Acceptance Sampling)

In order to solve the problem that visionary lenses has with time intensive quality checking, we are proposing that they implement the method of acceptance sampling. Acceptance sampling provides guidelines for determining acceptance or rejection of a lot of materials based on clearly defined sampling rules. This method is not intended to estimate product quality, but rather define the probability of accepting lots at defined quality levels. This method is a realistic compromise between conducting quality checks on 100% of the product and not conducting quality checks at all. Acceptance sampling is much less time-consuming and costly than conducting a full inspection of the lot, especially when dealing with situations where the lot size is large or testing results in the destruction of the unit. When conducting acceptance sampling, rather than sending back only the defective units, if a sample is bad enough to reject, the entire shipment is rejected and returned to the supplier. Under rectifying inspection, rejected lots undergo 100% inspection to screen out the defective units, and keep the good ones.

Acceptance sampling requires that inspection is performed on a random sample. In order to achieve a truly random sample, each unit in the lot has to have an equal probability of inclusion in the sample. This process can often be complicated by selecting a sample that consists of units that are the most assessable. One method for circumventing this human error is to assign

a unique number to each of the components in the shipment and then use a random number generator to pick out individual units.

There are four types of acceptance sampling plans: single sampling, double sampling, multiple sampling, and sequential sampling. Under single sampling, a sample of size n is selected from a shipment. If the number of nonconforming units, d , is less than or equal to the acceptance number, c , the lot is accepted. If it is more, the lot is rejected and returned to the supplier. Under a double sampling plan, the decision to accept or reject may be deferred until a second sample is taken. Multiple sampling involves deferring judgment on the sample until a pre-specified number of units or samples have been inspected.

In order to conduct acceptance sampling, you must first collect historical data and establish an acceptance plan or sampling plan which sets the product acceptability criteria. This is known as the decision rule which explicitly states how many out-of-specification items can be accepted in a shipment. Then, depending on the goals of the company, choose a type of sampling plan to implement. Single sampling plans are the most common to use, even though they are not the most efficient in terms of average number of samples needed. Double sampling involves taking a second sample if no decision can be made regarding the first sample and combining the information obtained from both samples to make a final decision on whether to accept or reject the lot. If both tests lead to contradictory results, a multiple sampling plan may be implemented which would continue sampling until a clear decision is reached (Exhibit 1).

The key assumption of the process is that each sample is representative of the entire product lot and is highly variable. This assumption, in and of itself, also represents the limitation of this method. The buyer cannot be certain of the consistency of each batch and the only way a true representative sample could be obtained is if the batch was of something homogenous such as testing chemicals produced in a factory. This is where the risk of acceptance sampling comes into play.

Supply Chain Solution (Implementation)

Minitab Software

As a recommendation for software to implement acceptance sampling, we found a program called Minitab. Minitab's acceptance sampling is a practical, affordable alternative to costly 100% inspection. It offers an efficient way to assess the quality of an entire lot of product and to decide whether to accept or reject it. When using Minitab, you can specify the worst quality that you'll accept on a regular basis (referred to as AQL), and the quality level that you'll rejected (the RQL) (Exhibit 2). With these boundaries, Minitab calculates the sampling requirements that match the risks that you can accept. The main concern is setting these levels correctly. Set your standards too low, and you could waste money on a lot of poor quality. Set your standards too high, and you could alienate your suppliers by rejecting acceptable lots.

Based on these limits and the size of the lot, Minitab will calculate your sample size and number of allowed defects (the acceptance number). Based on these factors, the producer's risk and consumer's risk are also calculated. These are important measures to consider when weighing the risks of accepting or rejecting a lot. Minitab also generates an OC Curve which shows you the probability that you will accept lots with various levels of quality (Exhibit 3).

Minitab also offers the capability for you to compare different sampling plans of varying sample sizes and acceptance numbers. This will allow you to weigh the benefits and risks by displaying the different OC curves for you to compare.

Minitab also offers different prices for the use of their software. A year subscription to their service costs \$300, but you can try out their software for a few months at \$30 per month. This would be a good way to test out the software without making a huge commitment to buying expensive software.

Analysis of alternatives

After discovering the main issues surrounding quality checking, our group started looking at

various solutions. We came to the conclusions that acceptance sampling was the most logical solution to VL's problem.

Monthly Checking

Our best alternative to acceptance sampling involved quality checks at the start of the month and not during the process. In some situations, Visionary Lenses is only quality checking a product months after it had been received in the warehouse. If the batch of lenses is faulty, the manufacturer wants to know ASAP in order to send Visionary Lenses a new batch of lenses. The manufacturer is less inclined to send a new batch, if the request for a replacement is three or four months after it has been received by Visionary Lenses.

2 Day Checking

Our alternative solutions involved dedicating the first two days of every month to quality checks. All other operations would stop and visionary lenses would dedicate all resources to quality checking the lenses currently in inventory

Recommendation

Our recommendation for Visionary Lenses is to implement acceptance sampling. This will significantly reduce costs and time involved in the shipping process. Instead of realizing a batch of lenses is defective 3 months after it arrives, acceptance sampling will allow Visionary Lenses to determine defective batches immediately. Visionary Lenses will need to immediately start recording the lens type, batch size and the amount defects associated with the batch in order to implement acceptance sampling.

Exhibits

Exhibit 1

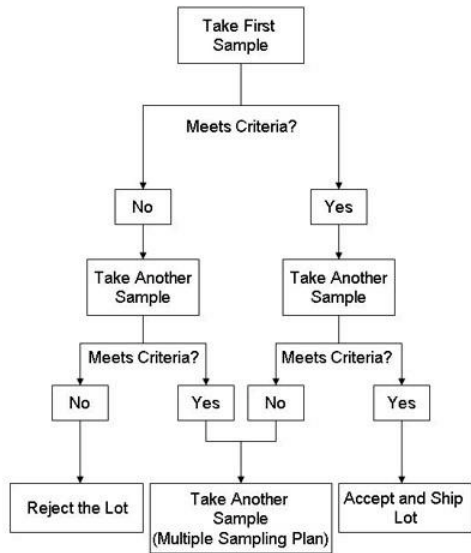
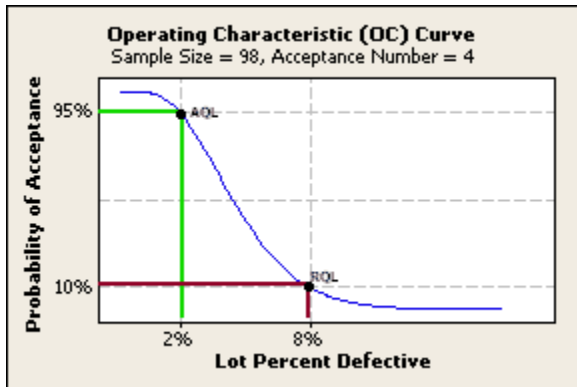


Exhibit 2

The screenshot shows the "Acceptance Sampling by Attributes" software window. The window title is "Acceptance Sampling by Attributes". The main area contains the following fields and controls:

- A dropdown menu set to "Create a Sampling Plan".
- Buttons for "Options..." and "Graphs...".
- "Measurement type:" dropdown set to "Go / no go (defective)".
- "Units for quality levels:" dropdown set to "Percent defective".
- "Acceptable quality level (AQL):" text box with value "2".
- "Rejectable quality level (RQL or LTPD):" text box with value "8".
- "Producer's risk (Alpha):" text box with value "0.05".
- "Consumer's risk (Beta):" text box with value "0.10".
- "Lot size:" text box with value "540".
- Buttons for "Help", "OK", and "Cancel".

Exhibit 3



Paint Room Materials Flow: Analysis and Recommendations

UGTeam: Christopher McClellan, Cody Kuntz, Sam Schwab, Ben Goodman, Lane Seals

Industry Sponsor: Mike Ulven, C.O.O., Rick Russ, Sales, Tom Wright-Hay, Lean Consultant,
OMEP

Faculty Adviser: Nagesh N, Murthy

Field Project: DSC 477, Spring 2012

Executive Summary

Our team was brought into Skookum to conduct an analysis of the painting process currently being utilized by the firm. Upon arriving at the site, our team was informed that the focus of our study and analysis should be on decreasing the amount of time it takes to a) decrease paint dry time, and b) create a materials flow pattern that would maximize the area's utilization.

Our team began our analysis by taking timed measurements of the various painting procedures. This allowed us to determine that out of any given process; approximately 12.29% of the time is spent on value added processes. Upon discovering this, we then aggregated all of the information we had gathered from interviews as well as annual reports to set goals for what we desired our solution to accomplish. In brief, this was to increase throughput and substantially reduce dry time per application.

In developing our solution, we followed a three step methodology. First, we examined the dimensions of the space and the constraints that were imposed due to property limitations. We identified walls that needed to be removed as well as support beams that could not be re-positioned. Second, we analyzed historical data for the painting process. We were able to

determine the characteristics of 80% of the annual flow through the process. The decision was made to design the materials flow pattern for the 80% of product that would flow through this area. Third, we constructed a 3D scale model of our solution to ensure that our measurements and proposed solution was feasible. By constructing this model we were able to determine that our solution was indeed feasible and that it was the best configuration to fully utilize the space.

We propose the following recommendations:

- Build a second paint booth
- Upgrade the current paint booth
- Restructure batch sizes for paint booth
- Create a single lane material flow pattern

There are two main justifications as to why these recommendations should be followed. First, we would be able to decrease dry time by 700%². Second, all changes increase throughput as we are able to increase both the product in the system while simultaneously decreasing the amount of time the product spends in the system. These recommendations accomplish all stated goals and objectives of the project, and therefore maximize the benefit received by the firm.

Company Overview

Skookum has been in business since 1890 and is part of the larger Ulven Companies. Its focus is assembling and painting products such as sheaves, blocks, hooks, and shackles for many different industries. Some of these industries include mining, dredging, and logging operations, especially those in the Pacific Northwest.

Each product that Skookum produces takes several hours to complete. This is especially true

² Refer to Appendix A for calculation

because of all of the individual pieces that are needed to create one finished product, such as a block. Skookum workers grab each piece from the shelves and then each worker meticulously assembles the product by hand. After this process is done, the assembled finished product is sent to the paint booth. Here, it is hand painted by being sprayed or dipped into paint. The workers then hang it to dry before it is sent to the customer. With all of these steps needed to complete the product, there are a lot of inefficiencies. As a result, our team was brought in to suggest how the paint booth could become more efficient under lean principles.

Project Scope

The scope of the project included:

- Analyzing painting area flow patterns
- Analyzing painting procedures and processes
- Analyzing annual production area requirements

Initial Analysis

During our initial visit to the Ulven Companies our team was given a tour of Skookum and educated on its history and the variation of products that Skookum sells. When entering Skookum we were taken through the process that products travel through starting with unmachined inventory, machining, machined inventory, assembly, and finishing with the final step of painting and shipping. Our team was instructed to analyze the paint booth and painting area with the objectives of working to establish a more efficient layout and eliminating inefficiencies by optimizing the entire painting process.

First our team split up and observed the tasks being completed in the paint room by Skookum employees. We observed that there were two ways to apply paint to Skookum products. Products like shackles and rings were dipped into the traditional Skookum colors and then hung to dry, while the parts for the blocks and pulleys were painted individually with a pneumatic spray gun before being assembled. The dipping process required two different value adding procedures of dipping the product in one color and allowing time to dry, then rotating and

dipping the unpainted end of the product and hanging to dry. After the already painted pieces of the blocks were assembled, they were sprayed again in the process of touch up before being shipped to the customer. This is to assure that the final product is of Skookum's highest standards.

We were informed that specific military orders required tougher paint that was applied via pneumatic spray gun must be painted in the existing paint booth to restrict the harmful gasses from escaping. To address this problem, Skookum designed a blueprint for an additional paint booth and gave it to our team to include into our analysis. We were instructed to include the possibility of constructing the new paint booth as an option during our evaluation of the painting process. Skookum had not decided whether or not the new booth was going to be built, but had listed it as a valid option to meet our objectives of eliminating inefficiencies and optimizing the painting process.

During our initial tour of the Skookum facilities we also analyzed the assembly area as it is an important step that is combined with the painting process. As noted earlier, blocks and pulleys are painted before assembly, then given a touch up coat of paint before shipment. While observing the assembly area our team recognized that there was the possibility of eliminating non load bearing walls to create easy access into the painting area. During the time that we were analyzing the assembly area it was also noted that the assembly area sits approximately one foot in elevation above the painting area meaning that modifications would have to be made to allow a forklift to travel from the assembly area to painting area and vice versa.

Additionally, after speaking with Skookum employees in the assembly area, our team discovered that a majority of the orders are large in size and require multiple days to complete assembly. This translates into moving pallets of assembled products to the paint booth less often making the transportation to the painting area less of an issue given that the transportation happens less frequently. For small product orders of manageable weight, Skookum employees can transport manually to the painting area via a standard size door leading directly into the

painting area in a time efficient manner.

Lastly, during our initial visit of the Skookum facilities we had the opportunity to interview the team of Skookum painters to gain the tribal knowledge needed to understand the procedures that take place in the painting process. This information was recorded, and the team left the facilities with a general understanding of how painting procedures must be completed to reach a finished product of the highest quality. Our team also acquired the Skookum parts catalog and the detailed instructions of all the paints being applied in both the dipping procedure and the spraying procedure. We combined all of this information and used it as a reference to aid in the process of reaching a recommendation that was realistic to the everyday procedures and specifications required during the painting process.

Project Goals

Our project goals were a byproduct of what we wanted to accomplish in accordance with our project scope. Since our project scope consisted of maximizing inflows and outflows of materials from the paint booth and paint area, we thought it would be sufficient to accomplish the four stated goals below:

- Increase throughput rate
- Improve on time shipping record
- Decrease overall product dry time
- Decrease painting costs

We feel confident that our overall recommendation we have prepared actively addresses all of the above stated project goals.

Problem Identification

As outside consultants for the Ulven Companies and more specifically Skookum, we have been able to analyze problems in their paint booth operations without any internal biases. This has helped us predominantly pinpoint four different problems within the company itself that we feel

have had a major impact on operations and process flows. Each of our problems will be explained in their entirety below:

Inefficient Flow through Paint Booth

The paint booth itself is a constrained space with no alternative plans for expansion. Not only does this put a cap on expansion for the company, but it also puts constraints on flow through the paint booth. Currently, the paint booth has a same lane directional flow. This means that products are forced to come in one way and go out the same way. This is not an ideal flow pattern because it prevents items that are placed in the back of the queue from being brought out when they are done because there are items in front that may not have been completed. Not only does this increase queue times for items, but it drastically reduces throughput rate.

Further, it was noticed that palletized items - those placed on pallets because they are too heavy to carry - impede flow for items waiting to be shipped. These items also take up a large amount of space in the paint booth because they do not appear to have a predetermined storage area. This not only impedes flow in the paint booth, but it is also cause for greater safety risks in the painting area.

Lastly, the layout of the facility itself causes problems for the inflow of large products because the forklifts face building barriers. In particular, the entry bays are relatively small and the wall separating the paint room drying racks from the parts storage area prevents forklifts from having greater maneuverability. This barrier is also one of the reasons that the paint booth is facing reverse directional flow.

Inconsistent Dry Time

One of the main things that we noticed throughout our time at the facility is that different painting processes require different drying times; mainly dipped versus sprayed products. Our general knowledge of painting processes, and the reinforcement in our knowledge from the painting employees allowed us to determine that the paint was not being dried in the proper controlled environment. This led to many of the problems that we witnessed in drying time. Firstly, we noticed that some of the paint would not stick properly - or what was referred to as running - because it was either too hot or cold on the product for the paint to stick. This raised quality control issues because the paint would fold over itself and leave inconsistent thickness. In addition, this is a cause for flaking in the paint coat, which is something that we noted, was quite frequent in their stored inventory.

Moreover, as our recommendation will further explain later, our main notice was that there is not proper ventilation or heating for efficient and effective painting process. It should also be noted that this could be a hazard to employee health and wellbeing. This was also one of the reasons for the EPA and OSHA complaints that were filed against Skookum.

Lastly, the dipping tubs do not have adequate room in the paint booth which consequently causes much longer drying times. We noticed that drying for dipped products ranged from one hour to four hours. This was also one of the biggest measures of waste that we noted. The drying time is something that can be mitigated with proper equipment in the painting booth.

Time and Materials Waste

As aforementioned, the biggest measure of waste that we were able to quantify is drying time. This is simply due to a lack of controlled heating and ventilation in the paint booth. This will be discussed in greater detail in our recommendation.

One of the other prevalent waste measures that we noticed was the fact that employees decided to paint product wherever there was room. The main cause for this was lack of capacity and space within the paint booth itself. This has already caused problems for Skookum in regards to painting products in inappropriate placed, more specifically, their military paint orders.

It should also be mentioned that placing their products on wooden planks causes waste in the process because it takes longer amounts of time to flip the product, reposition, and repaint. It would be advantageous if there was a non-stick surface for painting their products that cannot be hung on racks because paint is not allowed in the center. This is further illustrated in our process measurement section.

Another problem that we quickly noticed, and that was voiced by the employees, is that certain orders are placed on rush and force employees to forfeit their other duties until that order is filled, regardless of size. This not only decreases on time shipping, but also decreases overall productivity levels. These rush orders also take up valuable space in the paint booth which could otherwise be utilized for larger batch sizes and more important large orders. These orders contribute to inefficient process flow in the paint environment. It is recommended that you assign a specific employee to fulfilling rush orders because he will quickly become adept to filling them quickly and efficiently. This allows the other employees to keep their focus on finishing the other orders for the day.

Process Measurement Analysis

During our second visit to Skookum we had the opportunity to measure process waste and value added time in accordance with an above average batch size. We measured and timed

their process from initial paint mixing and material gathering, all the way to the last minute of dry time. Our process measurements for a batch of 43 units are explained below:

* Please note that measurements for waste (W) and value added (VA) are indicated.

Process	Top	Bottom	Sides	Dry Time	Gathering Materials
Primer (Clear)	31 sec (VA)	42.2 sec (VA)	3:23 (VA)	14:26 (W)	-
Primer (White)	42.3 sec (VA)	46.5 sec (VA)	2:45 (VA)	14:06 (W)	-
Paint	53.8 sec (VA)	41.3 sec (VA)	4:28 (VA)	29:04 (W)	-
Misc. Time	-	-	-	-	19:04 (W)
Total Time	-	-	-	-	1.26:13

As you can see from above, the value added time in the painting process itself does not offset, or even come close to matching the amount of waste in the painting process. In fact, only 12.29% of time spent painting is value added time.

A problem that we noted in the painting process was that the product itself was sticking to the paint benches, which meant that the worker had to individually *pull* the piece off the board and flip it over for further painting. Although we did not get the measurement for how much waste this process created, we feel that there is room for improvement.

As from above, the 19 minutes and 4 seconds spent for materials gathering could have been mitigated if the materials would have been prepped before the process began. This time also

includes time spent fixing spray guns - as we witnessed two gun malfunctions - , getting more paint, and divvying work up. Further, as illustrated in the graphic above, ~67% of the process was spent drying the product. We feel that this could be mitigated in a properly heated environment where the paint would dry quickly, efficiently, and properly. This will be discussed further in our recommendation later.

Overall, these process measurements are a large reason for our proposed recommendation.

Assumptions

In order to conduct the analysis and develop a solution, our team had to make a few assumptions that we had to make in order for our recommendation to make sense. These are explained below:

- Material flow to the paint booth is constant
- No possibility of building expansion
- Financially feasible recommendation

Our first assumption was critical in determining our final recommendation. If product flow and demand for the painting process was not there, then our overall recommendation would have changed. But by assuming this we are better able to determine increased throughput rate from the added capacity of a second paint booth.

Further, we had to assume that we are unable to work outside the current building framework. Both Mr. Hay-Wright and Mr. Ulven made it known that the property behind Skookum was unavailable for purchase, and the property below is not reasonable because of the large downward sloping gradient. This allowed us to make our focus specifically maximizing product flow for the current facility.

As a way to insure that Skookum is immediately able to implement our recommendation, we

wanted to make sure that our overall recommendation was financially feasible. By making it a financially feasible decision for them, they would immediately begin to reap the benefits of our process changes, which would translate to increased process efficiencies.

Recommendations

The team devised a proposal that has three distinct components. Below you will find the recommendations along with the analysis done to support the conclusions.

1. Construct a Level Working Surface with Minimum 4,000 psi Concrete

In order to be able to maximize capacity, improve process flow, and decrease working safety hazards, we propose that Skookum invest in leveling out the paint room floor among all rooms. Having a sloping floor, of any kind, increases the probability of worker injury as well as the difficulty in handling heavy inventory. Given that the majority of the products flowing through the paint area range in weight between 32lbs and 150 lbs., maneuvering pallets on forklifts or pallet jacks present a series of risks to the workers as well as the valuable inventory. These risks include dropping product on workers or the floor. This will cause either injury to the worker or damage to Skookum's inventory.

In addition to the safety concerns, installing a second paint booth on a sloped floor poses problems from a structural as well as an insurance liability standpoint.

2. Install the New Paint Booth but with Modifications

The paint booth Skookum initially had developed by Rohner LLC is not sufficient to improve process flow or accommodate larger batch and product sizes. After careful analysis, we determined that only 8.4% of Skookum's total product offering comprised 79.68% of all the work the paint booth completed for 2011. The totality of the customer orders had order quantities equal to or greater than 200 units, with the majority of orders being between 700 and 3,405 units.

Furthermore, if we were to include the totality of customer orders that were 50 units or more annually, in addition with the earlier calculation, we find that 18.32% of orders that were processed through the paint booth comprised 90.36% of all the work the paint booth completed for 2011. The weight of the units that comprise these statistics, on average, range between 32 lbs. and 150 lbs. These measurements clearly indicate that the processes within the paint booth must be designed for large batch quantities as well as the accommodation of heavy materials.

Under the current dimensions, the new paint booth would be severely limited in its ability to handle the majority of Skookum's requirements for material flow. We propose that the firm consider expanding the paint booth to 15' x 27' (See Appendix A for layout). These proposed dimensions require zero facility expansion to accommodate. By adjusting the dimensions of the paint booth, Skookum gains three very key advantages.

A. Increased Pallet Capacity

Standard pallets are 48" x 40". As the proposal stands from Rohner, the new paint booth would only be able to accommodate 5 pallets. Although this would expand present paint booth capacity in the facility, it is not a good investment given its limited ability to handle the large batch sizes required to fulfill the majority of the orders. By doubling the capacity of the new paint booth, Skookum will gain the ability to move the current batch sizes through the paint area at one time. By processing the batches at one time, Skookum will be able to become more efficient in moving larger product orders through the system as well as ship greater quantities of product to the customer at one time.

B. Increased Worker Maneuverability

The present proposal leaves less than a 1' x 2' space on all sides of a standard pallet. This is insufficient space for the paint booth workers to maneuver and it does not provide enough maneuverability for the forklift to effectively and efficiently move product through the paint booth. The modified paint booth dimensions create an environment that is user friendly and increases the utilization of the space.

C. Decreased Number of Paint Set Ups

One of the greatest detractors to the paint booth's efficiency is the large number of setups required under the current operating conditions. Small quantities of product are processed as they become available, despite that there is more of the same product coming down from the production line because of capacity constraints. We recommend processing these orders in larger batch sizes for the paint booth, effectively utilizing the additional 10 pallet capacity. It also decreases the number of times the paint must be mixed, the paint canister must be screwed/unscrewed into/from the spray gun, and the paint canister cleaned between uses and paint styles.

3. Upgrade the Current Paint Booth and Painting Equipment

The third aspect of our proposal is investing in upgrading the current paint booth. The paint booth currently operates at far less than optimum performance. This was substantiated by our observations of the poor ventilation abilities as well as its ability to control the temperature of the area. In addition to these observations, we noted that the painting spray guns malfunctioned frequently. The malfunctions were primarily caused by a clogged feeder into the gun or sprayer. Therefore we propose the following:

A. Invest in 4 Fuji 9600-4 XPC HVLP Turbine Spray Gun. These are the top of line spray guns. The major advantage of this sprayer is that the nozzle is adjustable. This will decrease the amount of paint that is wasted in the application processes. The new equipment will also malfunction less frequently, thereby allowing the employees to carry out their duties more effectively and efficiently.

B. Invest in one or two new ventilation fans for the current paint booth. This will more effectively remove the dangerous fumes discharged through the painting process and create a healthier environment for the employees.

C. Install new heater that will more efficiently heat the general work area to 77 degrees. This is to accommodate the days where materials flow exceeds the capacity of both paint booths.

D. Paint rack upgrades are worth considering. We propose that Skookum invest in placing wheels on the bottom of its racks. This will allow quicker dipping and drying, as the dipped product will be able to move into the paint booth quickly.

The cumulative effect of all these changes will increase the paint booth's efficiency tremendously and improve the firm's on time shipping percentage. The value added time will become a majority of the time spent in the process of painting the product, instead of only 12.29% of the time.

Alternatives Solutions

Although we strongly suggest that Skookum implement our full recommendation, we are aware that our recommendation may not be able to be implemented in its entirety. There are multiple

alternatives that Skookum can entertain if it is determined that they are unable to implement our recommendation.

Firstly, they could simply reorganize the painting area so that there are designated task specific areas for painting products. Along with this, it would be suggested that they implement a revamped order processing system and painting procedures. This would be relatively cheap, if there are any costs at all.

Moreover, they could also insulate, ventilate, and heat the entire painting area. This would eliminate the need for a paint booth altogether. However, there are certain drawbacks to this system. Some of these are increased overhead, operating costs, and OSHA regulations.

Lastly, and most drastically, they could choose to move the painting area to where the assembly warehouse is. This would allow for maximized flow and increased process efficiency. However, this would require relocation of their inventory, assembly, and shipping departments. This was one of the main recommendations that we analyzed. However, we determined that we did not have the proper tool set to analyze and suggest where to relocate the aforementioned departments.

Resistance to Implementation

We do not feel that there is going to be any resistance to our overall recommendation because Skookum was already heavily leaning towards what we recommended. If anything, we reinforced in our research why they should move forward with the new paint booth immediately. The only organization resistance that might be met will come from the employees. As such, we suggest that upper management take the necessary steps to reassure their employees that change is going to be good for them. It is important that upper management be there along the way to reassure the employees and show them that what is happening is important to both the employees and the organization. The only reason we think they might encounter resistance is because the painting procedures are heavily dependent on 'tribal knowledge'. We feel that they

may be able to benefit from a retraining program or standardized – more visible – painting procedures.

Conclusion

During our multiple trips to Skookum we acquired a lot of information regarding Skookum's paint booth and processes. Using this information we believe Ulven has a great opportunity to greatly improve the efficiency and safety of its painting area by realizing and correcting the following problems:

- Flow of materials through the booth is inefficient
- Dry times within the booth of painted products are inconsistent
- Materials and time are wasted within the current booth

Our solution of constructing a new level floor, adding a new modified paint booth, and upgrading the current paint booth and painting equipment will resolve these issues and give Ulven a more efficient and safer painting process.

Appendices

Appendix A: Time Savings Analysis

In order to determine the percentage of time saved, we determined that an average dry time - according to paint booth employees - was roughly four hours. It was then determined that with a properly controlled environment, where the temperature is a constant 77 degree, we could reduce average dry time to around 30 minutes. This gives us an overall time savings of 700%.

$$\text{Dry Time Savings} = \frac{(240-30)}{30} \times 100 = 700\%$$

Appendix B: Throughput Calculations

$$R = I/T$$

Where R is the throughput rate

Where I is the amount of material flowing through the system

Where T is the amount of time it takes for one unit of material to flow through the system

Current Throughput Rate:

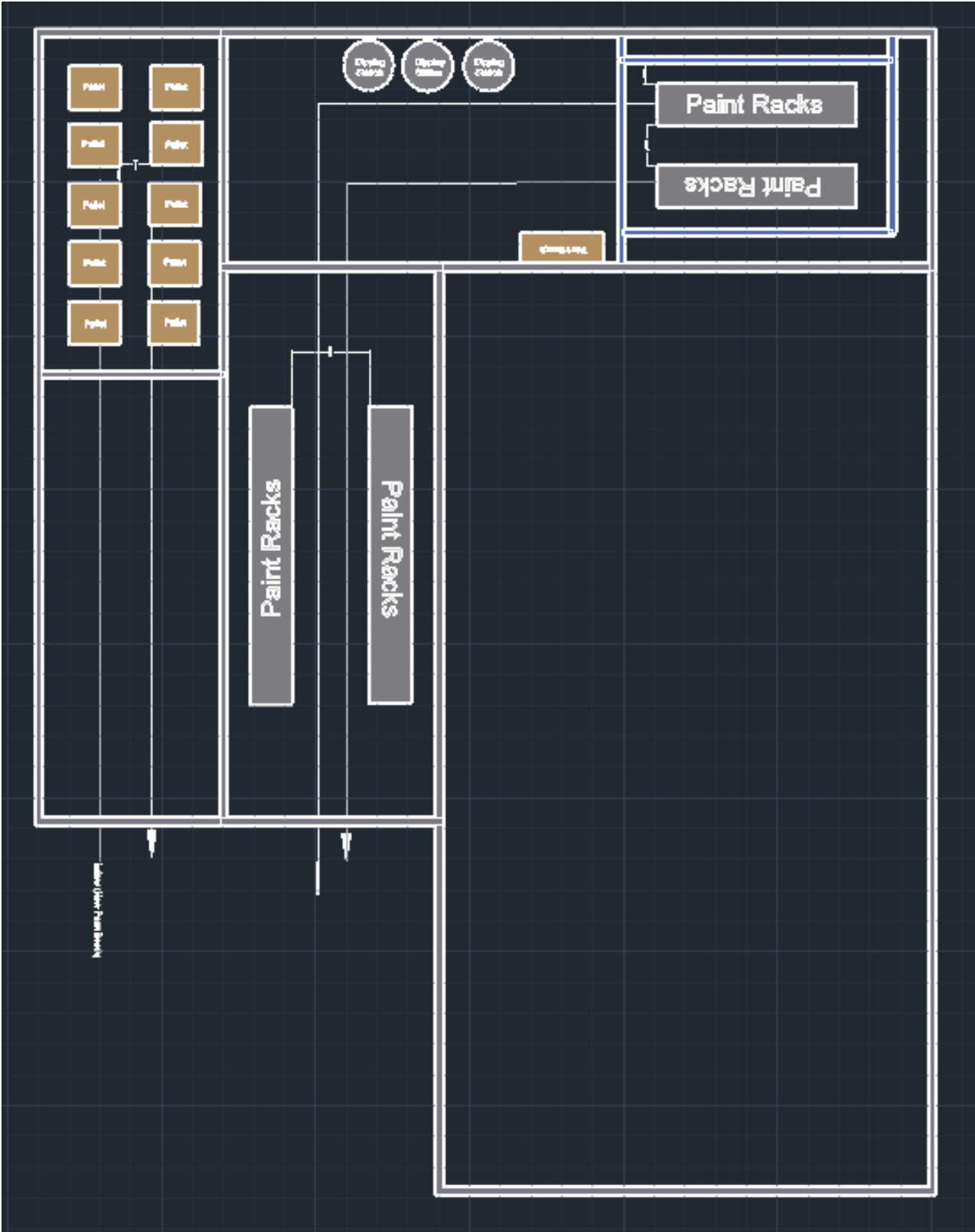
$$43(\text{units}) \div 86 (\text{min}) = .5 \text{ units/minute}$$

Post Improvements Throughput Rate:

$$60(\text{units}) \div 60(\text{min}) = 1 \text{ unit/minute}$$

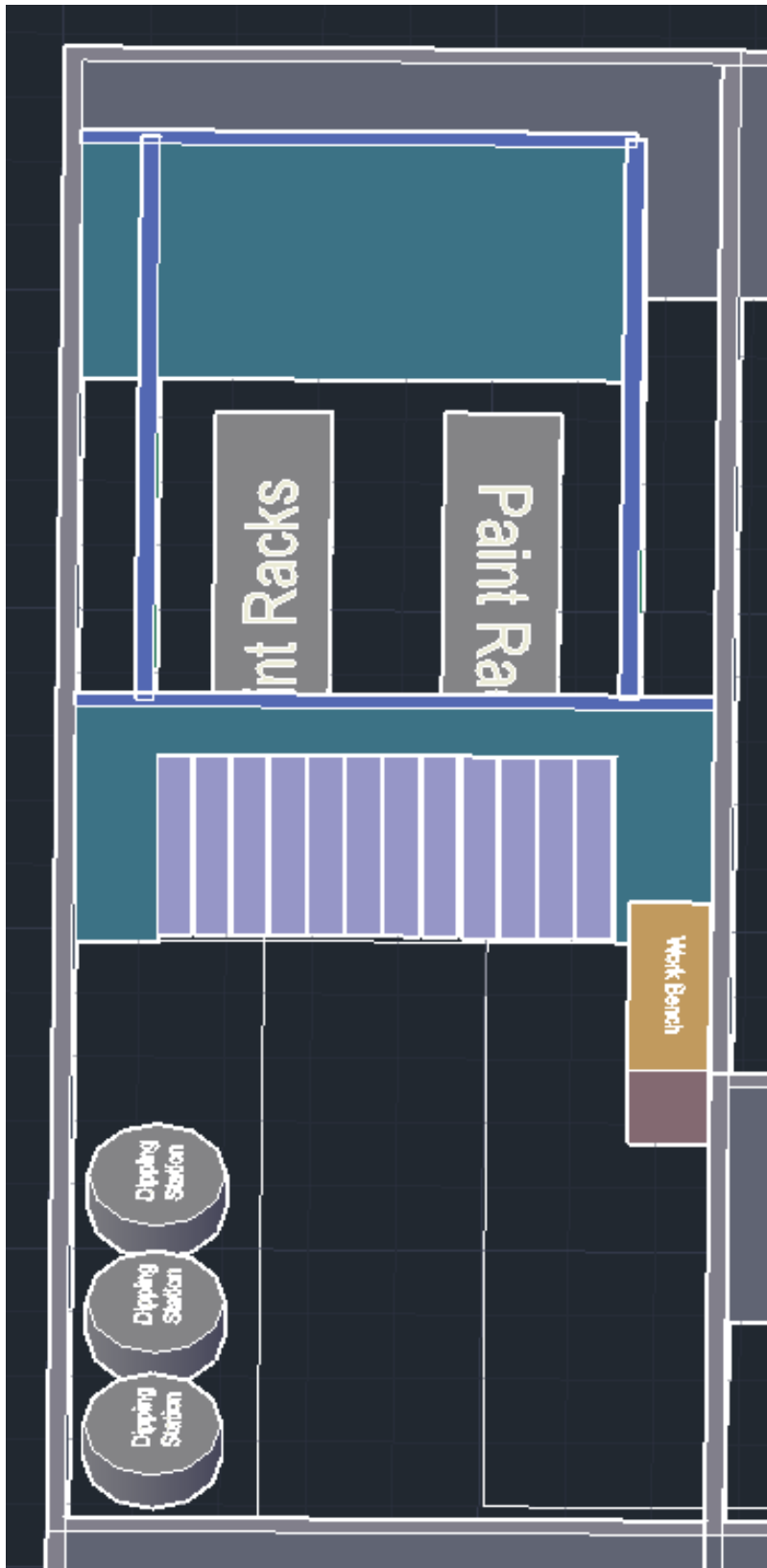
*we are on average able to increase throughput by 100% per day of production

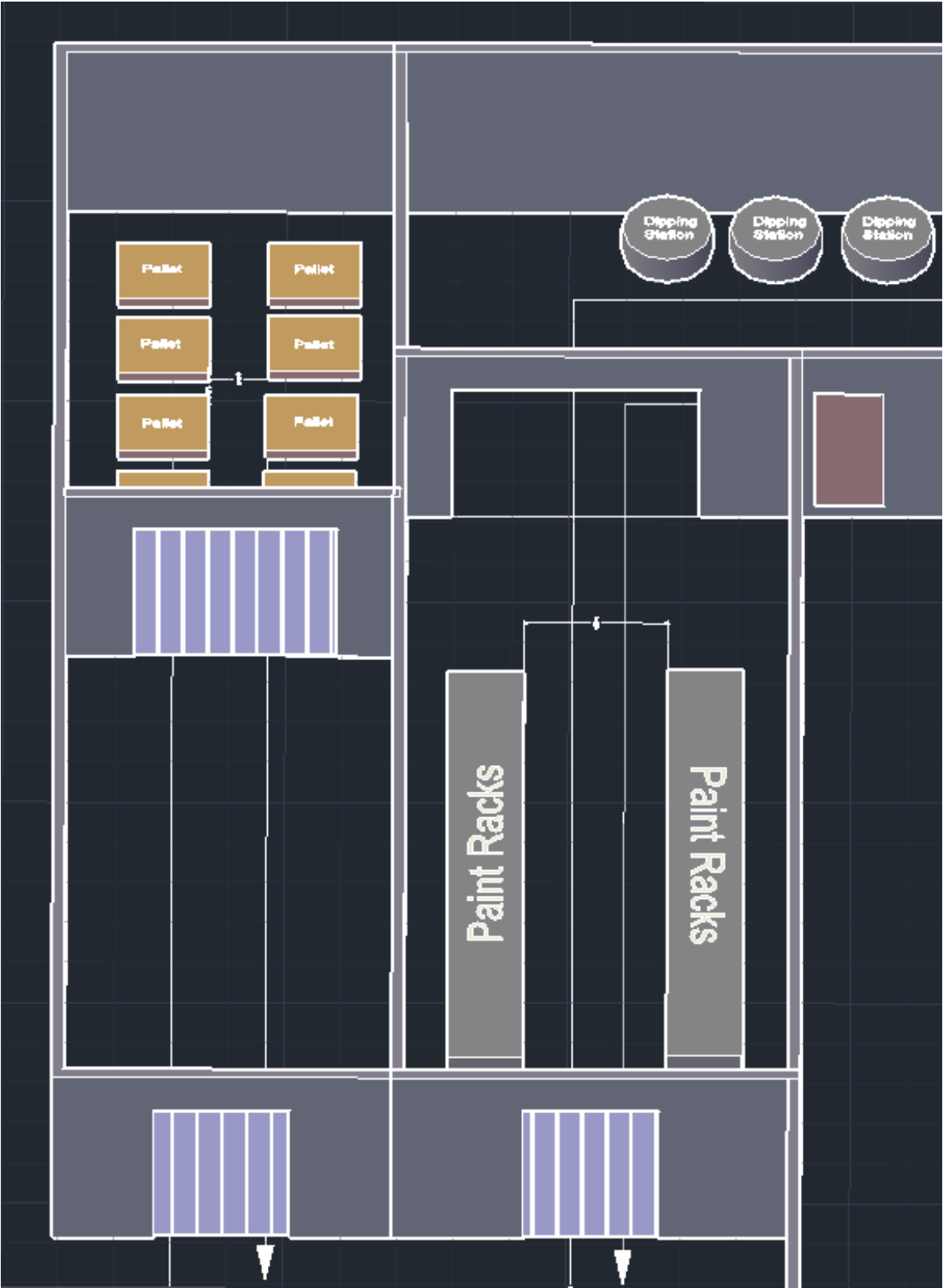
Appendix C: AutoCAD 3D Rendering of New Paint Booth



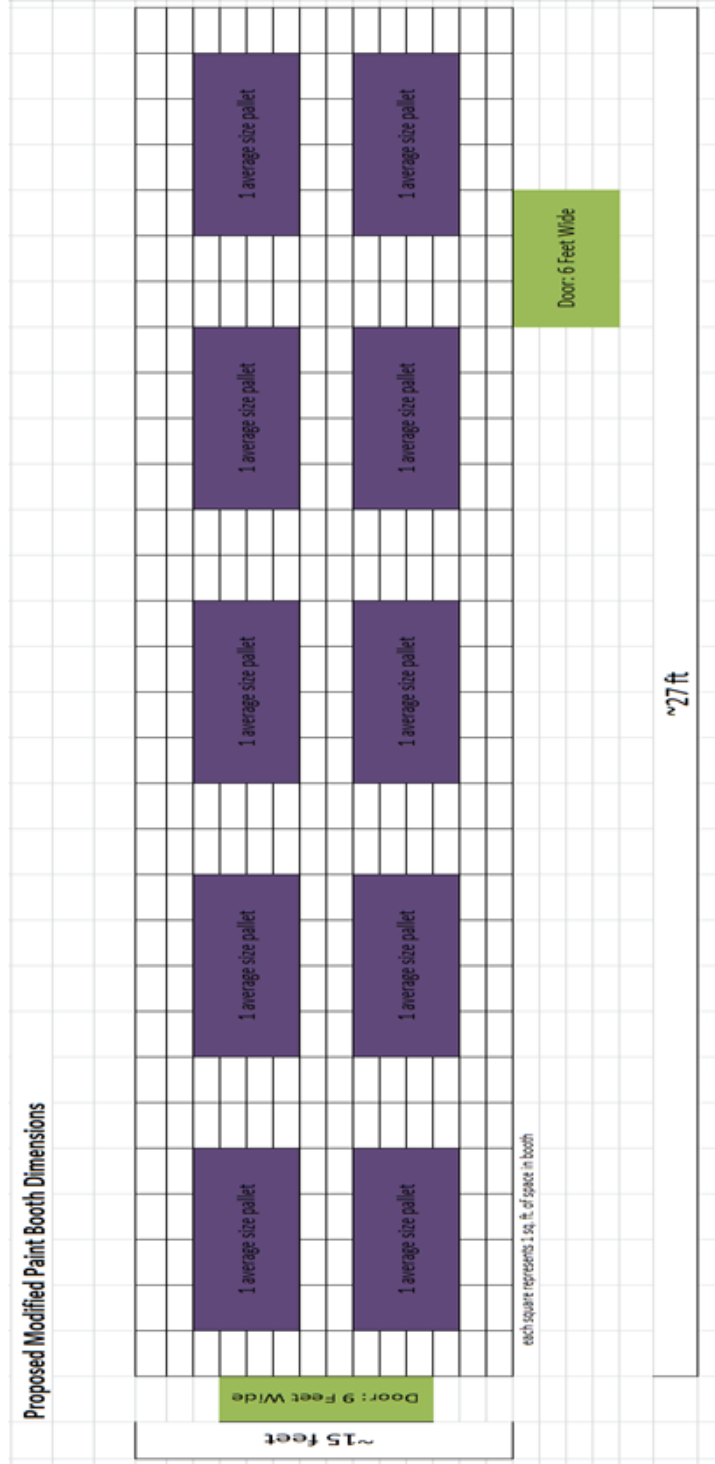


B1-FB11-19





Appendix D: Modified Paint Booth



Appendix E: Cost Analysis for Recommendations

New Paint Booth Costs

Material Addition	Cost
New leveled floor (4000 PSI concrete minimum)	\$10,000.00
Plastic door dividers	\$2,500.00*
New modified paint booth	\$85,000.00**

* Dependant on professional material or do it yourself installation and build.

** Includes the expansions suggested in our report (assuming \$208.00 per sq. ft.)

Current Paint Booth Upgrade Costs

Material Addition	Cost
New Ventilation System	\$4,000.00
New Insulation (whole painting area)	\$7,000.00
New Heating Units (x2)	\$2,000.00
Paint Guns (x4)	\$600.00*

*Varying depending on number purchased.



ReUse is the New Recycle

NextStep Recycling
Supply Chain and Operational Analysis and Recommendations

11 June 2012

DSC533 Spring 2012

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Executive Summary

Introduction

This team (Supply Chain Gang) had the assignment to evaluate and propose improvements to NextStep recycling. The scope of work was initially focused on their supply chain operations but in the course of completing the due diligence, further areas for improvement were identified. The team formulated the concept of applying an Enterprise Architecture approach to NextStep allowing for them to utilize an operating model and create a foundation for execution. This approach guided all three teams in their recommendations and together the three teams formulated actionable recommendations to help improve the efficiency of operations at NextStep Recycling. Team Supply Chain Gang was responsible for providing the Operating Model, SWOT Analysis, Triage Process Improvement, and Building Efficiency Improvements which are explained in detail throughout this document.

Enterprise Architecture

To ensure there is a framework for success and a foundation for execution it is recommended that NextStep employs an enterprise architecture approach creating this foundation through the adoption of a Coordination Operating Model. This operating model will help guide the transition from stage 1 maturity to stage 2 through the adoption of standardize technology and centralized IT solutions geared towards generating performance metrics, increased efficiency, and allowing for greater operational control of the enterprise.

SWOT Analysis

NextStep can capitalize on several of its core attributes and assets in order to increase operational efficiency and increase revenue. This begins by leveraging the existing barcode system to improve tracking of inventory as items move into the warehouse and through various phases of production. NextStep would also benefit by standardizing operations across different business silos and

taking advantage of flexible storage options to reduce costs and increase efficiency. The organization should use its relationship with the University of Oregon for material collections and sales, as well as a free labor projects that could bolster NextStep's IT infrastructure and marketing strategies.

Trends toward increased recycling provide steady demand for NextStep, but also bring external issues as well that will require strategic planning. Increased demand for recycling facilities and services will bring increased competition from organizations such as Garten Recycling and Goodwill. Uses of secondary markets created by eBay and Craigslist also have the potential to erode NextStep's revenue sources. Reliance upon the State funded recycling program is also an area of potential concern. To combat these risks, NextStep should focus on operational efficiency to improve revenue and profit margins across business units, and engage in local marketing that focus on the organization's impact and brand equity in the Eugene area.

Triage Operation Analysis

The triage operations represent an area that can see tangible results for minimal investment. The goal in this area is to evolve the operations using the framework defined in the operating model to ensure that the department is operating at efficient levels. Adding scan points to the existing workflow process will allow performance metrics and inventory tracking to occur via a centralized database supporting all facets of the organization including finance, eBay operations, and the retail store.

Building Efficiency

Considering the budgetary constraints at Next Step, we decided to focus our building efficiency efforts on low cost strategies. In addition, since the facilities themselves are rented and may only be occupied for a relatively short period of time, solutions requiring extensive retrofits to the building itself were excluded from consideration. Each identified problem and related solution strategy seeks to lower costs while improving the character of the working environment for both volunteers and permanent

employees. Our research identified two primary areas for improvement over current operations, energy efficiency and spatial efficiency. The following summary outlines the results from each category:

Energy Efficiency: By increasing natural lighting, more than 50% of the overhead lighting can be turned off. Only work areas need bright lighting, which can be augmented with task lighting at less energy expense. By using space heaters and coolers, energy efficiency will further increase, occupant comfort will increase, and energy cost will decrease.

Spatial Efficiency: Organization and optimization of storage spaces improves efficiency and workflow, especially in the case of temporary storage, and in locations when there is high worker turnover. Leveraging the under-utilized outdoor space by investing in more storage container storage will support more organizational clarity within the building itself.

Initial Analysis and a Future Framework for Success

While the scope of this analysis was to be initially limited to supply chain matters and internal process improvement, it became clear that there needs to be a framework in place to guide current process improvements, frame future business decisions, and provide a methodology to align all of the business units and operations. Ultimately, the recommendation of this report is to apply an Enterprise Architecture (EA) approach and tie it directly to the concept of supply chain maturity (SCM).

"[Enterprise architecture] allows for the controlled evolution of the supply chain function from good to great."¹

– Sourcing Innovation: Next Generation Supply Chain Management

The outcome of applying this framework is the implementation of a foundation for execution based around a common operating model. By applying this to Next Step it helps ensure that the organization has cohesive framework for making our recommendations and future business decisions to ensure a continued favorable cost structure to drive a competitive advantage.

Enterprise Architecture Overview

Enterprise architecture is generally defined as the organizing logic of business processes and IT infrastructure, reflecting the integration and standardization requirements of the company's operating model². A successful enterprise architecture exercise will result in the creation of a foundation for execution that is made possible by the implementation of a company-wide operating model.

Foundation for Execution

"A foundation for execution is the IT infrastructure and digitized processes automating a company's core capabilities."³

This encompasses the collective use of business processes, governance, infrastructure, and technology to support a company's strategic goals. A strong foundation for execution cannot exist without a tight

¹ <http://blog.sourcinginnovation.com/2010/09/19/want-a-successful-supply-chain-enterprise-architect-it.aspx>

² Adapted from Gartner's Enterprise Architecture (EA) definition found here: <http://www.gartner.com/it-glossary/enterprise-architecture-ea/>

³ Ross, Weill, and Robertson: Enterprise Architecture as Strategy

alignment of the strategic business outcomes and IT capabilities. In enterprise architecture, this states that IT will continue to be a cost center until value can be generated through the implementation of technology. In the case of Next Step, IT capabilities are somewhat of an opportunity cost versus a standard cost center in that they do not have large cost drivers within their IT systems and infrastructure, but they are incurring costs in other areas (i.e. triage, retail store, etc.) by not aligning IT with their core capabilities. At best, it supports the capabilities in a limited capacity.

Operating Model

“An operating model is the necessary level of business process integration and standardization for delivering goods and services to customers.”⁴

In this sense, an operating model dictates how an organization operates and behaves across business processes, organizations/departments, and technologies in order to meet strategic goals and drive value creation. For Next Step, they should implement a Coordination Model given that the business units have shared customers, products and suppliers. This fits their current business unit organizational structure as their operations are broken into unique business units/silos or functions but all of them can benefit from centrally mandated processes and procedures backed by common IT systems and infrastructure. Additionally, this model acknowledges that each business unit has an impact on other units' transactions and operations.

Enterprise Architecture and Supply Chains

The drive to integrate the enterprise is a core theme of value-chain optimization, encompassing elements of both the supply chain and the demand chain. As enterprise architecture is the framework used to integrate an enterprise, there is a direct linkage between the maturity of a company's supply chain and the maturity of their enterprise architecture.

The previous graphic⁵ shows the breakdown of supply chain maturity stages in the blue areas with the corresponding enterprise architecture maturity stages listed across the bottom. Currently Next Step

⁴ Ross, Weill, and Robertson: Enterprise Architecture as Strategy

operates in the first stage for both supply chain and enterprise architecture maturity. The goal is to improve efficiencies by leveraging standardized technologies, creating a greater information flow, and allowing for cross-functional integration. Next Step is not the type of organization that needs to aim for the higher stages of maturity. In fact, only 6% of firms will ever reach stage 4. However, moving from stage 1 to stage 2 should increase business flexibility and efficiencies while decreasing long-term IT expenditures by up to 25%. On average, 4% of firms that have undertaken an enterprise architecture approach have successfully entered the EA Standardized Technology/SCM Semi-functional stage⁶. Next Step can use the operating model and foundation for execution to help migrate from stage 1 to stage 2. Implementing a Coordination Model supports the decisions by all involved groups (Glasspond, Kiwit, and Supply Chain Gang) to push for integrated databases, more automated and traceable processes, and the integration of shared information across the business units. There needs to be a transition away from disjunctive business silos/operations towards a shared services/infrastructure model that integrates operations, supply chains, technology, and strategic goals to ensure there is greater operational control over the whole business and a solid framework for which to evaluate future business decisions.

This enterprise architecture framework has been applied across all involved groups but may only be explained in this session as this team was responsible for developing the framework.

SWOT Analysis

As part of the NextStep operational analysis, the following SWOT analysis has been constructed to provide an overview of all relevant strengths, weaknesses, opportunities, and trends. This SWOT analysis can be used as a set of guidelines to evaluate where certain action may be required to ensure continued success.

⁵ Adapted from http://www.apics.org/docs/about/cs_getting_started_chart.pdf

⁶ Ross, Weill, and Robertson: Enterprise Architecture as Strategy

Strengths:

- **Industry Standard Operating Procedures:** NextStep Utilize industry standard programs and procedures such as Memtest. They also leverage best practices for rebuilding systems such as using predefined images and systems requirements. This practice enables NextStep to streamline and facilitate its processes.
- **Local brand equity/reputation:** NextStep is a local company. People have many reasons to support local companies, especially those with goals and business mission that embrace serving the community. This would translate into stronger brand equity and reputation
- **Size/experience (compared to competitors):** NextStep was started in a garage in 1999, and was founded in 2002 as a non-profit business. NextStep has a longer presence in the market than some of its competitors, resulting in more experience in the recycling industry.
- **Volunteer pool:** A significant portion of NextStep day-to-day operations are conducted by volunteers, which would reduce NextStep's cost base.
- **Forecasting donation seasonality:** The seasonality of the recycling business is predictable to a certain extent.
- **Diverse revenue model:** NextStep's revenue comes from different sources, including their retail store, and the state's recycling program.
- **Business relationships with large local enterprises:** NextStep was able to establish excellent relationships with large local enterprises such as Sacred Heart Hospital, and EWEB. The donations from these businesses are very valuable to NextStep.
- **Employee relationships:** NextStep has employed several practices and initiatives to strengthen its relationships with employees and volunteers. For example, in addition to having the opportunity of gaining real life experience for the first time, many trainees receive free computers after completing their training.

- **Building:** NextStep's physical space is flexible to a certain extent. They can decrease the rented space to minimize their cost. A building that is used to store recyclable inventory to be sent to the states is leased on a month-to-month basis
- **Relationships with local technical experts:** NextStep was able to leverage its local focus to establish relationships with local technical experts who volunteer to support the company's business and training programs.

Weaknesses:

- **No inventory tracking (i.e. parts suitable to be used in rebuilds):** There's no effective way to track inventory or work in progress.
- **Throughput or other financial metrics:** Important financial metrics are based on estimates such as throughput and profit margin.
- **Web Apps at risk of becoming outdated quickly:** budget cuts required letting the developer go which means that nobody is maintaining the system.
- **Historical Documentation (i.e. yes/reject for prior systems):** NextStep doesn't maintain historical documentation to track important indicators such as the trend in donations, returns from the retail stores, demand for certain products, etc. Many of these indicators are based on estimates
- **State Program:** A major source of revenue for NextStep is the state's recycling program. The program has a stronger bargaining power and NextStep has to comply with existing and new regulatory requirements, which might limit NextStep's freedom of operation. For example, NextStep is forced to maintain its recyclable inventory until it reaches a full truckload, which might result in increased holding costs.
- **Uncertain supply and demand specifics:** For the recycling industry, both the supply/demand specifics have to be forecasted, which adds another layer of uncertainty to the business

- **Limited Financial Resources:** NextStep had to cut its budget to minimize its costs. On average, the company is not paying living wages to its employees, which would impact its employee retention rate. The company might not have enough resources to adopt new initiative to improve its business practices and embrace new strategic initiatives.
- **Low (and unknown) margins on product sales because of unknown process time by product:**
 - **Unknown which products make money and which products lose money for the organization:** By conducting its operations based on estimates, NextStep might not be able to fully optimize its resources and prioritize its activities to achieve the best financial performance. The company might not be able to identify and avoid unnecessary overhead costs that don't add value to its operations.
- **Excessive returns from the retail store:**
 - **Lack of inventory control and communication:** There is no centralized inventory and reporting system that would allow for better coordination and decision making with the retail store.
- **Tacit knowledge too great:** Only few people at NextStep have the necessary knowledge to run the business. Also, there is a significant amount of tacit knowledge that can't be easily transferred to other users.
- **Unfocused business mission with a wide variety of goals:**
 - **Wide variety of goals**
 - E-Waste Recycling
 - Computer Training Courses
 - Free Computers after Training
 - Socially-challenged Workforce
 - Selling computer equipment to low-income households

- **Operating as business silos:** NextStep has several business units and core competency.

Enhancing the coordination between units will add value to NextStep. For example, better coordination between the receiving staff and the E-Bay team and/or retail store would allow for better decisions making to satisfy customers' demand.

Opportunities:

A variety of opportunities for operational improvement exist within NextStep's existing operations. By effectively taking advantage of their internal competencies, as well as their location in Eugene, NextStep will be able to reduce its operating costs and improve profit margins. Analysis of potential opportunities is listed below.

- **Barcode system:** NextStep can increase utilization and leverage the existing barcode system to improve process tracking information. By implementing reusable barcode tags, NextStep will be able to maintain inventory and process information for individual units as they enter and exit various phases of production.
- **Operating model:** To increase operational efficiency, NextStep should move away from the current business silo model, and work to integrate its service offerings. Increasing communication and implementing standardized solutions across different aspects of the business will allow the company to find cost savings and use resources more efficiently.
- **Container Shipping:** NextStep could reorganize its outdoor storage system into a series of shipping containers. The containers would provide protection against weather and would increase operational flexibility by allowing NextStep to store and ship smaller quantities of material. Also, the added space would eliminate the need to use the graveyard for storage, providing additional capacity and organizational opportunities within the warehouse.
- **Enhanced Training:** Strong training programs with additional time-based incentives could help to reduce employee turnover and increase worker productivity. Improvement in these categories

would provide NextStep with a leaner and more stable base of core producers, ultimately benefitting the entire organization.

- **Short Technology Lifecycles:** Continual marketing and cyclical consumption of new products is an essential aspect of the technology business. New versions of products are released over increasingly short time frames. As consumers upgrade from last year's model to the next version of an item, NextStep will be able to do the same, taking advantage of recently discarded products.
- **Partnerships with UO:** NextStep should actively market themselves to the student population at UO. The seasonal nature of student residency will provide NextStep with regularly timed opportunities for both sales and reclamation. There are also a variety of potential partnerships that NextStep could develop with the UO in order to take advantage of free labor and increased expertise while also providing students with outstanding real-world experience. Potential opportunities include:
 - A computer rental program for students
 - Campus collection sites, events, and sales
 - Volunteer system through fraternities, sororities, and O-Heroes
 - Create recycling competitions between fraternities and/or sororities
 - Computer Science Department for database development, maintenance, updates to WebApps, Barcode System, Database, and Documentation
 - Business school (undergrad or MBA) marketing plan

Threats:

While societal trends toward increased recycling provide increased opportunity for NextStep, there are also several external threats that will require strategic planning on behalf of the organization.

- **Garten Recycling:** Garten is a well-established name in the recycling industry. Their central location in Salem provides them with access to the Portland, Salem, and Eugene markets. NextStep should focus on marketing itself in the Eugene area as a local Eugene-based organization. Emphasis on the

community outreach aspects of NextStep's operations will be essential in defending against Garten's potential intrusion to this market.

- **Increase in Recycling:** There is a burgeoning group of organizations getting involved in this industry, including Goodwill. One risk posed by this development is simply increased competition, which will require NextStep to ensure that it operates as smoothly and efficiently as possible to keep costs down. Attempting to gain economies of scale and establishing brand equity as the best and most comprehensive recycling organization in Eugene will also help NextStep to maintain their business. The organization must also be wary of potential employee poaching from new organizations. Enhanced training and development opportunities, as well as new or improved employee incentives may help to mitigate this risk.
- **Reliance on State Program:** A significant portion of NextStep's revenue is derived from Oregon's State recycling program. With the state currently in the midst of an extended recession and budgetary crisis, there is potential for NextStep to lose a large amount of their own operating budget if the State program is cut. NextStep should therefore work to improve the profitability of its non-State revenue streams. The organization may also consider engaging lobbyists on behalf of the program if political risks are anticipated.
- **Secondary Markets:** Craigslist and eBay provide consumers and prospective NextStep customers with alternatives that eliminate the "middle-man", and pilfer potential donation opportunities for the organization. NextStep should work to establish itself as a high credibility organization with guarantees that provide additional value to the consumer experience.
- **Property and Leasing:** As a non-owner, NextStep could also encounter a situation where the existing space is no longer available for leasing. There are two options for reducing this risk. If the existing location is expected to be adequate for NextStep's growth and future strategies, then the organization should approach the property owner to negotiate a long-term lease. If NextStep

anticipates that the company will grow out of the existing space, then the administration should continually search for other viable sites that could house future operations.

Triage Process Improvement

In evaluating where Next Step can improve their processes to gain efficiencies or reduce costs, the triage process stood out as an area that could yield substantial returns through incremental changes. For this project, the triage process is defined as the steps required to evaluate a computer or related component and the decision to rebuild the machine for resale or recycle it.

The two primary concerns that were identified after examining the triage process are:

1. The triage operation is a cost center that operates with an unknown cost structure. Operating costs such as overhead can be estimated but on a per unit basis, there is no method in place to evaluate the actual refurbishment costs.
2. The process lacks any specific performance metrics and inventory counts other than finished goods inventory and related physical counts. There is no accounting for parts inventory, machine inventory (unfinished), or work-in-process. There is no ability to calculate throughput time, efficiency, or even specific employee productivity on a per task basis.

The existing operations were compared to such industry PC triage standards created by Best Buy's Geek Squad⁷, Make it Work⁸, and Ultima Computers⁹. As previously mentioned in the SWOT analysis, this process already uses some industry best practices such as leverage standardize programs including MemTest and readily available hard drive wiping software to provide a standard benchmark for accomplishing the specified tasks in a timely manner. There is no need to change those processes and in fact Next Step should attempt to incorporate other best practices into their operations as part of the improvement plan.

⁷ <http://www.scribd.com/anon-523641/d/21527-Geek-Squad-Handbook>

⁸ Previous involvement or association by a team member.

⁹ Triage service provider for a team member's former company

The biggest area for improvement is implementing a tracking system that is capable of providing timely information to the enterprise. Driven by the operating model, this information needs to be sourced from a centralized database that is accessible to all business units including operations, finance, eBay, and the retail store. The end result is that information should flow from one unit to another and allow for a tighter control over inventory and prioritization. For example, this system should allow the retail store to leverage work-in-process inventory to request items be prioritized for restocking. As team Glasspond suggested, the drive towards a Coordination Model will push for the implementation of a centralized relational database system along with associated web applications or portals designed to be accessible by each business unit.

The path to implementing these improvements is detailed through the Triage Swimlane Process Diagram, detailed in the next section of this document.

Triage Swimlane Process Diagram

To help facilitate impactful change to the triage operations at Next Step, a swimlane process diagram (shown in Appendix A) has been created to map out the overall workflow of the process and to provide points and areas for change and suggestion. A before and after comparison was not created; rather the swimlane diagram is positioned as a best-case practice scenario and is focused on how the triage operations should evolve. Producing diagrams such as these is a key step in moving the Enterprise Architecture of Next Step from stage 1 to stage 2. Every effort has been made to ensure that terminology used in this diagram is consistent with terms and procedures currently used by Next Step. However, some modification may be required.

Triage Operation Stages

It is important to note that the entire triage operation actually needs to incorporate actions that are not directly related to evaluating and rebuilding a computer. The entire concept of performing computer and component triage is related to the evaluation and classification of components that pass through the process flow designed as the triage operation. The two exit points for the process are not

strictly defined triage points and a machine or component can only leave the process by being recycled or sold. For those reasons, the swimlane diagram reflects the two exit points but recognizes that components entering and exiting this process are subject to the constraints of the exit points in their respective operations. For example, the desired exit point for a rebuilt computer is an exit through sale via the retail store. The retail store's operations should have bearing on the work currently being conducted within the triage operations and therefore may have influence over a component's point of exit. Therefore, these considerations had been included in the process diagram where needed. The swimlane diagram decomposes the triage process into five main areas of activity.

Area 1: Initial Evaluation

The first stage in the process, this stage includes the first major decision point for any item entering into the triage process. The decision point, identified on the diagram as "Build or Recycle", reflects the decision to send a computer to Disposal, Salvage or Initial Evaluation. While an item may exit the triage process via the exit point in this stage, this does not mean the item simply leaves NextStep only that it has left the triage process and subject to other constraints not documented by this process diagram.

Area 2: Salvage

In this process, Salvage refers to the ability to decompose larger components such as Desktop PC's into individual components that can be evaluated and added to the internal parts/component supply stock. Examples of components include memory (RAM), hard drives, graphics cards, and power supplies. The goal of this stage is to identify and separate parts that can be used to augment or repair machines that are suitable to be rebuilt for sale. As part of the salvage process, standard testing procedures such as component testing and hard drive wiping are conducted before an item enters the internal parts stock.

Area 3: Initial PC Evaluation

Any machine that has been chosen for rebuilding and ultimately resale will be evaluated at this point in the process. This is an initial checkout to ensure the machine is suitable for rebuild and to potentially identify what work needs to be done in order for it to reach the retail store. At this point in the process, a Machine Tag will be created and follow the computer from now until a sale occurs.

Area 4: PC Build

This phase of the process diagram reflects the actual rebuilding of a PC. The Build Process as shown in the swimlane diagram encompasses every step taken from the moment the machine enters this phase until it exits. Sub-processes shown on the diagram include HD Wipe, Component Upgrade (i.e. RAM, Graphics Card, HD, etc.), OS Install, and Testing and Verification. Each machine may require a different combination of sub-processes and for simplicity of diagramming, not all sub-processes are shown on the swimlane diagram.

Area 5: Retail

When a machine has passed the testing and verification process in Area 4, it is verified as ready for sale and the component physically is transported to the retail store for sale. At this point, the item awaits sale and then exits the overall process via sale. Please note that this process diagram does not consider any returns of items from the retail store to the warehouse as that will probably occur for factors outside of this process rather than from addressable failures of any given process point. If an item is returned related to a problem with its time in triage then this diagram should provide a framework for evaluating where the process failed the specified item.

Triage Process Improvement End Results

By implementing the changes detailed in this document include the use of scan points and a centralized database, Next Step can overhaul their triage process to support business growth, reduce costs, and increase efficiency. Leveraging community and University of Oregon resources such as the

Computer Science department and internal existing resources such as the existing barcode generation and scanning system, Next Step could implement these improvements in phases with minimal expenditures. The end result of triage process improvements is that information is generated for two major categories as follows:

Inventory Data	Performance Metrics
<ul style="list-style-type: none"> • Parts Inventory (RAM, HDs, etc.) • Machine Supply Stock • Work-In-Process <ul style="list-style-type: none"> ○ Detail counts for each stage • Finished Goods Inventory • Retail Store Inventory 	<ul style="list-style-type: none"> • Throughput • Time-on-Station • Cost per station • Supply Stock utilization rate

Building Efficiency: Low Cost Strategies

Considering the budgetary constraints at Next Step, we decided to focus our building efficiency efforts on low cost strategies. In addition, since the facilities themselves are rented and may only be occupied for a relatively short period of time, solutions requiring extensive retrofits to the building itself were excluded from consideration. Each identified problem and related solution strategy seeks to lower costs while improving the character of the working environment for both volunteers and permanent employees. Our research identified two primary areas for improvement over current operations, energy efficiency and spatial efficiency.

Each of the following energy and spatial efficiency strategies should be considered a conceptual first-pass at actual solutions. We recommend approaching a professor within the Department of Architecture, Erin Moore for example, to discuss running a one to two term-long architecture design studio focused on the challenges and opportunities faced at Next Step Recycling. Under the one-term model, approximately 16 students would each spend 15 hours per week in the classroom, for 10 weeks, developing specific spatial and energy focused solutions. Under the two-term model, actual built solutions could be created when combined with the efforts of an organization such as designBridge.

Energy Efficiency

Problem: HVAC equipment is located at ceiling level. Heating and cooling equipment is less efficient when not located at the level of the human user. Especially in the case of a poorly-insulated warehouse, a significant amount of heat released at the ceiling will rise and escape through the roof. Furthermore, because heat rises, all of the air has to be heated for the warmth to reach the occupied level. Cool air released at the ceiling may become warm before it reaches the user until all of the air is cooled.

Solution: Use portable space heaters and coolers. Do not use ceiling-height HVAC equipment. Instead, use portable space heaters and coolers located where people work. Heat will rise though the occupied space, and cool air will pile up. Energy and money are saved by not conditioning the air above the occupied space.

Problem: Dirty skylights are not letting in enough light. Since the skylights are not letting in enough light, all of the overhead lighting must be turned on to adequately light the space.

Solution: Clean the skylights, turn off two bays of lights. Cleaning the skylights may allow enough additional light into the space for the bays of lights directly below the skylights to be turned off on days with enough natural light.

Problem: Overhead doors are blocked. Since the overhead doors are blocked, they are not opened. Keeping the doors closed is a wasted opportunity for natural light and ventilation.

Solution: Infill open overhead doors with removable glazed panels; turn off two more bays of lights. By opening the overhead doors, a significant amount of natural lighting will come into the work spaces. This will allow for the two external bays of lights to be turned off. These infill structures can be designed and built at a very low cost— particularly, if you pair with a local design–build group such as designBridge. Additionally, the infill structures can be designed with sensitivity to the need for ventilation and light, while at the same time, minimizing the amount of new dust entering the building.

designBridge operates out of the Department of Architecture and is a multi-disciplinary student organization linking the University of Oregon with the surrounding community by offering design and design-build services to local organizations that don't have resources to acquire professional design services (<http://designbridge.org/>).

Spatial Efficiency

Problem: Storage lacks clear ordering system. Because there is not an overriding ordering system for stored items, time is lost orienting new workers to the system, and locating specific items. Apparent disorder promotes actual disorder.







Solution: Sort storage in well-defined, well-labeled, and easily accessible aisles. Maintaining a strict ordering system for stored items will not only make storage more efficient, but more effectively accessed. This is particularly important for temporary storage, such as the goods and materials in the graveyard. Embracing this strategy will also help alleviate pressure when training new employees by making the organizational system more imageable.




Problem: Exterior space not optimized for use. The exterior space is under-utilized. Large equipment and materials clutter the space.

Solution: Add additional shipping containers for protected storage; keep yard clear for ease of access. By adding additional shipping containers, excess storage from inside can move to the yard. Once a container is filled, the items can be easily transferred to a truck for removal. Depending on the actual space available, you may be able to create adequate enclosed storage space so that the additional building on-site will be no longer needed. From our initial assessment, reorganizing the exterior space will accommodate at least two additional shipping containers.

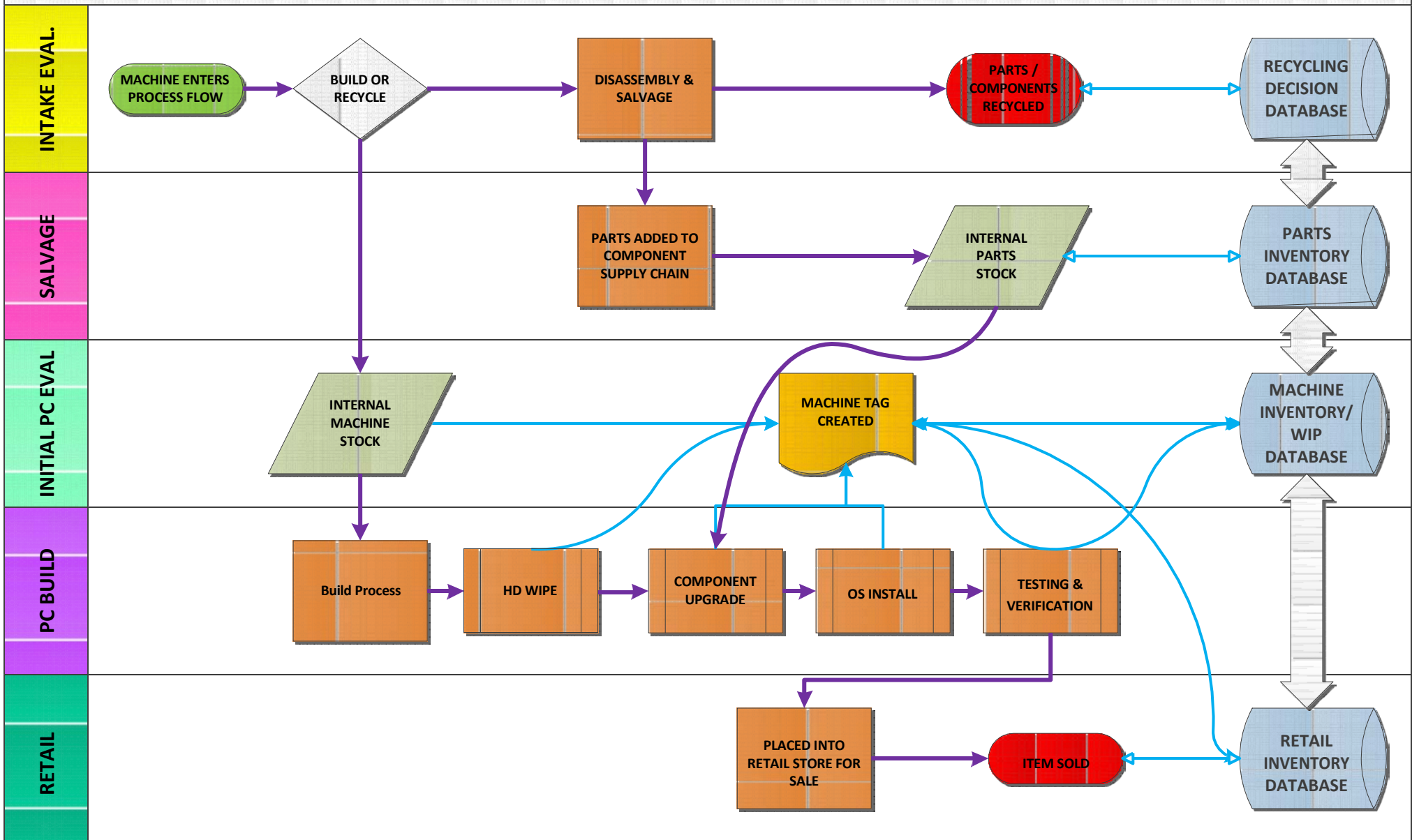
Appendix A: Triage Process Diagrams and Explanations

Triage Swimlane Process Diagram Icons and Descriptions

	<p>This icon represents the starting point of the entire process. In this diagram, there is only one start point as a machine or component cannot enter the process through any other means. If an item enters at a different point, then there is an increased risk of process failure which could lead to decreased efficiencies, process loops (not shown), or increased costs.</p>
	<p>Major decision points are identified by this icon and a description. In this diagram, only one major decision point is identified but that does not mean that other decisions do not occur along the way. In the stage-gate model, this would be a "Go/Kill" decision gate with a "Go" decision indicating a machine would enter the rebuild process and a "Kill" decision indicating it was ready for disassembly and salvage.</p>
	<p>A scan point represents an action or process that should be accompanied by a corresponding scan with the barcode system. This scan will update the related databases to indicate inventory levels (check in/out), work-in-process, or significant movement within the triage process. Every major movement or process should have its own defined scan points. The process diagram shows multiple scan points but is not intended to be complete list of available scan points. Using scan points will create data used to calculate key process metrics.</p>
	<p>The machine tag is the core component that allows for process tracking of a computer as it transits the triage process. The tags are based around the barcode system and will contain unique identifier numbers that follow a specific machine from Initial PC Evaluation through a sale at the Retail Store. The tags are designed to be reusable, but that will require further modification of the centralized data system. This machine tag will be the item that gets scanned at the Scan Points, along with a point identifier, to create data used to calculate performance metrics.</p>
	<p>Supply stocks are inventory stores of PC components. These components include power supplies, power adaptors, RAM, and hard drives. Every time an item is placed into or removed from a supply stock, it should be accompanied by a corresponding scan in/out to help calculate inventory levels. While supply stocks are bound by a single identifier within the diagram, physically they can be separated.</p>
	<p>A data store represents a database, or set of databases, that stores the data related to the triage process. It has been recommended by this team, and team Glasspond, that Next Step employs a centralized database system to track inventory and processing of triage actions. The data stores shown on the diagram are components of a centrally integrated relational database system that is available to support operations across the entire organization. This also corresponds to the Enterprise Architecture improvements previously</p>

	suggested, directly supporting the Coordination Operating Model.
	This icon represents an exit point for an item or component from the triage process.
 Physical Move	A physical move is a move of a component from one part of the process to another. In most cases, it really is a physical move with a machine going from the build bench to the testing bench. In some cases, it may only represent a process move depending on the physical layout of the triage area.
 Data Flow	Data flow arrows represent the flow of data from a scan point/machine tag to and from the data store. When a tag is scanned, the data created by the scan, often including a Machine Tag identifier is passed off to the corresponding database. In some cases, the data flow is shown as being two directions to account for the relation to a specific item such as work-in-process and the machine tag.

NEXT STEP TRIAGE SWIMLANE PROCESS DIAGRAM



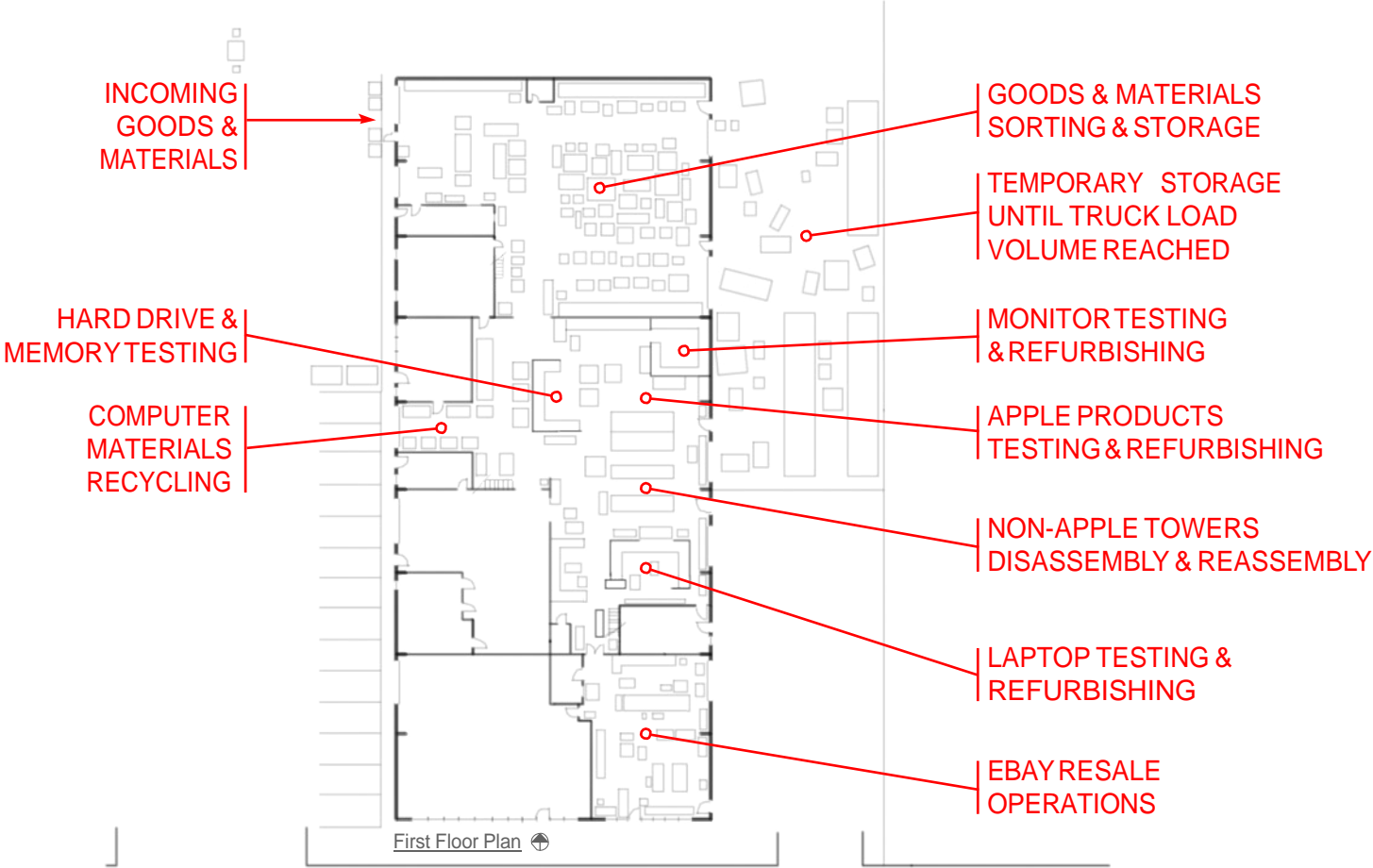


BUILDING EFFICIENCY: LOW COST STRATEGIES



ReUse is the New Recycle

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ReUse is the New Recycle

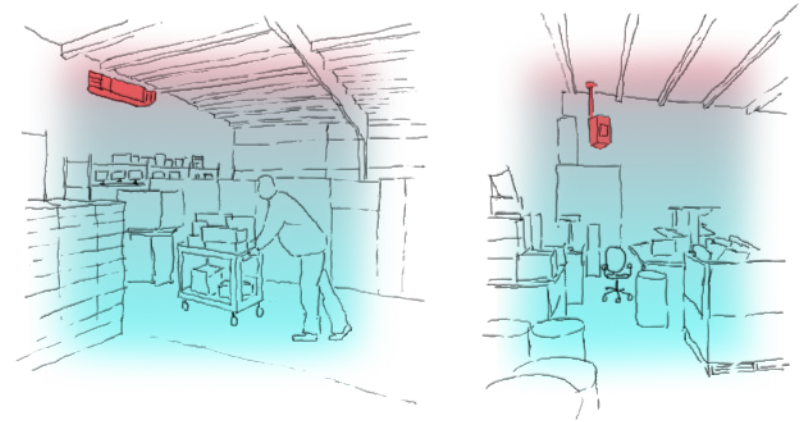
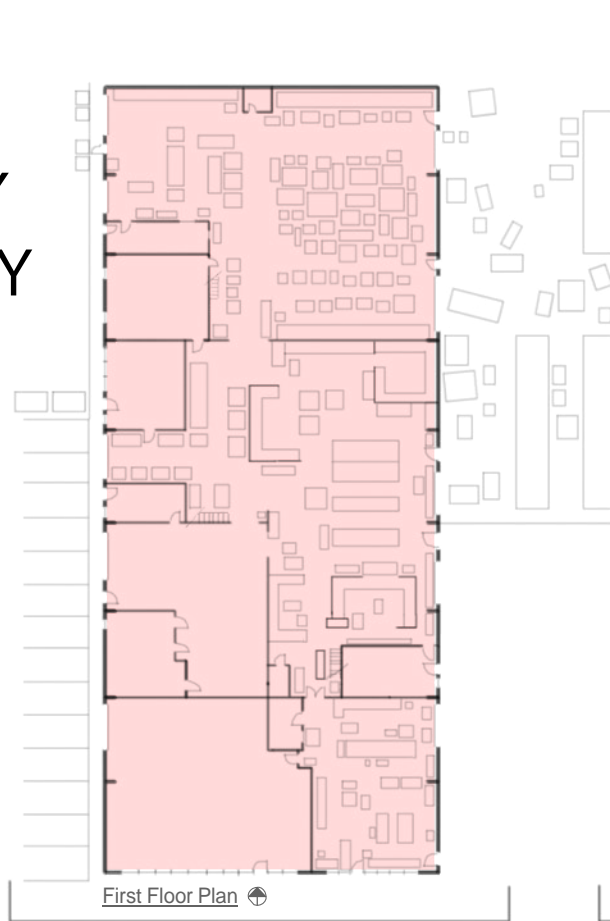
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ENERGY
EFFICIENCY



BUILDING EFFICIENCY: LOW COST STRATEGIES

ENERGY EFFICIENCY



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HVAC equipment is located at ceiling level.

Heating and cooling equipment is less efficient when not located at the level of the human user.

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BUILDING EFFICIENCY: LOW COST STRATEGIES

ENERGY EFFICIENCY



SOLUTION:
Use portable space heaters and coolers.

Do not use ceiling-height HVAC equipment.

Instead, use portable space heaters and coolers located where people work.

Heat will rise though the occupied space, and cool air will pile up. Energy and money are saved by not conditioning the air above the occupied space.



BUILDING EFFICIENCY LOW COST STRATEGIES

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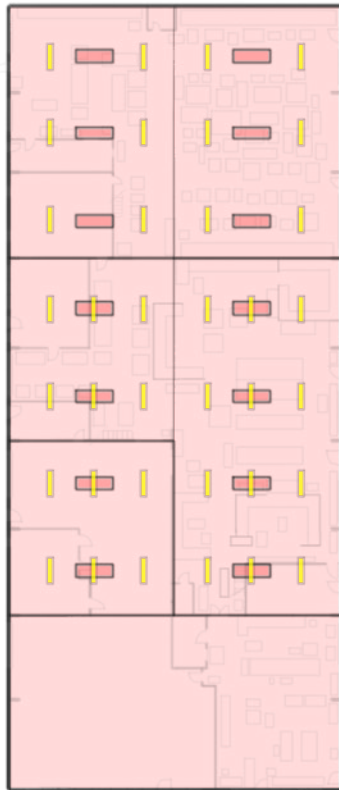
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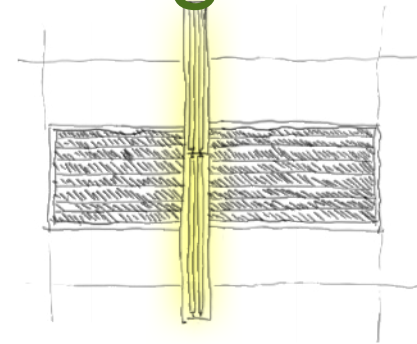
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ENERGY
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Reflected Ceiling Plan



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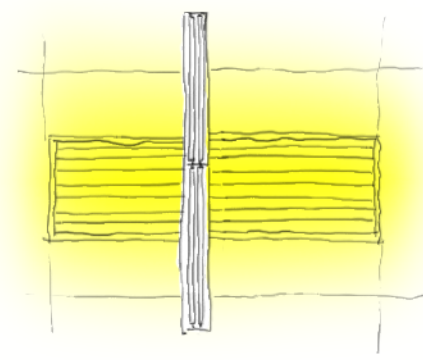


BUILDING EFFICIENCY: LOW COST STRATEGIES

ENERGY EFFICIENCY



Reflected Ceiling Plan



SOLUTION:

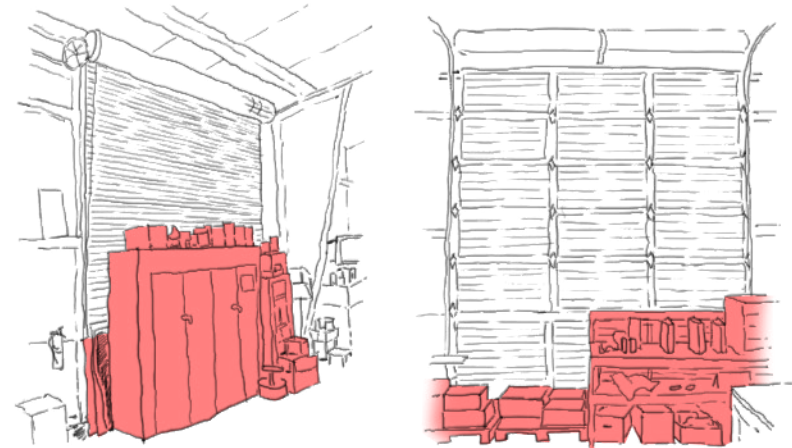
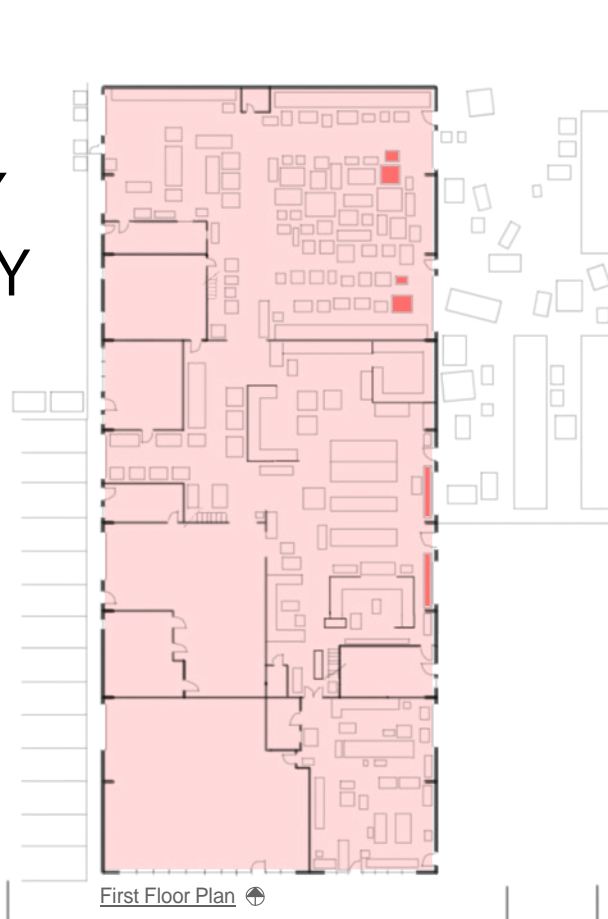
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BUILDING EFFICIENCY: LOW COST STRATEGIES

ENERGY EFFICIENCY



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Overhead doors are blocked.

Because the overhead doors are blocked, they are not opened. Keeping the doors closed is a wasted opportunity for natural light and ventilation.

BUILDING EFFICIENCY: LOW COST STRATEGIES

ENERGY EFFICIENCY



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SOLUTION:
Infill open overhead doors with removable glazed panels; turn off two more bays of lights.

By opening the overhead doors, a significant amount of natural lighting will come into the work spaces. This will allow for the two external bays of lights to be turned off.

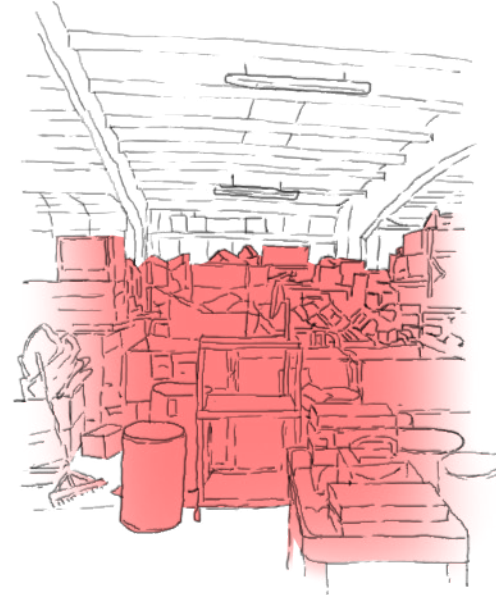
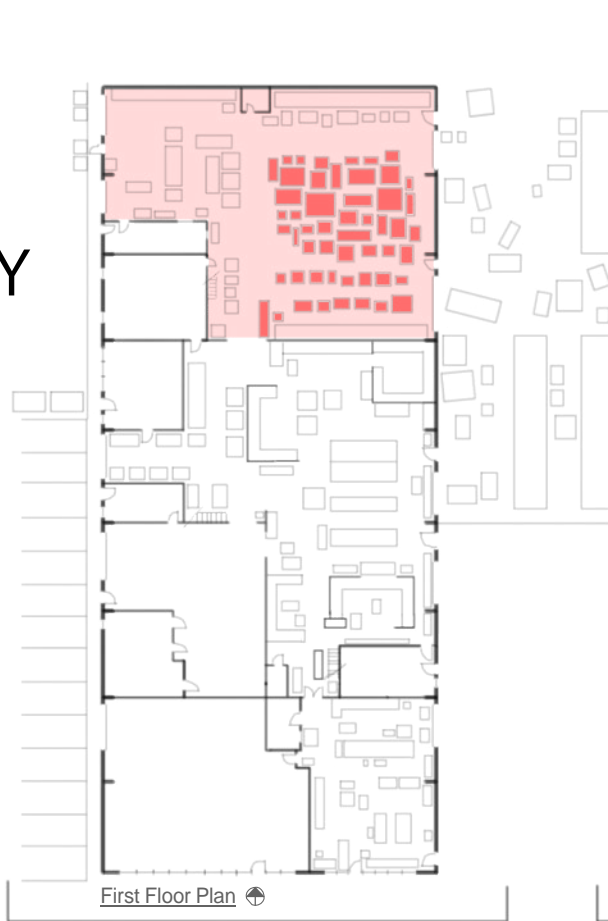
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BUILDING EFFICIENCY: LOW COST STRATEGIES

SPATIAL EFFICIENCY



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BUILDING EFFICIENCY: LOW COST STRATEGIES

SPATIAL EFFICIENCY



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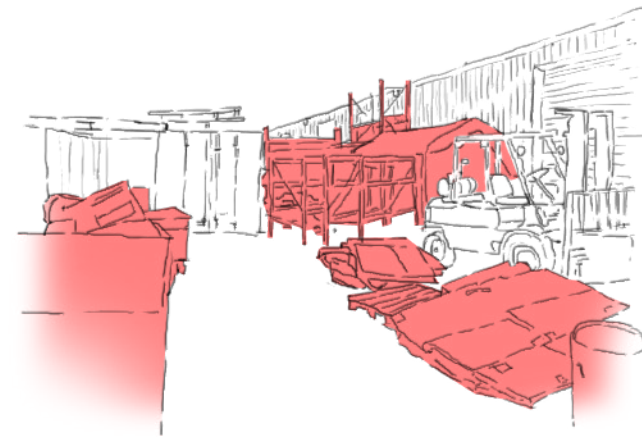
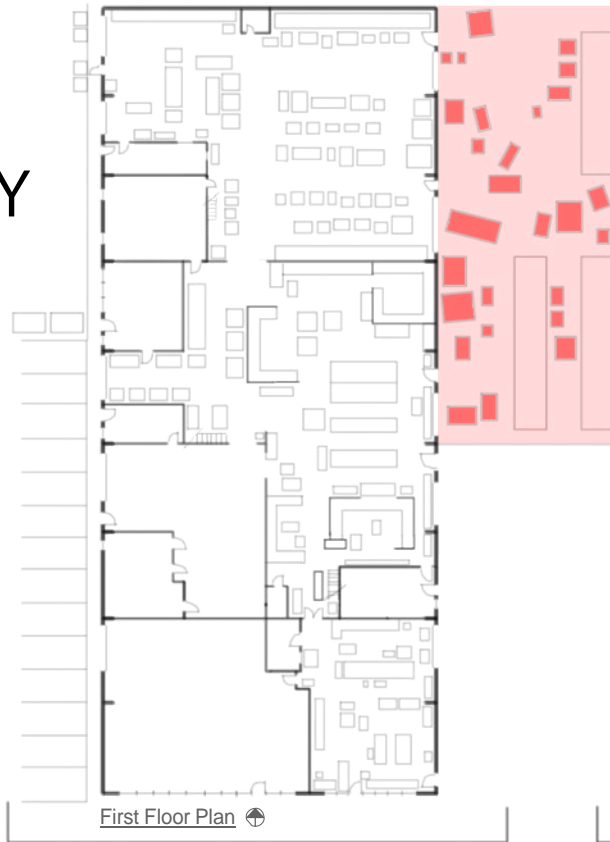
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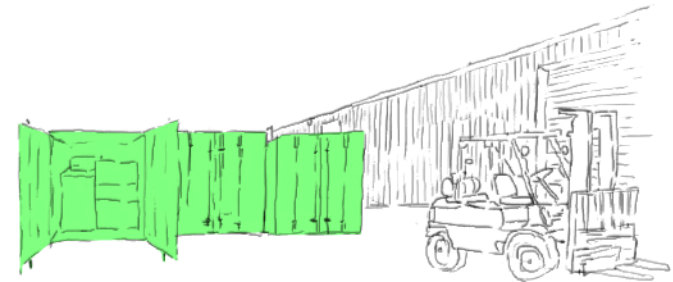


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The exterior space is under-utilized. Large equipment and materials clutter the space.

BUILDING EFFICIENCY: LOW COST STRATEGIES

SPATIAL EFFICIENCY



SOLUTION:

Add additional shipping containers for protected storage; keep yard clear for ease of access.

By adding additional shipping containers, excess storage from inside can move to the yard. Once a container is filled, the items can be easily transferred to a truck for removal.

BUILDING EFFICIENCY: LOW COST STRATEGIES

RESULTS



Organization and optimization of storage spaces improves efficiency and workflow, especially in the case of temporary storage, and when there is high worker turnover.



BUILDING EFFICIENCY: LOW COST STRATEGIES

RESULTS



Reflected Ceiling Plan

By increasing natural lighting, more than 50% of the overhead lighting can be turned off. Only work areas need bright lighting, which can be augmented with task lighting at less energy expense.

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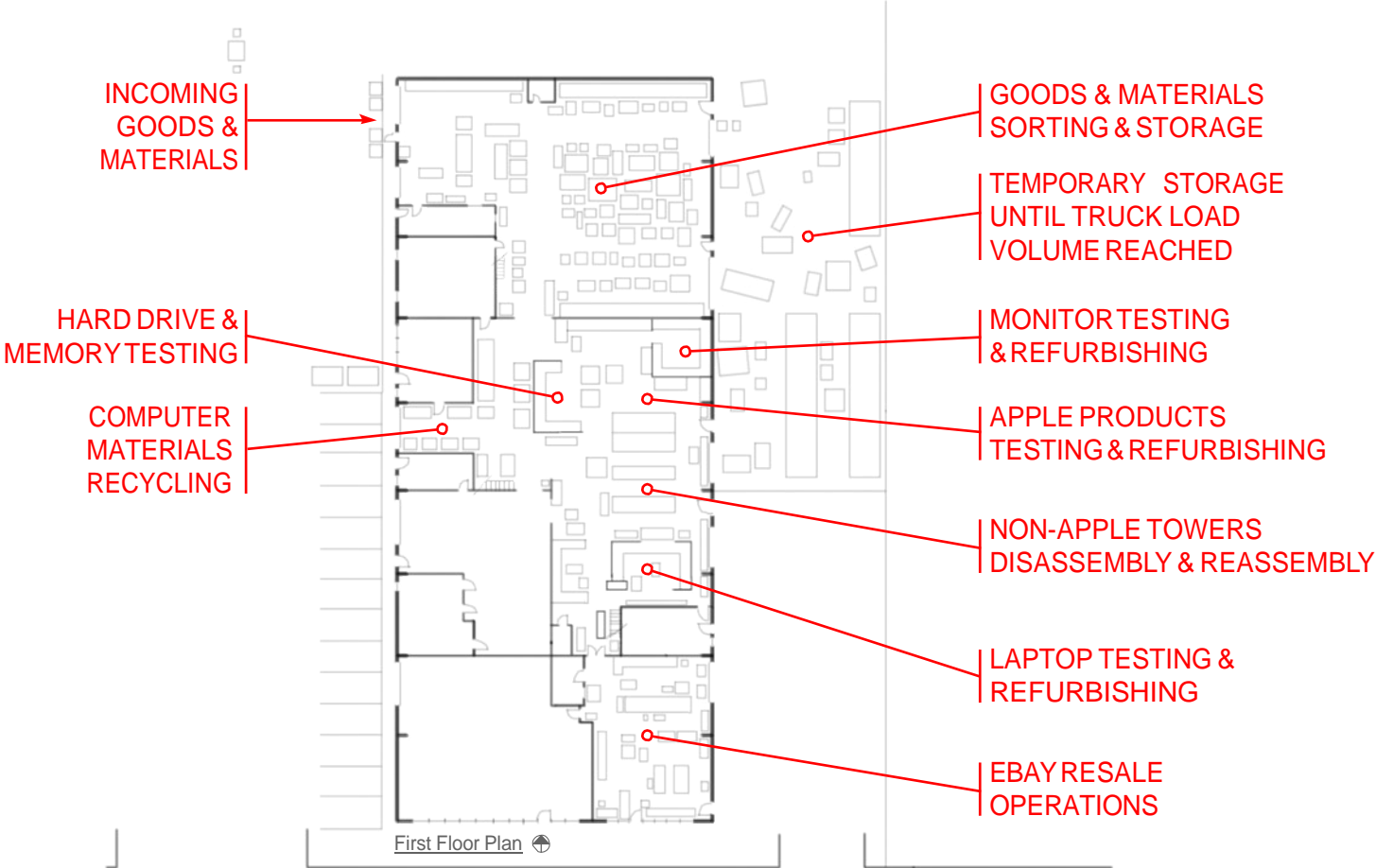
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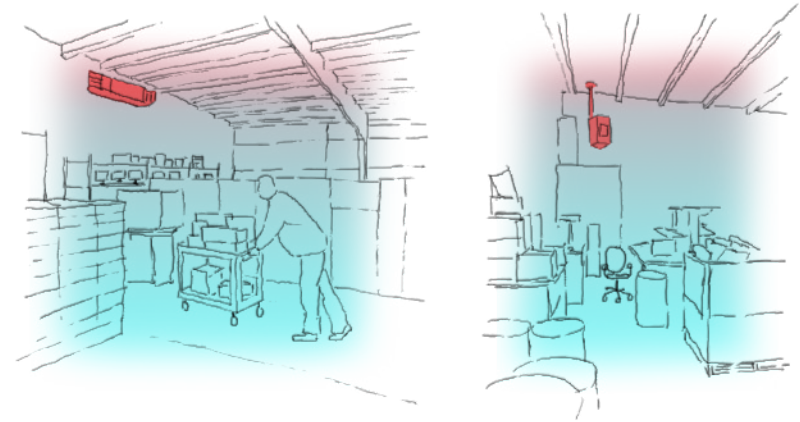
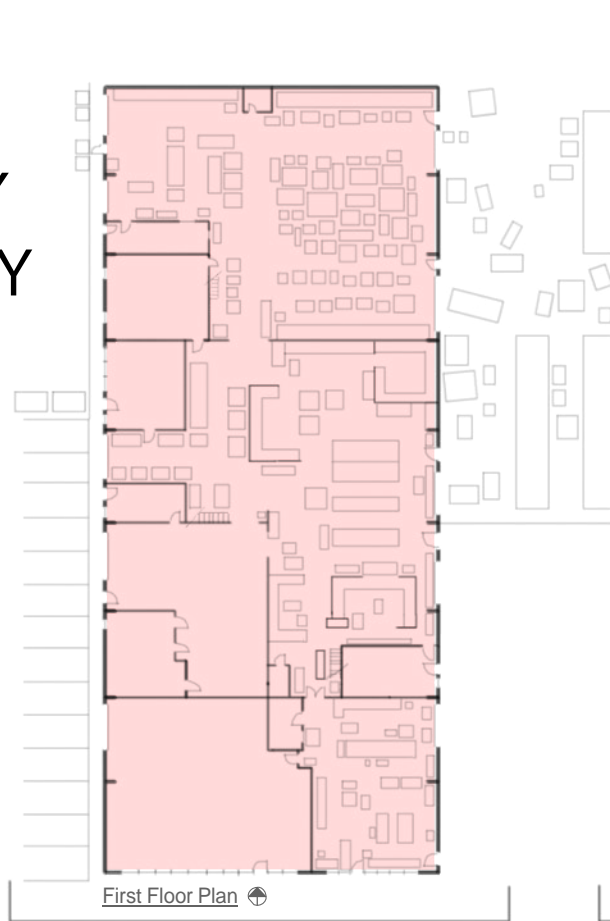
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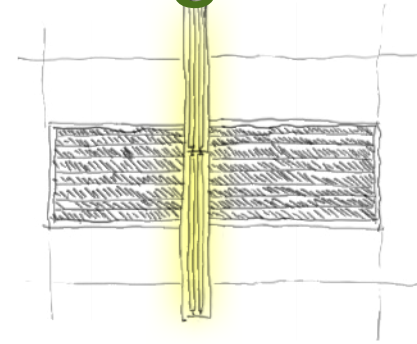
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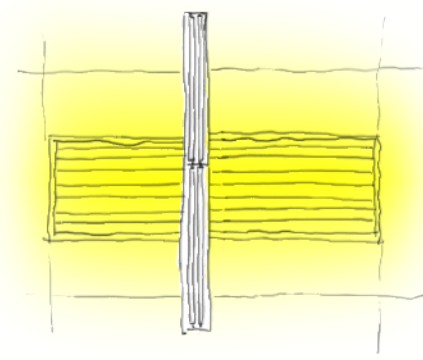


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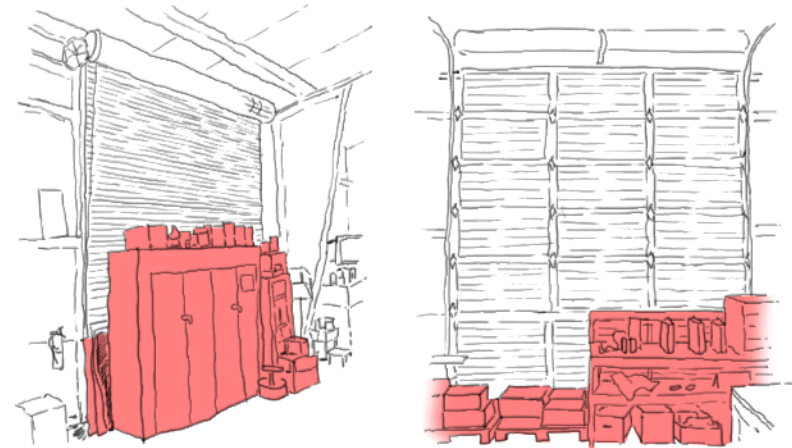
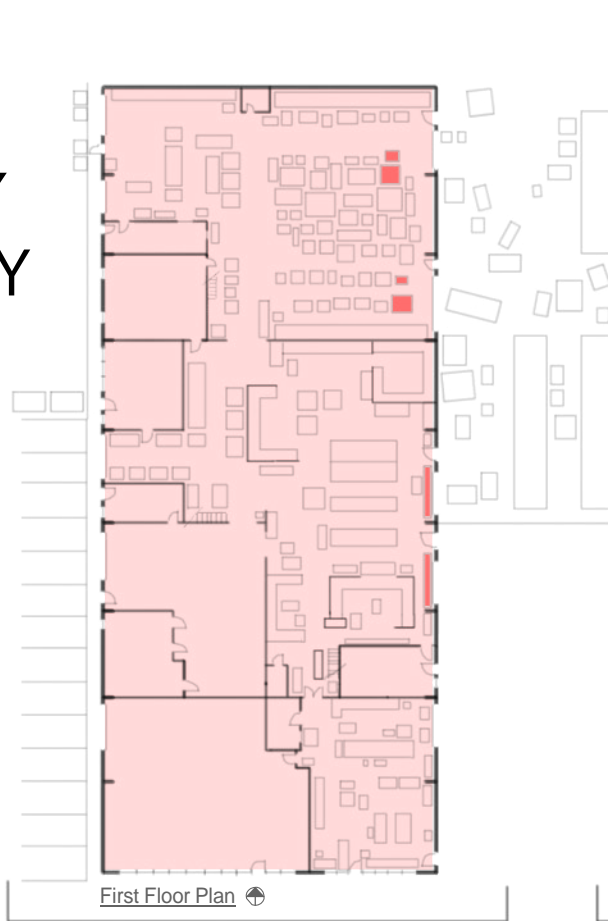
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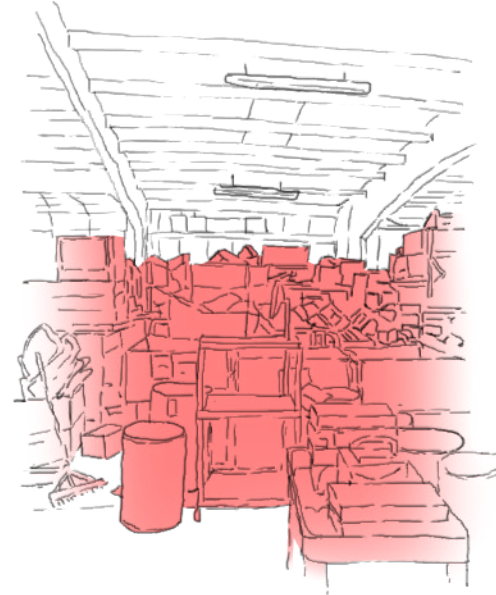
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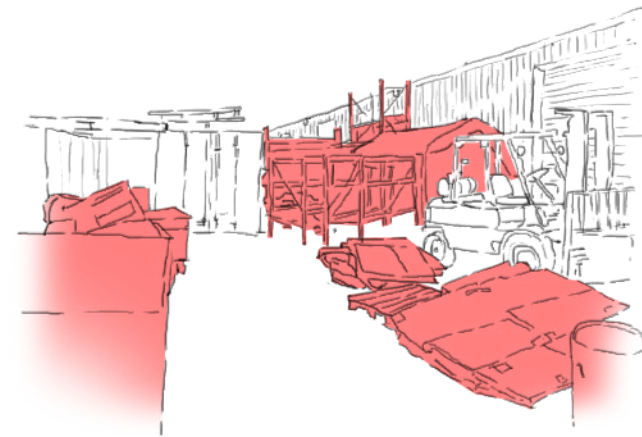
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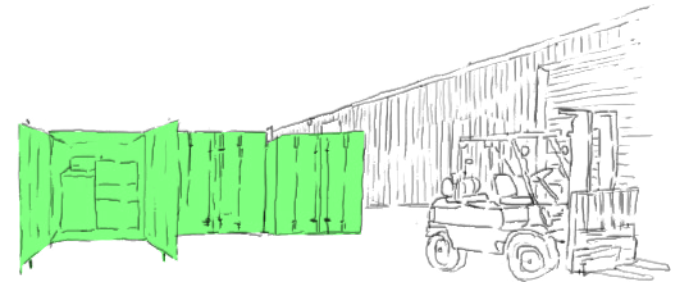


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BUILDING EFFICIENCY: LOW COST STRATEGIES

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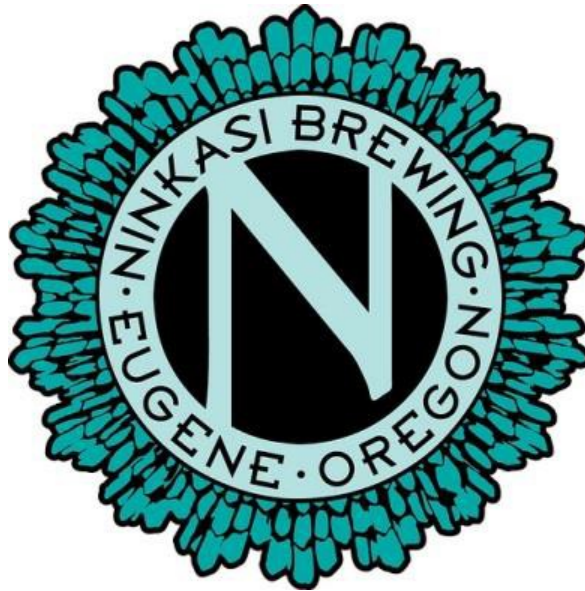


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Ninkasi

Process Capacity Analysis

Prepared for:

Ninkasi

Jessica Jones,

Director of Business Process Development

541-344-2739 x213

By:

University of Oregon

Bryan Schoen, Monir Jalili, Jake Heckathorn, Thomas Schwenger

DSC 577 Spring 2012

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Executive Summary

Ninkasi, a microbrewery founded in 2006 by Jamie Floyd and Nikos Ridge, has experienced tremendous growth as customers have fallen in love with the craft beer. Ranking No. 3 in the amount of Oregon-made beer sold at Oregon breweries and brew pubs, Ninkasi has nearly reached maximum production capacity.¹ This report analyzes Ninkasi's current production capacity, identifies bottlenecks in the system, and provides details recommendations for removing the bottlenecks to increase production. Our recommendations will help Ninkasi to meet its forecasted annual demand numbers. Our calculations are designed to minimizing the amount of capital tied up new equipment.

In 2006, Ninkasi produced 1,600 barrels per year. In only 5 years, customer demand has driven production levels above 56,000 barrels per year in 2011. In just one year, the Eugene brewery jumped from the 50th-largest craft brewery in the United States to the 32nd-largest, co-founder and CEO Nikos Ridge said.² Ninkasi is one of the fastest growing domestic breweries however it is not without growing pains. Project planning complexity increases when a company exhibits the high growth numbers that Ninkasi has seen since inception. "We weren't expecting to be in expansion mode again so soon," Nikos Ridge said when commenting on Ninkasi's \$15 million expansion that will add 70,000 to 80,000 square feet just west of its 20,000-square-foot facility. The new expansion will increase the brewery's capacity from 95,000 barrels to 200,000 barrels per year.

Our analysis calculates the specific pieces of equipment that Ninkasi can add to its production line to increase production to the predicted annual demand. Carefully planned out expansion will help minimize the total cost of the project while enabling Ninkasi to meet customer demand. James Book,

¹ www.bizjournals.com

² www.registerguard.com

Ninkasi Marketing Director, recently commented that production infrastructure has been a limiting factor, noting that, “We have these and other beers (lagers) we have been wanting to make on a larger scale. However, it has been a matter of what our production infrastructure can facilitate³.”

We recommend installing new fermenters in specific intervals to meet demand through 2016. (See the Analysis and Recommendation sections) The recommendations were calculated by using a process capacity analysis, projecting out demand, and applying Little’s Law to determine the appropriate increase in production. We used a combination of 2 -3 site visits, conference calls, emails, and archival data to analyze the problem. Our tasks included performing a through process capacity analysis of Ninkasi’s brewing operations in Eugene, mapping the current process; identify bottlenecks and estimates of overall capacity of the current facility.

³www.notsoprofessionalbeer.com

Problem

Ninkasi is currently planning to expand its brewing capacity as the company seeks to distribute into new regions. In order to do so this efficiently, Ninkasi would like to map the process capacity of its current operations to better understand how it can systematically add capacity while avoiding large one-time capital expenditures. To accomplish this goal, a detailed mapping of the processes and identification of the bottlenecks of the brewing process is imperative.

The Director of Business Process Development at Ninkasi, Jessica Jones, gave our group Ninkasi's targeted capacity goals for each year through 2016. It was the job of our group to find out how to add capacity to meet these targeted goals. Figure 1 below shows these goals:

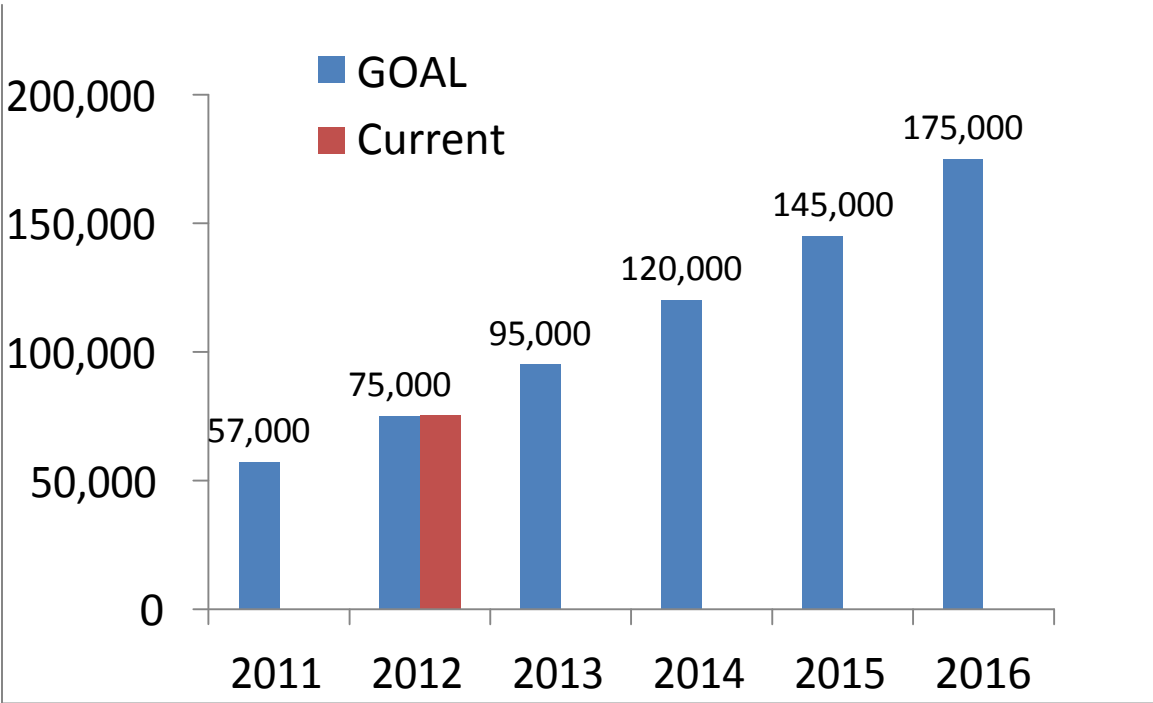


Figure 1: Capacity on the y-axis is in barrels

Scope

Perform a thorough capacity analysis of Ninkasi’s brewing operations in Eugene. This includes mapping the current processes, identifying bottlenecks, finding capacity, and determining how bottlenecks change as capacity is added. After this is accomplished, we will calculate how much capacity must be added to meet Ninkasi’s targeted goals.

Objectives

Determine the time and capacity of each process

Jones also provided us with the current capacities at each stage of the brewing process shown in Figure 2:

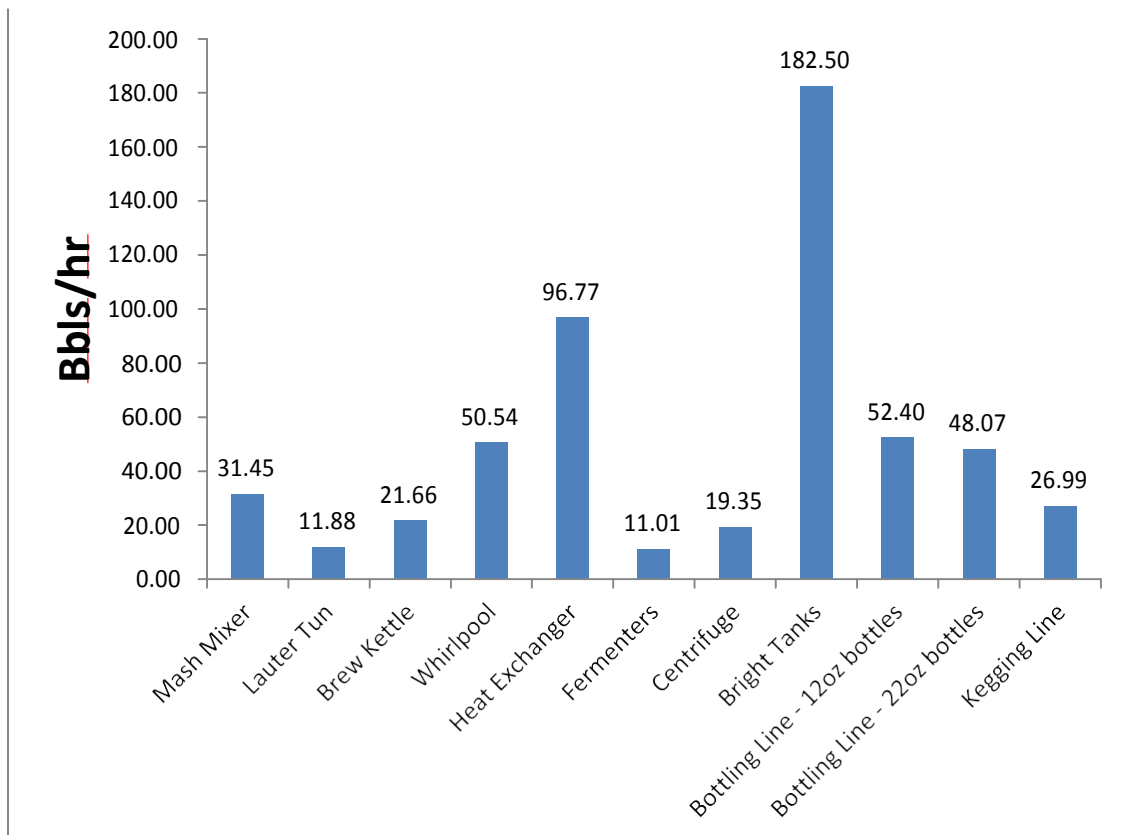


Figure 2: Current capacities at each stage of the brewing process

At first glance of figure 2, the fermenters look like the main bottleneck with a flow-rate of 11.01 bbls/hr, but the bright tanks can donate some of its excess capacity and to the fermentation process. Therefore, the lauter tun becomes the bottleneck at 11.88 bbls/hr. A slight change in capacity to the fermenter or lauter tun will change the bottleneck between the two.

Solution Methodology

We have used the bottleneck analysis perspective and the Little's law to calculate the capacities in each step of the process. Before explaining the details in every sub-process, here are the general assumptions and facts have been applied in the analysis:

- Brewing process is from Sunday afternoon to Friday afternoon. We are assuming 24 hours in a day and in average 5.5 working days per week. The 5 day process, 6th day use for flexibility maximum capacity, 7th is used for cleaning.
- Some activities can only happen on certain days (not 24 hours, because of cleaning)
- Shipping and Storage is outsourced.
- The values for the Inventory Type column indicate the type of variable being measured, a stock, a flow, or a batch flow.
- Stocks are basically snapshots: e. g. a weight or volume in tank at a given point of time. Usually parts of the production process the function as storage or holding tanks are the only stocks.
- Flows are measurements of units over time: e.g. Barrels per minute, pounds per hour, bottles per minute, etc. It means a continuously flowing process where units go in as other units move out, as on the bottling line.
- Batch flows are like a cross between a stock and a flow. They are processes like flows in that they handle units over time. However, they are different from regular Flows in that they are

discrete rather than continuous. They accept units in, enact a process on them for a time, and then output those same units before accepting new units. So, these parts of the process have both a unit capacity (like a stock) that measures how much they hold during the processing time, AND they also have a processing time. If you divide one by the other, their output can be measured in units per time like a flow, however it would be misleading to represent their output as continuous rather than discrete.

We have assumed Ninkasi recruitment efforts are successful enough that human capital never becomes a bottleneck. Right now, it is one. This is why they brew only 29 brews per week (rather than 30-something) and only 5.5 days per week rather than 6.0 or 6.5 days per week. This is a short-term problem and they do not anticipate that it will persist. Right now, 3 brewers are working 3 shifts @ 5 days (2 managers available to brew).

The tables below show the capacity number of each step in four main sub-processes: malt handling, Brew House, Cellaring and packaging. We have used the modified little's law for inventory type of FLOW and Batch Flow as below:

Sub-process one: Malt Handling

Step	Name	Type	Capacity
01	Malt Silo - Pale Malt	Stock	60,000 lbs
01	Malt Silo - Munich Malt	Stock	22,000 lbs
01	Malt Storage - Specialty Malts	Stock	Unlimited
02	Mill	Flow	1000 lbs/hr
03	Grist Case	Stock	6,000 lbs

Sub-process two: Brew House

Step	Name	Type	Capacity (lbs/hour)	Capacity (bbls/hr)
04	Mash Mixer	Batch Flow	3,750	31.45
05	Lauter Tun	Batch Flow	1,667	11.88
06	Brew Kettle	Batch Flow		21.66
07	Whirlpool	Batch Flow		50.54
08	Heat Exchanger	Flow		96.77

- Average loss rate of 15% has been applied to Lauter Tun in brew house. This loss rate can vary based on the type of the beer. For example, Tricerahops loss rate is 10% (Double IPA) and Helles Belles loss rate is 5% (German Pilsner)
- The machines in brew house are in a sequence, so the brew house is able to produce as much as its weakest machine, its bottleneck. 11.88 barrels per hour is approximately equal to 29 brews of 55 barrels per week. (24 hours each day and 5.5 days a week)
- It is very important to note that for Mash Mixer and Lauter Tun, we have two types of capacity: lbs per hour and bbls per hour. If we could somehow convert lbs/ hr to bbls/hr and add that to the capacity measured in bbls/hr, the total number would be much more accurate. We didn't do so, because 11.88 bbls/hr is already indicating the 29 brews per week which is happening in reality, beside we didn't have an accurate conversion method for lbs to bbls.
- There are some overlapping processing times between steps which doesn't affect our analysis, Here they are: Last 10 minutes of mash mixer overlap with first 10 of Lauter Tun since wort is transferring & sitting in both. Similarly, last 100 minutes of lauter tun overlap with first 100 minutes of brew kettle. Similarly, last 20 minutes of brew kettle overlaps with first 20 minutes of whirlpool.
- In heat exchanger, capacity is higher when the weather is cold, because it has to cool each volume of beer by fewer degrees.

Sub-process three: Cellaring

Step	Name	Type	Process Time	Loss Rate	Total Flow rate
09A-09F	16 Fermenters (different sizes)	Batch Flow	12 days	12.4%	3171 bbls per 12 days (11.01 bbls/hr)
10	Centrifuge	Flow		0%	19.35 bbls/hr
11A-11E	11 Bright Tanks (different sizes)	Batch Flow	0.5 day	0%	182.5 bbls/hr

- 16 fermenters: (One 20 bbl, Three 60 bbls, Three 100 bbls, Four 240 bbls, Two 360 bbls, Three 480 bbls)
- 11 Bright Tanks: One 50 bbl, One 100 bbls, Five 120 bbls, Two 240 bbls and Two 480 bbls)
- Bright tanks – B123 & B124 (each 120 bbls) can be used as fermenters in max capacity calculations. So two resources can be exchanged between fermenters and bright tanks.
- Capacity of Fermenters can bump up to $11.01+0.73=11.74$ bbls/hr. Still just a bit less than Brew house capacity.

Sub-process four: Packaging

Step	Name	Type	Process Time	Loss rate	Total Flow rate
12A	Bottling Line - 12oz bottles	Flow	250 Bottles/Minute	3.6%	52.40 bbls/hr
12B	Bottling Line - 22oz bottles	Flow	150 Bottles/Minute	3.6%	48.07 bbls/hr
12C	Kegging Line	Flow	56 Kegs/Hour	3.6%	26.99 bbls/hr

- 1 Case = 24 12oz bottles = .072 BBL
- 1 Case = 12 22oz bottles = .066 BBL
- 1 Keg = 1/2 BBL

Data Analysis

Current Bottlenecks

The Ninkasi team claims that Brew house is the bottleneck. But our data shows that Fermenters are. (At

least they are very close). That partly corresponds to Human capital availability in brew house. It also can change because of different loss rates varying among products. It also depends on how many hours a day, how many days a week we have used in our calculations. So the calculations are a function of all these factors and therefore not very deterministic.

Capacity Extension

- Old brew kettle is 60 bbls with actual yield of 55 bbls after brew house and only 49 barrels after passing fermenters.
- New brew kettle is 100 barrels, same expected loss rate (92 bbls yield). 80 barrels bottled per 100 input yield after fermenters
- With the new 100 bbl system in place in addition to the current 60 bbl system, the brew house will certainly have excess capacity.
- The brew house will not be the focus in bottleneck analysis anymore. The next candidates are: Fermenters.

Projections

Given the brew house expansion, the current bottleneck is the fermenters with a flow rate of 11.01 barrels per hour. 11.01 barrels per hour yields a 2012 capacity of 75,573 barrels per year given a 5.5 day brew week, running at 24 hours per day and 52 weeks per year.

See below for the forecasted demand (in barrels) for 2012 through 2016.

	<u>2012</u>	<u>2013</u>	<u>2014</u>	<u>2015</u>	<u>2016</u>
<u>Demand</u>	75,000	95,000	120,000	145,000	175,000

As seen above, the current capacity of 75,573 barrels will be sufficient for 2012, but not sufficient for the following years given the forecasted demand will increase from 75,000 to 175,000 by year 2016. As a

result, Ninkasi will need to add fermenters to increase the flow rate to match or exceed the forecasted demand.

See below for the flow rate and capacity shortage calculation for 2013 through 2016.

- **2013 Flow Rate Shortage = $95k / (5.5 \times 24 \times 52) - 11.01 = 2.83$ barrels per hour**
- **2013 Capacity Shortage = $2.83 \times 12 \times 24 = 815$ barrels**

Therefore, Ninkasi will need to install any combination of fermenters that add up 815 barrels by the beginning of 2013 in order to increase their flow rate by 2.83 barrels per hour and meet the forecasted demand of 95,000 barrels.

- **2014 Flow Rate Shortage = $120k / (5.5 \times 24 \times 52) - (11.01 + 2.83) = 3.64$ barrels per hour**
- **2014 Capacity Shortage = $3.64 \times 12 \times 24 = 1,049$ barrels**

Therefore, Ninkasi will need to install any combination of fermenters that add up 1,049 barrels by the beginning of 2014 in order to increase their flow rate by 3.64 barrels per hour and meet the forecasted demand of 120,000 barrels.

- **2015 Flow Rate Shortage = $145k / (5.5 \times 24 \times 52) - (11.01 + 2.83 + 3.64) = 3.64$ barrels per hour**
- **2015 Capacity Shortage = $3.64 \times 12 \times 24 = 1,049$ barrels**

Therefore, Ninkasi will need to install any combination of fermenters that add up 1,049 barrels by the beginning of 2015 in order to increase their flow rate by 3.64 barrels per hour and meet the forecasted demand of 145,000 barrels. In addition, since the fermenters 2015 flow rate is 21.13 barrels per hour, the centrifuge is now the bottleneck since its flow rate is 19.35 barrels per hour. As a result, Ninkasi should add another centrifuge of the same size to increase the flow rate to 38.7 barrels per hour.

- **2016 Flow Rate Shortage = $175k / (5.5 \times 24 \times 52) - (11.01 + 2.83 + 3.64 + 3.64) = 4.37$ barrels per hour**
- **2016 Capacity Shortage = $4.37 \times 12 \times 24 = 1,258$ barrels**

Therefore, Ninkasi will need to install any combination of fermenters that add up 1,258 barrels by the beginning of 2016 in order to increase their flow rate by 4.37 barrels per hour and meet the forecasted demand of 175,000 barrels.

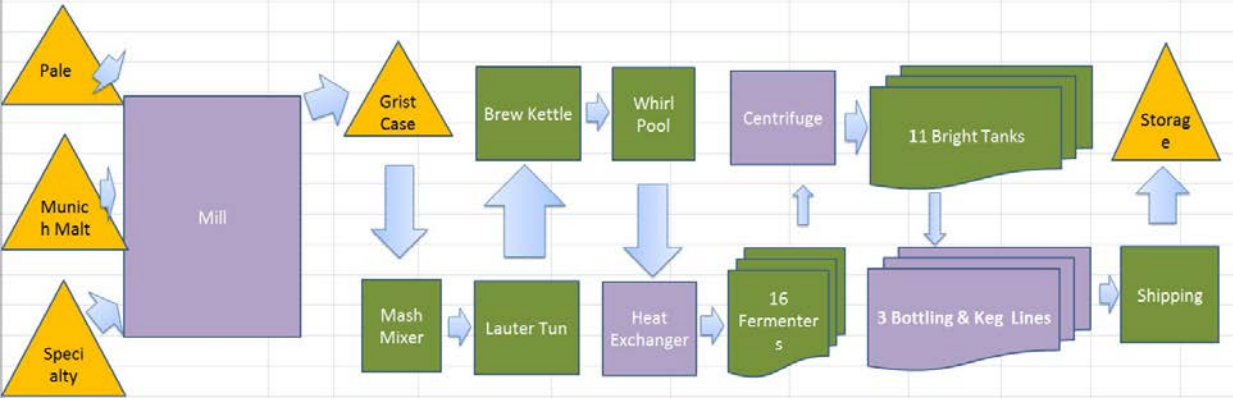
Recommendations

The following is a list of our specific recommendations that Ninkasi should implement in order to meet the forecasted demand:

- Install new fermenters (totaling 815 bbls) ASAP to increase capacity to meet 2013 demand
- Decide on using extra capacity in Bright Tanks in place of new fermenters
- Install new fermenters (totaling 1,049 bbls) by the beginning of 2014 to meet forecasted demand
- Install new fermenters (totaling 1,049 bbls) by the beginning of 2015 to meet forecasted demand
- Install new centrifuge (double current) by the beginning of 2015 to meet forecasted demand
- Install new fermenters (totaling 1,258 bbls) by the beginning of 2016 to meet forecasted demand
- Apply seasonal demand pattern to estimate the timing of capacity extensions more accurately

Appendix

Process Map





Exploring LCB / UO Project

DSC 409

Strategic Plan

Winter 2012

Kerin Green - Ty Kouri - Mitchell Eckberg

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EXECUTIVE SUMMARY

Paint Problem Analysis

The current paint process at Bulk Handling Systems has a number of benefits but it also has areas with room for improvement that range from set up time, touch points per part, to safety and ergonomics hazards. Each time an employee handles a part, efficiency decreases and risk of injury increases.

Key Goals

It is important to create a process that can better paint small parts while maintaining a strong commitment to the following:

1. Safety
2. Ergonomics
3. Efficiency

The goal of this project is to identify a concept that improves the paint process while maintaining, and if possible improving, strict standards in Safety, Ergonomics, and Efficiency. Based on the results of our observation and site visits, our ultimate objective is to find problems that can be eliminated from the current process and to provide a conceptual design that reduces the number of touches per part, increases movement in and out of the booth, and maintains quality; thus improving the overall process efficiency.

Recommendation

The best way to improve safety, ergonomics, and efficiency for small parts in the BHS paint process are to convert the current sawhorse set-up to a system of hanging parts. This will eliminate flipping parts inside the booth and allow more small parts to fit into a single booth load.

Measuring Success

After a solution is implemented, it is important to continually measure the improvements that have been added by the new process. The following metrics will serve as benchmarks to measure the success of implementing our proposed solution:

1. Capacity of paint booth
2. Time reduction of the overall paint process
3. Record and comparison of safety incidents
4. Touches per part

CURRENT PAINT PROCESS & PROBLEM ANALYSIS

The majority of the painting process at BHS takes place inside the booth where small parts are loaded, cleaned, primed, and painted. While the smallest parts are hooked onto a standing rack, most of the small parts category is staged for paint by using 2x4s and two sawhorses. The parts are elevated slightly on one side but remain relatively horizontal. The parts typically go through the Pre-Paint, Primer, and Final Paint stages before leaving the booth for DPY99 or the Final Assembly stage.

For a full description of the small parts paint process at BHS, see Appendix A.

Classification of Small Parts

Current classification of small parts is loosely defined with wide size and weight ranges, putting all parts up to 10 feet long and under 500 lbs in one category. Handling protocols restrict one person from lifting anything over 40 lbs. single-handedly, however part weights are not labeled and the handling process is left primarily to the discretion of the employee. Broad classification and the high degree of part variation in BHS's customized products leave different interpretations of what constitutes a "small part", as well as a degree of irregularity in how parts are handled by team members.

Touches

Touches occur when the paint team physically moves, lifts, or flips a part. Each touch potentially puts strain on the employee. Currently, small parts are moved between 5 and 6 times once inside the booth. A detailed description of typical touches is below:

<u>Touch</u>	<u>Process</u>
1.	Load onto horse / 2x4
2.	Middle of Acetone
3.	Middle of Primer
4.	Middle of Paint Coat 1
5.	Middle of Paint Coat 2
6.	Additional flip between coats (if needed for extra drying)

Other physical touches occur when moving horses and racks. For each row of small parts in the booth, horses are moved 4 times:

<u>Touch</u>	<u>Process</u>
1.	Horse 1 moved to middle of the booth
2.	Horse 2 moved to middle of the booth
3.	Remove horse 1 to clear booth
4.	Remove horse 2 to clear booth

Points where physical touches occur are areas with the largest need for improvement in the current paint system. Touches are both the bottleneck of the paint booth operation and the points that offer the greatest risk of injury to employees.

Benefits of Current System

Despite the problem with touches, there are a number of benefits with the current system.

- The sawhorses and 2X4s which are the structure of the process do not take up much space.
- The placement of parts on the 2X4s makes it easy to transport them to the drying yard.
- The horizontal nature of the process limits overspray and part movement during painting.

We aim to include these current process strengths with the recommended design.

KEY GOALS

The following are the three main areas of focus in determining opportunities for process improvements within the small parts paint process.

Safety

Employee safety is critical, especially in a facility such as BHS where there is a large amount of employee interaction with large, heavy, irregular parts. Every time an employee handles one of the parts, the risk of the employee being injured increases. To decrease the risk of injury, the solution must eliminate as many touches to the part as possible.

Along with decreasing the likelihood that employee safety is compromised, the solution must minimize the introduction of new hazards. Each piece of the solution will be analyzed for potential threats to employees and how the threats can be minimized or eliminated. It is also important to note that the benefits of increasing employee safety can have concrete financial savings as well as benefitting team morale.

Ergonomics

Ergonomics refers to how employees are moving through their work. For the BHS paint process, this means both the number of touches to parts as well as how those parts are being transferred from one location to another. Each time an employee moves a part; lifting, carrying or otherwise, that employee risks injury. The solution aims to eliminate as many opportunities for injury as possible by reducing the need for an employee to move a part without aid and by ensuring part movement is performed at safe heights and ergonomically friendly angles.

Efficiency

Efficiency is an important measure of any manufacturing process. Lack of efficiency can cause operational bottlenecks which reduce capacity and limit ability to reach revenue potential. While the small parts paint process is currently not a bottleneck, it could easily become one as BHS continues to grow. Efficiency, like safety, is reduced each time a piece is handled inside the paint booth.

The scope of this project looks primarily at efficiency within the paint booth, however staging parts outside of the paint booth, drying parts in the drying yard, and movement within the shop are all areas to keep in mind in thinking about process efficiency. Currently, the movement of parts from one area of the warehouse to another, example: from painting to assembly, is not standardized. The lack of standardization creates many opportunities for efficiency to be lost. Our solution aims to increase the level of standardization to the process.

RECOMMENDATION

The best way to improve safety, ergonomics, and efficiency for small parts in the BHS paint process is to convert the current sawhorse set-up to a system of hanging parts. This will eliminate the need to flip parts inside the booth and allow more small parts to fit into a single booth load. Though safety and efficiency in hanging heavy parts are concerns, the benefit of reducing touches maintains that a hanging system is optimal.

Several methods of how to hang parts were investigated. Specifically, we analyzed how a conveyORIZED system and wheeled hanging racks could work for BHS. An overview of these methodologies can be found in *Appendix B*. Ultimately though, a system of customizable and mobile beams will be best for BHS.

Overview of Proposed Hanging Structure

Hanging small parts safely, efficiently, and without creating increased need for storage space requires a permanent structure inside the booth. To capitalize on booth space while still allowing room for large parts, like screens, to enter the booth, we propose a system where posts along the booth walls support two tracks parallel to the side walls. A standard reverse arch shaped beam would be fork lifted into these tracks and house separate customizable beams, which the parts would actually be hung on. Reverse arcs could either stay stationary as painters move through the booth or could be stacked tightly at one end of the booth and moved along the tracks as parts are painted.

Categorized Beams

Classification of small parts beyond one catch-all category becomes necessary when hanging parts, because parts that only utilize several inches of vertical space can be stacked on top of one another, while others may occupy the entire height feasible for painting parts. The customized beams also allow ergonomic flexibility, because they can be loaded at varying heights to match the painter's ergonomic needs. Especially with the highly varied booth loads BHS experiences, this customization is essential. To allow for this flexibility in loading the booth, several classifications of small parts developed, each with their own style of categorized beam to be loaded into the reverse arch fixture. Categories include:

- **Large-end**—parts such as belly guards and bin walls that weigh greater than 100 lbs or require a crane. A design for the Large-end beam was conceptualized, though it is important to note that for safety reasons, we recommend this category is not considered as “small parts”. It should likely be handled similar to large parts at BHS.
- **Mid-size**—parts such as side panels that are less than 24 inches long and handled by one person.
- **Small-end**—parts less than 10 inches long that currently, are likely zip-tied. These are handled by one person.
- **Long**—parts such as bents and long bolt-ons that are greater than half the length of the categorized beam. These are handled by one to two people.

For full details on the beams that house each category and images of the general hanging structure, see Appendix C.

Flow of Process

It is important to note that this system could operate in either of the current two paint booths. It is recommended that either booth would become the primary space for painting small parts.

Once inside the booth, the hanging system will change the paint flow process in several places. While each part will need to be hung individually (just as each part was placed individually on saw horses), parts will not be flipped between paint coats or after wiping with acetone. Instead, the Paint Team can move each reversed arch fixture as they clean/paint. This takes advantage of booth space by increasing booth load size in addition to the space savings from painting vertically. The process also allows any movement to be performed on an entire rack simultaneously, opposed to one part.

Vertical painting does mean that racks will need to be spaced further apart than with the current system. Painters need 4-5 feet on either side of a hanging part to generate a quality spray and allow for ergonomic painting angles. However the track system does provide the ability to make booth space more flexible with this new process as reversed arch structures can be packed into the booth and pulled out as needed through the painting process.

Another key difference between the current and proposed processes is use of the paint booth's back door and staging fixtures in DPY99. Though currently, the back door of the booth is not being used, it is a huge opportunity for increasing efficiency of unloading the booth. We suggest that forklifts utilize this door to unload beams from the booth tracks. The new design allows flexibility to either unload the entire reversed arch structure or unload only the categorized beams. The racks then go to DPY99, where they are housed on vertical structures in the yard.

A complete process flow diagram of the new process can be found in Appendix A. DPY99 staging structures are in Appendix C.

Benefits of Proposed System

While a hanging system in general provides benefit, the following provide benefits specific to the proposed track system:

1. Improves Safety inside the Booth

Reducing touches inside the booth increases employee safety. With the proposed hanging process, parts will only be lifted when attached onto the beam. High-lift pallet movers can assist this movement while eliminating the level of forklift traffic inside the booth. This system also eliminates tripping hazards and allows hoses to travel underneath parts throughout the booth without catching on

sawhorses, hanging racks, or loose parts.

2. Improves Safety of Set-Up and Take-Down

Though any currently feasible process will require part lifting during set-up, a system of hanging beams should increase overall safety. Further classification of small parts makes set-up and safety protocols easier to follow. Once loaded onto the beams, parts will be locked into place through transportation into the dry yard. This eliminates a concern with sawhorses; that a row of parts could get bumped over, falling to the ground. Similarly, the same concern during unloading was mitigated with the new design.

3. Increases Efficiency inside the Booth

The mobility of the hanging structure increases efficiency inside the booth by eliminating the need to flip parts and increasing booth loads. A more detailed analysis of how efficiency is improved is in the section “measuring success” on page 11.

Challenges of Proposed System

Though benefits are believed to outweigh potential challenges, it is important to look at areas of concern where further research may be needed. Challenges specific to our proposal are as follows:

1. Dripping Paint

With any vertically hanging paint process, runoff is a concern. Painting vertically requires a more sensitive time-frame between coats than painting horizontally, because the degree that the prior layer has dried affects how new layers adhere. This issue of quality is an important concern to be aware of, but ultimately will not be an issue once a standardized time-frame is tested and specified. Therefore, a method needs to be written to lay out exactly how much time parts will sit after each stage of the paint process.

2. Part Movement

Part movement is another potential problem for both heavy and light parts. Of course, heavy parts are always a challenge for people to move safely. There is also potential that they will swing as they are moved within the paint booth and transported to the drying yard. When designing the structure, engineers should address the severity of this concern and how to reduce part movement during transportation.

While easier to load and transport safely, lighter parts create challenges inside the paint booth. The pressure from the paint gun causes light parts to spin, affecting quality. Our classification of parts, and respective customizable beams aims to account for this by attaching mid-sized parts to multiple hooks.

Overall, the design of such wide beams will also pose potential challenges. Space is needed for beams to be safely transported through the warehouse from staging to the booth or out to the drying yard. Our suggestion to utilize the outside paint booth door in transporting beams is one suggestion to reduce this challenge.

3. Injury Mitigation

One of the biggest safety concerns in our project scope, has been our Large-end classification. Despite attempts to creatively consider how Large-end parts can hang safely and efficiently, full analysis supports that there is not a safe way to hang these parts. Therefore part of our parts classification recommends that the Large-end category is no longer considered a small part.

MEASUREING SUCCESS

We have identified specific methods to measure the overall effectiveness of each of our safety, ergonomic, and efficiency goals. In the following chart, safety and ergonomic goals are identified with touches and safety incidents, while efficiencies are demonstrated with capacity and time metrics.

	Objectives	Measures	Targets
Capacity	Increase paint booth throughput capacity	Total change in time for small part painting process	Document and maintain new throughput capacity
Safety	Decrease safety hazards and incidents	Total change in safety incidents within the paint booth	0 safety incidents in the paint booth
Time	Time reduction of small parts painting	Total change in average time for small parts painting	Document and maintain changes in painting time for small parts
Touches	Reduce amount of touches per part	Total change in number of touches per part (-5)	Maintain 2 touches per part

Increased Efficiencies

To project and compare paint time between the current and proposed processes, we developed an equation summing the time of each step of the in-booth process. Flip time (of each category), spray time, and idle time were all factors of total processing time. Based on these calculations, we project a hanging process to cut booth time in half for all sizes of small parts. This decrease comes from the elimination of part flipping.

Flip time per part was determined based on interviews with the paint crew. Though our recommendation is that the Large-end category is not considered part of “Small Parts”, we have included it in our analysis. The breakdown is as follows:

- It takes one second to flip a small-medium sized part.
- It takes one minute to flip large sized and long parts

See Appendix D for a more detailed description of Time equation calculations.

Though paint time should certainly be reduced, hanging parts may increase loading time and will need to be further tested and investigated in the future. In addition, making accurate estimates for booth loading and unloading times will require further research and testing as engineering will determine the ease of which, and exactly how, beams will move on the tracks. Accurate projections to lift and carry beams also require testing given the new structure of the beams being transported and undetermined staging locations.

MOVING FORWARD

The conversion of the current paint process to a hybrid conveyer-hanging structure would decrease the risk of injury to employees and increase overall plant efficiency. The design proposed in this report suggests how this efficiency can be accomplished. This design, however, is only the beginning. The next steps moving forward are to perform a feasibility analysis, a cost analysis, and to begin research and development.

Feasibility Analysis

A feasibility analysis will involve taking a closer look at all stages of the new process.

Questions to be answered include:

- What is the most efficient way to stage parts?
- How will large/heavy parts be handled?
 - Will the parts swing on the beam while being transported?
 - How can employee safety be guaranteed?
- Where and how will the parts be stored to dry?
- How much weight will the structure be able to support at one time?

Cost Analysis

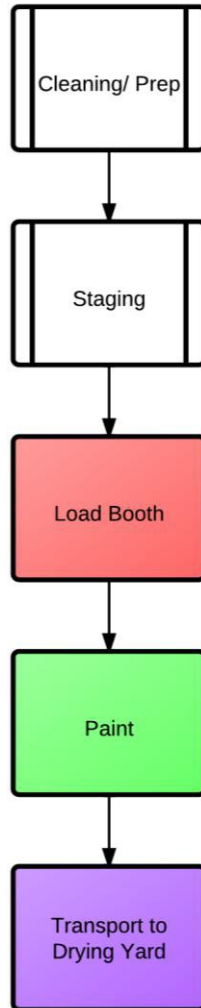
One of the biggest questions that needs to be answered is how much will the conversion cost? What is the range of options between cost and quality of materials to be considered? The analysis must also determine the number of beams and overhead racks that should be purchased.

Research & Development

Once feasibility and cost are approved, Research & Development will need to identify ways to engineer the concept. R&D will also involve prototyping and testing the final design.

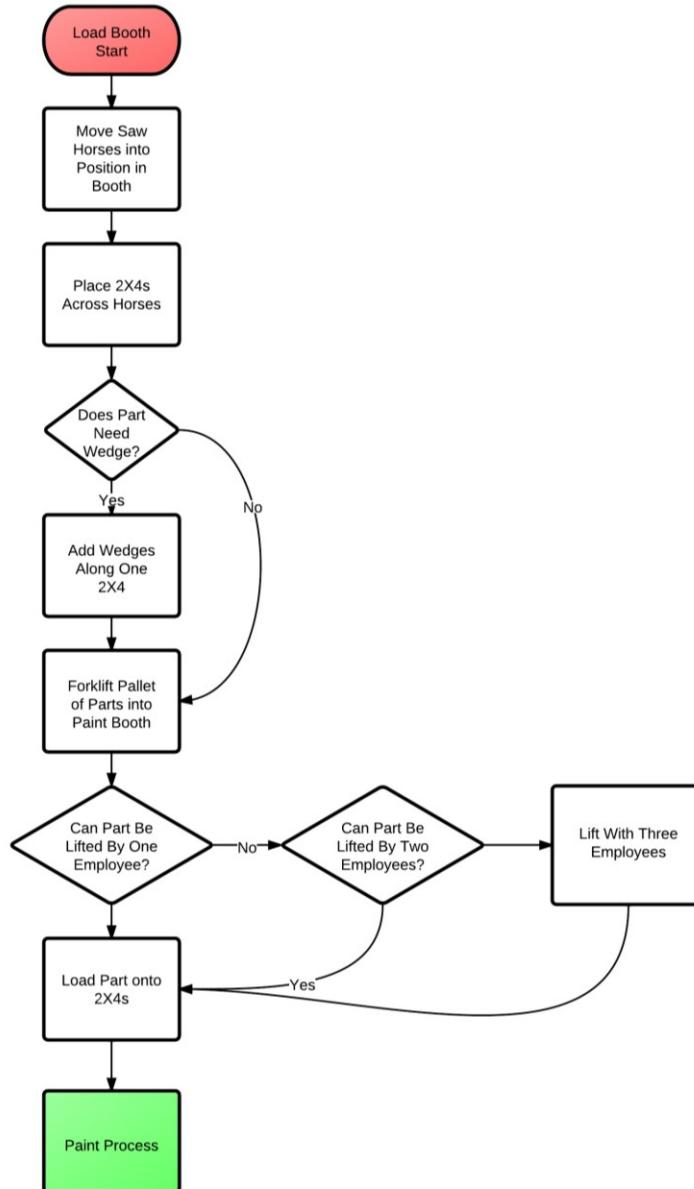
Appendix A: Process Flow Diagrams

Basic Paint Process Overview

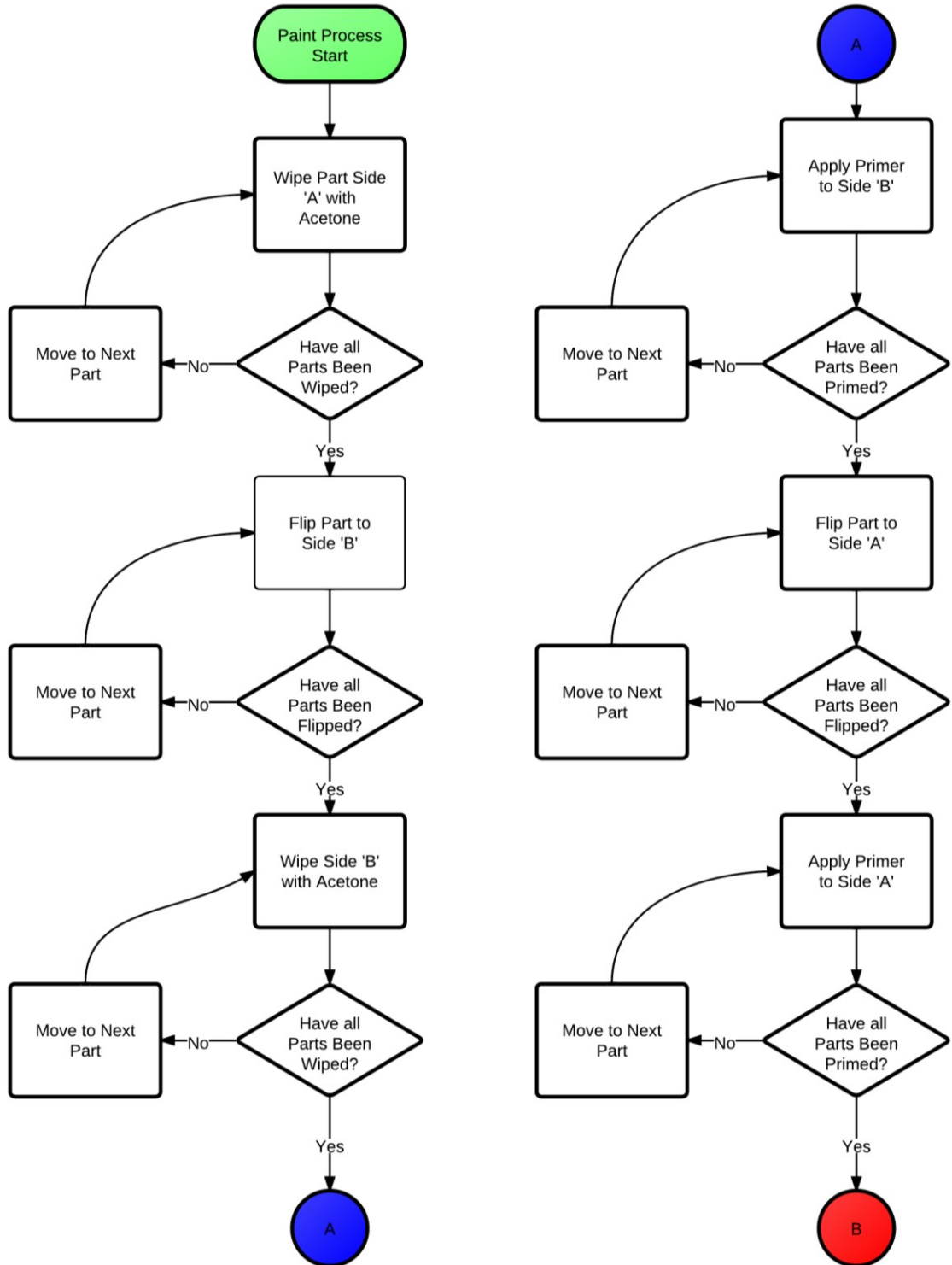


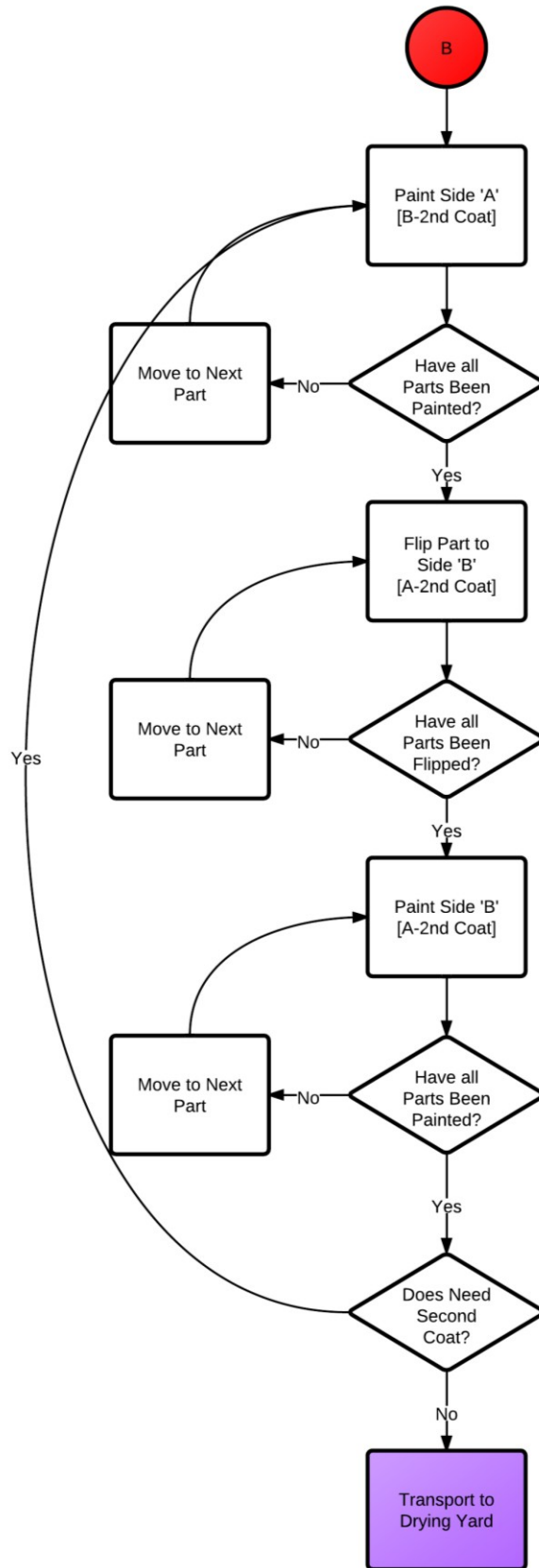
This is the general flow of parts for any painting at BHS.

Current Process: Load Booth

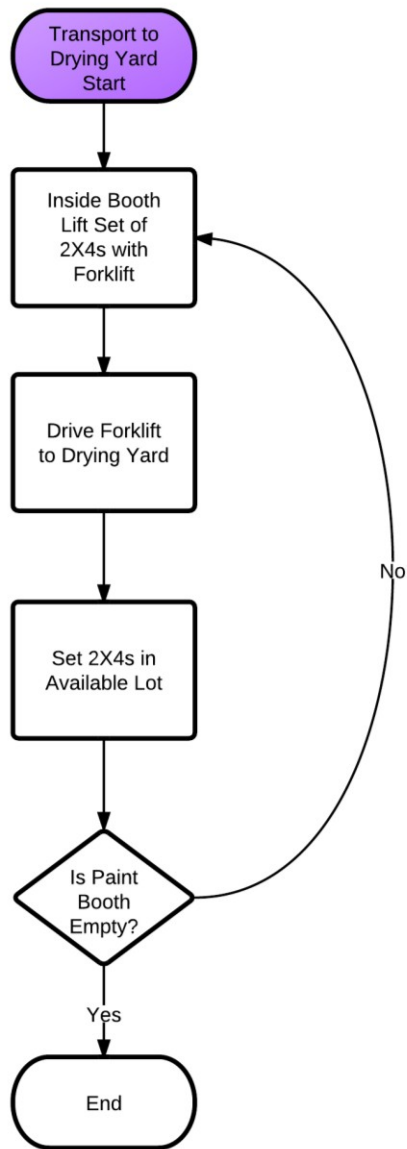


Current Process: Painting

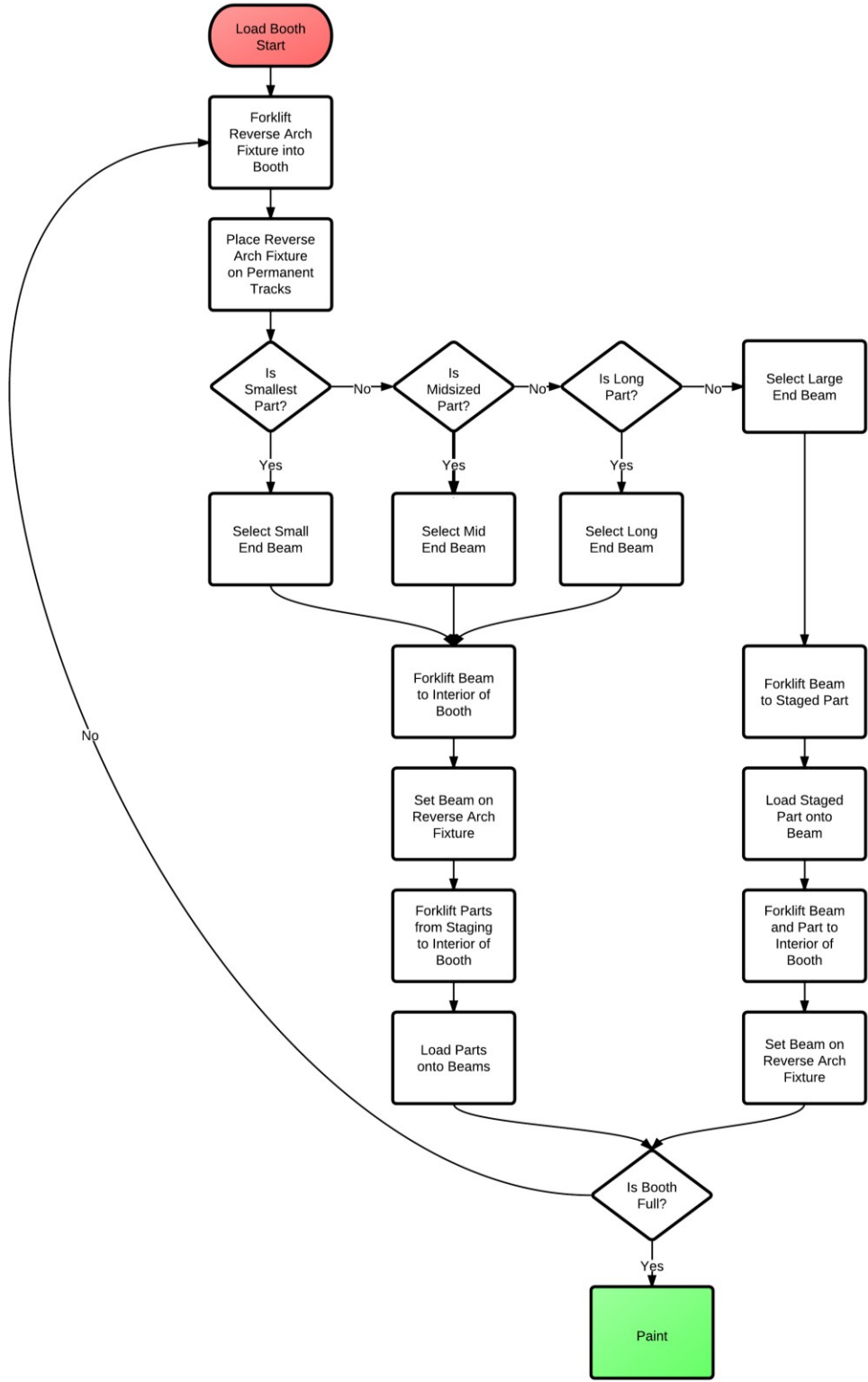




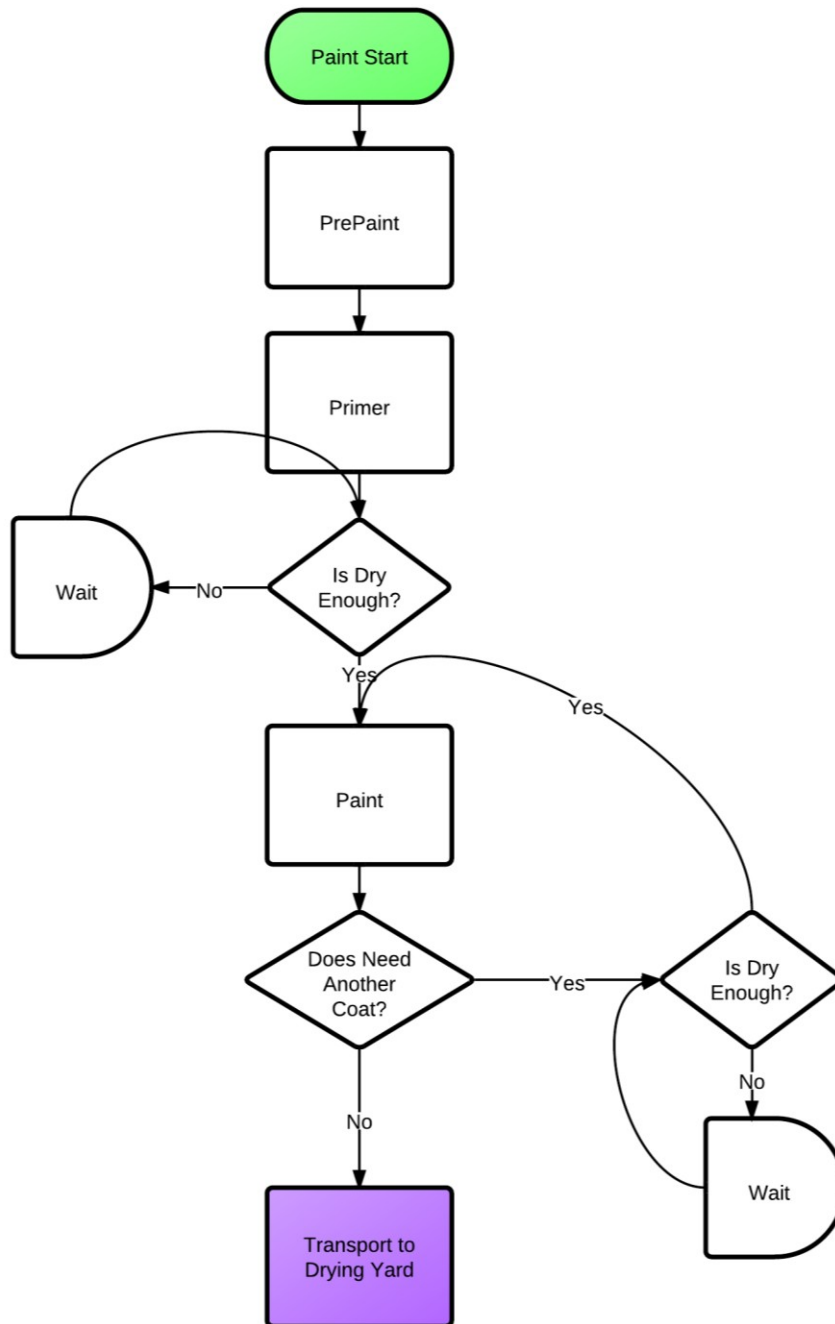
Current Process: Transport



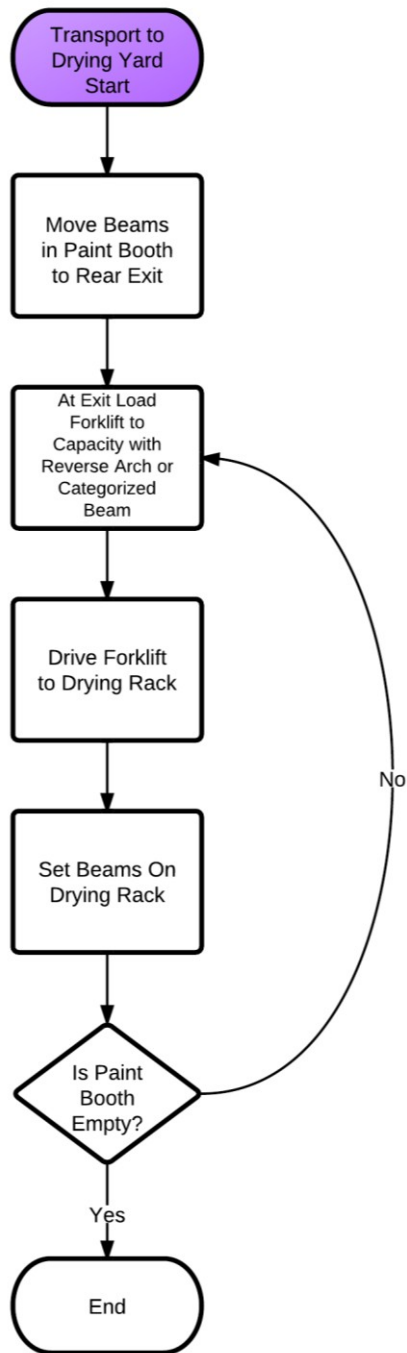
Recommended Process: Booth Load



Recommended Process: Painting



Recommended Process: Transport



Appendix B: Alternate Hanging Systems

Wheeled-Rack Fixture:



Pros

1. Not permanent
2. Simple
3. Wheels provide easy transportation across multiple surfaces
4. No flipping
5. Could customize with a nonpermanent beam inserted into the top
6. Common solution (real-life trials)

Cons

- Fixed height (potentially)
- Overspray accumulating on wheels could affect functionality (especially considering wheel positioning and gravity)
- Stability/floor space (in order to get a stable fixture, the rack would have to bow out, presenting a tripping hazard
 - How secure/stable is this type of rack without any reinforcement?
- Navigating paint hoses through the booth (around hanging fixtures)
- Storage space when not in use

Conveyor System:



Pros

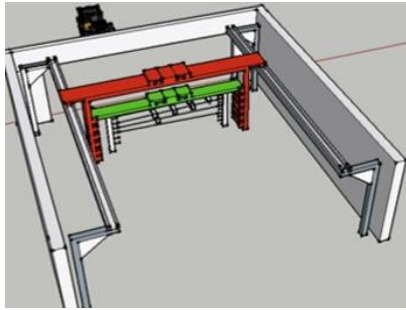
- Improve material handling through entire shop
- Efficient, fast
- Little material handling

Cons

- Cost
- Affects entire plant process (too large-scale for right now)
- Requires booth doors to be resealed
- Construction time

Appendix C: Recommended Design

Permanent Tracks & Removable Beams



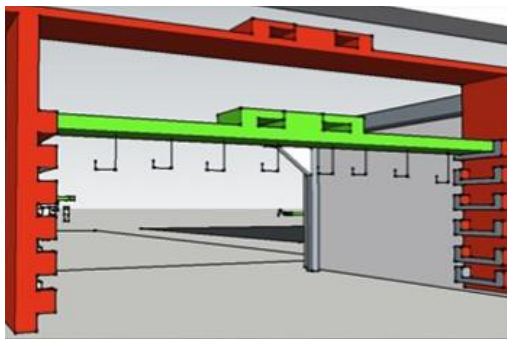
Red (reversed arch) beam slides in tracks.
Green (customizable) beam can sit at varying heights.

Customizable Beam



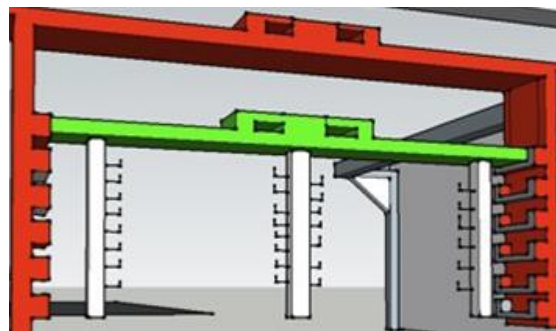
Like reversed arch beams,
customized beams have components
allowing for safe forklift transport

Large-end



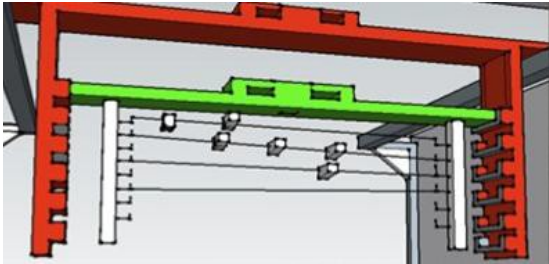
Removable/adjustable hooks for flexibility

Mid-size



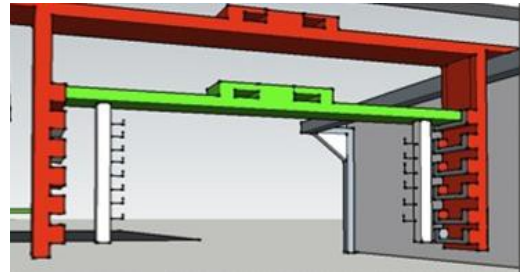
Removable/adjustable white bars for size
flexibility

Small-end



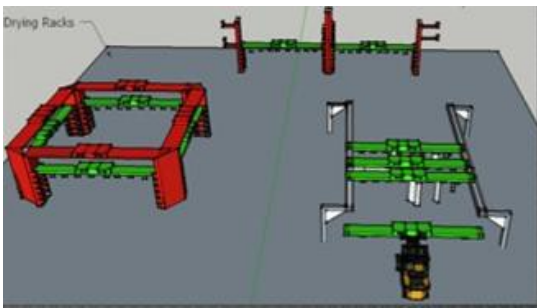
Small-end zip ties replaced with reusable cables. Cables attach directly to white bars without detaching individual parts

Long



Removable/adjustable white bars for length flexibility

Staging



Staging fixtures located in DPY 99, provide a central location for small parts to be staged. Potential designs are shown here.

Appendix D: Time Comparisons

Current Paint Process Equation

Given a part #N:						
N = one side of a part						
	Time Per Task	Task EQ	Small Part Time	Mid Size Part Time	Large Part Time	Long Part Time
Wipe Placen Flip n	t_flip	n*t_flip	1 sec	1 sec	1 min - two people	1 min
Wipe Wipe 2n	t_wipe	2n*t_wipe	1 sec	1 sec	1 min - two people	1 min
Prime 2n Flip N	t_prime	2n*t_prime	1 sec	1 sec	1 min - two people	1 min
Prime prime	t_flip	n*t_flip	1 sec	1 sec	1 min - two people	1 min
Paint 2n Flip N	t_paint	2n*t_paint	1 sec	1 sec	1 min - two people	1 min
Paint		n*t_flip	1 sec	1 sec	1 min - two people	1 min

Total Time Per Part	
Small	6
Mid size	6
Large	360
Long	360

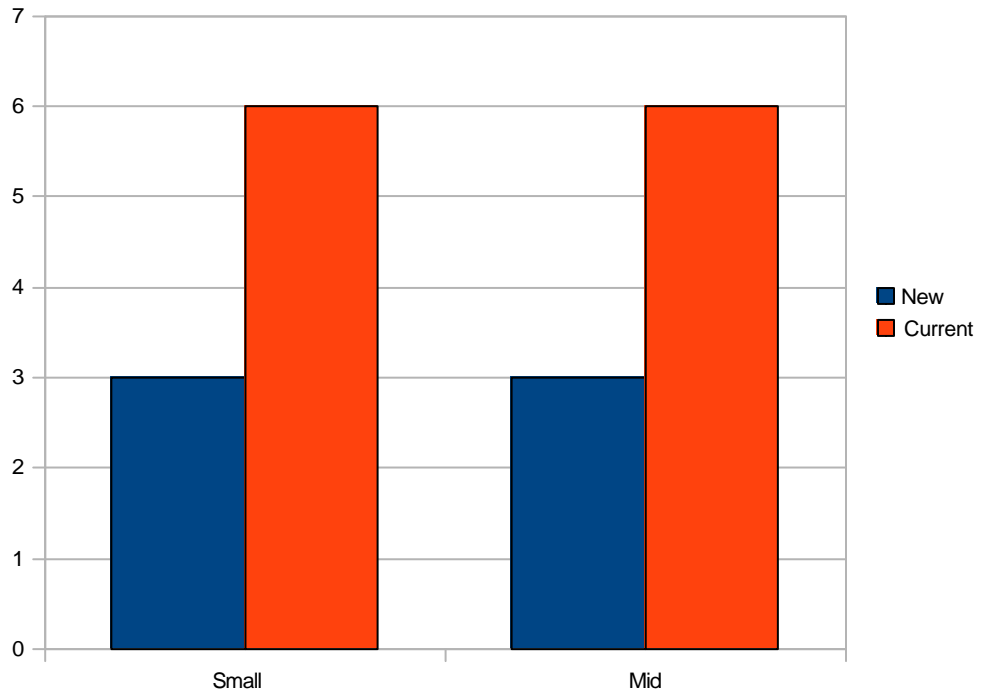
Dry

$$\text{Time of Process} = n * t_{\text{wipe}} + n * t_{\text{flip}} + n * t_{\text{wipe}} + n * t_{\text{prime}} + n * t_{\text{flip}} + n * t_{\text{prime}} + n * t_{\text{paint}} + \text{dry time} + n * t_{\text{flip}} + n * t_{\text{paint}} + \text{dry time}$$

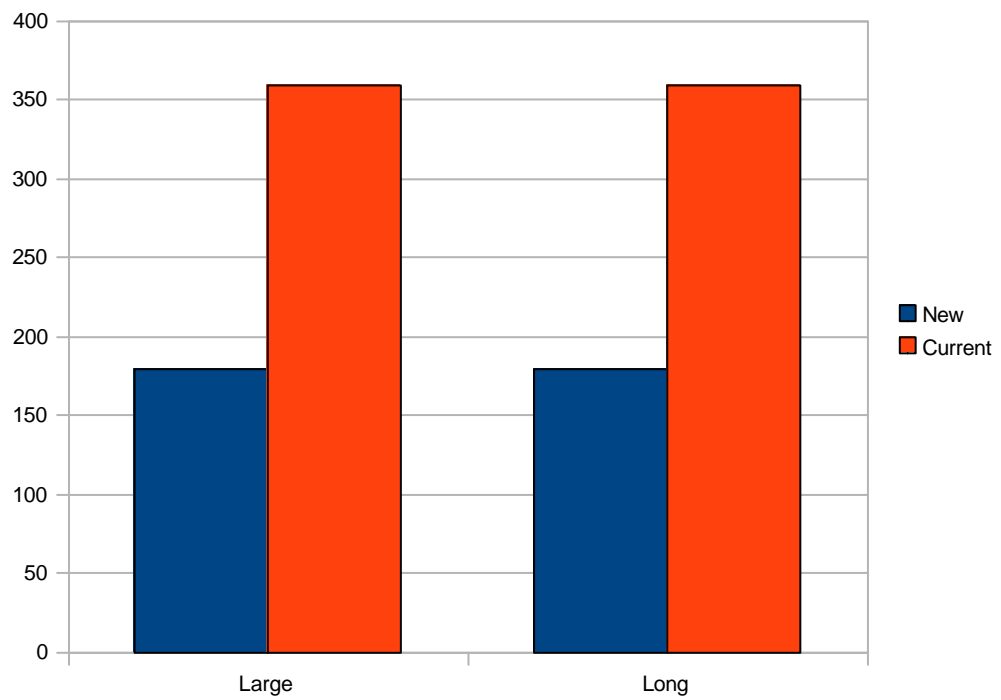
Equation explanation

We compared the paint process of the current set up and a hanging structure. To compare, we took the number of parts in the booth and multiplied that number by the time it takes to perform each of the process tasks plus wait time. In other words, the number 'n' is multiplied by acetone wipe time then flip time then wipe time then primer time. . . etc until the process is complete. Then add the idle time waiting for paint to dry. The idle time variable is zero for the hanging process, because fresh paint doesn't get damaged by being handled between coats. Idle time varies with the current process and is difficult to predict. Future work on the project will need to find a close estimate of idle time in order to determine more accurate values for efficiencies saved.

Process Time Comparison



Process Time Comparison



Appendix E: Observations

Mitch Eckberg Observations

Note: The following observations pertain to the days that I volunteered to take notes

January 30th 2012

Our first visit (with or without Nagesh?) to BHS's Danebo plant was focused on touring the facility to get a better idea of how day-to-day operations are conducted. It was very important that we learn the daily processes and how work flows through the shop before looking at the paint process. Although the paint process is the focus of our project, it is vital that we understood the process and work flow within the shop.

We also met Rick, *BHS Paint Manager*, on our first visit to the plant. Rick walked us through the basic flow of material through both paint booths. This was our first introduction to the paint booths, painter, and paint processes. Rick also pointed out some of the basic steps that need to be taken in order to properly paint a part, start to finish.

1. Part Preparation
 - a. All steel is cleaned with an automated wire brush before leaving the fabrication tables. It is important that all welding debris is taken off of the steel with the wire brush to ensure that the part has a smooth finish before reaching the paint booth
 - b. Once the parts are in the booth and have been set up to paint, the painters wipe the part down with acetone. This must be completed on every part to ensure that all rust, slag, and excess weld debris has been removed.
2. Painting
 - a. The first step a painter must take in painting a part is mixing the correct paint. This is done outside of the booth with automated mixers.
 - b. Primer must be applied to all the parts before applying paint.
 - c. Once the primer has been applied, paint is sprayed on the part using the *Air Assist Airless* technique.
 - d. Paint sets for 15-20 minutes before moving
3. Quality Check
 - a. After the paint has dried, it is important that the painters check the quality of their paints job to ensure it has met shop requirements.
 - b. Every piece is checked with a gauge that measures the depth or thickness of the layers of paint.
 - c. Every part is spot checked with the gauge in at least three different places.
 - i. Some equipment like screens wipe the paint finish off after first it's run of material; gauge measurements may not be as important in some cases.

The impression I got after the first day of observing the paint process is that it goes fast. The drying times are quite rapid and there are many parts to paint every day. It was

interesting to see how six painters keep up with about 100 fabricators every day. I learned that constant assessment and observation of the staging areas that create a queue for the paint booth would be very important throughout the duration of this project. It was also apparent that the painters keep a close watch on the queue in the staging areas. By gauging what is ready to paint, the paint department is able to keep up with all the fabricators.

One of the things that Ryan pointed out on the first observation day was the amount of movement for individual parts, especially during the painting process. How can we minimize the amount of movement per part? Because more movement can translate into a greater chance of damaging the part, or creating safety hazards, it is very important to minimize the number of touches in this department to alleviate current pressures and create a process that will not create additional hazards.

Fixtures for small parts were also brought up:

Can this be a possible solution to the problem?

Can fixtures alleviate safety hazards?

Or, does it simply create new hazards?

There is not much room for big racks and fixtures on site. Space is a concern due to the size of the facility. Safety is the most important consideration so any solution that can improve safety or reduce injury is beneficial. Fixtures offer a way to minimize the 6-7 different touches that occur on each small part.

Powder Coating: Make vs. Buy?

Buy: BHS outsources all powder-coated parts outsourced

Looking Ahead: Develop a Process Map

NDA's

Paint Log Analysis

January 31st 2011

Our second day included further observation of the processes to develop a process map, project goals, and problems or hazards to be eliminated from the paint booth. Ryan also laid out key aspects to pay attention to when thinking of a solution for painting small parts and reducing the number of touches per part.

1. Safety
 - a. Always the number once concern
 - b. Lifting/moving of parts can cause injury due to the wide range of weights and dimensions of BHS parts.
 - c. Workplace hazards can be reduced. How?
2. Ergonomics
 - a. A solution needs to be ergonomically acceptable.

- b. Will fixtures cause a negative ergonomic impact?
 - c. Human capital is the most important part of the production process. Therefore, any changes to the process need to consider how it could improve ergonomics
3. Efficiency
- a. Increased efficiency is key for any business
 - b. How can BHS be more efficient with the paint process?
 - c. Efficiency does not always translate into having a faster process. What if a new process is slower overall but leads to a higher quality finished product? Which is more efficient?

Another important aspect of this visit day was learning the tagging system at BHS. All parts are tagged with wire so that the paint team can maintain part numbers after painting over the original number written by a fabricator.

- Green Tag only: Final Paint → Yard
- Green and Yellow Tag: Final Paint → Final Assembly → Yard
- Yellow tag only:

We also learned about the Parts and Paint log on this visit. The paint log is a paper log that Rick keeps to determine what parts moved through the booth on a given day.

February 10th 2012

Looking Ahead:

- Start researching Air Assist Airless Painting and how parts are typically painted with a fixture.
- Start Qualitative observation/research: Are they relative?
- Define which measures are most important to BHS
- Make the existing processes better
- Material handling in a more efficient manner?
- Identify waste in the system/process
- Observe shift change/night shift

Paint Waste: Is this relevant? Do we need to compare time vs. cost vs. quality?

March 3rd 2012 – check date w/ Kerin

This visit was one of the most important observation days of the project. I was able to see how a large amount of small parts are painted at once. This was the day that Rick took us around the facility and gave us his view of how the shop works. It was interesting to see how people view the processes differently. Rick is focused on making the paint process as well as it can be. Therefore, he had a lot of different ideas of how to improve the process. While the painters were setting up for paint, we discussed how the set up and movement in and out of the booth could be improved. When we first started meeting with

Rick, it was 12:45 PM and the painters were beginning to prep about 60 small parts for paint. By the time the preparation and set up process was complete, it was 1:50 PM when painting began. It was obvious that this was a tedious set up process. This is when I really began noticing the real issues and allowed me to start thinking about how to solve the problem.

We then began discussing how a fixture that allowed parts to hang could cause problems with the paint running. However, it was apparent that Rick and the painters believe they can paint a part vertically without compromising the integrity of the paint job with paint runs. However, Rick believed that a hanging part would not be as glossy as one that is painted while laying on a flat surface. Rick also brought up the fact that adjustable, not rigid, racks would be necessary due to the many different custom parts that BHS produces. Mobility is also important to consider with a fixture system. How can we improve mobility while maintaining the same level of safety? A-Frame sawhorses create many safety hazards. How can these be eliminated?

20' x 8' 3-4 racks

Accessibility during painting

No electricity in the booth → a crane needs to be chain hoist

Long Narrow Cart → angle iron to replace palettes/wood beams for conveyer walls.

Kerin Green Observations

February 1st, 2011

February 1st was our fourth visit to BHS (including the initial tour with Nagesh) and the day we walked around looking at all types of parts and areas and taking pictures.

What has struck me most since the first visit is the disordered chaos. There is currently no system in place to track inventory and raw material is strewn everywhere yet it does not seem to slow the process down. Walking around and seeing all of the parts was overwhelming, we took pictures of everything to try and continue to familiarize ourselves later on.

The range of what are considered “small parts” is huge, everything from tiny bolt ons that you can hold in your hand to giant sidewalls. And the parts were stored everywhere.

Unpainted parts

Unpainted parts are mostly kept in the paint staging area next to the two paint booths.

They are staged in different ways

- on pallets
- smaller ones in boxes
- in stacks with like parts

Painted Parts

We spent a lot of time walking around the drying yard which is outside. Being outside poses a few problems, one being that the pieces will rust when left out too long. Those pieces need to be repainted.

February 2nd, 2011

February 2nd was our fifth visit to BHS and the day that we had our first interviews with the day shift paint crew. Before the interviews we met with Ryan as usual. We talked about what we were experiencing with our first few visits and how, with so much to take in, it was difficult to narrow down our focus. Then we went, met up with Rick and met the crew.

Painters per shift

1st shift: 4 painters, 1 overall supervisor

2nd shift: 3 painters, 1 lead painter (lead painter included in 3)

All of the crew members were very nice and welcoming to us which was fantastic because you never know how people are going to react to outsiders like us coming in and saying we are going to critique a system that they have known and helped build over years and years. First we talked to all of them with Rick and Ryan there. Then Rick and Ryan left and we talked more.

Input from the Painters

1. They wish the parts were cleaner when they receive them from fabrication
 - oil prevents marring
 - they have to wipe with acetone twice
2. Another way to paint the parts would be hanging but they do not think that it would work with the custom parts produced by BHS
3. When asked which parts are most difficult to paint they said pit plates and container bin walls
 - When asked what they think could be done to make the process easier they said that they did not mind the process as it was because it was a challenge that made the job more exciting.
4. Parts which need to be repainted due to rust can be somewhat predicted but mostly just depend on work being done by assembly.
 - No method, they just know.
5. Ultimately they all really enjoy their jobs at BHS
6. Their favorite part of the job and the most important element of the paint process is their teamwork.

Thoughts for Further Consideration

Hazmat issues: Does BHS have to dispose of the wood with paint on it as a hazardous material? How many times can it be used before it is thrown away? Is this a significant waste of time and money?

Employee safety: How dangerous are the parts they consider challenging?

If hanging were to be considered, classification would probably play a large role. How to classify parts?

Ty Kouri Observations

BHS Paint Process

Goals:

7. Safety
8. Ergonomics
9. Efficiency

What hinders those goals?

- Classification of small parts
 - No clear metric for what can be handled alone (visually)
 - Height, motion of lifting, length of time holding during a lift
 - So many different parts, sizes, shapes
- Sorting through parts (especially that are low to the ground)

Paths

- Typically, small parts follow the path from Primer → Final Paint → DPY 99

Note:

- Most small parts have holes
- Transitioning to “Syteline” – been working for 8 months
 - ERP Manager + another IT Manager
 - SQL + other programming
- Be thinking about:
 - Classification of parts
 - Ways to hang
 - Set-up space between horses, parts, etc.
 - Travel space
- 50 lb rule (currently)

Shifts:

- 1 paint supervisor overall
- 1 paint lead on 2nd shift
- 1st shift—4 painters plus manager

- 2nd shift—3 painters including lead

Team Members: Rick—
 Paint Manager Dan—Floor
 Manager Dom—IT Manger
 Terry—Fabrication Manager
 Tom—Screens Manager

Paint Team Interview:

Challenges

- Ensuring parts are clean upon getting into the booth
 - They clean parts or get fabricators to clean
 - Removing anti-splatter spray
 - The more wipes, the more time spent cleaning
- No cranes, lifts in booths
 - Technique in place of these is often to roll or slide the part (using the weight of it)
 - If bigger small-part, get more people or fork lift
- Hardest:
 - Pit plates (many per job, hard to add man-power)
 - Large end of the small parts
 - Ex. Container bin walls

Other

- Key: Angles
- If it doesn't get bolted on, small parts Primer → Final Paint
- Small parts are easy to paint on a pallet and move by fork lift
 - Similarly, 2 x 4 method often used
 - 2 x 4 disposal is then "Hazardous Material" by OSHA regulations
- Currently, not cleaning horses/2x4s on each batch (either disposing of 2 x 4 or waiting for build-up and cleaning it)

Safety Observations

- Other strenuous movements besides touches
 - Setting up horses & moving 2 x 4s
- Horses don't catch parts if 2 x 4s move (though they do provide area on either side that may prevent painters from walking under it)
- Currently painting undersides of some parts under horses

Questions/Look Into

- How much difference in cure time between personal handling and a crane handling a painted part?
- 50 lbs vs. 40 lbs.

- Prints of parts over weight limit
- Free standing crane (chain hoist)

Detailed Description of Paint Process

1. Fabrication brings parts to staging areas beside paint booth
2. Paint team then loads an empty booth by:
 - a. Physically moving horses across the booth. Horses are stored on outside edges of booth interior
 - b. 2 x 4s are moved from staging directly outside of the booth and get put onto horses.
 - c. One side of the 2x4s gets a small lift individually placed on it that will elevate the future part placed on the structure.
 - d. Palates of small parts are fork lifted in through the interior entrance and are then individually loaded horizontally onto the horses and 2 x 4s with each horse brought to the center (alternating horse, 2x4, parts, etc.) Some parts are handled by 2 team members, others are not. Parts lifted from about waist height and kept at a similar height for horse loading.
3. Top of parts are then wiped by hand with acetone, flipped, and wiped on the other side. Paint process then starts (flips described below)
4. Painters remove paint buckets from (???) (Not sure on paint prep, shaking, etc)
5. Hoses are put into bucket for priming and paint. These don't go through any switches other than transferring the hose to a different bucket between the steps.
6. Forklifts remove the whole 2x4 set-up with parts on the top to clear out the booth.
7. Cleaning is irregular. Part of the purpose of the 2 x 4s is to minimize cleaning. However these or horses can be scraped clean after use. 2x4s typically disposed of after ~ 10-12 cycles through booth.

Touches: average of 4-5 once in the booth (place on horse, half-acetone flip, half-primed flip, booth removal--no)

Appendix F: Presentation Slides

BHS BulkHandling SYSTEMS

Painting Small Parts at BHS
Exploring LCB / UO Project
Winter 2012



Kerin Green Ty Kouri Mitch Eckberg

SMALL PARTS



PROJECT GOALS

Safety

Ergonomics

Efficiency



Classification

WHERE ARE WE HEADED?

- ▶ Current process
- ▶ Potential solutions
- ▶ Process time comparison
- ▶ Classification



The Small Parts Challenge



CURRENT PROCESS

Hot Point

noun

1. Any time in the process when employee safety or overall efficiency could be negatively affected

LOADING

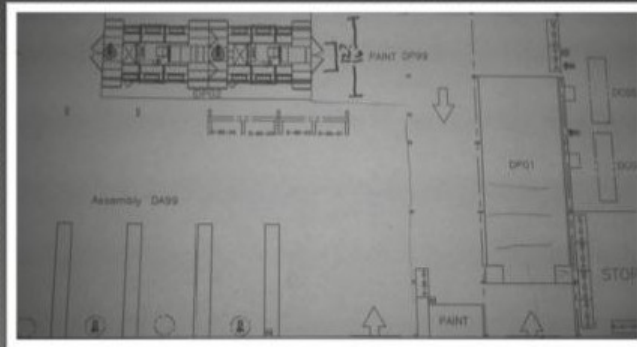
- Moving the Saw Horses
 - Safety
- Moving the Part
 - Safety



PAINTING

- Flipping the Part

- Safety
- Efficiency



UNLOADING

- Lack of Stability

- Safety
- Efficiency



PROS

- Does not take up much space
- Easy transport
- Limited over-spray
- Tested

HANGING

Pros

- **Reduces Touches**
- Ergonomic Angle

Cons

- Lifting and Removing Heavy Parts
- Requires Rigid Procedure

Potential Solutions

Rack with wheels

Pros : Simple design
 Mobile
 Customizable

Cons : Tripping Hazard
 Low Efficiency
 Space and storage within the shop



Potential Solutions

Conveyor System

Pros : Efficiency
 Safety
 Standardized Paint Process

Cons : Cost
 Rigid design
 Inadequate for BHS custom parts

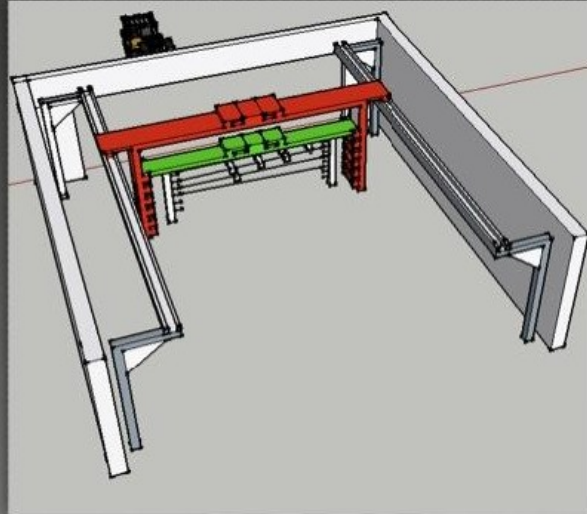


Potential Solutions

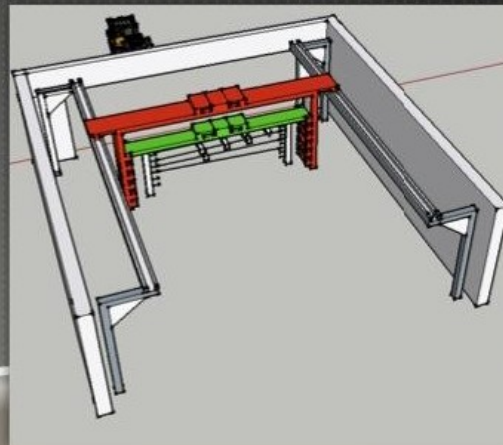
Overhead racks with customizable beams

Pros : Simple design
Customizable
Efficiency, Safety, Ergonomics

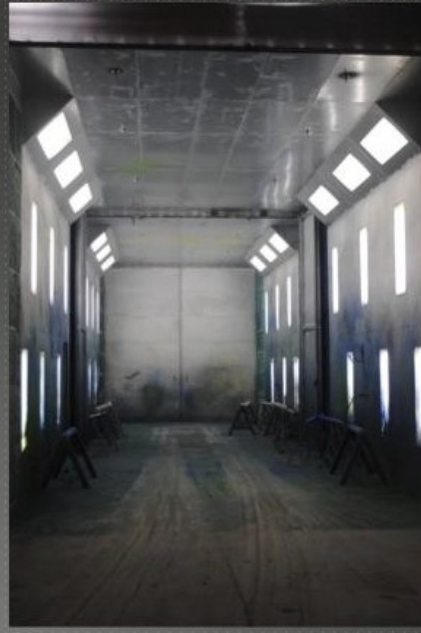
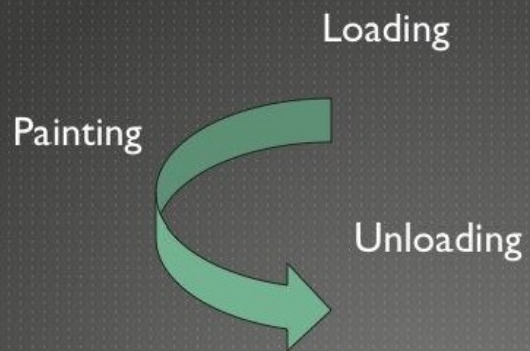
Cons : Permanent Structure
Staging parts
Cost



- ▶ Which solution is best?
- ▶ Racks with wheels
- ▶ Conveyor System
- ▶ **Overhead racks with customizable beams**



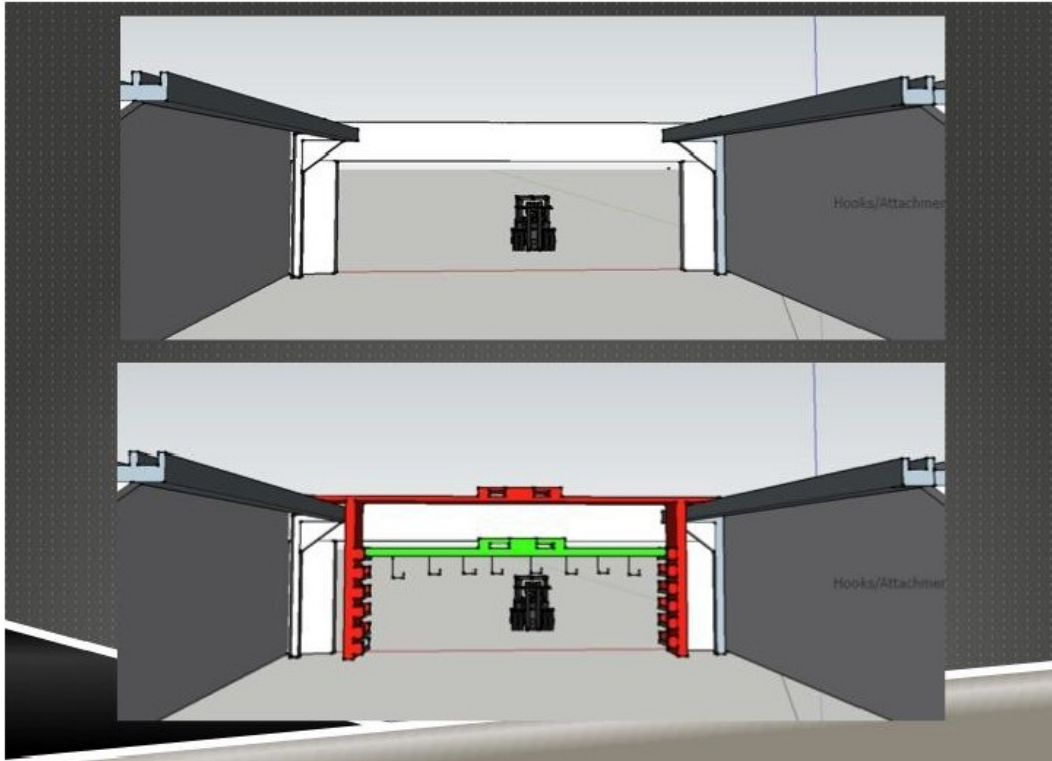
PROCESS MOVEMENT



LOADING

- ▶ Beam staging outside booth
- ▶ Hanging parts in the booth
- ▶ Simultaneous prep



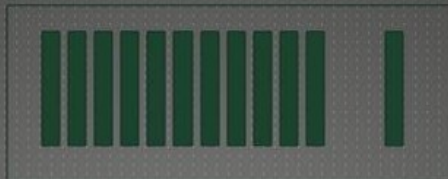


PAINTING PROCESS

▶ Stationary

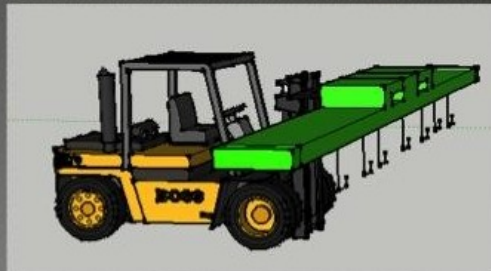
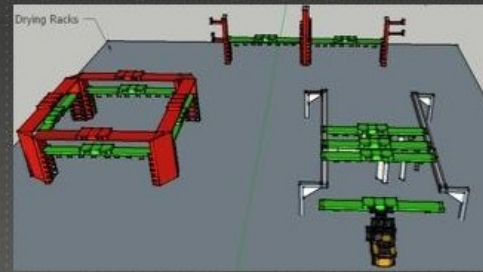


▶ Stacked

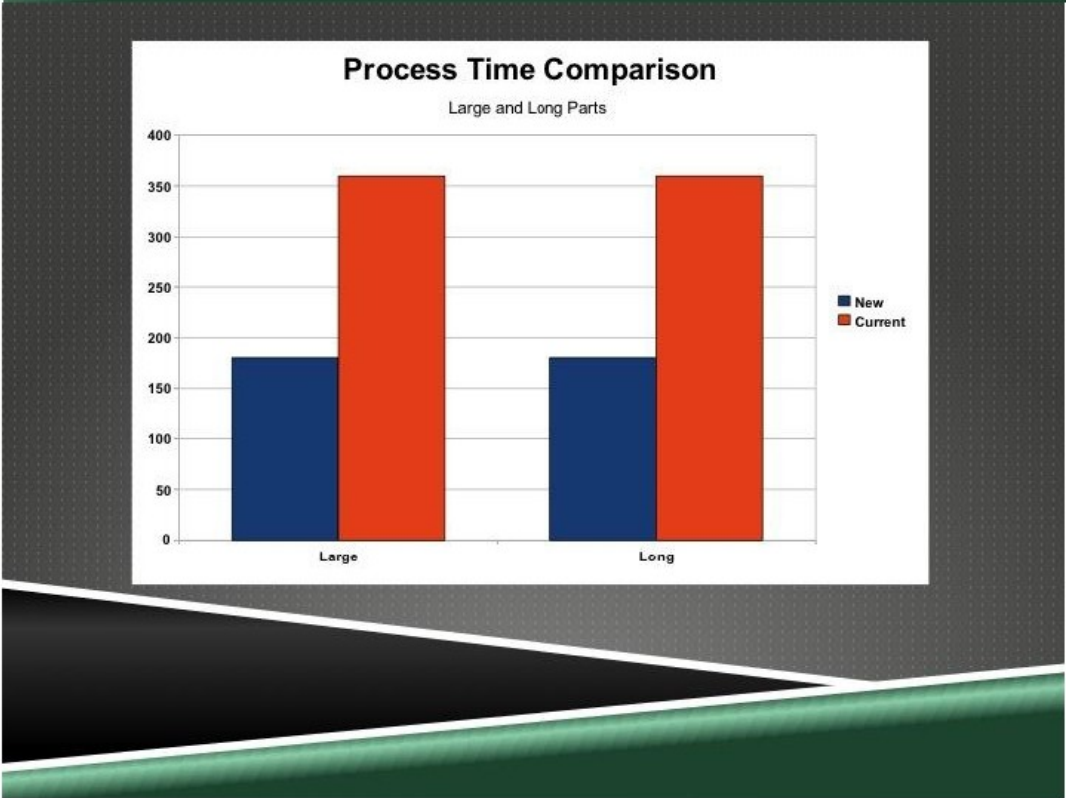
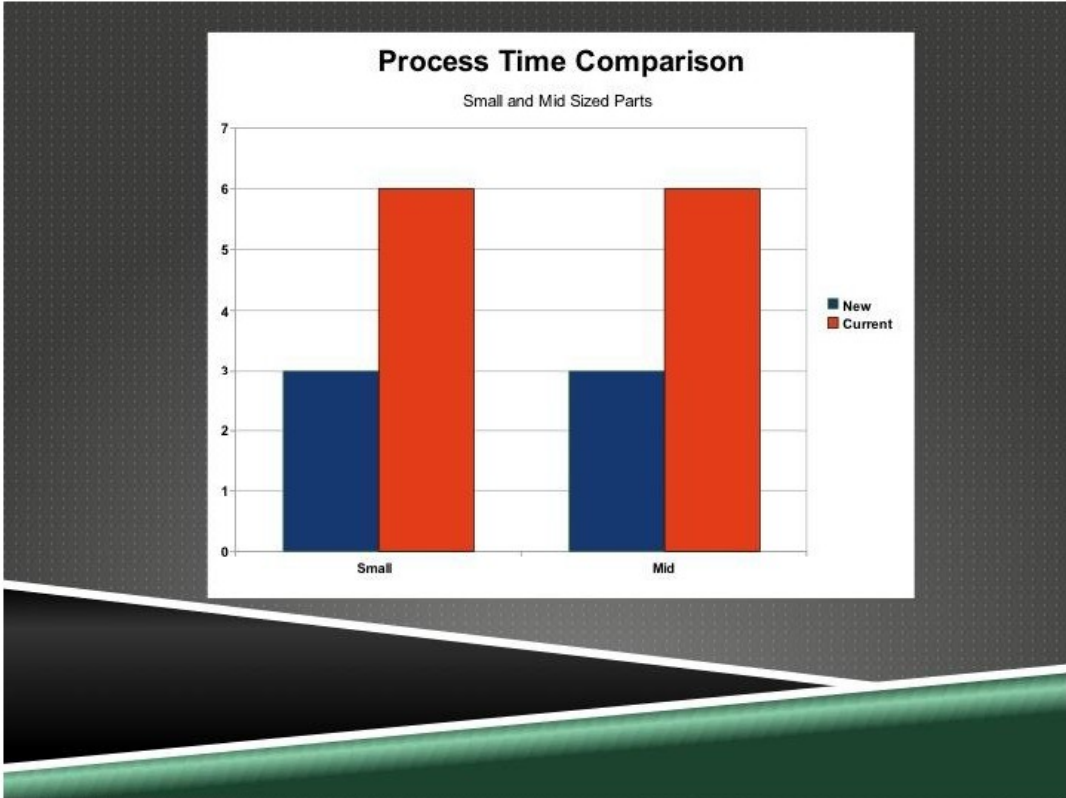


UNLOADING

- ▶ Move entire beams
 - ▶ Fork lift
 - ▶ Continue tracks outside
- ▶ Staging fixtures in Dry Yard



How Much Time is Really Saved?



CLASSIFICATION OF SMALL PARTS

▶ Material Handling Procedure

- ▶ Safety
- ▶ Ergonomics
- ▶ Efficiency

▶ Small Parts Categories

- ▶ Small - End
- ▶ Mid - Size
- ▶ Long
- ▶ Large - End

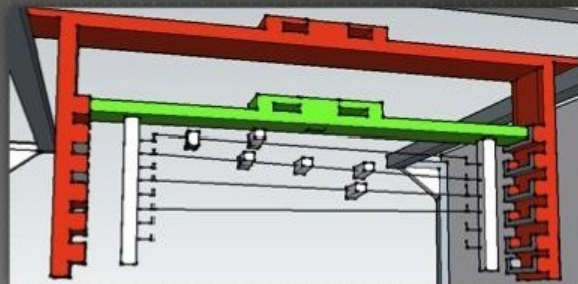
Classification of Parts

Small End Parts

- Zip-tied / Wired
- < 10" Long
- Handled by 1 employee



Categorized Beam →



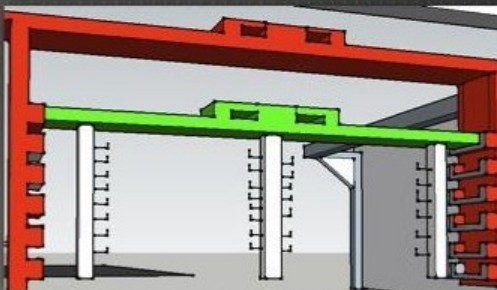
Classification of Parts

Mid – Sized Parts

- Side Panels
- < 24" Long
- Handled by 1 employee



Categorized Beam →



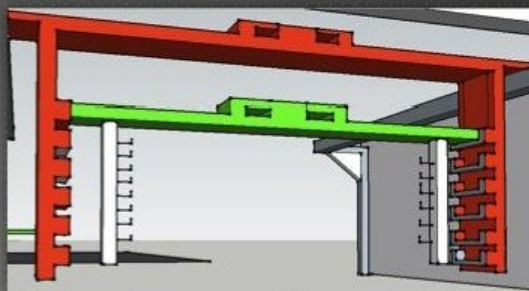
Classification of Parts

Long Parts

- Bents and Long Bolt-on
- > 1/2 of beam width
- Handled by 1-2 employees



Categorized Beam →



Classification of Parts

Large - End Parts

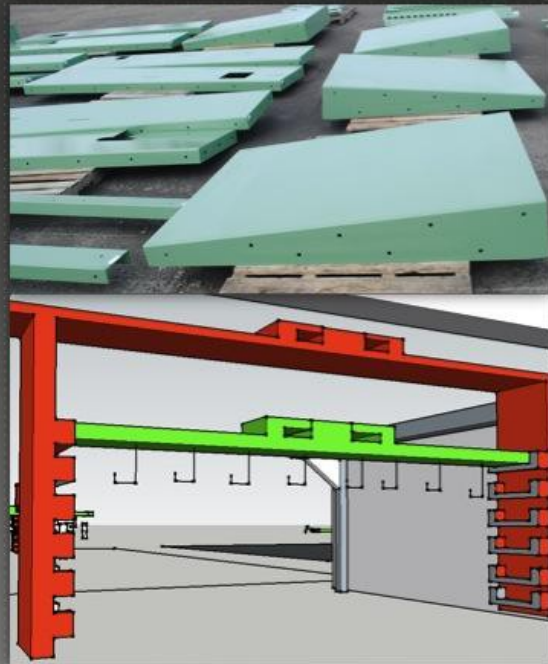
Belly Guards, Bin Walls

> 100 lbs.

Flipping requires crane

Handled by at least 2 employees

Categorized Beam →



FUTURE WORK

- Feasibility Analysis
 - Staging parts
 - Outdoor drying and staging
 - Maximum weight in system
- Cost Analysis
 - What are the total costs?
 - Materials - # of beams and overhead racks
- R&D
 - Prototyping
 - Engineer the design

Ulven-Blocks



Reducing Overlap in Product Lines at Skookum

DSC 477 Spring Term, 2013

UG team: Jordan Anzaldo, Ana Ibanez, Ian Needham, Jake Thomas, Eddie Zhu

Faculty Adviser: Nagesh N. Murthy

Sponsor Contact Info

Chris Reddy, General Manager, Ulven Companies

Rick Russ, Operations Manager, Ulven Companies

Executive Summary

Problem Scope

Skookum manufactures a vast array of its "blocks" product with certain specifications depending on the needs of its customers. As the customers in different industries require distinct functionalities from the product, such customization also requires the plant to carry an overwhelming amount of materials to serve all of their customers. This causes inventory overlap and reduces utilization capacity for the plant.

Solution Methodology

Several visits were made to the Skookum plant in Hubbard, Oregon to fully uncover project specifics. The team soon realized the issue related more to marketing than supply chain operation. Receiving sales data from operations manager Rick Russ supported our predictions; product margins and quantities sold differed greatly among the Skookum and Rope Master lines in question. After analyzing this data further, several team members discussed these findings in a conference call with our points of contact at the Skookum plant.

Rationale for Recommended Solution

Several elementary approaches were taken to evaluate sales data, progressing into more exhaustive analysis of the product lines. The team had received spreadsheets outlining 3 years of item costs, pricing, and quantities sold for the 38 different types of 8" blocks. We compared sales numbers across the Skookum and Rope Master brands, ultimately coming to the recommendation that the Rope Master line should be discontinued.

Background and Context

Skookum makes up one-fifth of Ulven Companies, a family owned and operated business based out of Hubbard, Oregon. Currently, Skookum manufactures a variety of plate, cast and custom sided blocks, as well as fairlead, lead and custom sheaves to fully

accommodate the needs of its customers. The expansive nature of their product lines allows Skookum to serve the logging, maritime, mining, commercial fishing, petroleum, military, and offshore industries.

For this project, our team had the opportunity to work with Skookum to evaluate their "Blocks" product segment. In analyzing several of the segment's components, including product overlap, inventory levels and pricing, we were to provide strategic recommendations for the company based on our research. Chris Reddy and Rick Russ of Skookum (general and operations managers, respectively) were our primary points of contact for this assignment.

Problem Scope

Our primary objective was to reduce the product line overlap that Skookum carried in its inventory. The problem with the blocks was initially difficult to uncover; simply replacing one line with another was not a simple linear equation problem or optimization experiment. We had to get to know the product in its entirety, reasoning as to why we should replace one line with another or completely eradicate the line altogether. When addressed with the problem of discovering the product overlap within the two brands, we did several different types of analysis.

This problem turned out to be more of a marketing problem than anything else. We focused on generating more sales in the more profitable Skookum line. This is only possible through the marketing of the brand to the current and loyal Rope Master customers. It was possible to do a linear programming problem, however, with the limited amount of time we had to work with, we could not gather all of the information needed to make a completely confident decision about the block lines. The two brands each provide the option of hook, swivel, latch, and snatch attachments. These also come in eight different diameters of block types. As we discovered a level of multi-functionality in the sheaves, we suggest narrowing these selections down to only one sheave size, then transfer our findings to the other seven block sizes.

Key Objectives

As mentioned previously, we were originally tasked with performing a strategic analysis of Skookum's product line "blocks". After exploring the product mix further, it became apparent that our main goals in satisfying the company's request were threefold: first, we decided to "rationalize", or streamline, their product mix. As was apparent in the catalog, a plethora of products are currently offered in various configurations. This requires Skookum to carry a large amount of inventory in stock. Our second objective, therefore, was to decrease the overlapping inventory that exists between the components they stock. Finally, we needed to mitigate the brand loyalty that Skookum customers have to their two brands of blocks, Skookum and Rope Master. This objective became necessary once we learned that the two brands' products perform almost identically but generate disparate amounts in total revenue as well as quantities sold.

Skookum has vastly outperformed Rope Master over the last three years in these metrics. While Skookum admitted to having very little understanding of their customers' needs, desires and purchasing criteria, customer brand loyalty was described to us as a "Ford versus Chevy" issue. Many end users of their products have been using a particular brand of block for a long time and flat out feel more comfortable using one brand over another.

Solution Methodology

To begin our project, the team took an on-site visit at Skookum's plant in Hubbard, OR. We started with a plant tour with Chris Reddy to get into specifics about what we were being tasked with. We left that meeting with a catalog and price list for Skookum's products and felt somewhat overwhelmed by the scope of our task. In the next visit, we spoke to Rick Russ and decided that it might help to scale down our project to evaluate just the 8" blocks. This way, we could come up with a framework to assess the other sizes of blocks that Skookum could utilize going forward.

Our next step for the project was to request specific sales data. We asked Rick if he could provide us with product margins and quantities sold of their 8" blocks for as far back as

possible, and received spreadsheets outlining sales for the past 3 years. After analyzing that data, we had a final conference call with Chris and Rick to discuss our findings and touch base one last time before offering our final recommendations. Our conclusions from that data and our recommendations are outlined in the following sections of this report.

Analysis of Alternatives

The data we collected from the Skookum company includes the sale information of all 8" blocks with the two different brands (Skookum and Rope Master). The data covers the item cost, item price, and the quantity sold of different types of 8" blocks with different bearing and tonnage types. From Exhibit 1, you can see that out of 38 blocks there are 14 that have had no sales in the past three years. Our group began shaping our recommendations based on this fact- the 8" blocks with zero sales could cause inventory overlap and reduce the capacity utilization.

The first approach we took was to see how many 8" blocks of both brands, Skookum and Rope Master, have had zero sales in the previous three years. This gave us a general idea of which brand tends to be more popular and what the demand allocation looks like. As you can see from Exhibit 2, among the Skookum blocks, 37% of the blocks have had zero units sold. Compared to Rope Master with 57% of its blocks with no units sold, we can say that Skookum may be more popular and generate more demand than Rope Master.

In order to prove this analysis, and further understand the extent of brand sales difference, we took a second approach. In the second chart of Exhibit 2, you can see that Skookum had 1,135 units sold and Rope Master had 252 units sold. Based upon these two alternatives, we found out that Skookum dominates the total sales and demand, which lead us to believe that Rope Master does not have to be an individual brand.

Recommendation

Our main recommendation to Skookum is that they discontinue the Rope Master line of products. As our data analysis clearly shows, the Skookum line of blocks is significantly more

popular. Because they have issues with how much inventory is necessary to stock, this eliminates a great deal of that inventory requirement. This does mean, however, that Skookum will have to convince Rope Master customers to switch to Skookum or risk losing them to competitors. Fortunately, switching costs in this utilitarian industry are much higher than in industries where purchasing decisions are purely emotional, less time-sensitive and less expensive to reverse. Customers of the Rope Master brand will be more likely to extend their perception of the Rope Master brand toward Skookum and not look to competitors for their product needs.

To further mitigate the risk of losing loyal customers, we propose developing a marketing plan which communicates to Rope Master customers the similarity in the service they can achieve with a Skookum block. Along with this campaign, we suggest initial promotions or discounts to entice customers to switch to Skookum. As Chris pointed out in our final conference call, it is important that these discounts be structured in a way that recoups those potentially lost revenues in the long run.

Our final recommendation is that Skookum send a survey out to its customers to better understand their desires, needs and purchasing criteria. As Rick Russ admitted during our second on-site visit, Skookum does not possess much insight into why their customers buy what they buy. We think it a customer survey would help them understand their customers and further clarify how to organize their product lines to better serve those customers.

Appendix 1

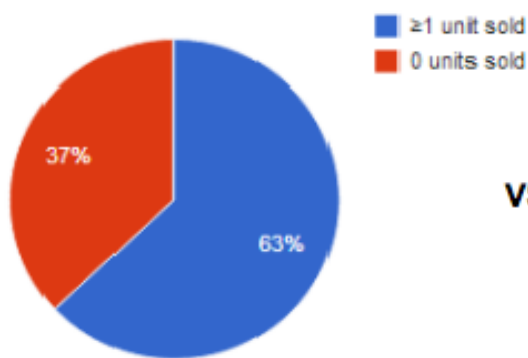
Sales information of all 8" blocks in the past three years

Item ID	Item Description	Item Cost	Quantity Sold	Net Sell
00-557700	SK BLOCK R8 RY	308.65	746.00	732.57
00-209800	RM BLOCK 508 RY	562.96	160.00	1056.75
00-564200	SK BLOCK A8 RY	222.21	144.00	450.25
00-799400	SK BLOCK 808 RY	319.76	83.00	695.44
00-205800A	RM BLOCK 108-RA NEW STYLE	504.31	36.00	565.01
00-204800	RM BLOCK 82-S RY	291.65	30.00	533.70
00-563600	SK BLOCK A8R RY	250.72	27.00	518.87
00-680000	SK BLOCK A8T RY	259.35	24.00	541.87
00-563101	SK BLOCK S8 SLSH	317.30	22.00	556.28
00-799401	SK BLOCK 808 SLSH	373.58	18.00	860.82
00-557903	SK BLOCK T8 RY	370.34	16.00	663.08
00-680900	SK BLOCK A8RT REGULAR YOKE	312.59	16.00	598.69
00-200800	RM BLOCK 8 RY	249.67	15.00	414.55
00-562701	SK BLOCK S8R SLSH	377.28	9.00	742.66
00-799402	SK BLOCK 808 SS	372.85	8.00	912.05
00-560600	SK BLOCK 80 RY	539.17	7.00	1423.58
00-205000	RM BLOCK 83 RY	558.86	6.00	777.22
00-563102	SK BLOCK S8 SLSS	337.75	6.00	736.35
00-563602	SK BLOCK A8R SS	337.70	4.00	686.83
00-790900	SK BLOCK 308 REGULAR YOKE	499.90	4.00	1308.56
00-204803	RM BLOCK 82-S SLSH	285.48	3.00	610.59
00-205802A	RM BLOCK 108-RA W/SS		2.00	794.23
00-564202	SK BLCOK A8 SS	314.39	1.00	620.79
00-200803	RM BLOCK 8 SLSH			539.07
00-200804	RM BLOCK 8 SLSS			532.21
00-204400	RM BLOCK 78 RY			530.45
00-204401	RM BLOCK 78 SH			575.32
00-204402	RM BLOCK 78 SS			618.22
00-204804	RM BLOCK 82-S SLSS			656.22
00-205801A	RM BLOCK 108-RA W/SH			734.16
00-557901	SK BLOCK T8 SWIVEL HOOK			869.98
00-557902	SK BLOCK T8 SS			914.90
00-562702	SK BLOCK S8R SLSS			795.11
00-563601	SK BLOCK A8R SH			602.45
00-680001	SK BLOCK A8T SH			657.21
00-680002	SK BLOCK A8T SS			762.85
00-680901	SK BLOCK A8RT SH			711.57
00-680902	SK BLOCK A8RT SS			762.85

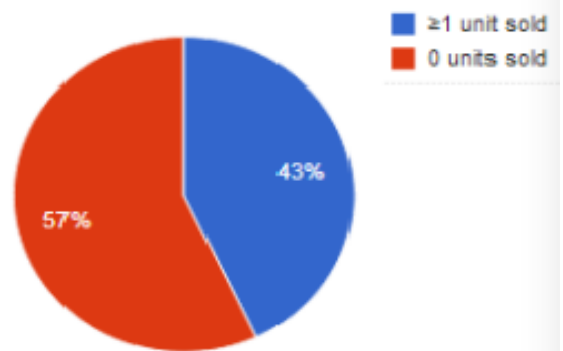
Appendix 2

% products with ≥ 1 unit sold

Skookum



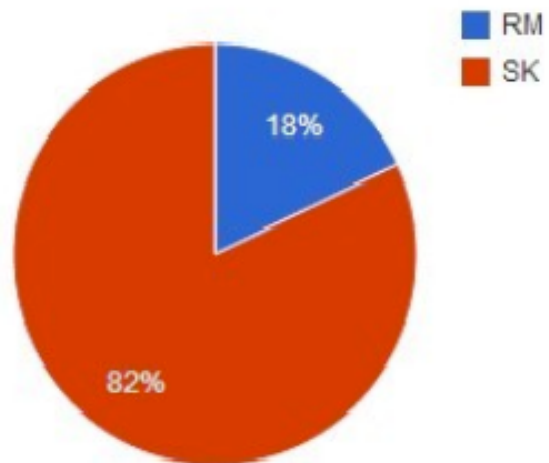
Ropemaster



VS.

RopeMaster Total Quantity Sold V.S. Skookum

Quantities 8" Blocks sold	
RopeMaster	252 Units
Skookum	1,135 Units
Total	1,387 Units



**Evaluating the logistics of inbound shipping/manufacturing at
alternative sites**



DSC 477 Supply Chain Management Spring term 2013

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Executive Summary

Background/Context

Bulk Handling System operates in Eugene with two facilities. Their facility at W 5th Avenue is their main office and is used for storage. Their facility at 460 N Danebo is where the main manufacturing of their product occurs. All of their suppliers deliver to their W 5th facility.

Problem Scope

How much can Bulk Handling Systems save if they deliver directly to their second facility and the return on investment of adding additional storage at BHS Danebo facility?

Key Objectives

The objective is to find the cost that is associated with shipping ranging from labor, time, and truck maintenance. Also cost with storing materials outside.

Solution Methodology

By analyzing the shipment between two facilities, and employee's working process, we will calculate the total cost with labor salary and damage of material.

Analysis of Alternatives/Final Recommendation

Instead of investing in a new facility, we recommend the investment of a new Pole Barn. A new Pole Barn would fit the budget and as well would still be able to cover the materials from damage and save on loading and unloading time. As well, any leftovers from the savings of a new Pole Barn should be used to invest in a new truck since the old one is costly for maintenance.

Background/Context

Bulk Handling System (BHS) operates in Eugene Oregon with two facilities. The facility located at 3592 W 5th Avenue is their main office and is used mainly for storage. The second facility located at 460 N Danebo Avenue is where the main manufacturing of recycling machinery occurs. There are some manufacturing processes that occur at the first facility (e.g. drilling holes in forming material). All of the materials BHS receives from their suppliers is shipped directly to their first facility at W 5th. The majority of manufacturing occurs at their Danebo facility but due to the lack of storage they can't ship their materials directly to the Danebo facility.

When material is needed for manufacturing BHS has to ship materials from the W 5th facility to the Danebo facility. There are 4-5 shipments between the two facilities daily. The shipping process requires two material handlers, forklift, truck, truck driver, gas, and time. The entire process requires an hour and a half or 1.5 hours. It takes 30 minutes to unload materials and an hour to load materials. The material BHS uses comes in all different shapes and sizes so getting them in the delivery truck takes more time than unloading. During the shipping process there's a chance that materials may be damaged. Damaged materials costs are roughly \$10-\$300/monthly depending on what type of materials are damaged. BHS doesn't keep an accurate log of the damage materials because only a few items are damaged monthly. The distance between the two facilities is roughly 2 miles. So, once the truck has delivered the materials to the second facility it has to go back to the first facility which round trip equals a total of 4 miles.

There are times as well, when the material that is delivered from W 5th needs to be stored outside at the Danebo facility. Since BHS is located in Oregon it tends to rain quite a lot. The material stored outside gets rained on and starts to rust and, before BHS can use these materials for manufacturing they have to clean it first. The amount of time BHS spends cleaning

the material from rust is 272 hr a month or 3,264 hr annually. Cleaning materials requires an immense amount of time for BHS.

Problem Scope

BHS wants to find out what the cost savings will be if they deliver directly to the Danebo facility. Currently, they don't deliver to Danebo because there isn't enough storage capacity at the Danebo. BHS is contemplating whether to invest in additional storage at the Danebo facility. If the return on investment is greater than the cost of storage it can benefit BHS in the long run. By deciding whether to build or not, we need to find the amount of cost associated with delivering materials and parts to the second facility from the first.

Key objectives

The key objectives of our project was to find out the main cost factors of each step and compare the current cost of BHS' process to adding more storage space at the second facility to lessen unnecessary expenses. To do this we calculated the return on investment to implement more storage space. During the factory tour and interview with the main employer, we obtained the main cost which consisted of average labor's salary, time, truck usage, maintenance cost of the truck, cleaning, and damage or lost materials. If we can reduce the number of steps BHS takes to deliver materials, it can help BHS save money on time and salary cost. Being that salary is paid by the hour, increasing the working efficiency is also a way to decrease the salary cost. If BHS were to deliver to the second facility directly there would be less cost because BHS is currently double handling their material.

Oregon tends to rain quite a lot and the weather can be unpredictable. During the delivery process, the materials have a high chance to be rained on and it will require cleaning which will also create large costs. If we can add additional storage at the new facility this cost will be eliminated. There will be damaged materials in a week, month or a year and the cost of each material will vary. Value can vary from 10 – 300 dollars depending on how many parts are damaged and/or how damaged the material is. As well, 1-2 items a month are damaged when

parts are loaded and unloaded making the ability to reduce trips more of a priority. BHS do not keep an accurate log of these damaged materials.

Solution methodology

The current shipment process of BHS is they receive materials from suppliers and ship them to 1st facility where they unload the materials for storage. Next, when they need the materials for manufacturing they load materials to the truck and ship it to the 2nd facility and unload again. So we can see the company has 1 loading and 2 unloading processes for current shipment process. If BHS can deliver materials to the 2nd facility directly, it only would need to unload material once. This would make it so they could save 1 unloading and 1 loading process.

Each loading process costs 1 hour and each unloading process costs 30 minutes. From this we can assume that BHS can save 1.5 hour for each trip. In addition, BHS needs at least 4 trips per day, and it will have 1 shipment between two facilities even they build new warehouse. Therefore, BHS can save 3 trips- $1.5*3=4.5$ hours daily. BHS has 2 handlers working for loading and unloading materials, and 1 truck driver working for delivering materials between two facilities. These workers work 5 days per week. Using the average salary of \$32/worker for calculation, BHS can save $32*4.5*5*4*12=\$34,560$ annually per worker. Hence, BHS can save \$69,120 for two handlers and \$34,560 for truck driver. In addition, the cleaning material cost is a huge amount. BHS spends 3,269 hours annually to clean materials, and the cost to do this can be calculated as such, $3269*\$32=\$104,448$ annually. Furthermore, BHS has damage costs between \$10 and \$300 monthly so the damage cost is between \$120 and \$3600.

Finally, we add these cost together and BHS can save costs between $69120+34560+104448+120=\$208,248$ and $69120+34560+104448+3600=\$211,728$.

Calculations can be further seen in Appendix B.

Analysis of Alternatives/Final Recommendation

As seen in the solution methodology, the costs associated with delivery are of significance and should be taken into consideration. To formulate these results, multiple trips to

BHS and questioning of the logistics of shipping between their two facilities was required. Conversely, the main issues at hand were the costs associated to cleaning the equipment from it staying outside and becoming damaged from the rain, the time and energy it took to clean this inventory, and the extra trips to and from each facility that could be potentially mitigated. To reduce these expenses a few suggestions and recommendations were formulated.

Initially, we were asked to calculate the return on investment (ROI) for implementing an entire new manufacturing facility that would also be equipped with a crane. The cost to fund this project was to be over \$2 million. From our calculations, which can be seen in the solution methodology, the total annual costs that could be saved if they were to ship directly to a new second facility at the Danebo facility, instead of using the current main facility and then to the Danebo Facility, would be \$208,248 (using the minimum cost savings to be safe with our results). With these two variables, our calculated ROI equaled -90% and would take approximately 10-12 years to break even. Ultimately, since the general rule of thumb for a manufacturing business is to take no longer that 2 years maximum to break even, this investment was deemed not feasible.

Instead, the solution we recommend can be seen by way of a new pole barn that would cover the additional storage space currently available at the 2nd facility. By implementing a new pole barn this would not only eliminate the time spent cleaning the inventory that gets damaged from sitting outside, it would also reduce the travel, load and unloading time, and energy spent from using the original process of the main facility. The cost of the new Pole Barn can be seen in Appendix A.

Since the cost of implementing a new facility is too high and the resulting ROI is not feasible, the cost of implementing a new pole barn ended up being a lot more practical. As seen in Appendix A, the cost of implementing this new Pole Barn would be roughly \$161,870 or closer to \$175,000 (for a safer estimate). Using this estimate and the cost savings of \$208,248, the new calculated ROI would be 19% and thus would be feasible. As well as being feasible,

using these estimate still allowed for \$33,248 of leftover savings. Using these additional savings, we also recommend that BHS invest in a new truck. Since the current truck that BHS uses is outdated and costing the company annually roughly \$14,000 in maintenance cost annually, we feel this investment is needed now and would be beneficial in the long run as well.

In summary, we believe that by implementing a new pole barn at the second facility would allow for reduced expenses and as well would allow for funding of a new truck with lower annual maintenance costs.

Appendix

Appendix A

<p>60' x 120' x 16'</p> <p>width x length x height</p> <p>Hansen Buildings - Pole Barn Kit</p> <p>Estimated Ship Date: 06/21/13</p>		<p>Starting at:</p> <p>\$31,499</p> <p>Customize My Building Kit</p>
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Simple: $\text{area} = 60 \times 120 = 7200$ feet worth \$31,499. BHS needs 37000 feet so the cost of pole barn is $31499 \times (37000 / 7200) = \$161,869.86$

Appendix B

Cost Savings if Shipped directly	cost/hr	Monthly Savings	Total Cost/Yearly Minimum	Total Cost/Yearly Maximum
Handler	\$ 32	\$ 2,880	\$ 69,120	\$ 69,120
truck driver	\$ 32	\$ 2,880	\$ 34,560	\$ 34,560
Cleaning material		\$ 8,704	\$ 104,448	\$ 104,448
damage (minimum \$10)		\$ 10	\$ 120	
damage (maximum \$300)		\$ 300		\$ 3,600
Total			\$ 208,248	\$ 211,728

Myers Container Final Report

Matt Fanelli, Eric Ringer, Rob Woltl

DSC 577 – Nagesh Murthy

6/10/13

Executive Summary

Myers Container, a steel drum manufacturer based in Portland, asked us to evaluate its operations at its Killingsworth steel drum manufacturing facility and make some recommendations for how it can operate more efficiently and sustainably in the next three to five years. After taking a plant tour, meeting many of the company's executives, researching various sustainability-related programs, and evaluating its key competitors, we came up with five primary recommendations that we think will allow Myers to further its sustainability mission in cost effective ways and evaluate and prioritize their projects moving forward. First, we recommend that Myers classify its emissions sources by scope. Second, we recommend that Myers measure each machine's energy usage in its Killingsworth facility. Third, we recommend that Myers track its waste streams. Fourth, we recommend that Myers look to improve its transportation efficiencies. Fifth and finally, we recommend that Myers continue to take lessons from industry leaders. With these recommendations we think that Myers can own its market space as an efficient sustainability leader in the Pacific Northwest.

Introduction

Myers Containers (Myers) is a Portland-based steel drum manufacturer that has a passion for sustainability. In order to develop and maintain their brand as a leader in sustainable business practices, Myers CEO Kyle Stavig asked our UO MBA team to develop an executive plan outlining potential next steps to make Myers' Killingsworth facility more sustainable over the

next five years, and to improve the company's framework for making decisions about sustainability. While Myers has plant operations in California, North Carolina, and Oregon, our project focused primarily on the Killingsworth facility. Our objectives were to identify a list of achievable sustainability initiatives that would allow Myers' Killingsworth facility to be run more efficiently, effectively, and sustainably. Following Myers' definition of sustainability, each project will focus on constant improvement of the company along people, profit, and planet metrics.

Analytical Methods

In order to make our recommendations we asked Myers for a lot of its sustainability data. After our plant tour and on-site meeting, we had some idea of the scope and depth of the production at Myers. Kyle Stavig, Jay Letter and Cody Stavig, were all incredibly generous with their time and data in helping us get information that we might need for this project. We pored over emissions reports, Myers' own carbon calculator, training manuals, quarterly reports, and other client data. We took pictures and notes during our visit and used them to try to identify potential problem areas that Myers could both control and improve. We also analyzed industry leaders' sustainability efforts in the steel drum manufacturing industry to see if we could apply any lessons from their efforts to Myers. In understanding Myers' short investment window (approximately two years), we then pared our recommendations down into five recommendations that might give an adequate return on investment in the allotted period.

Recommendations

1. Classify Emissions by Scope

It is important to classify Myers' emissions by scope to help in the decision-making process when considering what new sustainability projects to take on. Scope 1 emissions are those that the firm is directly responsible for emitting, such as company facilities and company-owned vehicles. Scope 2 emissions are indirect emissions, typically just emissions from purchased electricity. Scope 3 emissions are also indirect but encompass all supporting activities for the company. These emissions could include business travel, outsourced freight, employee commutes, and contracted waste disposal. See Figure 1 in the appendix for a graphic depicting the scopes and example emissions sources. Once Myers' emissions have been classified into scopes it can assess the impact certain sources have on overall emissions and the degree to which it has control over those sources. Sources that Myers has significant control over and have a high impact on overall emissions will become the highest priorities for Myers. See Figure 2 in the appendix for a graphical representation of this tool. This recommendation is most relevant for GHG emissions as estimated in Myers' carbon calculator.

Additionally, the carbon calculator needs to be updated with proper emissions factors. For example, the emissions factor used for electricity GHG emissions comes from PG&E. Myers buys electricity from PGE, which has a different emissions factor

(1.337 lbs/kWh, source: http://cfpub.epa.gov/egridweb/view_egcl.cfm); see Figure 3 in the appendix for PGE's emissions based on its unique generation resource mix.

2. Individualize the Energy Usage in the Plant

We recommend installing power meters at each piece of electrical equipment to identify the major power users and monitor power consumption of each machine for indications of functional issues. Early detections of equipment malfunction can help prolong the life of the machine, reduce unnecessary power consumption that would raise electric bills, and reduce unexpected down time. The major power users can be flagged for review and upgraded to more efficient models when circumstances and budget allow. Eaton offers an energy management solution through intelligent hardware and software. More information about its system can be found at this link:

http://www.eaton.com/ecm/idcplg?IdcService=GET_FILE&allowInterrupt=1&RevisionSelectionMethod=LatestReleased&noSaveAs=0&Rendition=Primary&dDocName=BR02601012E

3. Track Waste Streams

Tracking waste streams by a common unit of either weight or volume will allow Myers to first establish a baseline so it knows how much waste it is producing and what

types. From here Myers can look for opportunities to reduce production of waste, divert more from landfills, and possibly turn waste from a cost to a revenue generator.

4. Freight

Outbound freight accounts for 37% of Myers' carbon footprint, making it the second-largest greenhouse gas contributor for the company. Because outbound freight accounts for so much of Myers' greenhouse gas footprint, it should be a large focus for Myers' ongoing sustainability efforts. We researched best practices in shipping and freight and recommend that Myers investigate three potential steps to reduce its freight carbon footprint and further its mission of sustainability. Myers should investigate the Environmental Protection Agency's SmartWay Program, try to partner with customers to creatively ship product, and collaborate with its recycling and reconditioning service by backhauling from customer sites.

Our first transport recommendation is for Myers to explore the EPA's SmartWay Program. Started in 2004, the SmartWay program is a partnership between private companies and the EPA to encourage more efficient management of transportation-related emissions. The program has five components, and focuses on everything from partnerships with freight carriers to creative financing and a testing and design program all intended to achieve more efficient transportation of goods. By partnering only with the EPA, companies like UPS, Lowes, Sharp, and Ikea have all significantly reduced their

transportation emissions. Reductions like this save money on fuel costs, and help the environment by reducing overall greenhouse gas emissions. Part of the SmartWay program is for partnering companies like Myers with certified SmartWay shippers. These shippers keep detailed track of their emissions and efficiencies, follow best practices in fuel economy, and report to the EPA their successes and areas for improvement. With over 600 companies now members of the SmartWay Program, there are more options for customers to meet their orders efficiently. Myers should focus primarily on working with SmartWay-certified shippers, and on using SmartWay's efficient technologies on its own fleet. The technology innovations in the SmartWay program reduce idle time, make trucks more aerodynamic, and employ "low rolling resistance" tires. If Myers can take advantage of even a small number of these options, it will reduce Myers' carbon footprint.

Our second transport recommendation is for Myers to collaborate with its customers to see if it can more creatively ship its steel drums. As CEO Kyle Stavig put it "we basically ship air." Due to the nature of the steel drum product, a shipment fills up capacity by volume far more quickly than it fills up by weight. If Myers could find creative ways to pack more drums in each shipment, it would reduce the number of shipments it has to make, and reduce its overall greenhouse gas emissions from CO₂ discharge. One way in which Myers could creatively pack more drums in each shipment is to nest different size drums inside each other. This would involve collaborating with Myers' customers because the type of order generally dictates the shipment type and size. However, if

Myers can partner with some of its customers and nest smaller drums inside larger drums, it could result in significant reduction of shipping costs.

Our third and final transport recommendation is to examine if Myers could backhaul more used drums to its reconditioning and recycling site. We think this has the potential to both reduce Myers' overall carbon footprint and to expand Myers' recycling and reconditioning business. It is our understanding that shipping trucks often travel north without a load, which makes each empty northbound trip a waste of gas and adds strain to the environment. Myers can reduce that strain and make the northbound trips worthwhile if it can bring back used steel drums to its reconditioning site in Portland. Links to the EPA SmartWay program can be found at the end of the appendix.

5. Industry Inspiration

Our last recommendation is for Myers to continue to follow and learn from industry leaders like Mauser, Greif, and Schutz. Myers already closely watches these companies' sustainability efforts, and can continue to leverage lessons from their actions and build its own place in the Pacific Northwest as a trusted steel drum manufacturer. Specifically, we think Myers should look to vertical integration, product diversification, and ISO certifications to reach best practices in the steel drum manufacturing industry.

Many of the other leaders in steel drum manufacturing own their own shipping fleets and have expansive recycling operations. While Myers does have a reconditioning and

recycling facility, it pales in comparison to a company such as Mauser, which owns and operates twenty-eight recollecting sites. This sort of vertical integration allows Mauser to control more of its environmental impact, and allows for another strong revenue stream beyond just selling drums.

As more of a long-term recommendation, we recommend that Myers look to offer more products. Product diversification has benefited Myers' competitors both in expanding their businesses and in recycling more of their materials. This recommendation is more food for thought than an immediate priority, but product diversification remains a key area in which Myers competitors are becoming more profitable and more sustainable.

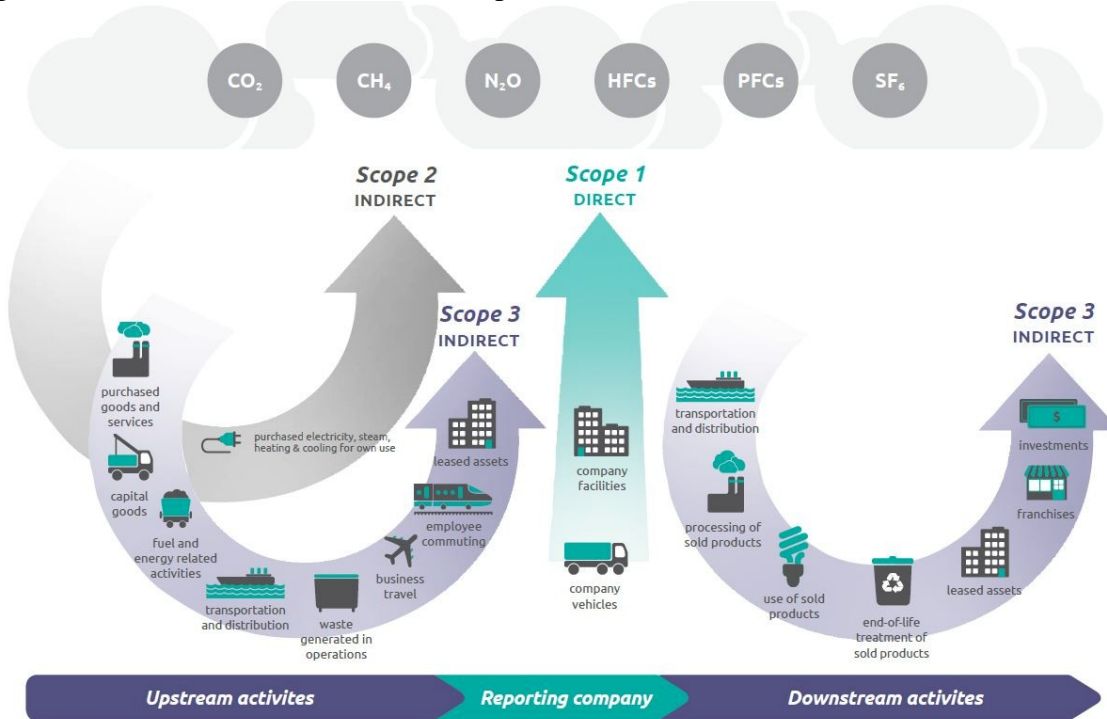
Finally, we think that Myers could benefit from third-party certification of its sustainability efforts. With environmental regulations becoming ever more stringent and with the potential of a carbon tax on the horizon, staying ahead of the curve environmentally is becoming even more crucial. We think that a third-party certification - such as an ISO audit - would be beneficial to Myers' mission of being sustainable in everything that it does. We understand that an environmental audit can feel limiting to a company, but we think that the benefits of a full audit outweigh its limitations. A full audit can identify problem points for Myers far more accurately than a piecemeal investigation can.

Conclusion

In conclusion, we believe that Myers is already a company that practices the triple-bottom-line mission well. And we appreciate the opportunity to work with such an outstanding group of business leaders. We applaud the Myers team's efforts to continuously improve their operations and hope that these five broad recommendations can help them move forward and become even more sustainable. By classifying emission sources, measuring machine energy usage, tracking waste streams, improving transport efficiencies, and following industry sustainability leaders, Myers can further its mission of being one of the most sustainable companies in the Pacific Northwest.

Appendix

Figure 1: Overview of GHG Protocol scopes and emissions across the value chain.



Source: <http://www.lawandenvironment.com/2011/10/ghg-protocol-finalizes-scope-3-and-product-life-cycle-methodology/>

Figure 2: Using scope emissions to prioritize sustainability projects.

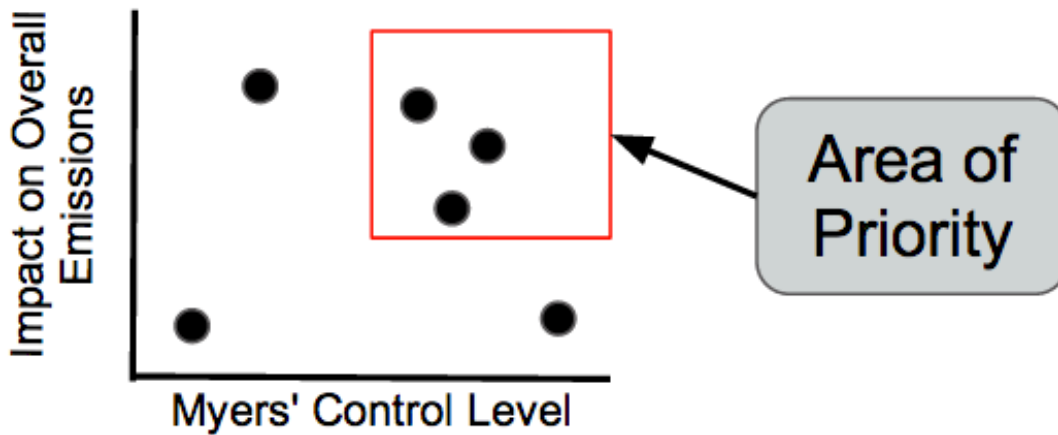
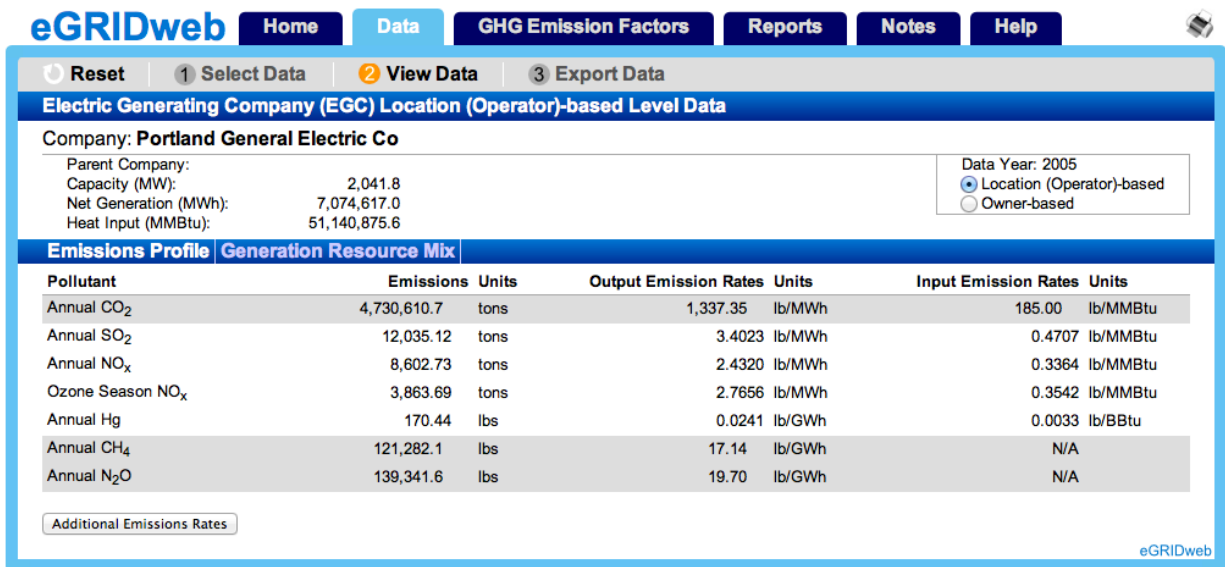
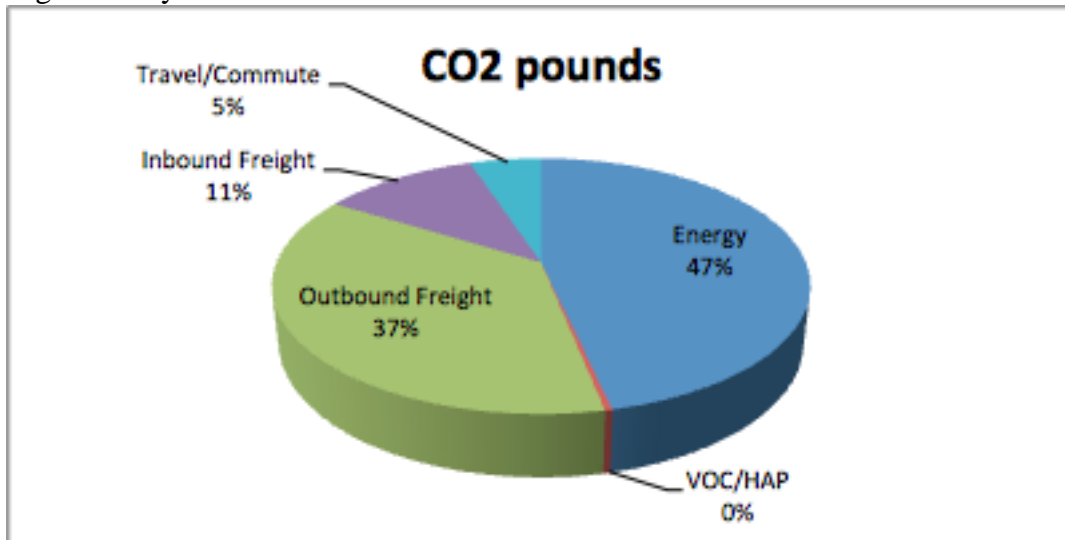


Figure 3: PGE's Emissions based on its unique generation resource mix.



Source: http://cfpub.epa.gov/egridweb/view_egcl.cfm

Figure 4: Myers' Carbon Emissions



Source: Myers Carbon Calculator

2012 EPA SmartWay Links:

Homepage: <http://www.epa.gov/smartway/index.htm>

Transport: <http://www.epa.gov/smartway/partnership/index.htm>

Technology: <http://www.epa.gov/smartway/technology/index.htm>

Society or the Environment?

Understanding How Consumers Perceive Corporate Sustainability Initiatives

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Society or the Environment?

Understanding How Consumers Perceive Corporate Sustainability Initiatives

Abstract:

This research examines how and why consumers evaluate a company's environmental and social practices differently. Using secondary data, a field experiment, and laboratory experiments, we show that the tangibility of a company's product offering and the process to develop the offering influence consumers' evaluations of environmental practices relative to social practices. Specifically, environmental practices generate greater impacts for goods companies, companies with tangible offerings, and companies with a tangible process. By contrast, social practices are more influential for services companies, companies with intangible offerings, and companies with an intangible process. Increased awareness rather than an obligation to compensate underlies the role of tangibility.

Keywords: corporate social responsibility, environmental sustainability, social sustainability, tangibility

Companies in today's business environment can no longer afford to single-mindedly maximize profitability. Corporate social responsibility, or sustainability more generally, is a strong area of focus by many companies as they balance financial performance with doing good for society and the environment. In a report by Verdantix (2013), a survey of 2,856 companies including 3M, Johnson & Johnson, KPMG, and eBay found that spend on sustainable business initiatives will reach \$43.6 billion in 2017. Indeed, engaging in sustainability practices has also been found to result in marketing benefits including enhancing corporate image (McKinsey 2011), increasing consumer purchase intentions (Sen and Bhattacharya 2001), and minimizing consumer backlash following a product crisis (Klein and Dawar 2004). Despite these positive findings, the marketing literature has been surprisingly silent on how—or if—companies should position themselves in terms of sustainability initiatives and, if so, what criteria could be used to determine their area of investment.

When formulating a corporate sustainability plan (Brown and Dacin 1997), a company can choose to emphasize environmental sustainability practices—initiatives that aim to minimize exploitation of the earth's natural resources and reduce negative environmental effects (Hart 1995; Bansal 2005). For example, Amazon's Packaging Feedback Program focuses on minimizing extraneous packaging materials and using recycled and recyclable supplies for shipments that come from their fulfillment centers. In addition, Patagonia's In Common Threads Partnership encourages customers to take a pledge to reduce what they buy, reuse what they have, repair what they can, and recycle everything else. On the other hand, companies can also choose to focus on social sustainability practices—activities that emphasize the betterment of consumers and local communities, charitable giving, education, and other societal impacts (Elkington 1998). For example, Cisco Systems highlights four primary social investment focus areas on its website, including education, healthcare, economic empowerment, and critical human needs to "help communities worldwide thrive" (Cisco 2013). In addition, the U.S. Bank Foundation focuses on providing nonprofit organizations with grants in the areas of education,

economic opportunity, and artistic and cultural enrichment. An examination of the top 30 companies in the Forbes 500 list found that 87 percent featured a corporate citizenship or corporate responsibility section of the website that delineated between environment and social initiatives.

While it is clear that environmental and social sustainability practices are important focus areas for many businesses, companies need to prioritize their sustainable contributions and expenditures given limited resources and an increased emphasis on return on investment (Welford, Chan, and Man 2008). Yet, the marketing literature suggests little in terms of where this prioritization should take place, when it is advantageous for companies to concentrate their efforts on one area over the other, and what guiding criterion should be used to make such resource allocation decisions. Despite the proliferation of studies in the domain of corporate social responsibility in the past decade, almost all of prior studies have treated CSR and sustainability as an encompassing construct without differentiating the environmental and social activities within it.

Recently, researchers have proposed that future research should distinguish environmental sustainability practices from social sustainability practices and examine their differential effects on consumer-level and company-level outcomes (e.g., Pelozo and Shang 2011; Chabowski, Mena, and Gonzalez-Padron 2011). The need for such a focus is rooted in both conceptual and empirical considerations. Conceptually, social and environmental resources and capabilities are distinct and tend to have different impacts on stakeholders' perceptions and business outcomes from a resource-based view (Chabowski et al. 2011). Accordingly, CSR activities that focus on environmental and social dimensions trigger different consumer preferences when enacted by different companies (Pelozo and Shang 2011). The marketing literature and practice support this delineation and such a focus on the environment and society. "Planet" and "people" are two of the three pillars of the triple-bottom line approach to corporate sustainability (Elkington 1998) and the marketing literature has confirmed that

corporate sustainability activities should be studied as an environmental and social construct (Aguilera, Rupp, Williams, and Ganapathi 2007; Ellen, Webb, and Mohr 2006).

Empirically, the lack of consistent empirical findings on the success from CSR and sustainability efforts is partially due to the lack of consistency in the specific activities researchers use to define sustainability practices (Maignan and Ferrell 2004; Pelozo and Shang 2011). In his review of the financial metrics used to calculate the business case for CSR, Pelozo (2009) finds 39 unique CSR activities used in studies over four decades. The broad array of sustainability-related activities suggests that not all are viewed equally positive, or positive at all by stakeholders. Results from these analyses suggest that different types of sustainability initiatives have different effects on consumer perceptions and firm value.

Industry studies have provided intriguing yet inconclusive evidence. For example, a 2010 Guardian News and Media survey found that consumers' expectations of environmental sustainability for the energy and manufacturing sectors are significantly higher than expectations for financial and health industries. On the other hand, a 2011 Sustainability Leadership Report of 100 global brands found that social factors such as community involvement, employee diversity and opportunity, and human rights were two times more significant than environmental factors in determining consumer perceptions of good corporate citizenship (Brandlogic Inc. and CRD Analytics 2011). Given these conflicting findings and an absence of marketing research on the topic, this paper focus on the differential importance of environmental versus social sustainability practices from a consumer's perspective. Specifically, we aim to answer the following research questions: What type of sustainability practice matters most to consumers, and what drives the preference for one type of sustainability practice over the other? We suggest that consumers' perceptions of sustainable practices are affected by the degree of tangibility in the company's offering, as well as the company's process of developing the product or service offering.

Multiple approaches were utilized to investigate our questions of interest, including secondary data analysis, a field experiment, and three lab experiments. First, we analyze a secondary dataset to find that sustainable practices that benefit the environment are relatively more common for goods companies, while the practices that benefit the society occur more often for services companies. We then replicate this pattern in our primary studies, finding that consumers deem environmental practices as more impactful for goods companies and social practices as more important for services companies. Second, we propose and empirically test the notion of tangibility as the key differentiator that drives the pattern. Specifically, we show how the tangibility of a company's offering as well as its process to develop the offering influences consumers' perceived importance of different sustainable practices. Lastly, we examine the underlying mechanism that explains why tangibility drives consumers' perceived importance of environmental versus social sustainable practices. We propose competing mechanisms—awareness or compensation—and show that it is the increased awareness of the environment rather than an obligation to compensation that underlies the role of tangibility.

Our study contributes to the literature by systematically examining consumers' differential perceptions of environmental and social sustainable practices in different types of companies, offerings, and processes. More importantly, we uncover the mechanism through which consumers' perceptions operate when they evaluate a company's sustainable practices.

We start by presenting the findings from our analysis of a secondary data source—the sustainability ratings of certified benefit corporations. We report findings regarding the relationship between company type and the relative importance of environmental versus social sustainability practices and propose the first hypothesis. Next, we develop the theory and hypotheses regarding consumer perceptions of environmental and social sustainability practices around the concept of tangibility. Four additional studies are reported and tested. We conclude with a discussion of the theoretical and managerial implications of our work and provide avenues for future research.

Environmental versus Social Sustainability

To start, we turn to a project initiative by B Lab, a nonprofit organization that provides certification for sustainable businesses. Founded in 2006, B Lab has certified for over 800 companies (certified benefit corporations, or B Corps) in 29 countries representing 60 industries. B Lab's initiative features a wide variety of companies, from small local businesses to large corporations such as Patagonia and Method cleaning products. At B Lab's website (www.bcorporation.net), any consumer can search for a company and find a detailed report of the company's sustainability performance from a multi-dimensional perspective.

To become a certified B Corp, each company must complete a B Impact Assessment and attain at least 80 total points to be considered certified. These scores will then be verified by B Lab via phone interview and randomly selected on-site visits. The B Impact Assessment categorizes sustainability-related performance in four broadly defined impact areas: governance (corporate accountability and transparency), workers (e.g., job creation, compensation, workplace culture, and healthcare and safety issues), community (e.g., service, charitable giving, diversity, and involvement in social issues), and environment (e.g., facilities and supply chain management, resource conservation, waste reduction, and provision/use of renewable energy). Because B Lab's project initiative focuses on a multi-dimensional categorization of sustainability performance, it is particularly relevant to our research questions.

For each of the 833 companies, we compiled information regarding its scores on governance impact, workers impact, community impact, environment impact, and the total. Additionally, we gathered information about each company's headquarters location, website, year of certification, and a description of the company's operations. We looked up the SIC code and used that to categorize each company into one of the three categories (Rathmell 1966; Zeithaml, Parasuraman, and Berry 1985, 1 = goods company, 2 = services company, 3 =

hybrid/mixed). Two independent coders reviewed the company description for each B Corp and provided a rating of the company type. For example, if the company description included the word “product” or “manufacturing”, it was categorized as a goods company. If additional information was required to make a judgment, the coders were directed to review the company’s website. Inter-rater reliability for the firm type variable was 0.83. Due to unequal cell sizes between goods companies and services companies (209 versus 573 in the original dataset), we randomly selected 209 services companies to attain equivalent cells. We also removed any companies that were coded as hybrid or mixed. A total of 418 companies were used for analysis.

An independent samples t-test comparing the ratings between company type indicated that goods companies were more likely to earn environment impact area points than services companies ($M_{Goods} = 29.17$ vs. $M_{Services} = 14.66$; $t(416) = 10.87$, $p < .001$, see Figure 1). By contrast, services companies were more likely to earn community impact area points ($M_{Goods} = 36.01$ vs. $M_{Services} = 47.06$; $t(416) = -5.40$, $p < .001$) as well as workers impact area points ($M_{Goods} = 18.69$ vs. $M_{Services} = 22.45$; $t(669) = -3.12$, $p < .01$). The total score did not differ based on company type ($M_{Goods} = 99.43$ vs. $M_{Services} = 102.95$; $t(416) = -1.85$, $p > .05$).

Insert Figure 1 about here

These results suggest that goods companies are more likely to focus their sustainability efforts on environmental sustainability practices, while services companies are more likely to concentrate on social sustainability practices (community impact and workers impact). Since a company’s focus on certain sustainable practices is likely to be driven by consumers’ perceived importance of such practices, we expect that consumers’ perceptions of a company’s sustainability practices will follow the same pattern. Specifically, consumers will consider environmental sustainability practices to be more impactful for goods companies and social

sustainability practices as more impactful for services companies. Accordingly, we hypothesize:

H1: Consumers perceive social sustainability practices to be relatively more impactful for services companies while environmental sustainability practices are perceived to be more impactful for goods companies.

One key difference between a goods company and a services company resides in the tangibility of the product it offers and the process through which it offers the product (Bebko 2000; Zeithaml et al. 1985). Accordingly, we propose that the difference in consumers' perceived importance of environmental versus social sustainable practices maybe driven by the degree of tangibility of a company. In the following section, we introduce the concept of tangibility and develop hypotheses regarding how tangibility influences consumers' perceived importance of environmental versus social sustainable practices.

Tangibility and Sustainable Practices

Tangibility is defined as the actual physical existence of an object that can be detected by the senses (Zeithaml et al. 1985). While tangibility is one of many characteristics that differ between products and services (i.e., inseparability, perishability, heterogeneity), it is the key attribute and directly observable characteristic that separates a service company from a good company (Bateson 1979; Zeithaml et al. 1985). Tangibility among goods and services can differ across a continuum, with purely tangible goods (e.g., bread, pen) on one side and pure intangible services (e.g., investment banking, consulting services) on the other side. In marketing, tangibility of a company can be defined on two different dimensions: the product it offers and the process it engages in (Bebko 2000).

The product offering can vary based on the degree of physical elements present during

the consumption process. Service offerings are inherently more intangible and abstract (Stafford 1996), while the products offered by goods companies are characterized by greater tangibility (Shostack 1977). While service offerings are clearly less tangible than product offerings, the degree of tangibility may differ even within a product offering. For example, physical products (e.g., CD) are more tangible than virtual products (e.g., MP3; Koiso-Kanttila 2004, Rowley 2008), despite the fact that core offering is the same.

The tangibility of the company's process in producing the offering is another key tangibility aspect, which involves the amount of physical evidence and tangible commodities that are created through the development of a product or service (Bebko 2000). Process tangibility is defined by the existence of physical evidence of the process (Bebko 2000). In the services literature, "physical evidence is the environment in which the service is delivered...and [involves] any tangible commodities that facilitate performance or communication of the service" (Zeithaml and Bitner 1996, p. 518). Given this definition, we can easily see how goods companies can also be characterized by the degree of physical evidence or tangible commodities that are produced through the delivery of the product offering. Therefore, companies that minimize tangible elements during the production process and produce the offering via more virtual means are representative of an intangible process, while companies that generate a great deal of physical evidence in the production of the offering illustrate a tangible process.

Goods products, or the process of producing goods products, involve a greater degree of tangibility and physical elements. The product itself or the process of making the product may involve extracting physical substances (e.g., coal, and petroleum) from the lithosphere, and/or introducing man-made substances (e.g., pesticides and other chemicals) to the biosphere. These substances are concrete, observable, and measurable, and come from the natural environment (Malthus 1798). Therefore, an individual will be more likely to perceive a closer connection between the company and the environment if the company's offering is mainly

goods, if the format of the offering is physical, or if this company adopts a process that involves highly concrete physical elements. We propose that the association between the environment and companies that offer a tangible product or engage in tangible processes will hold true when it comes to sustainability practices. Consumers will be likely to associate environmentally-related sustainable practices with companies that produce tangible products and/or engage in tangible processes to generate the offering. Along the same logic, environmental sustainability practices should be perceived to be more impactful than social practices relatively for these types of companies.

By contrast, perceptions of services companies, companies that produce intangible offerings (e.g., digital products, legal services, etc.), and companies with a more virtual process to construct the offering (e.g., software development, website design) are based less on concrete, natural, or physical substances. For these types of companies, sensory information and concrete, physical elements are less observable to consumers. The lack of observable tangible elements makes the intangible social aspects such as a company's values, customer orientation, and interpersonal communication more salient to consumers (Parasuraman, Zeithaml, and Berry 1988). As such, we propose that when it comes to sustainability practices in intangible cases, consumers are more likely to think in the domain of social benefits and that they will expect those sustainability practices to be more impactful than environmental-related practices. Formally stated:

H2: Socially sustainable practices are perceived as more impactful for companies that produce low tangibility products while environmentally sustainable practices are perceived as more impactful for companies that produce high tangibility products.

H3: Socially sustainable practices are perceived as more impactful for companies that adopt virtual production processes while environmentally sustainable practices are perceived as more impactful for companies that adopt concrete production processes.

Compensation versus Awareness

So far, we have established the role of tangibility in forming consumers' perceptions of a company's sustainability practices. A follow-up question to the proposed connection between high-tangibility companies and environment is, is it the increased awareness of the environment or an obligation to compensate that underlies the higher perceived impact of environmentally sustainable practices? Based on the compensation mechanism, the more tangible a company's offering/process is, the more physical and concrete elements are taken from the environment and unwanted ones are introduced back to the environment. According to The Natural Step (TNS) Framework, the essential conditions of sustainability involves causing no systematic increases in environmental concentration of substances from the Earth's crust, environmental concentration of synthetic substances, or ecosystem degradation (Robèrt 2000). The more tangible a company's offering/process is, the more likely the company is related to one or more of the above-mentioned environmental impacts. As a result, there is an expectation to give back or compensate due to these impacts.

The alternative awareness explanation could argue that in high tangibility cases, the presence of physical elements simply makes people become more aware of the environment, and as a result, the relative importance of environmental sustainability practices increases. In the literature on corporate sustainability, people's awareness of a sustainable issue has been found to significantly influence the importance people put on that specific issue (McWilliams and Siegel 2001; Sen, Bhattacharya, and Korschun 2006). The presence of concrete physical

elements serves as a reminder of the association a tangible company has with the environment. Accordingly, consumers' awareness of environmentally sustainable practices becomes more salient for tangible companies. The next set of hypotheses formally state these two competing explanations:

H4a: The relatively high impact of environmental practices in high tangibility cases is due to an expectation to compensate for impacts to the environment.

H4b: The relatively high impact of environmental practices in high tangibility cases is due to an increased awareness of the environment.

A field experiment and three lab experiments were designed to test these hypotheses. In Study 1, we created a fictitious company and described it to be either a goods or a services company. We then provided various sustainability practices in both the environmental and social domains and showed that consumers' perceptions of the relative impact of these practices differ depending on company type (H1). Study 2a was conducted in a field setting where we asked consumers their opinion of a company's sustainability advertising campaign and requested that participants choose between an environmental-focused and a social-focused campaign. The company's product offering was manipulated to be either physical or virtual. Using the same company and product offerings but in a controlled setting, Study 2b asked participants to rate the impact of some strong and weak practices in both the environmental and social domains and investigated whether the format of the product offering affects their perceptions of each type of sustainable practice (H2). Study 3 further broadens the context and studies the tangibility of the company's process to develop the offering (H3). In addition, we introduced a case of a highly tangible process yet with environmentally-beneficial physical elements to test the compensation versus awareness account (H4a and H4b).

Study 1

In this study, participants read a description of a company that was manipulated to be either more goods-centered or services-centered, then rated how impactful they felt different types of sustainability practices would be if the firm were to engage in them. This study adopts a 2 Company Type (Goods vs. Services) x 2 Sustainability Practice (Environmental vs. Social) repeated measures design. We expect consumers to perceive environmental sustainability practices to be relatively more impactful when the company type is goods and social sustainability practices to be relatively more impactful when the company type is services.

Research Design

Procedure and Participants. The study was administered in the behavioral lab at a large northwestern university. A total of 192 participants completed the survey in exchange for a course credit. A one-page description of the company was presented to participants, followed by a survey that included statements that described sustainability practices. The first page provided participants with a general description of a fictional company, MATRIX.

The manipulation of company type was executed on the first page of the stimuli. In the goods company type condition, participants were told that MATRIX is a manufacturer of information technology products such as laptops, desktops, and printers, which comprises 85% of MATRIX's total revenues. The other 15% of the revenue comes from their IT consulting services. In the services company type condition, participants were told that MATRIX provides information technology consulting services, which comprises 85% of MATRIX's total revenues, and the IT products such as software only comprises 15% of MATRIX's total revenues.

On the next page, participants were presented four sustainability practices: two environmental ("Purchase carbon credits to offset emissions generated from facilitates" and "Install double-paned windows on facilities to reduce energy consumption") and two social

“Provide free weekly computer training courses to children and low-income families, and offer free tax preparation software” and “Invest in small businesses in many developing countries in order to create job opportunities and support the economy”). These practices were pretested ($N = 48$) to be equivalent on strength (weak/strong sustainability practice), amount of effort required, and perceived impact. We created a single strength index combining the strength, effort, and impact measures ($\alpha = .94$) and compared the mean for each statement to the grand mean for all statements ($M = 5.03$). The means for the environment statements ($M_{Environment-Carbon} = 5.06$, $t(48) = .19$, $p > .5$; $M_{Environment-Windows} = 5.21$; $t(47) = 1.18$, $p > .2$) nor the social statements ($M_{Social-Training} = 4.74$, $t(48) = -1.32$, $p > .1$; $M_{Social-Invest} = 5.28$, $t(48) = 1.58$, $p > .1$) differed from the grand mean for all statements, confirming their equally moderate strength.

After reading the company description, participants rated the impact of each sustainability practice (i.e., “What do you think would be the impact of the following sustainability practices if MATRIX, a goods/services company, were to engage in them?” 1 = Low Impact, 7 = High Impact). We also asked participants to rate the degree to which MATRIX was a goods company or a services company (i.e., “MATRIX is a company that primarily...” 1 = Manufactures Products, 7 = Offers Services), which served as a manipulation check.

Results

Manipulation Check. An independent samples t-test confirmed our company type manipulation ($M_{Goods} = 2.31$ vs. $M_{Services} = 5.57$, $t(190) = -17.86$, $p < .001$).

Perception of Impact of Sustainability Practices. For our analysis, we collapsed the two environment statements and two social statements after finding no significant differences between each set of statements (i.e., repeated measures analysis between the two environmental and the two social sustainability practice statements, $ps > .7$). A 2 Company Type (Goods vs. Services) x 2 Sustainability Practice (Environmental vs. Social) repeated measures ANOVA on impact revealed a significant interaction ($F(1,190) = 12.10$, $p < .01$). When MATRIX was described as a goods company, consumers were more likely to report that environmental

sustainability practices would be more impactful ($M_{Environment} = 4.87$ vs. $M_{Social} = 4.34$, $t(95) = 3.06$, $p < .01$, see Figure 2). By contrast, when MATRIX was described as a service provider, consumers reported that social sustainability practices would be more impactful ($M_{Environment} = 4.20$ vs. $M_{Social} = 4.48$, $t(95) = -1.79$, $p < .08$).

Insert Figure 2 about here

Discussion

Study 1's results mirror the pattern we found in the B Lab data, such that consumers put greater importance on environmental practices for goods companies than for service companies, and consider social practices to be more impactful for service companies than for goods companies. These results suggest the dominant role of environmental sustainability practices for goods companies and social sustainability practices for services companies in positive consumer perceptions, supporting H1.

As discussed earlier, a key distinction between goods and services companies is tangibility, or the degree to which the company's offering or process involve physical elements. In Study 2, we focus on the tangibility of the company's offering. While the tangibility of the offering will contribute to defining the company type (e.g., a car manufacturer is a goods company based on its tangible automobile offering created from physical elements; an insurance company is a services firm because its offering lacks concrete, physical elements but rather includes more interpersonal and abstract features), two companies of the same type may provide an offering which differs in terms of its tangibility. For example, Blockbuster (brick-and-mortar stores) and iTunes—both film rental service providers—offer the same end product, but the on-site selection and delivery of the film product is clearly more tangible in the Blockbuster example than the online experience of iTunes. Therefore, we extend beyond company type and explore offering tangibility as a key factor that influences consumers' perceptions of corporate

sustainability practices.

Study 2a

Study 2a explores whether the tangibility of the company's product offering can reveal the relative importance of environmental versus social sustainability practices. In a field setting, we create a realistic situation in which consumers recommend an advertisement for a company's upcoming campaign. We expect that consumers who are shown a description of a physical product offering (tangible product) will be more likely to recommend an advertisement featuring the company's environmental sustainability practices, while consumers who are exposed to a virtual version of the product offering (intangible product) will be more likely to recommend an advertisement featuring the company's social sustainability practices.

Research Design

Procedure and Participants. Study 2a was conducted in two locations on the campus of a large northwestern university. At each location, we had confederates posing as employees of a fictional company called ViewMAX, a movie content provider. The confederates sat at a table that included a sign about ViewMAX's offering, a sign detailing an incentive for participation, and a laptop computer. As people walked by the table, the confederate encouraged him or her to learn about ViewMAX's offering on the poster and take a short survey about ViewMAX's upcoming advertising campaign. A total of 94 U.S. adults participated in this study (age range = 16–75, $M_{Age} = 27.68$, 64.9% male).

The manipulation of product offering was executed on the poster presented at the table. In the tangible/physical offering condition, the poster described ViewMAX as a company that offers DVD and Blu-ray rentals to its customers via mail. In the intangible/virtual condition, the poster described ViewMAX as a company that offers online downloads of movie and television programs via computer or other Internet-enabled device. Images representing the physical or

virtual nature of each offering were included on each poster to strengthen the manipulation. See the Appendix for actual stimuli. The confederates alternated the poster between the tangible version and the intangible version every two hours.

After learning about ViewMAX's product offering, participants were presented two advertisements, one environmental-focused and one-social focused. The environmental-focused ad detailed ViewMAX's commitment to the environment, including installing solar panels on its facilities and creating a recycling program for electronics. The social-focused ad, on the contrary, detailed ViewMAX's commitment to society, including providing discounts to local income customers and investing in small businesses in developing countries. Each advertisement also featured a photo to strengthen the manipulation. A pretest showed no difference on attitudes toward the two ads ("Good-Bad", "Like-Dislike", $\alpha = .95$, $M_{Environment} = 2.40$ vs. $M_{Social} = 2.27$, $t(36) = -.32$, $p > .7$). The advertisements used are included in the Appendix. We randomized the presentation of the two ads so that the left or right position did not influence our results.

In the survey, participants were asked to recommend their preferred advertisement (i.e., "ViewMAX is looking for advice from people like YOU for their new advertising campaign. Please look closely at each advertisement. Which advertisement do you recommend for ViewMAX's campaign?", 1 = Strongly Recommend Ad on the Left, 6 = Strongly Recommend Ad on the Right). Following the advertisement recommendation question, we asked participants to rate the degree to which ViewMAX's product offering was more virtual or physical, as a manipulation check.

Results

Manipulation Check. An independent samples t-test revealed that participants who saw the poster of ViewMAX described as offering a DVD by mail service reported the offering to be more physical than participants who saw the poster of ViewMAX described as offering online streaming ($M_{Physical} = 4.95$ vs. $M_{Virtual} = 2.76$, $t(92) = 5.78$, $p < .001$).

Advertisement Recommendation. While we randomized the presentation of the ads, the following results are reported based on the social-focused ad being placed on the left-hand side of the participants' screen and the environment-focused ad being placed on the right-hand side of the participants' screen, such that a number closer to one (1) represents a preference for the social-focused ad and a number closer to six (6) represents a preference for the environment-focused ad. When ViewMAX was described as providing a physical product offering, participants were more likely to recommend the environmental-focused ad. When ViewMAX provided a virtual product offering, the social-focused ad was more highly recommended ($M_{Physical} = 3.62$ vs. $M_{Virtual} = 2.86$, $t(92) = 2.04$, $p < .05$).

Insert Figure 3 about here

Discussion

The results of Study 2a suggest that consumers have a more positive perception of a company that advertises its environmental sustainability efforts if it offers a physical or tangible product. By contrast, we find that consumers prefer that a company that produces a virtual or intangible offering advertise its social sustainability efforts, thus supporting H2. This study provides support for our proposition that it is not only company type that drives consumers' perceptions of sustainability initiatives, but also the underlying degree of tangibility of the company's offering that affects the differential importance of environmental versus social sustainability practices. Study 2b provides additional support for the effect of offering tangibility in a controlled environmental setting.

Study 2b

Study 2b further investigates the effect of offering tangibility with a different research design. In this study, we manipulated the strength of environmental and social sustainability practices to be strong or weak, and examined how influential these two types of actions are on consumers' sustainability perceptions and attitudes towards the company depending on its product offering type. This study adopts a 2 Offering Tangibility (Physical vs. Digital) x 2 Environmental Sustainability Practice (Strong vs. Weak) x 2 Social Sustainability Practice (Strong vs. Weak) between-subjects design. We expect that the strength of environmental practices is more influential on consumers who are shown a physical version of the product offering, while consumers who are exposed to a virtual version of the product will be affected more by the strength of the social sustainability practices.

Research Design

Procedure and Participants. The study was administered in the behavioral lab at a large northwestern university. A total of 138 participants completed the survey in exchange for course credit. The first page of the stimuli provided participants with a general description of ViewMAX, a company that provides a library of over 2 million movies and television programs via a monthly subscription program. On the second page, participants were presented with a list of four sustainability practices that ViewMAX incorporates into their business.

The manipulation of product offering was executed as part of the first page description of ViewMAX, mirroring the manipulation in Study 2a. In the tangible/physical offering condition, participants were told ViewMAX offers DVD and Blu-ray rentals to its customers via mail. In the intangible/virtual condition, participants were told that ViewMAX offers online downloads of the movie and television programs via computer or other Internet-enabled device. Images representing the physical or virtual nature of each offering were included to strengthen the manipulation.

The manipulation of sustainability practice strength was executed on the second page. In each condition, two statements focused on environmental sustainability (either two strong, e.g., “Created a free take-back recycling program for all types of used electronic products” or two weak, e.g., “Installed double-paned windows on 1 out of 5 facilities”) and two statements focused on social sustainability (two strong, e.g., “Invests in small and mediums businesses in many developing countries in order to create jobs and stimulate the economy in those communities at their request” or two weak, e.g., “Provides discounted pricing to some low-income customers, usually ranging from 3-5% off, and limited to 6 customers per year”).

Pretest. We pretested the statements ($N= 29$) to ensure that the strength of the statements differed on the strong-weak dimension, but was comparable on the environment-social dimension. Paired samples t-tests revealed that the strong statements were significantly different from the weak statements when averaged ($ps < .01$; $M_{StrongEnvironment} = 5.92$; $M_{StrongSocial} = 5.47$; $M_{WeakEnvironment} = 3.44$; $M_{WeakSocial} = 2.94$), and we found no differences between the environment and social statements at each strength level ($ps > .05$).

Measures. After reading about ViewMAX and its sustainability practices, participants were asked to rate their attitude toward ViewMAX (4 items, $\alpha = .97$, 1 = Not Positive, 7 = Very Positive) and their perceptions of ViewMAX’s dedication to sustainability initiatives (3 items, e.g., “MATRIX is dedicated to incorporating sustainable practices into their business to benefit the environment and society”, $\alpha = .94$, 1 = Strongly Disagree, 7 = Strongly Agree). We also asked participants to rate the degree to which ViewMAX’s product offering was more tangible or intangible, concrete or abstract, and physical or virtual (i.e., 1 = Tangible, 7 = Intangible) as a manipulation check. These three items were combined to create a tangibility index ($\alpha = .67$).

Results

Manipulation Check. A 2 x 2 x 2 ANOVA revealed only a main effect of offering tangibility ($F(1,130) = 39.40$, $p < .001$). Participants in the tangible/physical offering condition reported that ViewMAX’s offering was more tangible, less abstract, and more physical than participants in the

intangible/virtual condition ($M_{Tangible} = 5.69$ vs. $M_{Intangible} = 4.44$).

Tangible Product. When ViewMAX's offering was presented as a physical product, analysis only revealed a significant main effect of environmental sustainability practices on consumer attitudes ($M_{Strong} = 5.70$ vs. $M_{Weak} = 5.06$; $F(1,62) = 5.06$, $p < .05$), as well as consumers' perceptions of the company's sustainability efforts ($M_{Strong} = 5.92$ vs. $M_{Weak} = 5.16$; $F(1,62) = 6.06$, $p < .05$, see Figure 4). Strong versus weak social sustainability practices did not make a difference on attitudes or positive perceptions of a company's dedication to sustainability.

Intangible Product. When ViewMAX's product offering was manipulated to be virtual, there was a main effect of social practices on attitude ($M_{Strong} = 5.71$ vs. $M_{Weak} = 4.78$; $F(1,68) = 8.20$, $p < .05$) as well as environmental practices ($M_{Strong} = 5.71$ vs. $M_{Weak} = 4.80$; $F(1,68) = 8.02$, $p < .05$). However, there was a marginally significant interaction on sustainability perceptions ($F(1,68) = 3.58$, $p < .07$, see Figure 4). When ViewMAX engaged in strong social sustainability practices and delivered an intangible product, environmental sustainability practices at either strength did not influence sustainability perceptions ($M_{StrongSStrongE} = 5.89$ vs. $M_{StrongSWeakE} = 5.54$, $F(1,68) = 1.01$, $p > .05$). However, when ViewMAX's social sustainability practices were weak, strong environmental sustainability practices had a greater influence on consumer sustainability perceptions ($M_{WeakSStrongE} = 5.90$ vs. $M_{WeakSWeakE} = 4.61$, $F(1,68) = 13.55$, $p < .001$). Additionally, we found a marginally significant main effect of social practices ($M_{Strong} = 5.71$ vs. $M_{Weak} = 5.22$; $F(1,68) = 3.39$, $p < .08$) and a main effect of environmental practices on consumers' perceptions of the company's dedication to sustainability ($M_{Strong} = 5.90$ vs. $M_{Weak} = 5.06$; $F(1,68) = 11.00$, $p < .01$).

Insert Figure 4 about here

Discussion

The results of Study 2b provide additional support for our contention that environmental sustainability practices are more impactful for companies with tangible product offerings. Relatively, when the product offering was intangible, consumers were more likely to perceive that the company was dedicated to sustainability initiatives when strong social sustainability practices were emphasized.

However, the results in this study did show that environmental and social sustainability practices were both influential when ViewMAX offers an intangible product. This finding could be due to a perception of higher tangibility in general. Relative to a DVD, online streaming is virtual, but consumers may still picture the infrastructure, data centers, and warehouses required to deliver the movie offering in the virtual case. Indeed, tangibility is a multi-dimensional concept that includes both the offering itself, as well as the process of delivering the offering (Bebko 2000). As such, in Study 3, we explore a case in which the company type and offering are the same, but the process that the company engages in to create and deliver new offerings is more (or less tangible).

Study 3

Study 3 further extends the concept of tangibility to explore the company's process to develop the offering, and examines whether the tangibility of the process affects consumers' preferences for environmental or social sustainability practices in a consistent way. An additional purpose of Study 3 is to test the awareness versus compensation accounts that explain the relationship between high tangibility and environmental sustainability practices. To that end, we introduce a condition in which the process is tangible, but has explicit environmental benefits. Compared to the default tangible condition, the tangible with environmental benefit condition makes environmental information more salient, increases consumers' awareness of the environment, but alleviates potential negative associations between tangibility and the environment. According to the awareness explanation,

environmental sustainability practices should be preferred compared to the default tangible condition. On the other hand, the compensation account predicts the opposite, such that social sustainability practices would be preferred because the company has engaged sufficiently in environmental practices to compensate for environmental damage.

Research Design

Procedure and Participants. A scenario was created as the stimulus for Study 3 in which participants read a description of a company and the process it engages in to produce new offerings, and were asked to rate the relative impact of environmental and social sustainability practices. This study adopts a 3 Process (Tangible vs. Intangible vs. Tangible with Environmental Benefit) x 2 Sustainability Practice (Environmental vs. Social) repeated measures design.

The study was administered via an online survey and participants were recruited via Amazon's Mechanical Turk, which has been validated as a reliable source of experimental data (Paolacci, Chandler, and Ipeirotis 2010). A total of 119 U.S. adults (age range = 18–63, $M_{Age} = 30.87$, 52.9% male) completed the survey in exchange for a small payment. A two-page description of the company and the process to develop the offering were presented to participants, followed by a survey that rated both environmental and social sustainability practices. The first page provided participants with a general description of a fictional company called AccuSoft. AccuSoft was described as a company that developed an online software program that allows businesses to send custom-designed emails to their customers to announce special sales, send coupons for free items, etc. The second page provided a detailed description of AccuSoft's process of generating new offerings for their consumers.

The manipulation of process tangibility was executed on the second page. In the tangible process condition, participants were told that when AccuSoft generates new product features, employees brainstorm on-site by gathering around a large mahogany table with bright lights, air conditioning, large reams of paper, and a cork bulletin board. In the intangible process

condition, participants were told that AccuSoft's employees work from their home offices and submit ideas via a virtual meeting software program using electronic files and online chat boards to communicate. In the tangible process with environmental benefit condition, environmental benefits were emphasized including the recycled nature of the conference table, ream of paper, and bulletin board material, in addition to energy-efficient lights and solar panels powering air conditioning. We also included images for each process tangibility condition to reinforce the manipulation. See the Appendix for images.

Pretest. New sustainability practice statements were introduced in Study 3 to increase generalizability. Similar to our procedure in Study 1, we pretested the statements ($N = 33$) to ensure that they were of equally moderate strength by measuring the overall strength of the practice (i.e., 1 = Weak Sustainability Practice, 7 = Strong Sustainability Practice), the effort the company would put into maintaining the practice (i.e., 1 = Low Effort, 7 = High Effort), and the impact the practice has on social and/or the environment (i.e., 1 = Low Impact, 7 = High Impact). Paired samples t-tests revealed no differences between the environment and social statements (range of statement means = 4.74–5.01; all p 's > .2). See Table 1 for a list of statements and their means.

A pretest of the process tangibility manipulations also confirmed that the tangible with environmental benefit description increased environmental awareness (one-way ANOVA: $F(2,70) = 55.19, p < .001$; $M_{Tangible\ with\ Benefit} = 5.76, M_{Tangible} = 2.63, M_{Intangible} = 2.23$) and depicted a positive relationship to the environment.

After reading about AccuSoft and its process, participants were asked to rate three environmental sustainability statements ($\alpha = .79$) and three social sustainability statements ($\alpha = .73$) on how impactful it would be if AccuSoft were to engage in them. Participants were also asked to rate AccuSoft's process on four dimensions of tangibility: tangible, concrete, physical, and amount of physical evidence, which served as a manipulation check. The four items were combined to form the process tangibility index ($\alpha = .82$).

Results

Manipulation Check. A one-way ANOVA on the process tangibility index revealed a significant difference ($F(2,116) = 41.86, p < .001$). Participants who read about the two tangible processes rated AccuSoft's process to be more tangible than participants who read about the intangible process ($M_{Tangible} = 5.36$ vs. $M_{Intangible} = 3.45$ vs. $M_{TangiblewithBenefit} = 5.36; p < .001$). Additionally, the tangible and tangible with environmental benefit conditions did not differ on the process tangibility index ($F < 1$).

Sustainability Practices. A 3 Process Tangibility x 2 Sustainability Practice repeated measures ANOVA revealed a significant interaction ($F(2,116) = 3.85, p < .05$). When the process was intangible and involved minimal physical elements, subjects were more likely to rate social sustainability practice statements as more impactful than environmental sustainability practice statements ($M_{Environment} = 4.28$ vs. $M_{Social} = 4.63; F(1,116) = 4.85, p < .05$). This pattern is consistent with our previous studies, which find that when the company is a services company and the company's offering is intangible, consumers perceive social sustainability practices as more impactful. This result extends our findings to show that an intangible process of developing the offering additionally influences consumers' relative preference for social practices over environmental practices.

Furthermore, we found differences between the two tangible conditions. When the process described was tangible with an environmental benefit, environmental sustainability practices were found to be more impactful than social sustainability practices, despite extensive activities in that area ($M_{Environment} = 5.20$ vs. $M_{Social} = 4.92; F(1,116) = 2.95, p < .09$). In the default tangible condition, environmental sustainability practices and social sustainability practices were found to be equally impactful ($M_{Environment} = 4.64$ vs. $M_{Social} = 4.70; F(1,116) = .13, p > .5$).

Insert Figure 5 about here

Discussion

This study demonstrates further support for the relative impact of environmental sustainability practices under tangible conditions and social sustainability practices under intangible conditions by extending beyond company type and offering type to the company's process to develop the offering. In addition, Study 3 delineated the underlying reason for our results by testing two competing hypotheses. If this compensation hypothesis were confirmed, we would expect that participants would rate environmental practices as less impactful in the tangible with benefit condition, because it would indicate that the company is compensating for damage by incorporating beneficial environmental sustainability practices. Accordingly, social practices would become relatively more impactful. If the awareness hypothesis were confirmed, we would expect that participants would rate environmental practices as more impactful in the tangible conditions, particularly the tangible with environmental benefit condition, where awareness of the environment is stronger. Our findings suggest that it is increased awareness of the environment, rather than compensation for environmentally damaging behaviors, that drives the impact of environmental sustainability practices when tangibility elements are more salient.

General Discussion

Across four studies, we find that company type and tangibility of the company's product offering and process to develop the offering influence consumers' perceptions of corporate sustainability initiatives. We show that environmental sustainability practices have a relatively greater impact and produce more positive consumer evaluations when they are aligned with a goods company or a company that offers a tangible product. By contrast, we demonstrate that social sustainability practices are more impactful when they are associated with a services

company, a company that offers an intangible or digital product, or a company that participates in an intangible product development process. We also demonstrate, using secondary data, that not only do consumers prefer this emphasis, but companies that are highly focused on CSR initiatives (i.e., B-Corp certified) are currently engaging in this pattern in the marketplace. Furthermore, we identify increased awareness of the environment, as opposed to compensation for environmental damage, as the mechanism underlying the influence of tangibility.

The contribution of this study is threefold. While researchers have suggested that sustainability should be analyzed from an environmental and social perspective (Brown and Dacin 1997; Chabowski et al. 2011), no study to date has systematically examined the differential impact of a company's environmental and social sustainable initiatives on consumers' perceptions. Environmental and social sustainable practices represent distinct resources and capabilities possessed by a company (Chabowski et al. 2011) and therefore, trigger different consumer preferences when enacted by different companies. Our study demonstrated that environmental sustainable initiatives have more positive impact on consumers' perceptions for goods-oriented companies, whereas social initiatives have more positive impact on consumers' perception for service-oriented companies.

Second, we proposed a theoretical explanation on why consumers show different preferences of environmental and social sustainable practices for goods- vs. service-oriented companies. We argue that the degree of perceived tangibility of a company's product offerings and the production process is the driving force of consumers' differential perceptions of environmental and social sustainable practices. Our findings confirm that when the offering or the process to develop the offering is more tangible, consumers perceive environmental sustainability practices to be more impactful. On the other hand, when the offering and process are characterized by greater intangibility and more virtual, abstract elements, consumers find social sustainability practices to be more impactful. Consequently, the tangibility perspective provides a fresh and meaningful theoretical lens for studying corporate social responsibility in

general and the differential effects of environmental and social sustainable practices in particular.

Last but not least, this study offered a theoretical underpinning that explains why tangibility drives consumers' perceived importance of environmental versus social sustainable practices. We propose competing mechanisms—awareness or compensation—and show that it is the increased awareness of the environment rather than an obligation to compensation that underlies the role of tangibility.

Managerial Implications. This study provides important insights for practitioners as they formulate the suitable mix of environmental and social sustainable practices. Managers need to realize that corporate sustainability initiatives in the environmental domain and social domain involve different consumer perceptions depending on the company's product tangibility characteristics and the tangibility in the value-adding process. If a company mainly offers intangible, digital, remote or virtual offerings, or the company's value-adding process involves less concrete physical elements, such as financial services, legal services, consulting services, digital services, and software development, then the allocation of the company's sustainability investment should be aligned toward the social domain. By contrast, if a company is providing highly tangible products or the value-adding process (infrastructure, development, and delivery) involves more concrete physical elements, such as wood, pulp and paper product, heavy machinery, automobile, semi-conductor manufacturing, etc., then an investment in the environmental sustainability domain is more likely to be impactful.

This study also provides guidance to managers as they decide how to communicate their sustainability efforts to the market place. For firms that are active in a wide variety of sustainable practices, being strategic in communicating their efforts is important in influencing consumers' attitudes. Companies can take a more holistic approach in presenting their products, work environment, and their efforts to be good citizens. For example, a firm can highlight its intangible assets such as corporate value, philosophy, employees when promoting

their socially relevant campaigns. For companies that invest more in the environmental domain, they can showcase their state-of-the-art facilities, concrete products, and packaging. Our findings suggest that this integrated communication can increase consumers' perceptions of the firm being socially responsible, and lead to favorable attitudes. Given our finding that awareness of the environment rather than compensation is the driver of the environment-tangible connection, companies with tangible products need not emphasize compensation language in their sustainability messaging. Rather, they should emphasize the association between a company's tangibility-related aspects and environmental initiatives when possible, as this seems to be an inherent association in consumers' minds. Anecdotal evidence supports this assertion, using the multinational oil and gas company, Shell, as an example. When they released an advertisement in the United Kingdom featuring refinery chimneys emanating flowers along with the tagline, "Don't throw anything away. There is no away," the Advertising Standards Authority called for Shell to remove the ad at the urging of environmental lobby groups.

Limitations and Future Research. As the first study investigates the differential impact of environmental and social sustainability practices on consumers' perception, this study opens up a new venue for future sustainability research. For instance, we focus on positive sustainability efforts, i.e., benefits to the environment and society, in this study. Future research could address how consumers perceive sustainability-related crises. For example, if a goods company were to be associated with production materials that damage the rainforest, how would consumers like this company to proceed with their sustainability portfolio? Should the company continue to engage in efforts in the same realm, or would consumers prefer that the company participate in efforts that differ from the domain of damage? Our results would suggest that awareness of the environment would drive a preference for environmental sustainability practices in this case, but in the context of consumer preference of sustainability focus following a negative event, this prediction has yet to be empirically tested. Using a real example, Dow Chemical, the plastics, chemical, and agricultural product manufacturer, who has been linked to

a gas leak tragedy that killed thousands in 1984, received a great deal of negative press following its sponsorship of the 2012 Summer Olympics in London. Linkage to the gas leak disaster caused negative press for both Dow and the Olympics, so much so that the London Assembly said that Dow “caused damage to the reputation of the London 2012 Olympic and Paralympic Games” (Rallis 2012). Did Dow seek to sponsor the Olympics, a social event, to distract consumers from previous environmental issues? Future research should explore such cases and whether overcoming negative sustainability-related events indeed follows our awareness hypothesis, i.e., recover in the same realm.

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Table 1

Sustainability Statement Pretest Means and Standard Deviations

(Study 3)

Sustainability Statement	Strength	Effort	Perceived Impact
Purchase and consistently use non-toxic janitorial products to maintain cleaner water	5.45 (1.12)	4.52 (1.56)	5.06 (1.20)
Facilitate a quarterly equipment take-back program, in which members of the community can bring their used cell phones, computers, printers, and other technology devices for proper reuse and disposal	5.45 (1.00)	4.39 (1.54)	5.09 (1.28)

Provides employees with a \$25 monthly bonus if they ride public transportation or car pool	5.27 (1.53)	4.06 (1.82)	4.88 (1.58)
Put on free educational workshops for the community on topics such as energy-saving tips for electronics	4.94 (1.41)	5.30 (1.13)	4.48 (1.37)
Allow employees to volunteer in the community 5 hours per month with pay	5.12 (1.54)	4.64 (1.77)	5.21 (1.64)
Offer a \$10,000 scholarship each year to a high school graduate in the community who pursues an education in green business or sustainability	5.15 (1.50)	4.73 (1.79)	5.12 (1.80)

Figure 1

B Lab Sustainability Impact Factor Ratings by Company Type

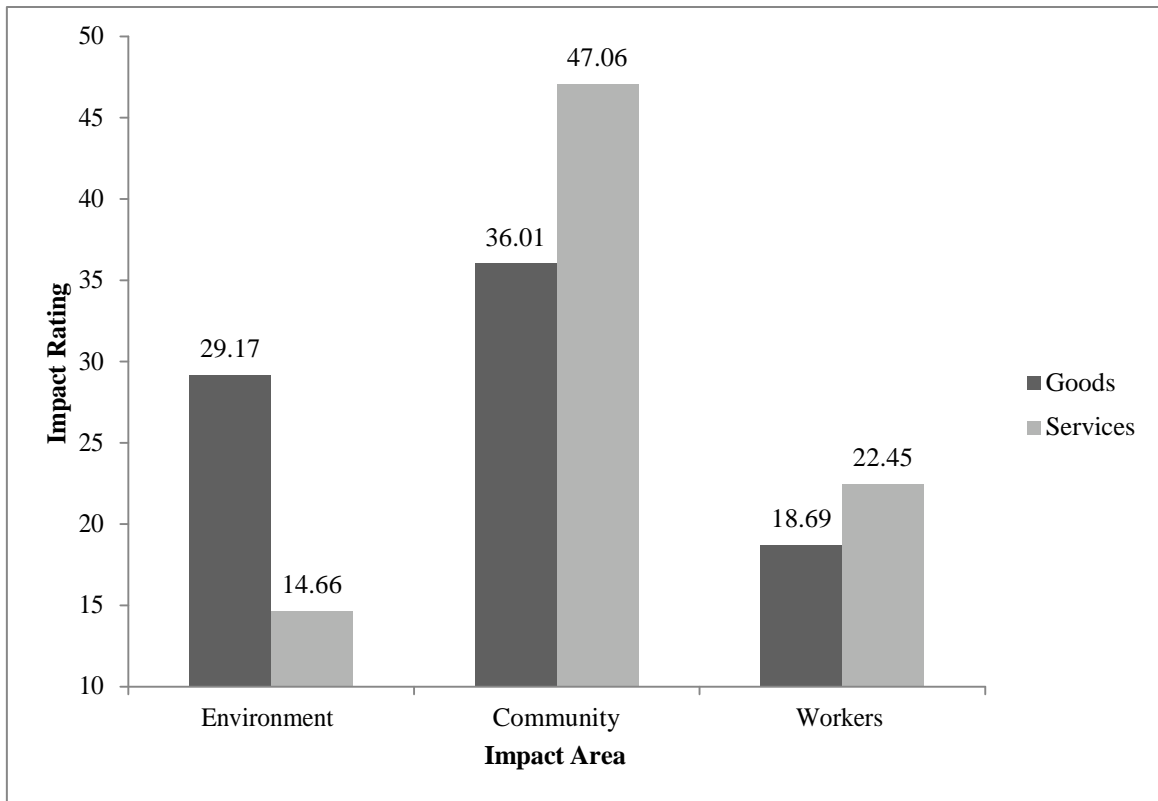


Figure 2

Perception of Impact as a Function of Company Type and Sustainability Practice Type
(Study 1)

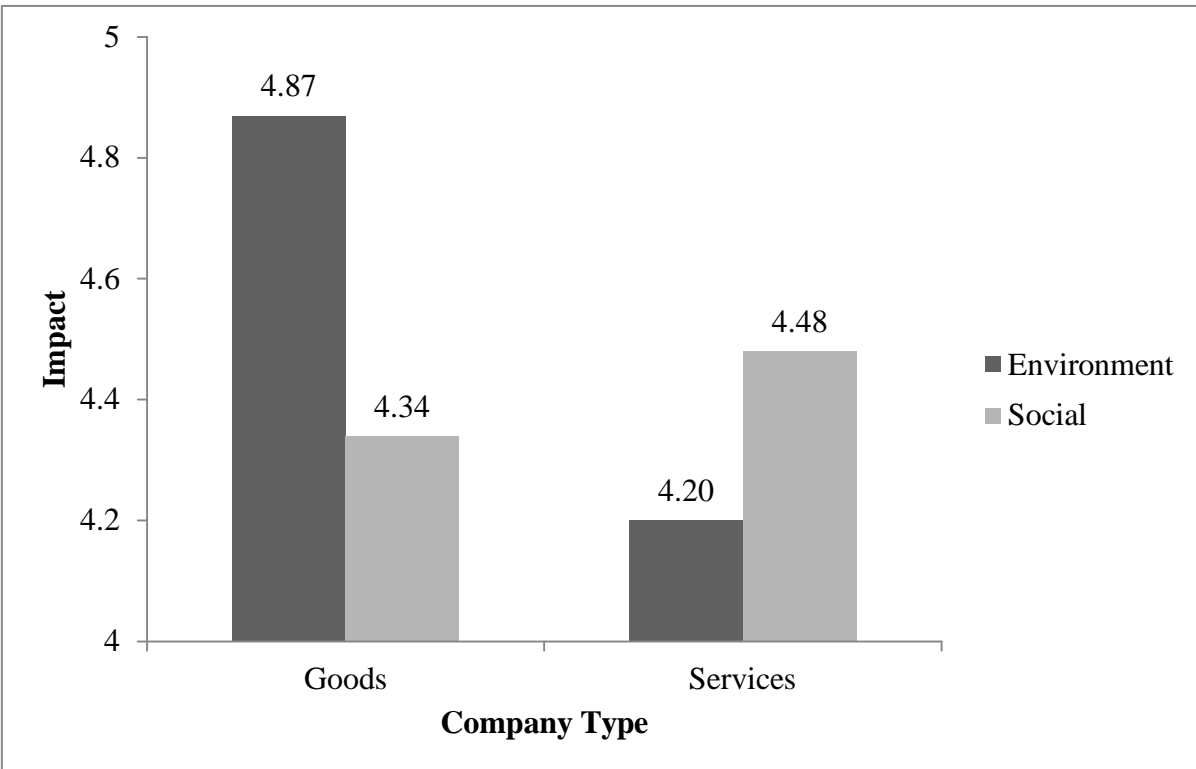


Figure 3

Sustainability Advertising Recommendation as a Function of Offering Type

(Study 2a)

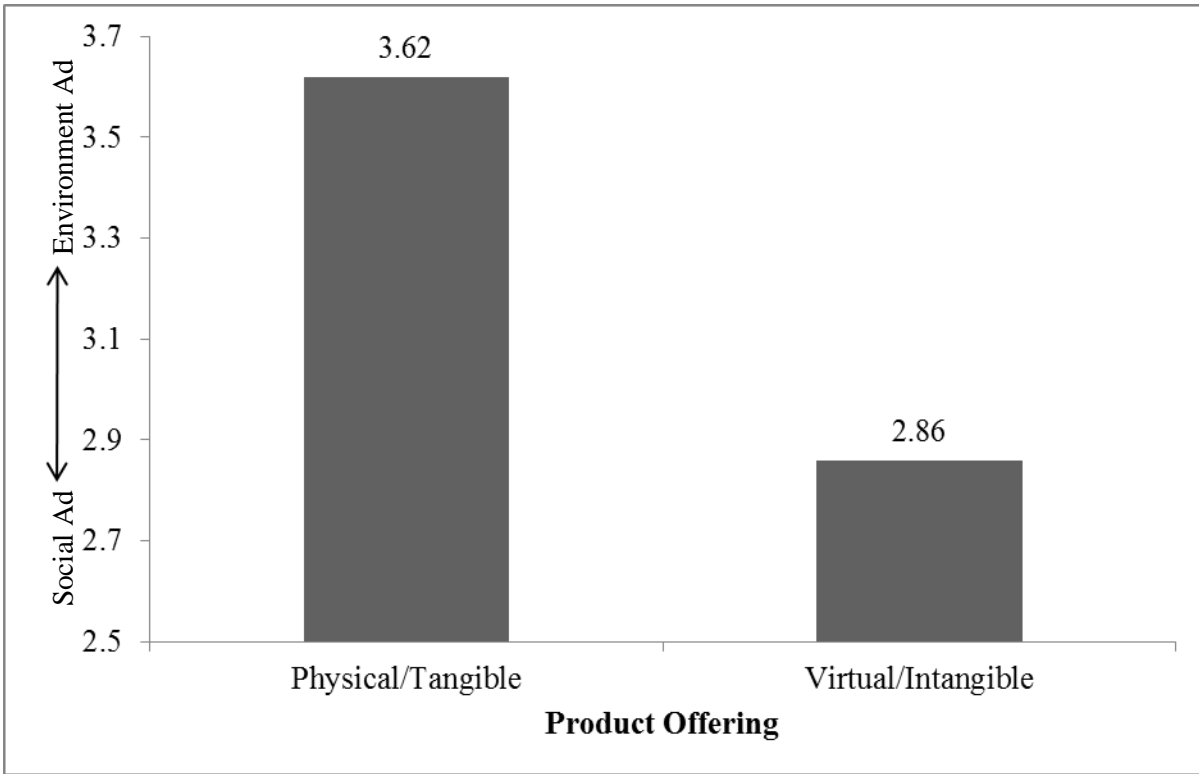
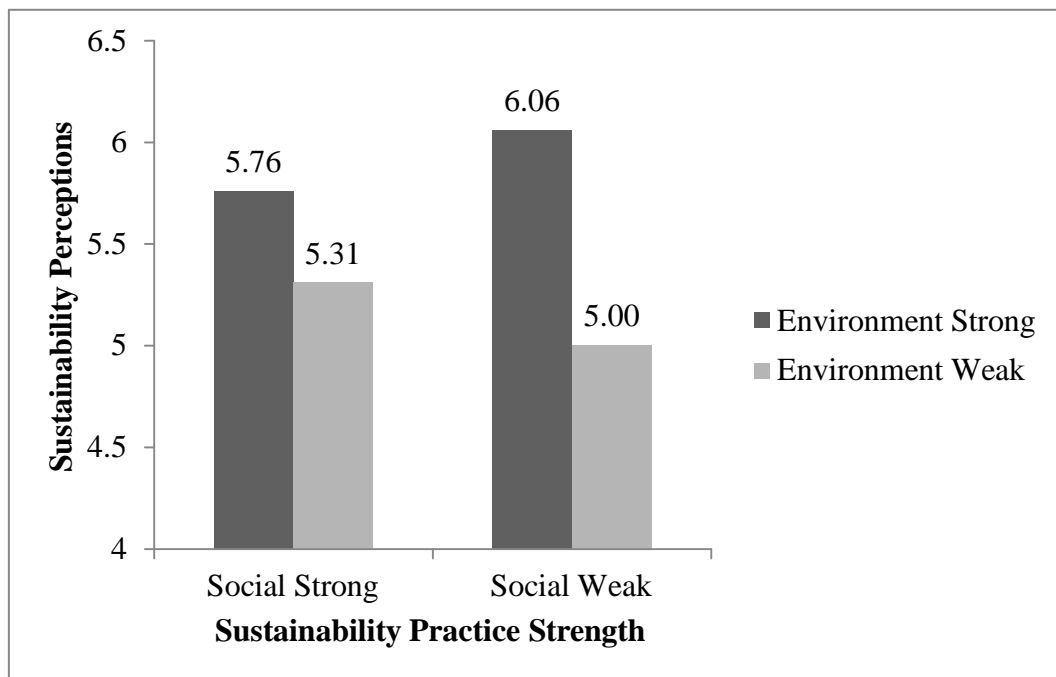


Figure 4

Sustainability Perceptions as a Function of Offering, Environmental Sustainability Practice Strength, and Social Sustainability Practice Strength

(Study 2b)

Tangible Offering



Intangible Offering

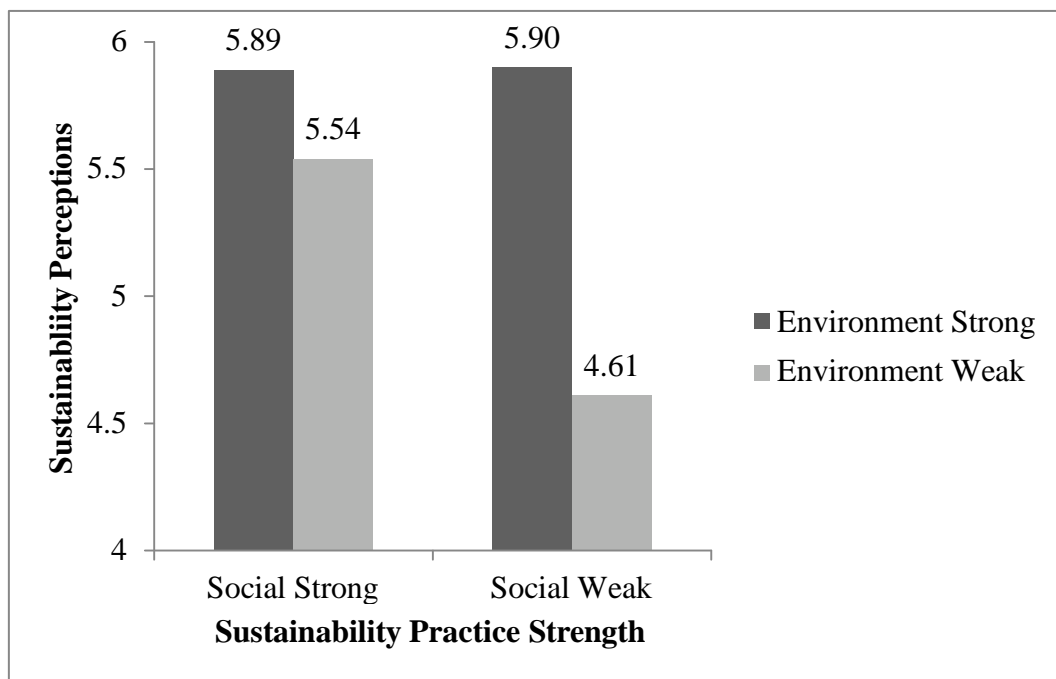
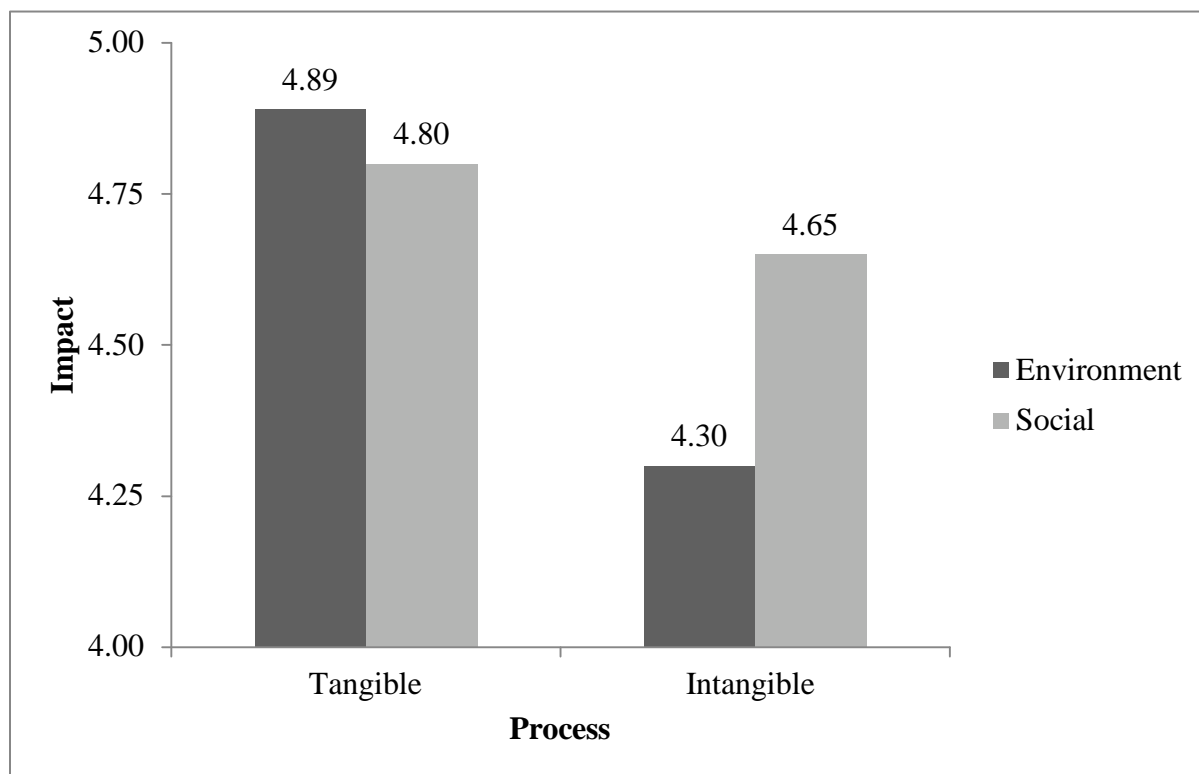


Figure 5
Perception
of Impact as

a Function of Process and Sustainability Practice Type

(Study 3)



Appendix

Study 2a Stimuli

Environment-focused Advertisement

ViewMAX is committed to serving the environment. This means that it devotes 10% of profits to maintaining the long-term viability of the environment. From installing solar panels in its facilities to creating a recycling program for electronics, ViewMAX is dedicated to making an impact on the environment.



ViewMAX
Watch.Now.

Social-focused Advertisement

ViewMAX is committed to serving society. This means that it devotes 10% of profits to helping the local community—and the community beyond. From providing discounts to low-income customers to investing in small businesses in developing countries, ViewMAX is dedicated to making an impact on the social good.



ViewMAX
Watch.Now.

Study 2a and 2b

Product Offering Manipulation

Tangible/Physical

ViewMAX needs your opinion!

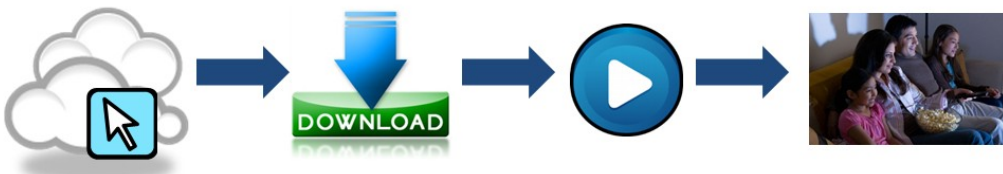
ViewMAX is a company that offers DVD and BluRay rentals to its customers via mail through a monthly subscription program. Customers select rentals using an online ordering system, and the DVDs are delivered by the US Postal Service. ViewMAX focuses on providing a high-quality viewing experience for its customers.



ViewMAX has a library of over 2 million movies and television programs for customers to choose from. ViewMAX competes well with its competitors on price, quality, and the value of its offering.

ViewMAX needs your opinion!

ViewMAX is a company that offers online downloads of movies and television programs through a monthly subscription program. Customers select rentals using an online system, and can stream videos virtually on their computer or other Internet-enabled device. ViewMAX focuses on providing a high-quality viewing experience for its customers.

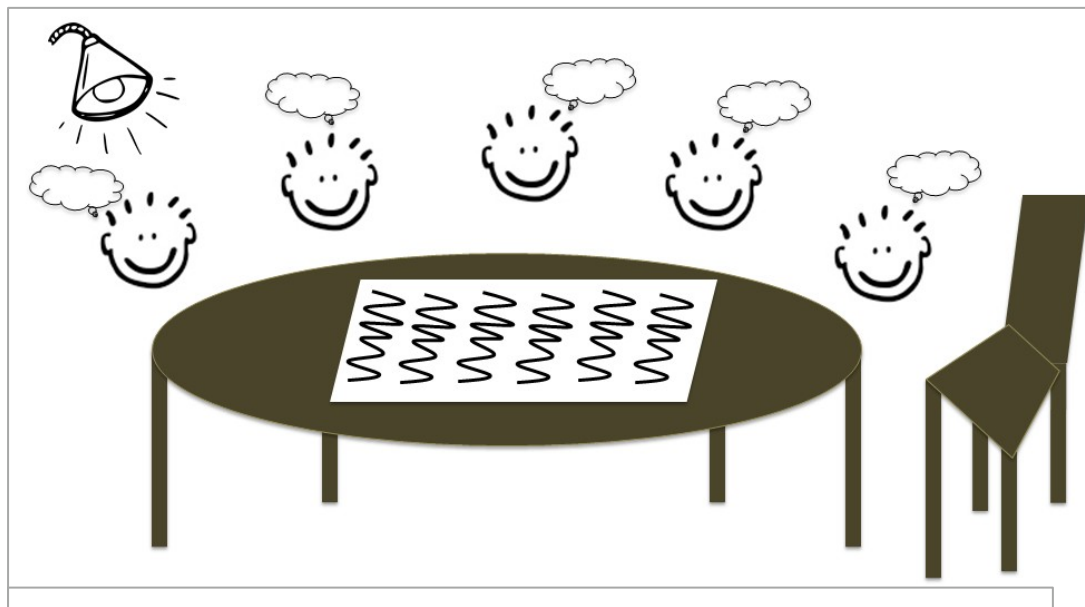


ViewMAX has a library of over 2 million movies and television programs for customers to choose from. ViewMAX competes well with its competitors on price, quality, and the value of its offering.

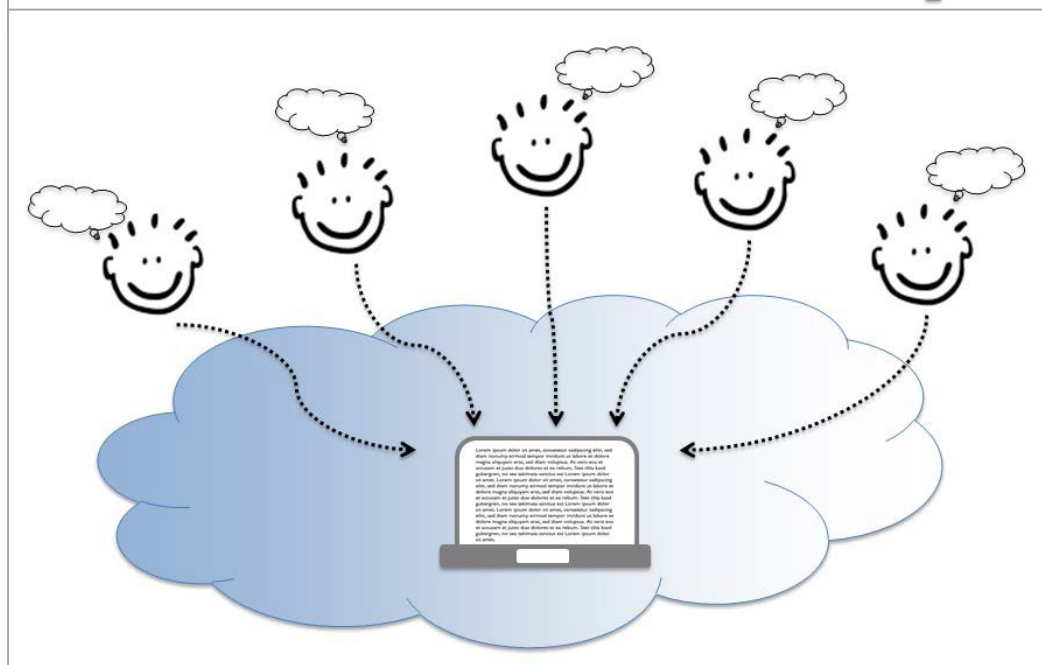
Intangible/Virtual

Study 3 Process Tangibility Manipulation

Tangible Process



Intangible
Process



Tangible Process with Environmental Benefit



Making the Monopolist's Product Line Green: The Effects of Consumers' Opposing
Perceptions of Recycled Content, Material Cost Savings, and the Diseconomies of Scope in
Production

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Abstract:

In this study, we consider a two-stage “product line and pricing” problem for a monopolist firm who (potentially) offers two variants: Ordinary and Green. The first stage involves

choosing the optimal recycled content percentage $\beta\%$ (i.e., the vertical differentiation gap between the two variants) of the green product, where a 0% recycled content decision implies offering *only* the ordinary product. Then, in the second stage the firm determines the optimal prices for the two variants to be included in its product line. Our analysis and findings contribute to the literature at the interface of operations, marketing and sustainability, and offer managerial insights for practitioners who must assess the trade-offs while introducing green variants with recycled/reused material in their product lines.

Making the Monopolist's Product Line Green: The Effects of Consumers' Opposing Perceptions of Recycled Content, Material Cost Savings, and the Diseconomies of Scope in Production

1. Introduction

Over time, a continuously expanding consumer base and non-government organizations have pushed firms' operations and products to be less taxing on the environment. Despite the increasing pressure, firms have responded to such demands cautiously—especially when there is no binding legislation in place, as it is unclear whether the inclusion of products with less environmental impact in a firm's product line supports traditional profit measures. Take, for example, products with recycled content.

On the cost side, provided unit collection costs are not excessive, using recycled materials may reduce variable input costs as recycled materials are typically procured at a lower cost compared to virgin materials. However, using recycled content instead of virgin material may require a different technology, thus implying an increase in production costs that are increasing in the amount of recycled content. For example, Starbucks white paper cups contain the industry standard liner, which makes the hot beverage cups unrecyclable in most paper recycling systems, thus requiring Starbucks to subsidize recyclers to invest in necessary technology. Even after such investments, if Starbucks procures fully recyclable cups from its suppliers, the unit cost for a cup would more than quadruple compared to the current design with only 10% recycled content, thus making this proposition economically hard to justify. Starbucks has recently announced that it does not have any plans to offer its beverages in fully recyclable cups until at least 2015. The net cost effect might be significant, thus causing the firm to charge a premium for the "green" product variant. Through its "Reuse-a-shoe" and "Nike Grind" programs, Nike repurposes recycled materials by incorporating them in various products, such as Air Jordan XX3 and Nike Pegasus 25, which are typically priced higher than similar Nike shoes.

On the demand side, whereas some “green” consumers are more environmentally conscious and, in some cases, are willing to pay more for green product variants,¹ there are others—undeniably, the majority—who perceive products with recycled (or reused) content inferior. The latter segment, which we henceforth refer to as “ordinary” customers, would not consider purchasing the green product unless that variant is available at a sufficiently high discount.

Here are other real world examples:

gdiaper is the first earth-friendly diaper in US with 100% disposable insert. Due to green design of the product, the snap-in liner of the diaper can have a useful life of 6 months, so the firm is saving on virgin raw material every time a diaper is sold. In the market, there are some environmentally conscious customers as we refer to them as green consumers, who are educated about product performance and willing to use the product in an appropriate manner



pay a price premium for gdiaper. On the other hand there are consumers who prefer regular diapers because they tend to conceive low performance for used liners. We refer to them as ordinary consumers.

Another example for this is Starbucks. Currently Starbucks offering 10 cents discount to customers who bring their own tumbler to save cups usage in the store. Clearly there are people who happily prefer to drink in their own tumbler while at the same time they are helping to save more paper cups, but others are not comfortable with carrying their



is

¹ 30% of consumers in the United Kingdom say they plan to spend more, and 49% plan to spend the same amount on green products.

tumbler with them every time they want to purchase a coffee.

- Offering both green and ordinary products can also affect the cost structure of the firm. For example, Patagonia, outdoor clothing manufacturer, now recycle used soda bottles, unusable second quality fabrics and worn out garments into polyester fibers to produce many of their clothes. They are clearly saving in material costs by recycling, but since it is a new challenge to their production line, their unit processing cost has increased.



- A few years ago, Nike started using pre-consumer Nike Grind – (scrap material from their manufacturing facilities) – in new Nike products like Air Jordan XX3 (world-famous shoe) and Nike Pegasus 25 – (Nike’s beloved running shoe). Apparently the material is almost free but the process of turning the material into the new shoe is more expensive than just producing the new shoe. Yet consumers are still willing to pay more for these shoes when they strongly care about sustainability. The question for Nike could be that should they invest in making their shoes greener.



2. Research Questions:

The collection of these real-world examples carries three distinct features, which are the focus points of this research note: Firstly, we have two consumer segments with opposing perceptions of “green quality.” It means that more of one quality dimension is not necessarily better for all consumers. Ordinary consumers prefer the ordinary product variant, while green consumers prefer the green product (with recycled content) variant. Secondly, the firm is saving material cost by producing green product. And thirdly, including both green and ordinary in the product line increases the firm’s average production costs due to technology requirements and diseconomies of scope.

The aforementioned cost/demand dynamics give rise to a series of managerially relevant research questions. Firstly, given the varied (and opposing) consumer perceptions of the green product variants, what is the optimal product line for a monopolist, which also prices its product optimally? In other words, should the firm target each segment with a unique product, i.e., offer a green product (with some recycled content) for green consumers, and an ordinary product (with no recycled content) for the ordinary customers; or should the firm offer only one product, and price appropriately to attract some demand from the segment with the opposing perception? Secondly, if the firm chooses to offer a green variant, just by itself, or, in addition to the ordinary variant, what should be the optimal degree of vertical differentiation (as measured by the percentage of recycled content) between the product variants? Finally, how do the optimal quality and price decisions drive the firm’s demand and profit, and consequently, how does the firm’s optimal product line decision transition from one to another as key problem parameters, such as the relative proportion of green and ordinary customer segments, the marginal (dis)utility of each customer segment from

additional recycled content, unit virgin and recycled material costs, and the degree of diseconomies of scope in production, change?

3. Literature Review

This research lies at interface of marketing, operations and sustainability. The main stream of research related to this problem is Mussa and Rosen (1978) and Moorthy seminal work (1984, 1988) on vertical differentiation and price discrimination. On the monopoly pricing and quality decision, they have assumed that there is only one quality dimension in the product and more of that quality is perceived better by all consumer types in the market. In our model though, we let one quality dimension being perceived higher by one consumer segment while perceived lower by other segment, so essentially the single crossing property doesn't hold in our model. There are other models in the literature (Cattani et. al ,2006; Vandenbosch et. Al. ,2005), which have addressed a single product with multi attributes while those attributes are perceived differently by consumer segments. Still they either haven't modeled the quality decision or haven't studied the cost implications while our model accounts for both of them.

There is also a second stream of literature with the focus on market segmentation and pricing decisions in presence of green consumers. In most of the literature such as in Atasu et. al (2008), it is assumed that the green version is perceived of lower quality by the ordinary consumers and at best is considered the same quality by green customers and then always priced lower than its new version. We, on the other hand, let the green segment of the market value the green product higher than new version. Therefore cannibalization can happen both ways. Atasu et. al (2008) also assumes "The remanufactured product costs less than ordinary product". But in our model, the green product may cost us more than ordinary product to manufacture. Other papers like Debo's (2005) leverage the single-crossing property and reflect a demand context that differs from our model.

A great deal of empirical research indicate that consumers are concerned enough to consider paying more for environmentally friendly products. Chen (2001) analytically has

applied this fact about green purchasing behavior in his model. However he did not treat the difficulty of processing a mix material input. He also imposed selection constraints for consumers while we let the consumers self-select the less-preferred product.

4. Modeling Approach

In this study, we consider a two-stage “product line and pricing” problem for a monopolist firm who (potentially) offers two variants: Ordinary and Green. The first stage involves choosing the optimal recycled content percentage $\beta\%$ (i.e., the vertical differentiation gap between the two variants) of the green product, where a 0% recycled content decision implies offering *only* the ordinary product. Then, in the second stage the firm determines the optimal prices for the two variants to be included in its product line. Given the price levels, each consumer *self-selects* to purchase the product variant giving him/her the highest surplus.² In other words, the demand split across product variants is determined endogenously. In the second stage, it is possible that the firm’s price choices do not induce any demand for one of the two products; in which case, the product line would consist of *only* the other product. The market size is normalized to 1. To model the inherent horizontal differentiation due to consumers’ heterogeneous willingness-to-pay levels, we permit consumers’ valuations of the ordinary product (v) to vary uniformly between 0 and 1. We capture consumers’ opposing perceptions of the green product’s recycled content by assuming that a green consumer’s valuation of the green variant is more than his/her valuation of the ordinary product by a factor of the *recycled content percentage* (β) times his/her *marginal utility from consuming a fully recycled product* (α_g). (We will henceforth refer to this marginal utility as the consumer’s sensitivity to recycled content.) In contrast, we assume that an ordinary consumer’s valuation of the green variant is less than his/her valuation of the ordinary product by a factor of the *recycled content percentage* (β) times his/her *marginal disutility from consuming a fully recycled product* (α_o).

² Consumers whose valuations are not high enough to yield a positive surplus from purchasing either option do not buy anything.

Table 1 summarizes the valuations for the products, Table 2 lists the parameters and variables of the model and Figure 1. draws the model setup.

Table 1: Consumer Valuations

Valuation/Customer	Ordinary Customer	Green Consumer
Ordinary Product	v	v
Green Product	$(1 - \alpha_o \beta)v$	$(1 + \alpha_g \beta)v$

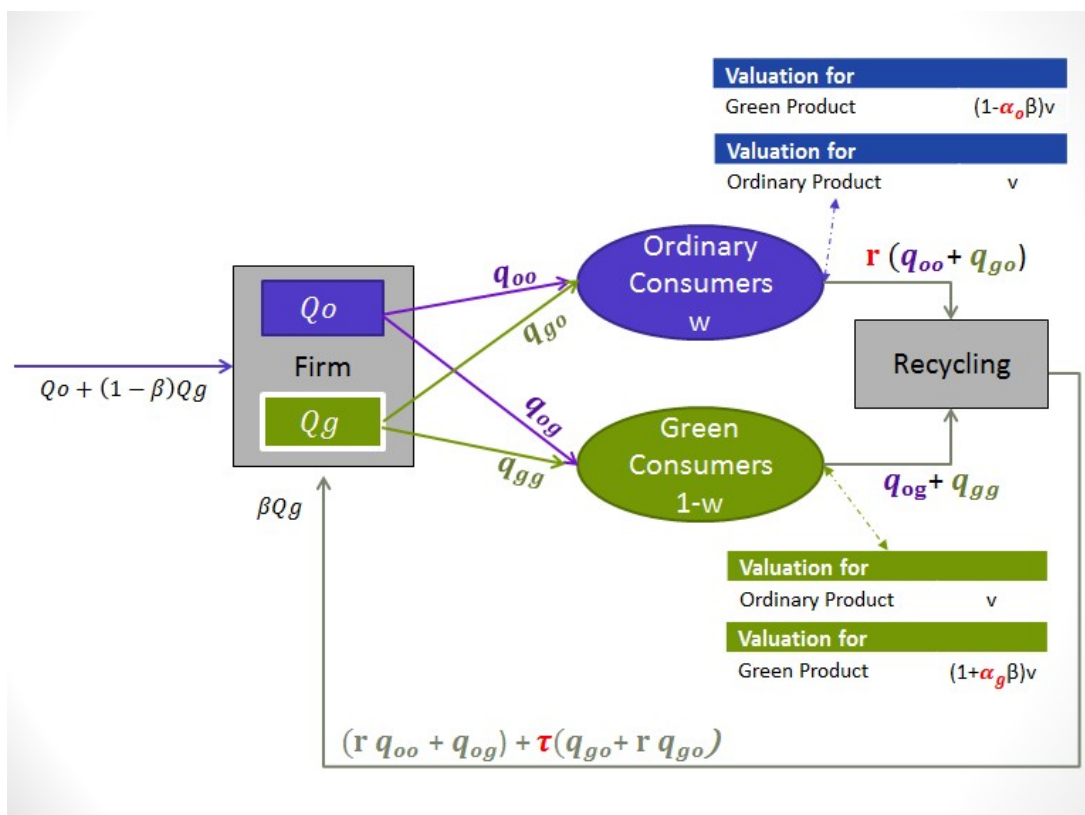


Figure 1: Model Set-up.

Table 2: Monopoly Model Parameters/Variables

Parameters	
w	ordinary consumers' proportion in the market
α_o	ordinary customers sensitivity (disutility) factor to β

α_g	green customers sensitivity (utility) factor to β
τ	% of returned green products which are still recyclable
r	% of quantity sold to ordinary customers is collected for recycling

Variables

β	recycled percentage of green product
q_{oo}	" of ordinary products sold to ordinary customers
q_{og}	" of ordinary products sold to green customers
q_{go}	" of green products sold to ordinary customers
q_{gg}	" of green products sold to green customers
p_o	Ordinary product price
p_g	Green product price

As shown in Table 3, the product cost is composed of material and production cost. Since in the most real world practices, unit recycled material cost C_r is less than unit virgin material cost C_v , the firm is saving on material cost by producing a green product that has β % recycled content with unit material cost of C_r . However on the production cost, aiming for a higher β becomes more technologically difficult or expensive. Also, marginal unit production cost is increasing in β due to introducing two variants (green and ordinary) in the same product line. For this reason, we assume the unit processing cost of the firm is an increasing convex function in β (recycled content) and for our model we have chosen the form of $K(1 + \beta)^2$. Note that this choice allows us to model "diseconomies in scope" for the inclusion of the green product variant in the product line. We denote C_o and C_g unit variable cost of ordinary and green products respectively, which are the sum of unit material and production costs.

$$C_o = C_v + K(1 + \beta)^2 = \text{unit variable cost for ordinary product}$$

$C_g = (1 - \beta) C_v + \beta C_r + K(1 + \beta)^2 =$ unit variable cost for green product

Table 3: Cost parameters

Material cost	Cr	Unit virgin raw material cost
	Cv	Recycled material cost
	TMC	$C_v [(q_{oo}+q_{og})+ (1- \beta)(q_{go}+q_{gg})]+ \beta C_r(q_{go}+q_{gg})$
Processing Cost	Ko	Unit processing cost for virgin material
	Kg	Unit processing cost for mixed material
	K	Unit processing cost
	TPC	$\frac{K_o(q_{oo}+q_{og})+ K_g(1 + \beta)^2 (q_{go}+q_{gg})}{K(1 + \beta)^2(q_{oo}+q_{og}+q_{go}+q_{gg})}$ Equivalent to $K(1 + \beta)^2(q_{oo}+q_{og}+q_{go}+q_{gg})$ *K is a function of realized demands, Ko and Kg

4.1. Third Stage: Demand Realization

After solving the consumer maximization problem (Table 4), without forcing any ordering on p_o and p_g (prices of ordinary and green products), we confirmed that demand realization depend of the relative magnitude of prices. (Table 5)

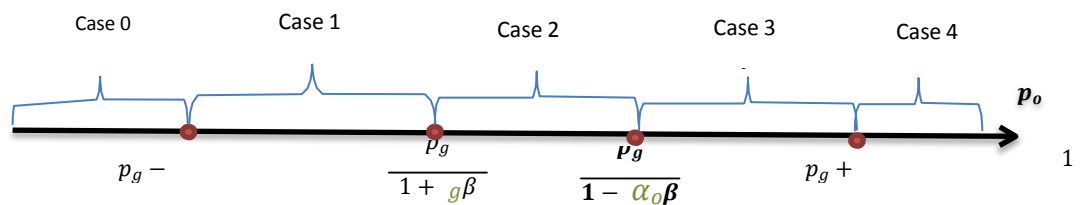
Demand is realized in a way such that we either price the ordinary relatively cheaper than green (case 0 and 1), comparably price both products (case 2), or price the green relatively cheaper than ordinary (case 3 and case 4).

Table 4: Demand functions

Demand	Participation	Selection	Aggregated constraints
q_{oo}	$v - p_o \geq 0$	$v - p_o > (1 - \alpha_o \beta) v - p_g$ $v > \frac{p_o - p_g}{\alpha_o \beta}$	$1 - \max \left\{ \min \left\{ \frac{p_o - p_g}{\alpha_o \beta}, 1 \right\}, p_o \right\}$
	$v \geq p_o$	$\alpha_o \beta$	$\alpha_o \beta$

q_{go}	$(1 - \alpha_o\beta) v - p_g \geq 0$	$(1 - \alpha_o\beta) v - p_g > v - p_o$	$\max \{0, \min\{\frac{p_o - p_g}{\alpha_o\beta}, 1\} - \frac{p_g}{1 - \alpha_o\beta}\}$
	$v \geq \frac{p_g}{1 - \alpha_o\beta}$	$v < \frac{p_o - p_g}{\alpha_o\beta}$	
q_{gg}	$(1 + \alpha_g\beta)v - p_g \geq 0$	$(1 + \alpha_g\beta)v - p_g \geq v - p_o$	$1 - \max \{\min\{\frac{p_g - p_o}{\alpha_g\beta}, 1\}, \frac{p_g}{1 + \alpha_g\beta}\}$
	$v > \frac{p_g}{1 + \alpha_g\beta}$	$v > \frac{p_g - p_o}{\alpha_g\beta}$	
q_{og}	$v - p_o \geq 0$	$v - p_o > (1 + \alpha_g\beta)v - p_g$	$\max \{0, \min\{\frac{p_g - p_o}{\alpha_g\beta}, 1\} - p_o\}$
	$v \geq p_o$	$v < \frac{p_g - p_o}{\alpha_g\beta}$	

Table 5: A more detailed Demand functions model

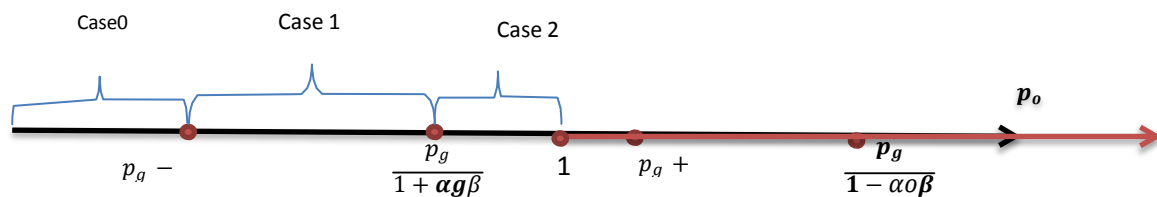


q_{oo}	$1 - p_o$	$1 - p_o$	$1 - p_o$	$1 - \frac{p_o - p_g}{\alpha_o\beta}$	0
q_{go}	0	0	0	$\frac{1 - p_o}{1 - \alpha_o\beta}$	$1 - \frac{p_g}{1 - \alpha_o\beta}$
q_{gg}	0	$1 - \frac{p_g - p_o}{\alpha_g\beta}$	$1 - \frac{p_g - p_o}{1 + \alpha_g\beta}$	$1 - \frac{p_g - p_o}{1 + \alpha_g\beta}$	$1 - \frac{p_g}{1 + \alpha_g\beta}$
q_{og}	$1 - p_o$	$\frac{p_g - p_o}{\alpha_g\beta} - p_o$	0	0	0

Each demand realization form corresponds to a certain marketing strategy. When prices are comparable (case 2), no cannibalization happens. Consumers optimally choose their targeted product variant. We call this case as “Targeted Marketing”. In case of cheap ordinary (case 1), ordinary product is priced relatively lower than green product.

Here cannibalization occurs in green segment in which some green consumers switch to ordinary product ($q_{og} > 0$) because of relatively low p_o . We call this case as “Ordinary Marketing” since most consumers buy ordinary product. In case of cheap green (case 3), green product is priced relatively lower. Here cannibalization occurs in ordinary segment in which some ordinary customers switch to green product ($q_{go} > 0$) due to relative lower price of p_g . We call this case as “Green Marketing” since most consumers buy green product. If we price green much lower ($p_o > p_g + \alpha\beta$), then all consumers who buy, will buy green. We call this case as “Bargain Green” due to very low price of green product. If we price Ordinary much lower ($p_o < p_g - \alpha\beta$), then all consumers who buy, will buy Ordinary. We call this case as “Bargain Ordinary” due to very low price of ordinary product.

Note: If $\frac{p_g}{1-\alpha\beta} > p_g + \alpha\beta \rightarrow p_g + \alpha\beta > 1 \rightarrow$ there won't be any case 3 and 4 and upper boundary for case 2 ordinary price will be 1.



When the customers observe the prices in the market, they optimally choose to be in one of the five below regions:

4.2. Second-stage: Optimal Pricing

Regarding the firm's second stage pricing problem,³ we characterize the five optimal demand segmentation outcomes (and the corresponding product line decisions) that might result depending on key problem parameters: The *targeted*, *green*, and *ordinary marketing* scenarios where the firm optimally offers both product variants; the *bargain green marketing*, and *bargain ordinary marketing* scenarios when the firm's product line optimally consists of only one product. In targeted marketing, all purchasing customer self-select the unique

³ These findings apply to firms which cannot optimize the recycled content level. For example, the firm might be a retailer who buys and resells the green variant as is; or the production costs to increase the green variant's recycled content might be prohibitively costly.

product targeting their own segment. In green (ordinary) marketing, all purchasing green (ordinary) customers and some ordinary (green) customers purchase the green (ordinary) product. In order for FOC to be a necessary and sufficient tool to find the maximum point on the profit function, we first need to insure that the profit function is jointly concave in p_o and p_g . We performed the joint concavity analysis using Hessian Matrix and proved that our profit function is jointly concave in p_o and p_g in all five cases. So now, we need to solve five separate maximization problems that each is subjected to the corresponding constraints on price changes.

$$\text{Max}_{p_o, p_g} \text{Profit} = (q_{oo} + q_{og})(p_o - C_o) + (q_{go} + q_{gg})(p_g - C_g)$$

Subject to:

- Constraints in Table 6
- Demand function in Table 5

Table 6: Case Constraints

Five Cases	Case constraints
Bargain Ordinary Marketing	$0 \leq p_o \leq p_g - \alpha g \beta$
Ordinary Marketing	$p_g - \alpha g \beta \leq p_o \leq \frac{p_g}{1 + \alpha g \beta}$
Targeted Marketing	$\frac{p_g}{1 + \alpha o \beta} \leq p_o \leq \frac{p_g}{1 - \alpha o \beta}$
Green Marketing	$\frac{p_g}{1 - \alpha o \beta} \leq p_o \leq p_g + \alpha o \beta$
Bargain Green Marketing	$p_g + \alpha o \beta \leq p_o \leq 1$

Table 6: Optimal prices and Optimal/Feasible regions

Cases	Prices	Feasible Region	Optimal Region
Bargain Ordinary	$P_o = \frac{cv+k(1+\beta)^2+1}{2}$ $P_g = \frac{cv+k(1+\beta)^2+1}{2} + y - 1$	$0 < cv < cr - ag$	
Ordinary - LC	P_o : Same as Bargain Ordinary P_g	$cv = cr - ag$	
Ordinary - I	$P_o = \frac{cv+k(1+\beta)^2+1}{2}$ $P_g = \frac{(1-\beta)cv+\beta \frac{cr+k(1+\beta)^2+y}{2}}{2}$	$cr - ag < cv < \frac{cr-ag k(1+\beta)^2}{1+ag}$	
Ordinary - UC Targeted - LC	$P_o = \frac{(1-w)((1-\beta)cv+\beta \frac{cr+k(1+\beta)^2+y}{2})+(cv+k(1+\beta)^2+1)w}{2((1-w)y+w)}$ $P_g = \frac{(1-w)((1-\beta)cv+\beta \frac{cr+k(1+\beta)^2+y}{2})+(cv+k(1+\beta)^2+1)w}{2((1-w)y+w)} - y$	$cv = \frac{cr-ag k(1+\beta)^2}{1+ag}$	
Targeted - I	P_o : Same as Ordinary - I	$\frac{cr-ag k(1+\beta)^2}{1+ag} < cv <$	Feasible region+

	Pg		$\frac{cr+ao k(1+\beta)^2}{1-ao} + q1$	$\frac{cr+ao(1+\beta)^2 k+(ag+ao)q3}{1-ao} > cv >$ $\frac{cr+ao(1+\beta)^2 k-(ag+ao)q3}{1-ao}$ $x - q4 < (1 - \beta)cv + \beta cr + k(1 + \beta)^2 < x +$ $q4$
Targeted - UC Green - LC	Po	$\frac{(1-w)x((1-\beta)cv+\beta cr+k(1+\beta)^2+y)+(cv+k(1+\beta)^2+1)wy}{2(wy+(1-w)x^2)}$	$cv \geq \frac{cr+ao k(1+\beta)^2}{1-ao} + q1$	Feasible region+
	Pg	$\frac{(1-w)x((1-\beta)cv+\beta cr+k(1+\beta)^2+y)+(cv+k(1+\beta)^2+1)wy}{2(wy+(1-w)x^2)}$	$cv \leq \frac{cr+ao k(1+\beta)^2}{1-ao} +$ $\frac{q2}{\beta(1-ao)}$	
Green - I	Po	$\frac{1+cv+k(1+\beta)^2-x}{2} + \frac{xy}{2((1-w)x+wy)}$	$\frac{cr+ao k(1+\beta)^2}{1-ao} + \frac{q2}{\beta(1-ao)} <$	Feasible region+
	Pg	$\frac{(1-\beta)cv+\beta cr+k(1+\beta)^2}{2} + \frac{xy}{2((1-w)x+wy)}$	$cv < cr + ao$	

				$cv < \frac{cr+ao(1+\beta)^2k-(ag+ao)\sqrt{q^3}}{1-ao}$
Green - UC	Po	$\frac{(1-\beta)cv+\beta cr+k(1+\beta)^2}{2} + \frac{xy}{2((1-w)x+wy)} + 1 - x$	$cv = cr + ao$	
	Pg	Same as Green -I		
Bargain Green	Po	Same as Green -UC	$cv > cr + ao$	Feasible region+ $(1-\beta)cv + \beta cr + k(1+\beta)^2 < x - \sqrt{q^4}$ or $(1-\beta)cv + \beta cr + k(1+\beta)^2 > x + \sqrt{q^4}$
	Pg			

$$y = \frac{1 + ag\beta}{ao + ag} \quad x = \frac{1 - ao\beta}{(1-x)(1-y-w)(y-x)}$$

$$q1 = \frac{(w-x)x}{x} \quad q2 = \frac{1}{(y-x)}$$

$$q3 =$$

$$\frac{(y-x)^2(1-w)}{x + (y-x)w}$$

$$q4 = x \sqrt{(1 - (cv + k(1 + \beta)^2))^2} +$$

4.3. Key Findings in Pricing Stage:

Our study addresses three distinctive issues which have hitherto not been considered in an integrated manner: (i) Consumers' opposing perceptions of green product attributes, (ii) diseconomies of scope in production which might negate material cost savings due to recycling, and (iii) the link between the firm's green quality decision, i.e., the recycled content percentage, and its effect on costs due to the closed-loop nature of our setting. Therefore, our analysis and findings contribute to the literature at the interface of operations, marketing and sustainability, and offer managerial insights for practitioners who must assess the aforementioned trade-offs while introducing green variants with recycled/reused material in their product lines.

In each graph included in Figure 1, we report the optimal product line for all unit virgin and recycled cost pairs. We grouped these graphs into rows, where each row sheds light on the optimal policy transitions (from left to right) as a) the recycled content percentage, b) the green consumers' sensitivity to recycled content, and c) the percentage of the ordinary consumers in the market increases, *ceteris paribus*. We find that significant unit material cost savings (i.e., a high virgin-recycled material cost differential) is necessary—but not sufficient—for the firm to optimally offer a “green-only” product line (i.e., bargain green marketing). In addition, the green variant's recycled content percentage and the green customers' sensitivity must remain below unique thresholds, respectively (see Figure 1a and 1b), and the percentage of ordinary customers must be above a minimum (see Figure 1c).⁴ In other words, contrary to the common belief, for an optimal green-only product line to sustain, one does not need a “very green” product variant, or “many” green consumers, or for green customers to pay a “high premium” for a green variant.

⁴ The firm's optimal policy choices with respect to the changes in the ordinary consumers' sensitivity to green transition as anticipated; a green-only product line necessitates the ordinary customers' marginal disutility factor to be below a threshold.

Transition of optimal regions

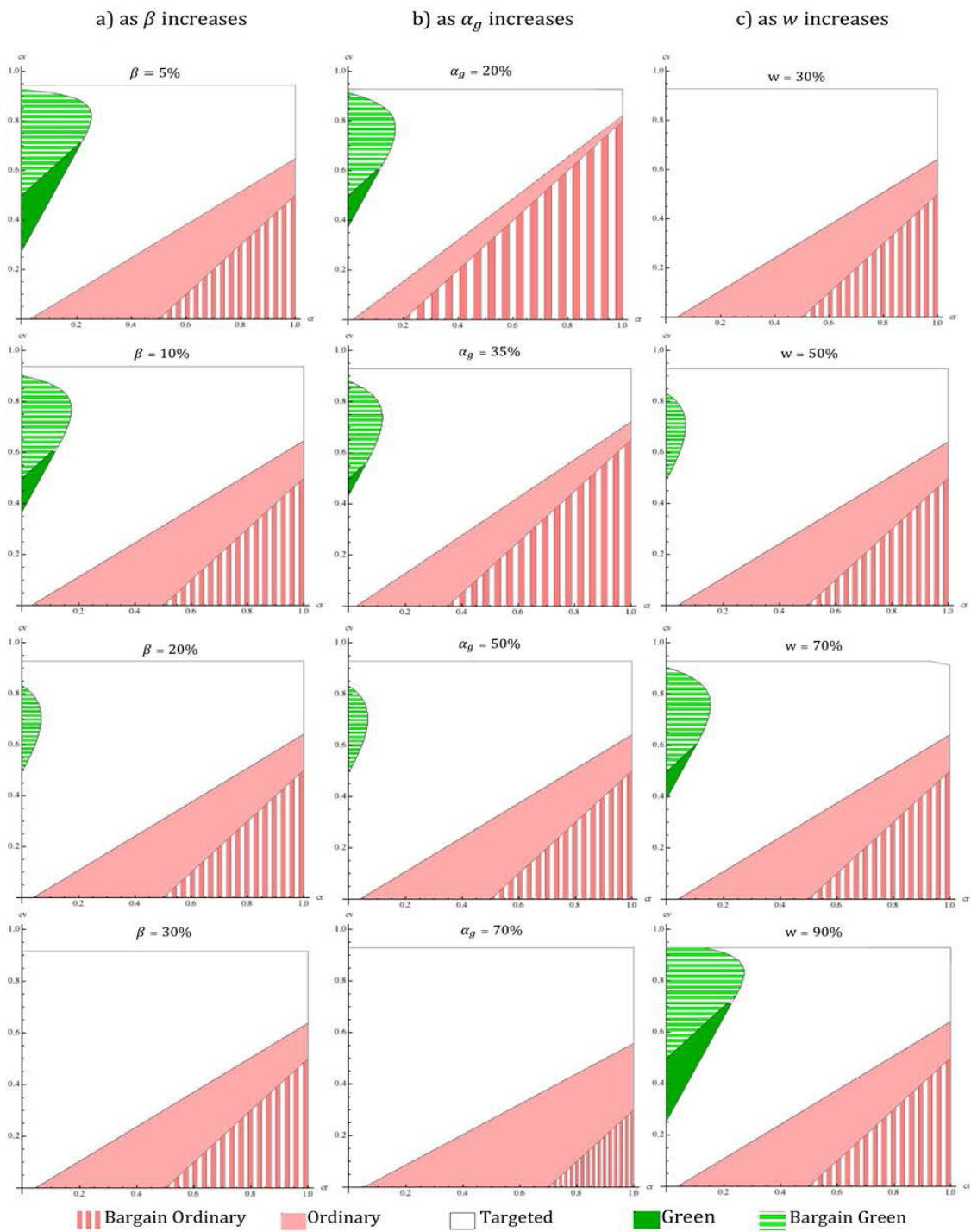


Figure 2 – The firm’s optimal product line decisions for each pair of unit virgin material (y-axis) and recycled material cost (x-axis). In each row, increasing from left to right are, ceteris paribus, **a)** the recycled content percentage, **b)** the green consumers’ sensitivity to recycled content, and **c)** the percentage of ordinary consumers in the market.

4.4. First Stage: Optimal Quality Decision

After deriving the optimal prices in second stage, we can solve the green quality decision problem by maximizing firm's profit using price best responses and Optimality/Feasibility Constraints in second stage (read from Table 6).

$$\text{Max}_{\beta} \text{ Profit} = (p_o - C_o)(q_{oo} + q_{og}) + (p_g - C_g)(q_{go} + q_{gg})$$

S.t:

$$\frac{r\phi q_{oo} + \tau q_{go} + \phi q_{og} + \tau q_{gg}}{q_{go} + q_{gg}}$$

- $0 \leq \beta \leq \min$

$$q_{go} + q_{gg}$$

1,

- Optimality/Feasibility Regions from Stage 1 (Table 6)

The first constraint addresses the limit on β . Clearly β cannot exceed the supply available. So we need to consider the amount of recyclable product supply available or by other words, the amount of products that are returned to firm and are good to get recycled. For this, we introduced two parameters (Table 2). We reasonably assume that only $\tau\%$ of returned green products are still qualified for recycling. We also assume that only $r\%$ of sold products to ordinary consumers will be collected back.⁵ Also there might be an upper boundary on (β_{\max}) due to technology constraint for the firm. For a firm that can optimize its green variant's recycled content, we find that the possible optimal product line outcomes are limited to the targeted, bargain green and bargain ordinary marketing scenarios. This finding also implies that, for cases when targeted marketing is not optimal, the firm should increase or decrease the recycled content significantly to induce a demand shift for one customer segment towards the opposite product. For example, in Figure 3a, the optimal recycled content is 50% or more and the firm optimally implements targeted marketing if 75% or less of the market consists of ordinary consumers; beyond that threshold, the firm does not offer the green variant. Similarly, in Figure 3b, we highlight that the firm should not offer a green variant unless the green segment is willing to pay at least a 40% premium for a fully recycled product variant.

⁵ Toktay (2003) and Guide et al. (2006) report that accessibility rates range from 5% to 35% and reusability rates range from 40% to 93%

Note that these dynamics highlight a stark contrast to the conclusions from Figure 1. When the firm can optimize the green variants' recycled content percentage, the green variant cannot sustain unless there are "enough many green consumers" who are willing to pay a "sufficiently high premium" for the green variant. Finally, we find that a green-only product line may still be optimal only if the ordinary consumers' sensitivity to recycled content is below a threshold. (E.g.: That threshold is 0.2 for the instance we highlight in Figure 3c.)

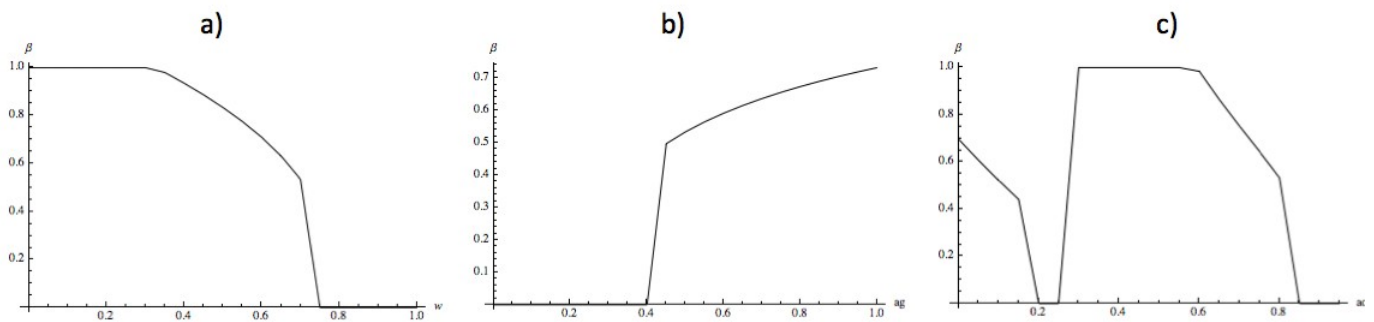


Figure 3 – The optimal recycled content decision vs. **a)** the fraction of the ordinary consumers in the market, **b)** the green consumers' sensitivity to recycled content, and **c)** the ordinary consumers' sensitivity to recycled content.

5. Conclusion

We consider the optimal (green) quality and pricing decisions of a monopolist offering two (ordinary and green) product variants. Two distinct consumer segments with contrasting perception of green quality. Green product variant permits material cost savings, but induces diseconomies of scope.

We find that "ordinary marketing" is never optimal with higher virgin material costs.

"Green marketing" is optimal when:

- Virgin raw material is relatively more expensive than recycled material.
- AND green segment is small,
- OR selling a mildly green product.

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7. **Appendix: Mathematica Outputs**

```

PSet := 8 ao 0.5, ag 0.5, beta 0.7, w 0.9<
PSetk := 8 ao 0.5, ag 0.5, beta 0.7, w 0.9, k 0.12, cv 0.5<

$Assumptions =
  0 <= w <= 1 && 0 <= ao <= 1 && 0 <= ag <= 1 && 0 <= beta <= 1 && 0 < cv && 0 < cr && k > 0;

```

H*CASE Bargain Ordinary*L

```

phi0 @po_D := Hw * H1 - poL + H1 - wL * H1 - poLL * Hpo - coL
poI0cvcr = H1 + coL ê 2 ê. co 0 cv + k H1 + betaL^2
pgI0cvcr = H1 + 2 ag beta + coL ê 2 ê. co 0 cv + k H1 + betaL^2
poI0 = H1 + coL ê 2
pgI0 = H1 + 2 ag beta + coL ê 2
ProfitI0 = FullSimplify@phi0@poI0DD
ProfitI0cvcr = FullSimplify@phi0@poI0cvcrDD ê. co 0 cv + k H1 + betaL^2

$Assumptions =
  0 <= w <= 1 && 0 <= ao <= 1 && 0 <= ag <= 1 && 0 <= beta <= 1 && 0 < cv && 0 < cr && k > 0;
Reduce@poI0cvcr <= pgI0cvcr - ag beta && $AssumptionsD êê FullSimplify

```

$$\frac{1}{2} (1 + cv + H1 + betaL^2) kM$$

$$\frac{1}{2} (1 + 2 ag beta + cv + H1 + betaL^2) kM$$

$$\frac{1 + co}{2}$$

$$\frac{1}{2} (H1 + 2 ag beta + coL)$$

$$\frac{1}{4} (H - 1 + coL^2)$$

$$\frac{1}{4} (I - 1 + cv + H1 + betaL^2) kM I - 1 - cv - H1 + betaL^2 k + 2 I cv + H1 + betaL^2 kMM$$

True

H*CASE Ordinary*L

```
phi1@po_, pg_D := Hw*H1-poL+H1-wL HHpg-poLêHagbetaL-poLL*Hpo-coL+
H0+H1-wL*H1-Hpg-poLêHagbetaLLL*Hpg-cgL
```

```
Solve@D@phi1 @po, pgD, poD ã 0 && D@phi1 @po, pgD, pgD ã 0, 8po, pg<D
```

```
poI1 = H1+coLê2 ;
pgI1 = H1+ag beta+cgLê2 ;
ProfitI1 = FullSimplify@phi1@poI1, pgI1DD;
```

```
poI1cvcr = H1+coLê2 ê. co Ø cv+k H1+betaL^2
pgI1cvcr = H1+ag beta+cgLê2 ê. cg Ø H1-betaL cv+beta cr+k H1+betaL^2
ProfitI1cvcr = FullSimplify@phi1@poI1cvcr, pgI1cvcrDD ê. co Ø cv+k H1+betaL^2 ê.
cg Ø H1-betaL cv+beta cr+k H1+betaL^2
```

```
$Assumptions =
0 <= w <= 1 && 0 <= ao <= 1 && 0 <= ag <= 1 && 0 <= beta <= 1 && 0 < cv && 0 < cr && k > 0;
Reduce@pgI1cvcr-ag beta <= poI1cvcr && $AssumptionsD êê FullSimplify
```

```
Reduce@poI1cvcr <= pgI1cvcr êH1+ag beta L&& $AssumptionsD êê FullSimplify
```

```
::po Ø  $\frac{1+co}{2}$ , pg Ø  $\frac{1}{2} + \frac{ag\beta}{2} + \frac{cg}{2}$ >>
```

```
1
- I1+cv+H1+betaL^2 kM
2
```

```
1
- I1+ag beta+beta cr+H1-betaL cv+H1+betaL^2 kM
2
```

```
 $\frac{1}{4 ag}$  JagJ1-Icv+H1+betaL^2 kM^2 +2 Icv+H1+betaL^2 kM Icv+H1+betaL^2 k-wM+
2 Ibeta cr+H1-betaL cv+H1+betaL^2 kMH-1+wLN+Hcr-cvL
IbetaHcr-cvL+2 Icv+H1+betaL^2 kM-2 Ibeta cr+H1-betaL cv+H1+betaL^2 kMM
H-1+wL+ag^2 Hbeta-beta wLN
```

```
cr § cv >> Hcr < 1+cv && ag+cv ¥ crL >>
Hbeta ã 0 && cr ^1 ≠ 1+cvL >> Hcr ã 1+cv && Hag ¥ 1 >> beta § 0LL
```

```
beta ã 0 >> Icr ¥ H1+agL cv+ag H1+betaL^2 k && beta > 0M
```


H*CASE Taregetd*L

```
phi2 @po_, pg_D :=
  Hw*H1-poL+0L*Hpo-coL+H0+H1-wL*H1-pgêH1+Hag*betaLLLL*Hpg-cgL
```

```
poI2 = H1 + coL ê 2 ;
pgI2 = H1 + ag beta + cgL ê 2;
ProfitI2 = FullSimplify@phi2@poI2, pgI2DD;
```

```
poI2cvcr = H1 + coL ê 2 ê. co Ø cv + k H1 + betaL^2
pgI2cvcr = H1 + ag beta + cgL ê 2 ê. cg Ø H1 - betaL cv + beta cr + k H1 + betaL^2
ProfitI2cvcr = FullSimplify@phi2@poI2cvcr, pgI2cvcrDD ê. co Ø cv + k H1 + betaL^2 ê.
  cg Ø H1 - betaL cv + beta cr + k H1 + betaL^2
```

$$\frac{1}{2} I1 + cv + H1 + betaL^2 kM$$

$$\frac{1}{2} I1 + ag beta + beta cr + H1 - betaL cv + H1 + betaL^2 kM$$

$$-\frac{1}{4 + 4 ag beta} I1 + ag beta - beta cr - cv + beta cv - H1 + betaL^2 kM$$

$$I1 + cv + k - 2 I beta cr + H1 - betaL cv + H1 + betaL^2 kM + beta Hag + cr - cv + H2 + betaL kLM$$

$$H - 1 + wL - \frac{1}{4} I - 1 + cv + H1 + betaL^2 kM I1 + cv + H1 + betaL^2 k - 2 I cv + H1 + betaL^2 kMMw$$

H*CASE Green*L

$$\begin{aligned} \text{phi3 @po_ , pg_D} &:= \text{Hw} * \text{H1} - \text{Hpo} - \text{pgL} \hat{=} \text{Hao betaLL} + 0\text{L} * \text{Hpo} - \text{coL} + \\ &\text{Hw} * \text{HHpo} - \text{pgL} \hat{=} \text{Hao betaL} - \text{Hpg} \hat{=} \text{H1} - \text{ao betaLLL} + \\ &\text{H1} - \text{wL} * \text{H1} - \text{pg} \hat{=} \text{H1} + \text{Hag} * \text{betaLLLL} * \text{Hpg} - \text{cgL}; \end{aligned}$$

$$\begin{aligned} \text{poI3} &= \text{H} - \text{H} - 1 + \text{ao betaL H1} + \text{Hag} + \text{aoL beta} + \text{coL} + \text{Hag} + \text{aoL beta Hao beta} + \text{coL wL} \hat{=} \\ &\text{H2 H1} + \text{ao beta H} - 1 + \text{wL} + \text{ag beta wLL}; \\ &-\text{H} - 1 + \text{ao betaL H1} + \text{ag beta} + \text{cgL} + \text{Hag} + \text{aoL beta cgw} \end{aligned}$$

$$\text{pgI3} = \frac{\quad}{2 \text{H1} + \text{ao beta H} - 1 + \text{wL} + \text{ag beta wL}};$$

$$\text{ProfitI3} = \text{phi3 @poI3, pgI3D};$$

$$\begin{aligned} \text{poI3cvcr} &= \text{H} - \text{H} - 1 + \text{ao betaL H1} + \text{Hag} + \text{aoL beta} + \text{coL} + \text{Hag} + \text{aoL beta Hao beta} + \text{coL wL} \hat{=} \\ &\text{H2 H1} + \text{ao beta H} - 1 + \text{wL} + \text{ag beta wLL} \hat{=} . \text{co} \emptyset \text{ cv} + \text{k H1} + \text{betaL}^2 \hat{=} . \end{aligned}$$

$$\begin{aligned} \text{cg} \emptyset \text{ H1} - \text{betaL cv} + \text{beta cr} + \text{k H1} + \text{betaL}^2; \\ -\text{H} - 1 + \text{ao betaL H1} + \text{ag beta} + \text{cgL} + \text{Hag} + \text{aoL beta cgw} \\ \text{pgI3cvcr} = \frac{\quad}{2 \text{H1} + \text{ao beta H} - 1 + \text{wL} + \text{ag beta wL}} \hat{=} . \end{aligned}$$

$$\begin{aligned} \text{co} \emptyset \text{ cv} + \text{k H1} + \text{betaL}^2 \hat{=} . \text{cg} \emptyset \text{ H1} - \text{betaL cv} + \text{beta cr} + \text{k H1} + \text{betaL}^2; \\ \text{ProfitI3cvcr} = \text{phi3 @poI3cvcr, pgI3cvcrD} \hat{=} . \text{co} \emptyset \text{ cv} + \text{k H1} + \text{betaL}^2 \hat{=} . \\ \text{cg} \emptyset \text{ H1} - \text{betaL cv} + \text{beta cr} + \text{k H1} + \text{betaL}^2; \end{aligned}$$

$$\text{pgLC3} = \text{HH} - 1 + \text{ao betaL}$$

$$\begin{aligned} \text{H1} + \text{cg} + \text{ao beta H1} + \text{cgL H} - 1 + \text{wL} - \text{cgw} + \text{cow} + \text{ag beta H1} + \text{ao beta H} - 1 + \text{wL} + \text{co wLLL} \hat{=} \\ \text{H} - 2 + 2 \text{beta Hao H} - 2 + \text{ao betaL H} - 1 + \text{wL} - \text{ag wLL}; \text{poLC3} = \\ \text{HH} - 1 + \text{ao betaL H1} + \text{ag beta} + \text{cgL} - \text{H} - \text{cg} + \text{ao beta H1} + \text{ag beta} + \text{cgL} + \text{co} + \text{ag beta coL wL} \hat{=} \\ \text{H} - 2 + 2 \text{beta Hao H} - 2 + \text{ao betaL H} - 1 + \text{wL} - \text{ag wLL}; \end{aligned}$$

$$\text{poUCTLCG} = \text{HH1} - \text{wL x Hcg} + \text{yL} + \text{Hco} + 1\text{L wyL} \hat{=} \text{H2 Hw y} + \text{H1} - \text{wL x}^2 \text{LL}$$

$$\text{pgUCTLCG} = \text{HH1} - \text{wL x Hcg} + \text{yL} + \text{Hco} + 1\text{L wyL x} \hat{=} \text{H2 Hw y} + \text{H1} - \text{wL x}^2 \text{LL}$$

$$\frac{\text{H1} + \text{coL wy} + \text{H1} - \text{wL x Hcg} + \text{yL}}{2 \text{IH1} - \text{wL x}^2 + \text{wyM}}$$

$$\frac{\text{x HH1} + \text{coL wy} + \text{H1} - \text{wL x Hcg} + \text{yLL}}{2 \text{IH1} - \text{wL x}^2 + \text{wyM}}$$

$$\text{poLC3} - \text{poUCTLCG} \hat{=} . \text{x} \emptyset 1 - \text{ao beta} \hat{=} . \text{y} \emptyset 1 + \text{ag beta} \hat{=} \hat{=} \text{FullSimplify}$$

$$\text{pgLC3} - \text{pgUCTLCG} \hat{=} . \text{x} \emptyset 1 - \text{ao beta} \hat{=} . \text{y} \emptyset 1 + \text{ag beta} \hat{=} \hat{=} \text{FullSimplify}$$

0

0

\$Assumptions = 0 < w < 1 && 0 < ao < 1 && 0 < ag < 1 && 0 < beta < 1;
Reduce@ProfitI3 > ProfitI2 && \$AssumptionsD êê FullSimplify

$$co \in \mathbb{R} \&\& \left| \begin{aligned} &cg + ao \beta co + \sqrt{\frac{ao Hag + aoL^2 \beta^3 H - 1 + ao \beta aL H - 1 + wL}{1 - ao \beta + Hag + aoL \beta a w}} < co \gg \\ &cg + ao \beta co > co + \sqrt{\frac{ao Hag + aoL^2 \beta^3 H - 1 + ao \beta aL H - 1 + wL}{1 + ao \beta H - 1 + wL + ag \beta a w}} \end{aligned} \right|$$

FullSimplifyB $cg + ao \beta co + \sqrt{\frac{ao Hag + aoL^2 \beta^3 H - 1 + ao \beta aL H - 1 + wL}{1 - ao \beta + Hag + aoL \beta a w}} > co \hat{e}.$

$co \in \mathbb{C}v + k H1 + \beta aL^2 \hat{e}.$

$cg \in H1 - \beta aL cv + \beta a cr + k H1 + \beta aL^2 F \hat{e} \hat{e} \text{TraditionalForm}$

FullSimplifyB $co + \sqrt{\frac{ao Hag + aoL^2 \beta^3 H - 1 + ao \beta aL H - 1 + wL}{1 - ao \beta + Hag + aoL \beta a w}} > cg + ao \beta co \hat{e}.$

$co \in \mathbb{C}v + k H1 + \beta aL^2 \hat{e}.$

$cg \in H1 - \beta aL cv + \beta a cr + k H1 + \beta aL^2 F \hat{e} \hat{e} \text{TraditionalForm}$

$$\sqrt{\frac{ao \beta^3 H w - 1L Hag + aoL^2 Ha \beta a - 1L}{ag \beta a w + ao \beta a H w - 1L + 1}} + \beta a la o H \beta a + 1L^2 k + Ha o - 1L cv + cr M > 0$$

$$\sqrt{\frac{ao \beta^3 H w - 1L Hag + aoL^2 Ha \beta a - 1L}{ag \beta a w + ao \beta a H w - 1L + 1}} > \beta a la o H \beta a + 1L^2 k + Ha o - 1L cv + cr M$$

$$\left(\begin{aligned} &lc r + ao H1 + \beta aL^2 k M + Hag + aoL \sqrt{\frac{ao \beta a H - 1 + ao \beta aL H - 1 + wL}{1 + ao \beta a H - 1 + wL + ag \beta a w}} \end{aligned} \right) \hat{i} HH1 - aoLL >$$

$cv \&\&$

$$cv > \left(\begin{aligned} &lc r + ao H1 + \beta aL^2 k M - Hag + aoL \sqrt{\frac{ao \beta a H - 1 + ao \beta aL H - 1 + wL}{1 + ao \beta a H - 1 + wL + ag \beta a w}} \end{aligned} \right) \hat{i}$$

HH1 - aoLL ê. PSetk êê FullSimplify

$-0.0567171 < cr < 0.209917$

$$\begin{aligned} \text{po3} &= H\text{co} + 1 - xL \hat{e}^2 + xy \hat{e} H^2 Hw y + H1 - wL xLL; \\ \text{pg3} &= HcgL \hat{e}^2 + xy \hat{e} H^2 Hw y + H1 - wL xLL; \end{aligned}$$

$$\begin{aligned} \text{phi33} @ \text{po}_, \text{pg}_D &:= Hw * H1 - H\text{po} - \text{pg}L \hat{e} H1 - xLL + 0L * H\text{po} - \text{co}L + \\ &Hw * HH\text{po} - \text{pg}L \hat{e} H1 - xL - H\text{pg} \hat{e} HxLLL + H1 - wL * H1 - \text{pg} \hat{e} yLL * H\text{pg} - \text{cg}L \end{aligned}$$

$$\text{Profit3} = \text{phi33} @ \text{po3}, \text{pg3D}$$

$$\text{Profit2} = - \frac{Hy - \text{cg}L^2 H - 1 + wL}{4y} + \frac{1}{4} H - 1 + \text{co}L^2 w$$

$$\text{\$Assumptions} = 0 < w < 1 \ \&\& \ 0 < x < 1 \ \&\& \ 1 < y < 2;$$

$$\text{Reduce} @ \text{Profit3} < \text{Profit2} \ \&\& \ \text{\$AssumptionsD} \hat{e} \hat{e} \text{FullSimplify} \hat{e} \hat{e} \text{TraditionalForm}$$

$$\begin{aligned} w \left| 1 - \frac{-\frac{cg}{2} + \frac{1}{2} H1 + \text{co} - xL}{1 - x} \right| & \left| -\text{co} + \frac{1}{2} H1 + \text{co} - xL + \frac{xy}{2 HH1 - wLx + w yL} \right| + \\ \left| -\frac{cg}{2} + \frac{xy}{2 HH1 - wLx + w yL} \right| & \\ w \left| \frac{-\frac{cg}{2} + \frac{1}{2} H1 + \text{co} - xL}{1 - x} - \frac{\frac{cg}{2} + \frac{xy}{2 HH1 - wLx + w yL}}{x} \right| & + H1 - wL \left| 1 - \frac{\frac{cg}{2} + \frac{xy}{2 HH1 - wLx + w yL}}{y} \right| \end{aligned}$$

$$\frac{1}{4} H - 1 + \text{co}L^2 w - \frac{H - 1 + wL H - \text{cg} + yL^2}{4y}$$

$$\frac{\text{cg} + Hx - yL \sqrt{\frac{HwLHxLx}{-wx + wy + x}}}{x} < \text{co} < \frac{\text{cg} + Hy - xL \sqrt{\frac{HwLHxLx}{-wx + wy + x}}}{x}$$

H*CASE Bargain Green*L

$$\text{phi4 @po_ , pg_D} = \text{Hpg} - \text{cgL} \left(\left(1 - \frac{\text{pg } 1}{\text{+ ag beta}} \right) \text{H1} - \text{wL} + \left(1 - \frac{\text{pg}}{\text{1-aobeta}} \right) \text{w} \right);$$

$$\text{pgI4} = \frac{-\text{H}-1 + \text{ao betaL H1} + \text{ag beta} + \text{cgL} + \text{Hag} + \text{aoL beta cg w}}{2 \text{H1} + \text{ao beta H}-1 + \text{wL} + \text{ag beta wL}};$$

$$\text{poI4} = \text{FullSimplify@pgI4} + \text{ao betaD};$$

$$\text{ProfitI4} = \text{FullSimplify@phi4@poI4, pgI4DD}$$

$$\text{pgI4cvcr} =$$

$$\frac{-\text{H}-1 + \text{ao betaL H1} + \text{ag beta} + \text{cgL} + \text{Hag} + \text{aoL beta cg w}}{2 \text{H1} + \text{ao beta H}-1 + \text{wL} + \text{ag beta wL}} \hat{e}. \text{co } \emptyset \text{ cv} + \text{k H1} + \text{betaL}^2 \hat{e}.$$

$$\text{cg } \emptyset \text{ H1} - \text{betaL cv} + \text{beta cr} + \text{k H1} + \text{betaL}^2;$$

$$\text{poI4cvcr} = \text{FullSimplify@pgI4cvcr} + \text{ao betaD } \hat{e}. \text{co } \emptyset \text{ cv} + \text{k H1} + \text{betaL}^2 \hat{e}.$$

$$\text{cg } \emptyset \text{ H1} - \text{betaL cv} + \text{beta cr} + \text{k H1} + \text{betaL}^2;$$

$$\text{ProfitI4cvcr} = \text{FullSimplify@phi4@poI4cvcr, pgI4cvcrDD} \hat{e}. \text{co } \emptyset \text{ cv} + \text{k H1} + \text{betaL}^2 \hat{e}.$$

$$\text{cg } \emptyset \text{ H1} - \text{betaL cv} + \text{beta cr} + \text{k H1} + \text{betaL}^2$$

$$\frac{-\text{H}-1 + \text{ao betaL H1} + \text{ag beta} - \text{cgL} + \text{Hag} + \text{aoL beta cg wL}^2}{\text{H4 H1} + \text{ag betaL H}-1 + \text{ao betaL H1} + \text{ao beta H}-1 + \text{wL} + \text{ag beta wL}}$$

$$\text{IH}-\text{H}-1 + \text{ao betaL H}-1 + \text{cv} + \text{k} + \text{beta H}-\text{ag} + \text{cr} - \text{cv} + \text{H2} + \text{betaL kLL} +$$

$$\text{Hag} + \text{aoL beta Hcv} + \text{k} + \text{beta Hcr} - \text{cv} + \text{H2} + \text{betaL kLL wL}$$

$$\text{I}-\text{H}-1 + \text{ao betaL I1} + \text{cv} + \text{k} - 2 \text{I beta cr} + \text{H1} - \text{betaL cv} + \text{H1} + \text{betaL}^2 \text{kM} +$$

$$\text{beta Hag} + \text{cr} - \text{cv} + \text{H2} + \text{betaL kLM} + \text{Hag} + \text{aoL beta I cv} + \text{k} -$$

$$2 \text{I beta cr} + \text{H1} - \text{betaL cv} + \text{H1} + \text{betaL}^2 \text{kM} + \text{beta Hcr} - \text{cv} + \text{H2} + \text{betaL kLM wMM} \hat{e}$$

$$\text{H4 H1} + \text{ag betaL H}-1 + \text{ao betaL H1} + \text{ao beta H}-1 + \text{wL} + \text{ag beta wL}$$

```

phi44 @po_, pg_D = Hpg - cgL  $\left( \left( 1 - \frac{pg}{y} \right) H1 - wL + \left( 1 - \frac{pg}{x} \right) w \right);$ 
pg4 = cg ê 2 + x y ê H2 H w y + H1 - wL xLL;
po4 = FullSimplify@pg4 + aobetaD;
Profit4 = FullSimplify@phi44@po4, pg4DD

```

```

y = 1 + ag beta
x = 1 - ao beta
Profitttt = FullSimplify@phi3@po4, pg4DD
Profit4 - Profitttt ê FullSimplify

```

$$-\frac{HcgH-1+wLx-cgwy+xyL^2}{4xyHH-1+wLx-wyL}$$

```
1 + ag beta
```

```
1 - ao beta
```

```
-HH-1+aobetaLH1+agbeta-cgL+Hag+aoLbeta cgwL^2
```

$$H4H1+agbetaLH-1+ao betaLH1+ao betaH-1+wL+ag beta wLL$$

```
0
```

```
FullSimplifyB
```

$$aobeta + cg + - \left(H-1 + aobetaL \left(-H-1 + coL^2 + \frac{Hag + aoL^2 beta^2 H-1 + wL}{1 - aobeta + Hag + aoL beta w} \right) \right) > 1 \&\&$$

$$1 + - \left(H-1 + aobetaL \left(-H-1 + coL^2 + \frac{Hag + aoL^2 beta^2 H-1 + wL}{1 - aobeta + Hag + aoL beta w} \right) \right) > ao beta + cg ê.$$

$$co \emptyset cv + k H1 + betaL^2 ê. cg \emptyset H1 - betaL cv + beta cr + k H1 + betaL^2 F$$

```
$Aborted
```

```
ManipulateB ShowB
```

```

RegionPlot@Hcg - ag beta <= co <= cg ê H1 + ag betaLL ê. co ê cv + k H1 + betaL^2 ê.
cg ê H1 - betaL cv + beta cr + k H1 + betaL^2 &&
H1 - betaL cv + beta cr + k H1 + betaL^2 <= 1 + ag beta
&&
cv <= 1 - k H1 + betaL^2, 8cr, 0, 1<,
8cv, 0, 1<, PlotStyle ê 8Lighter@PinkD<, Frame ê NoneD,

```

```
RegionPlotB
```

```
Hcg ê H1 + ag betaL <= co <= cg ê H1 - ao betaL + beta Hag + aoL ê H1 - ao betaLL ê.
```

```

co Ø cv+k H1+betaL^2 ê. cg Ø H1-betaL cv+beta cr+k H1+betaL^2
&&
H1-betaL cv+beta cr+k H1+betaL^2 <= 1+agbeta
&&
cv <= 1-k H1+betaL^2
&&
((( (cg-HHag+aoL betaL SqrtB  $\frac{aobetaH1-wLH1-aobetaL}{H1-aobeta+Hag+aoL beta wL}$  F) i
      H1 - ao betaL <= co <= (cg+HHag+aoL betaL
      SqrtB  $\frac{aobetaH1-wLH1-aobetaL}{H1-aobeta+Hag+aoL beta wL}$  F) i H1 - ao betaL »»
      1 - ao beta - Sqrt@H1 - ao betaL HH1 - coL^2 + HHag+aoL betaL^2
      H1 - wL ê H1 - ao beta + Hag+aoL beta w LLD <= cg <=
      1 - ao beta + Sqrt@H1 - ao betaL HH1 - coL^2 + HHag+aoL betaL^2
      H1 - wL ê H1 - ao beta + Hag+aoL beta w LLD))) ê.

co Ø cv+k H1+betaL^2 ê. cg Ø H1-betaL cv+beta cr+k H1+betaL^2,
8cr, 0, 1<, 8cv, 0,
1<,
PlotStyle Ø
8White<, Frame Ø
NoneF,

RegionPlotBHcgêH1-ao betaL+H1-wLHaobetaLHao+agL
      beta ê H1 - ao beta + Hag + aoL beta w L <= co <= cg + aobetaL ê.
co Ø cv+k H1+betaL^2 ê. cg Ø H1-betaL cv+beta cr+k H1+betaL^2 &&
((( (cg-HHag+aoL betaL SqrtB  $\frac{aobetaH1-wLH1-aobetaL}{H1-aobeta+Hag+aoL beta wL}$  F) i
      H1 - ao betaL >= co »» co >= (cg+HHag+aoL betaL
      SqrtB  $\frac{aobetaH1-wLH1-aobetaL}{H1-aobeta+Hag+aoL beta wL}$  F) i H1 - ao betaL))) ê.

co Ø cv+k H1+betaL^2 ê. cg Ø H1-betaL cv+beta cr+k H1+betaL^2 &&
H1-betaL cv+beta cr+k H1+betaL^2 <= 1+agbeta
&&
cv <= 1-k H1+betaL^2, 8cr, 0, 1<,
8cv, 0, 1<, PlotStyle Ø 8Darker@GreenD<, Frame Ø NoneF,

RegionPlot@Hcg+ao beta <= co <= 1L ê. co Ø cv+k H1+betaL^2 ê.
cg Ø H1-betaL cv+beta cr+k H1+betaL^2 &&
      HH1 - ao beta - Sqrt@H1 - ao betaL HH1 - coL^2 + HHag+aoL betaL^2
      H1 - wL ê H1 - ao beta + Hag+aoL beta w LLD >= cg »»
      cg >= 1 - ao beta + Sqrt@H1 - ao betaL HH1 - coL^2 + HHag+aoL betaL^2
      H1 - wL ê H1 - ao beta + Hag+aoL beta w LLDLL ê.
co Ø cv+k H1+betaL^2 ê. cg Ø H1-betaL cv+beta cr+k H1+betaL^2 &&
H1-betaL cv+beta cr+k H1+betaL^2 <= 1+agbeta
&&
cv <= 1-k H1+betaL^2, 8cr, 0, 1<, 8cv, 0, 1<, Mesh Ø 80,
MeshFunctions Ø 802 &<, MeshShading Ø 8Green, None<, Frame Ø NoneD,

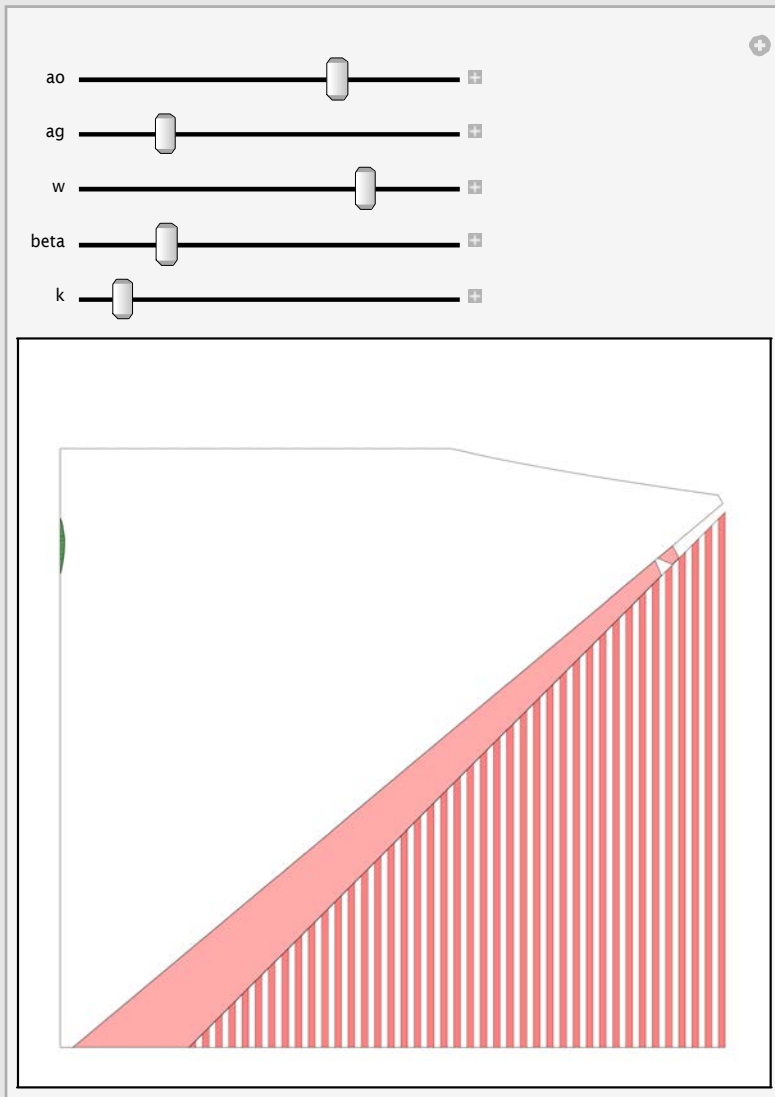
```

```

RegionPlot@H0 <= co <= cg - ag beta L ê. co Ø cv + k H1 + beta L^2 ê.
cg Ø H1 - beta L cv + beta cr + k H1 + beta L^2
&&
H1 - beta L cv + beta cr + k H1 + beta L^2 <= 1 + ag beta
&&
cv § 1 - k H1 + beta L^2, 8cr, 0, 1<, 8cv, 0, 1<,
AxesLabel Ø Automatic, Axes Ø True, Frame Ø None, Mesh Ø 80,
MeshFunctions Ø 801 &<, MeshShading Ø 8Pink, None<DF,

8ao, 0, 1<, 8ag, 0, 1<, 8w, 0, 1<, 8beta, 0, 1<, 8k, 0, 1<F

```



H*prove the relation between q1 and q2*L

$$q1 = H a o + a g L \hat{e} H 1 - a o L$$

$$q2 = H a o \beta H 1 - w L H a o + a g L H 1 - a o \beta a L L \hat{e} H H 1 - a o L H 1 - a o \beta a + \beta a w H a o + a g L L L$$

$$q3 = H 1 - w L a o \beta a H 1 - a o \beta a L \hat{e} H 1 - a o \beta a + \beta a w H a o + a g L L$$

$$\frac{a g + a o}{1 - a o}$$

$$\frac{a o H a g + a o L \beta a H 1 - a o \beta a L H 1 - w L}{H 1 - a o L H 1 - a o \beta a + H a g + a o L \beta a w L}$$

$$\frac{a o \beta a H 1 - a o \beta a L H 1 - w L}{1 - a o \beta a + H a g + a o L \beta a w}$$

```
$Assumptions = 0 < w < 1 && 0 < a o < 1 && 0 < a g < 1 && 0 < beta < 1 && c r > 0 && k ≠ 0;
Reduce@q1 > q2 && $AssumptionsD êê FullSimplify
Reduce@Hcr+aokH1+betaL^2LêH1-aoL+q1>cr+ao && $AssumptionsDêê
FullSimplify
Reduce@q1 > ao && $AssumptionsD êê FullSimplify
Reduce@q1 Sqrt @q3D > q2 && $AssumptionsD êê FullSimplify êê TraditionalForm
Reduce@q1 Sqrt @q3D < ao && $AssumptionsDêê FullSimplify
Reduce@q1 < 1 -kH1+betaL^2&& $AssumptionsDêê FullSimplify
```

True

True

True

True

$$H a g + a o L^2 \beta a \S H - 1 + a o L^2 a o \gg$$

$$I H - 1 + a o L^2 a o < H a g + a o L^2 \beta a \&\& I H - 1 + a o \beta a L I - H - 1 + a o L^2 a o + H a g + a o L^2 \beta a M M \ddot{e}$$

$$H H a g + a o L \beta a H a g H - 1 + a o \beta a L + a o H - 2 + a o H 2 - a o + \beta a L L L L L <$$

$$w M \gg a g + a o + a o^3 \hat{e} 2 \S \sqrt{a o}$$

$$a g + 2 a o < 1 + H - 1 + a o L H 1 + \beta a L^2 k$$

```
pgI3cvcrêH1-ao betaL < poI3cvcr ê. cr Ø 0.2 ê. ao Ø 0.2 ê. ag Ø 0.8 ê. k Ø 0.1 ê.
w Ø 0.5 ê. beta Ø 0.2 êê FullSimplify
```

1. cv > 0.308642

H*DOUBLE CHECK*L

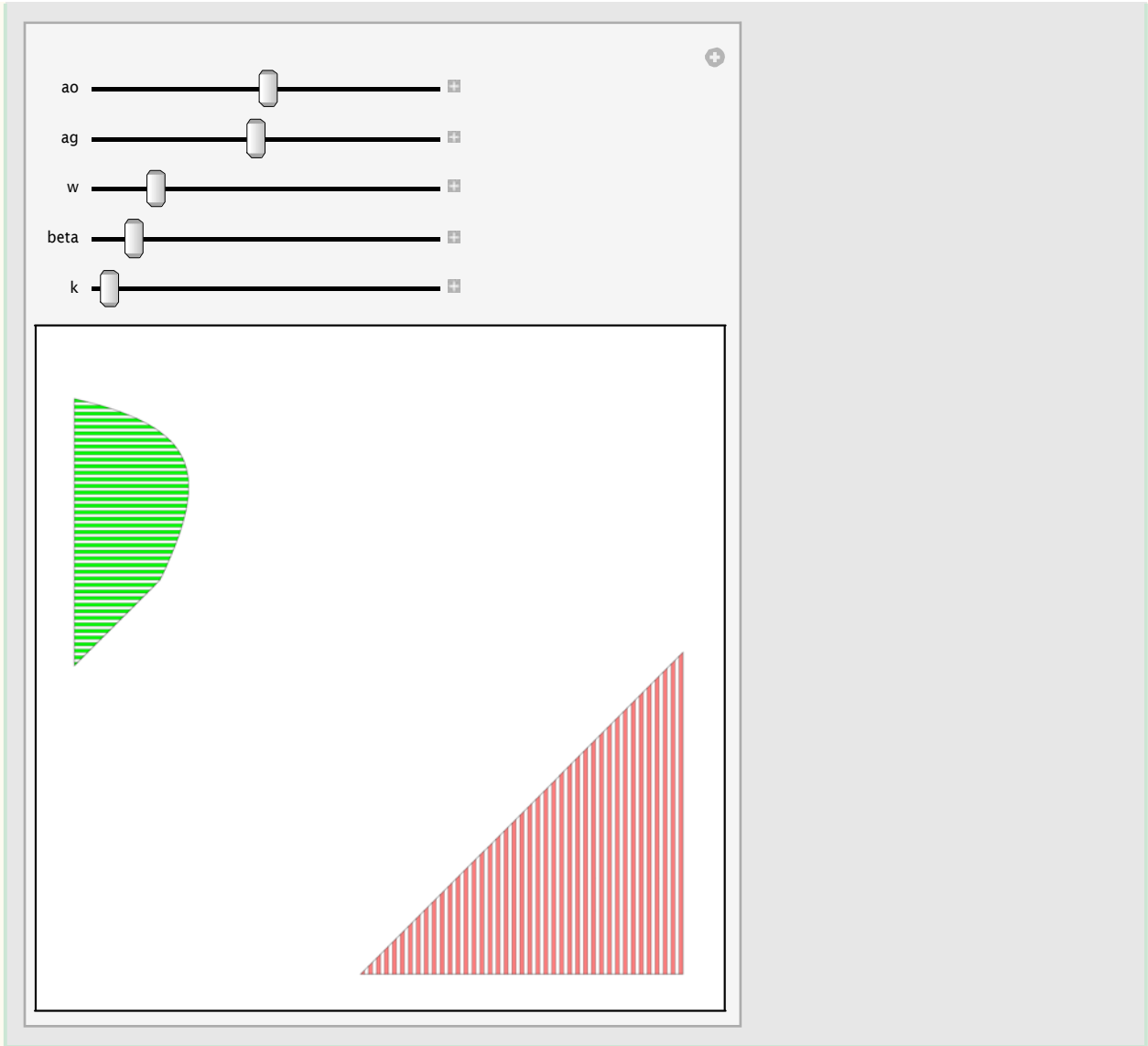
```

Manipulate@ Show@
  RegionPlot@
    Hcg + ao beta <= co <= 1L ê. co Ø cv + k H1 + beta L^2 ê. cg Ø H1 - beta L cv + beta cr +
      k H1 + beta L^2 && 1 - ao beta - Sqrt@H1 - ao beta L HH1 - co L^2 +
      HHag + ao L beta L^2 H1 - w L ê H1 - ao beta + Hag + ao L beta w LLD >= cg ê.
      co Ø cv + k H1 + beta L^2 ê. cg Ø H1 - beta L cv + beta cr + k H1 + beta L^2 &&
      H1 - beta L cv + beta cr + k H1 + beta L^2 <= 1 + ag beta
      &&
      cv <= 1 - k H1 + beta L^2 , 8cr, 0, 1<, 8cv, 0, 1<, Mesh Ø 80,
      MeshFunctions Ø 8O2 &<, MeshShading Ø 8Green, None<, Frame Ø NoneD,

  RegionPlot@H0 <= co <= cg - ag beta L ê. co Ø cv + k H1 + beta L^2 ê.
    cg Ø H1 - beta L cv + beta cr + k H1 + beta L^2
      &&
      H1 - beta L cv + beta cr + k H1 + beta L^2 <= 1 + ag beta
      &&
      cv § 1 - k H1 + beta L^2 , 8cr, 0, 1<, 8cv, 0, 1<,
      AxesLabel Ø Automatic, Axes Ø True, Frame Ø None, Mesh Ø 80,
      MeshFunctions Ø 8O1 &<, MeshShading Ø 8Pink, None<DD,

  8ao, 0, 1<, 8ag, 0, 1<, 8w, 0, 1<, 8beta, 0, 1<, 8k, 0, 1<D

```



H* taking care of UCT*L
 H* comparing profits of UCT with BG since they overlap in feasible region *L

profitUCT = phi2@poUCTLcG, pgUCTLcGD ê. x Ø 1 - aobeta ê. y Ø 1 + agbeta

\$Assumptions = 0 < w < 1 && 0 < ao < 1 && 0 < ag < 1 &&
 0 < beta < 1 && co ¥ cg && 0 <= co § 1 && 0 <= cg § 1 + ag beta;
 Reduce@Profit4 < profitUCT && \$AssumptionsD

wI1 - HH1 - aobetaLH1 + agbeta + cgLH1 - wL + H1 + agbetaLH1 + coLwLë
 I2 IH1 - aobetaL²H1 - wL + H1 + agbetaLwMMM
 I - co + HH1 - aobetaLH1 + agbeta + cgLH1 - wL + H1 + agbetaLH1 + coLwLë
 I2 IH1 - aobetaL²H1 - wL + H1 + agbetaLwMMM + H1 - wL
 I - cg + HH1 - aobetaLHH1 - aobetaLH1 + agbeta + cgLH1 - wL + H1 + agbetaLH1 + coLwLë
 I2 IH1 - aobetaL²H1 - wL + H1 + agbetaLwMMM
 I1 - HH1 - aobetaLHH1 - aobetaLH1 + agbeta + cgLH1 - wL + H1 + agbetaLH1 + coLwLë
 I2 H1 + agbetaLIH1 - aobetaL²H1 - wL + H1 + agbetaLwMMM

Balancing Production and Distribution in Paper Manufacturing

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Balancing Production and Distribution in Paper Manufacturing

Abstract

A paper manufacturing plant minimizes its production cost by using long production runs that combine the demands from its various customers. As jobs are completed, they are released to distribution for delivery. Deliveries are made by railcars, each of which is dedicated to one customer. Long production runs imply that maximizing railcar utilization requires holding the cars over several days or holding completed jobs within the loading facility. Each of these methods imposes a cost onto the distribution function. We find how distribution can minimize its cost, given production's schedule. We then consider the problem of minimizing the company's overall cost of both production and distribution. A computational study using general data illustrates that the distribution cost is reduced by 25.80% through our proposed scheme, and that the overall cost is reduced an additional 4.40% through our coordination mechanism. An optimal algorithm is derived for a specific plant's operations.

Key words: *coordination, distribution, bin-packing, non-bipartite matching, paper industry*

1 Introduction

Despite the rise of e-commerce and predictions of ubiquitous paperless offices, the paper industry is still a major contributor to the world's economy. The total revenue generated by the 100 largest forest and paper companies in the world for 2010, 2011, and 2012 were \$322.8 billion, \$353.8 billion, and \$354.2 billion, respectively (PwC 2013). Worldwide, there are approximately 10,000 paper and paperboard mills in operation, producing about 300 million metric tons of paper and paperboard each year (TAPPI 2014). The paper manufacturing subsector in the United States has over 500 mills in operation, employs 377,800 (Bureau of Labor Statistics 2014), and produces about 87 million metric tons of paper and paperboard (TAPPI 2014). Europe has 993 mills in operation, employs 221,537, and produces 91 million metric tons of paper and paperboard (European Pulp and Paper Industry 2014).

Paper production is a quintessential capital-intensive continuous process that uses a very large, very expensive, highly-specialized machine that produces non-stop. A typical paper plant produces *reels* of a fixed width (called the *trim*) that corresponds to the width of the machine. Each reel is rewound into four *sets*, so these sets have the same width as the trim and approximately one-half of the diameter of the reel. As a set is rewound, a *slitter* cuts it into typically four to seven *finals* of varying smaller widths (see Figure 1). These finals, which average over 2.5 tons, are used to satisfy customers' orders. A customer's order contains many finals, each of which is specified by its width and its *basis weight*. Basis weights measure the actual weight in pounds of one ream of paper. The basis weight is a characteristic of a set, so each final that is cut from a given set has the same basis weight. Technical properties of the machines require that transitions between basis weights be only between adjacent basis weights

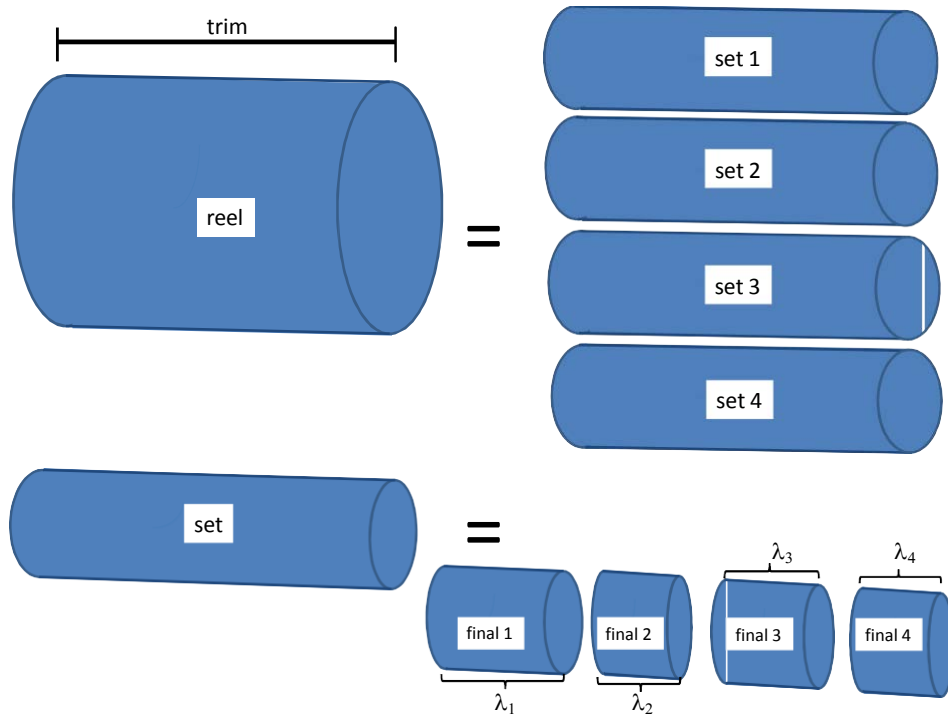


Figure 1: Demonstration of the terms *reels*, *set*, and *final*

and that this transition be so slow that an entire set, called a *transition set*, is produced in the time (approximately thirty minutes) that the basis weight changes from the first basis weight to the second one. Customers generally will not buy the paper produced in a transition set because its basis weight varies between these two standard production basis weights.

Production's prime objective is to minimize pulp usage. It does this by minimizing the number of transition sets plus the number of standard production sets. Obviously, minimizing the number of transitions between basis weights minimizes the number of transition sets. The number of standard production sets is minimized by pooling all finals (from all customer orders), separating them by basis weight, then assigning the finals to sets. Naturally, the total width of the finals in a set cannot exceed the trim. This assignment is Production's most important decision for minimizing its cost, and it requires solving a Bin-packing problem (defined in Appendix A) for each basis weight. (We capitalize *Production* and *Distribution* when referring to the departments within our client company.) Finals are transferred to Distribution as they are completed.

Distribution regroups finals by customer and loads them onto railcars for delivery. Each railcar is

dedicated to one customer. Distribution wants to minimize its expenses by minimizing the number of railcars used. However, several days of production may be required to fill a customer's car, since production sets are created with no consideration of to which customer a final belongs. Thus, Distribution must weigh the cost of poor railcar utilization against that of storing completed finals.

Because optimizing Production has been studied extensively for the paper industry, we focus mainly on Distribution's problem. The contributions of this study are both practical and theoretical. For practitioners,

- We develop a sequence of procedures that allows Distribution for a general paper factory to reduce its costs by 25.80% when compared to our client's current practice.
- We propose a method for cooperation between Production and Distribution and demonstrate how it can reduce the company's overall costs by an additional 4.40%.

In summary, we show how the company can reduce expenses by over 30% by changing its methods for scheduling railcars and by scheduling Production to reduce Distribution's cost. From a theoretical perspective,

- We prove the optimality of some of our procedures designed for Distribution.
- We demonstrate that our algorithm finds an optimal distribution plan for our client plant and that First-Fit Decreasing is optimal for the Bin-packing problem if all items are larger than one-third of the bin size (i.e., railcar height).

After the literature review (Section 2), the general model for both Production and Distribution is described in Section 3. Section 4 presents our processes for reducing Production's and Distribution's individual costs when the two act independently. Section 5 describes a method to reduce the overall system's cost: Production changes its schedule so that Distribution can operate more efficiently; this allows Distribution to reduce its cost by more than the increase in Production's cost. Section 6 focuses on a particular company with which we have worked. Section 7 reports on our computational study that determines the savings realized from our distribution algorithms and from cooperation; it also details how these savings are affected by the system's parameters. Section 8 concludes this study and provides suggestions for future work.

2 Literature Review

We place this study within the literature by examining two different streams of research. The first addresses the paper manufacturing industry in particular and continuous process industries in general. The second is the coordination of production and distribution via scheduling in systems with minimal inventory between the two.

Keskinocak et al. (2002) is a major research work concerning the paper industry, along with its practice-oriented companion paper Murthy et al. (1999). These researchers created a large agent-based decision support architecture that allocates orders to mills, then to production lines within those mills. Their system forms production runs and sequences them on each machine, determines how to cut the resulting reels into finals (sets are not considered), then plans their loading for shipment. The system tries to balance multiple objectives, including minimizing weighted tardiness, minimizing transitions between product types, minimizing trim waste from poor allocation of finals to reels, minimizing transportation cost, load balancing, and minimizing deviations from ordered quantities. In contrast, our problem comes from a single plant with one production line. This smaller scale allows us to meet many of these same objectives concurrently by calculating each objective's cost and minimizing the sum of these costs. By combining the multiple objectives into one, we generate better solutions because the objectives can all be evaluated on the same metric, which leads to greater precision with less computational expense. Additionally, we examine the distribution problem in greater detail. This includes scheduling each railcar's arrival and departure to minimize storage and handling costs and coordinating Production and Distribution to minimize overall cost.

Menon and Schrage (2002) focus on order allocation to plants. Hence, unlike our study, they do not consider production details such as scheduling or the differing basis weights of paper, and they ignore distribution completely. Weigel et al. (2009) seek new strategies for allocating fibre types to process streams to benefit Canadian pulp and paper producers. Lehoux et al. (2011) address the coordination of a producer and a merchant through Collaborative Planning, Forecasting, and Replenishment (CPFR) in the paper industry. They consider various incentives and their effectiveness in coordinating the supply chain, but the details of paper production are merely background with little impact on the results.

Research in other continuous process industries has addressed the integration of production and distribution. Geismar et al. (2007) consider the problem for an industrial chemical with a short shelf life, so no inventory is carried between production and distribution. Because the product is homogeneous,

production scheduling is simpler than it is in our study, though the shelf life is a binding constraint on the overall schedule. Customers orders are combined into multiple milk runs, and the objective is to minimize the makespan for completing all deliveries. Grossman (2005) studies enterprise-wide optimization for the various functions either within a single firm or across a supply chain via integration of information and decision making through modern information technology. Chen et al. (2003) examine techniques for fair profit distribution among the different parties in such a supply chain. Vila et al. (2006) examine the softwood lumber industry to develop a generic methodology for designing a global production-distribution network for process industries. Other works on the development of supply chain infrastructure for process industries include Papageorgiou (2009) and Shah (2005). These studies focus on strategic issues rather than operational scheduling ones.

The past twenty years have seen an upsurge in the study of the coordination of production and distribution in systems that hold little or no inventory between these two functions. The integration is generally done at the operational level through scheduling. Chen (2010) provides an excellent overview of this research stream. We now summarize a few works that closely relate to our current project.

Chandra and Fisher (1994) minimize the total cost of setups, transportation, and inventory for a system producing multiple products across multiple periods. They determine the conditions under which the value of coordination increases and show that much of the savings comes from moving delivery from period t to period $t-1$ in order to fill the last truck of period $t-1$. We use a variant of this last idea when packing railcars with finished paper and also detail the parameter values for which coordination is more valuable. Chen and Pundoor (2006) use order assignment and scheduling to minimize lead time plus total production and delivery costs for a system with multiple overseas plants and a single domestic distribution center. They examine how to batch orders efficiently for shipping, as is required in our study.

Dawande et al. (2006) demonstrate the value of coordination by first solving the production and the distribution problems separately, then solving the integrated problem. Their objectives are to minimize production setups, to minimize the maximum lateness of deliveries, and to minimize the amount of inventory held between production and delivery. Li and Vairaktarakis (2007) also compare the combined solution to the sum of the two individual solutions, but their objectives are to minimize flow time and to minimize the number of shipments and the distances covered, plus customers' waiting costs. Rizk et al. (2008) demonstrate the savings realized by an integrated solution for a system with a predetermined

production sequence, multiple transportation modes, and unlimited finished goods inventory. Our study uses this technique of comparing the coordinated solution to the uncoordinated solution. However, our current project is distinguished from all previous works of this research stream by its more complex production (combining finals into sets) and loading environments (fitting completed finals onto railcars), each of which requires solving a Bin-packing problem to maximize efficiency.

3 The Model

Section 1 described the production process from reels to sets to finals. For consistency with the production planning literature, we call the finals *jobs*. The machine can produce Ω discrete basis weights. Production prefers manufacturing several sets of a given basis weight before transitioning to an adjacent basis weight, as this reduces the number of transitions. An example of Production's schedule for basis weights produced during a planning horizon is shown in Figure 2. This figure shows monotonically increasing basis weights; the succeeding horizon would most likely have monotonically decreasing basis weights so that there is minimal time spent on transitions between the horizons. Monotonicity is preferred within a horizon because it ensures that each basis weight will be visited at most once during the horizon, i.e., at most $\Omega - 1$ transition sets will be produced during the horizon if such a schedule is used. We formally state Production's problem as follows:

Problem P: Assume we are given J jobs, indexed $j = 1, \dots, J$. Each job has a width λ_j and a basis weight that is one of Ω discrete basis weights $w_1, w_2, \dots, w_\Omega$, where $w_1 < w_2 < \dots < w_\Omega$. Jobs must be combined into sets. All jobs in a particular set must have the same basis weight, and the widths of the jobs in a set cannot total more than given parameter τ (i.e., the trim). Sets are processed sequentially on one machine. Two consecutive sets can differ by at most one step in basis weight, i.e., if set s has basis weight w_i (denoted $W(s) = w_i$), then set $s + 1$ must have basis weight w_{i-1}, w_i or w_{i+1} ($W(s + 1) \in \{w_{i-1}, w_i, w_{i+1}\}$). If $W(s) \neq W(s + 1)$, then a *transition* occurs between the production of set s and set $s + 1$. Production's objective is to assign all jobs to sets and to order the resulting sets in a way that minimizes the number of sets plus the number of transitions. □

Each manufactured job is transferred to Distribution's loading area, where it is either loaded onto a railcar or stored in the loading area if no car for the job's customer is currently at the loading facility. Storing a job inside the loading area rather than loading it immediately onto a car requires additional handling, which implies a non-trivial expense (denoted ϕ) because these items are very heavy. This

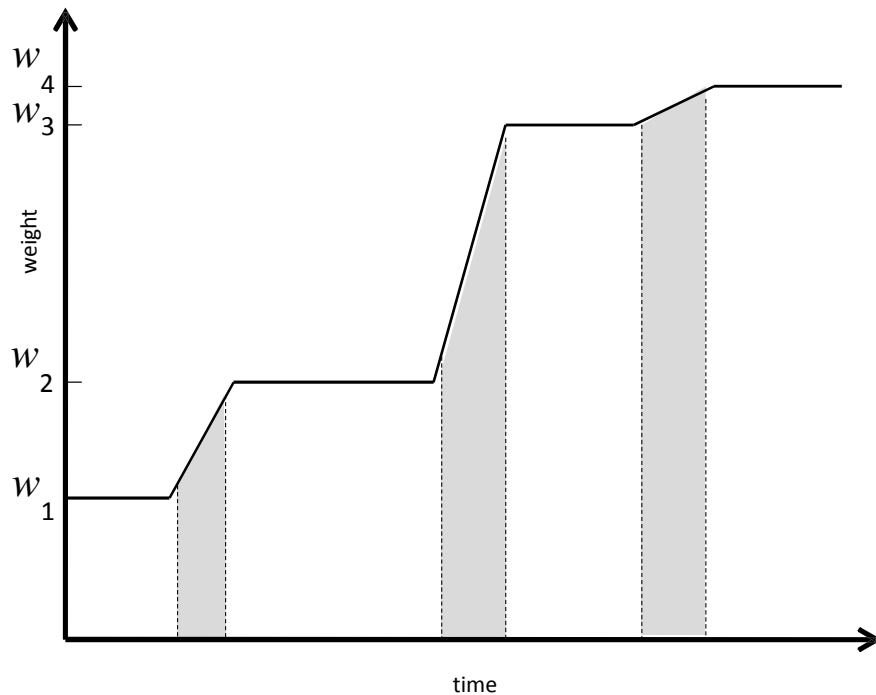


Figure 2: Example schedule of basis weights w_1, w_2, w_3, w_4 produced in one planning horizon. Shaded areas are transitions. The succeeding horizon would produce basis weights in decreasing order.

additional handling cost is assessed per job *one time*, not once per time period, because it covers the labor and equipment required to physically handle the completed job a second time (obviously, all jobs must be handled at least once to be loaded onto a railcar, so we need not consider the cost for the actual loading). The time period in question is one day, so the value of a traditional inventory holding cost (interest, deterioration, insurance, etc.) is trivial.

There are several reasons that each railcar carries jobs only for a specific customer. Having jobs for more than one customer on the same railcar would increase the handling required at the early destinations, because jobs for those destinations may have been stacked under jobs for later destinations. This could be avoided by changing the order of loading at the factory, but that, too, would require extra handling, unless the jobs arrived from Production in the preferred order, which is highly improbable. Additionally, because unloading the paper from a car requires a non-trivial amount of time, the train leaves the appropriate railcars at the customer's facility then continues to other customers. Thus, if a car contains jobs for more than one customer, later customers would be subject to long and varied transportation lead times because the car could not depart to serve those customer until another train

departs from this location. Furthermore, travel to those customers would be with a less-than-full car; this would greatly reduce the tons per mile, which is a key measure of efficiency and economic viability for rail usage.

The availability of railcars is not a constraint, as they are ordered in advance, based on Production's schedule. Distribution may choose to have a car arrive days after some of the jobs for its intended customer have been produced because Distribution suffers a *demurrage* charge of χ each time that a car is held overnight, and a handling charge for a small number of jobs may be less than one night's demurrage. Alternatively, if the handling charge were greater, then Distribution could request that the car arrive earlier, then hold it overnight to combine the production from two (or more) consecutive days into one car.

Because all jobs have the same diameter, they are stacked in columns inside the railcars (see Figure 3). Let μ be the number of such columns that a car can hold and η be the height of the car, which determines the maximum height of each column. (The railcars used by our client company have two options for μ and two for η . We use μ and η in our development to maintain generality.) Distribution's objective is to minimize its total cost, which is the sum of the costs of the railcars used (ψ per car), of handling the jobs stored in the loading facility, and of holding railcars overnight. We formally state Distribution's problem as follows:

Problem D: Assume we are given J jobs, indexed $j = 1, \dots, J$. Each job has a customer, a width λ_j , and a production date δ_j . All dates are integers representing days of the planning horizon. Jobs must be sorted by customer, so all remaining requirements must be performed for each customer separately. Jobs are combined into columns such that the widths of the jobs in a column cannot total more than given parameter η . Columns are then combined into railcars such that the number of columns in each car is at most μ . Each railcar used incurs a cost ψ . Let \mathbf{J}_r be the set of jobs on car r . Car r cannot depart before $\max_{j \in \mathbf{J}_r} \delta_j$. Car r 's arrival date a_r is a decision variable, and $\min_{j \in \mathbf{J}_r} \delta_j \leq a_r \leq \max_{j \in \mathbf{J}_r} \delta_j$. Distribution suffers a demurrage cost χ for each day that a railcar is kept at the facility beyond its arrival date: $(\max_{j \in \mathbf{J}_r} \delta_j - a_r)\chi$ for each car r . For each job j that is produced before its car arrives ($\delta_j < a_r, j \in \mathbf{J}_r$), a handling cost of ϕ is incurred. Distribution's objective is to load all jobs onto cars and to schedule each car's arrival to minimize its total cost arising from the number of cars used, the cars kept beyond their arrival days, and the number of jobs produced before their cars arrive. \square

To aid the reader, we now summarize the parameter definitions:

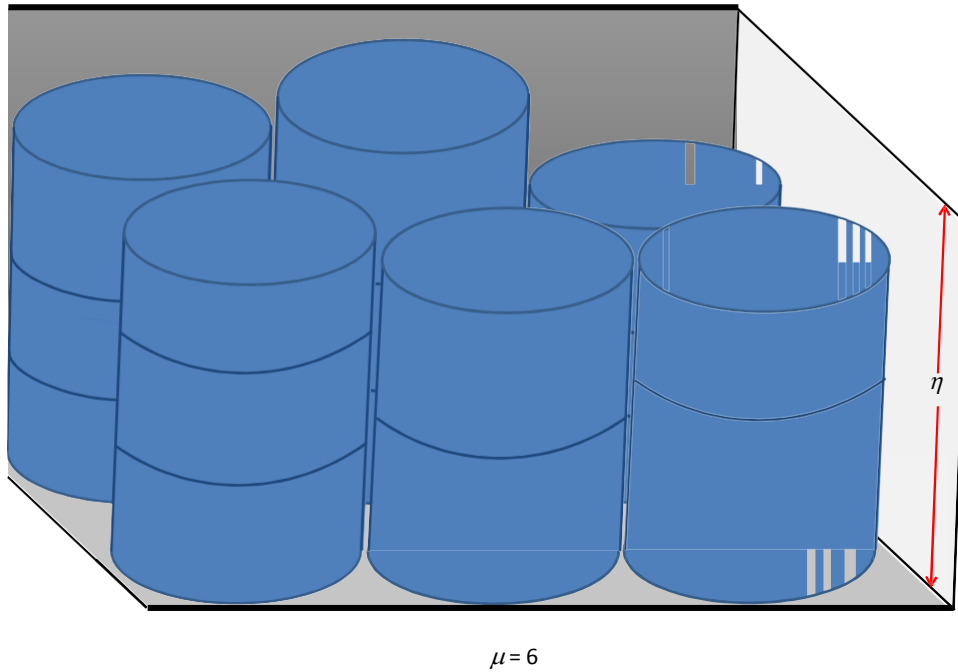


Figure 3: Jobs loaded in a railcar

Parameters:

ψ : cost per railcar used

ϕ : cost of handling one job that is stored in the loading area

χ : cost of holding one railcar overnight (demurrage)

η : maximum height of a column in a railcar

μ : number of columns that fit in a railcar

τ : width of the paper manufacturing machine, called the *trim*

λ_j : width of job j

D : number of days in the planning horizon

D_k : the last day that a job is produced for customer k

K : number of customers

J_k : number of jobs for customer k ; $J = \sum_{k=1}^K J_k$

δ_j : date on which job j is produced (decided by Production, input to Distribution)

4 General Problem 1: No Coordination

We consider the current situation in which each party acts independently. Because Production acts first, it may choose its preferred schedule. This determines the release dates of the jobs to Distribution, which must then react to create a schedule that minimizes its costs.

4.1 Production's Solution

We now explain how Production can minimize the number of sets plus the number of transitions. Creating the minimum number of production sets is a Bin-packing problem, so it is strongly NP-hard (Garey and Johnson 1979). We solve it using the First Fit Decreasing (FFD) Algorithm (described in Appendix A). The proven worst case bound for using FFD (Dósa 2007) implies that the number of sets created for a basis weight is at most $11/9 \cdot OPT + 2/3$, where OPT is the optimum number of sets produced. Most earlier works on paper production (e.g., Gilmore and Gomory 1961, 1963, Murthy et al. 1999, Keskinocak et al. 2002) create sets by formulating a cutting stock problem. That is an appropriate choice for a mill producing a small variety of job widths because the number of cutting patterns would also be relatively small. In contrast, the orders received at the plant in which our project is based have a large variety of widths—almost to the point of appearing random from week-to-week—so the more flexible bin-packing formulation is a better choice.

After each job is assigned to a production set, all sets for each basis weight are produced, either by ascending or descending through the basis weights. One visit per basis weight per planning horizon is preferred because that minimizes the number of transition sets produced. Planning horizons should alternate between ascending or descending so that no transition is required between two consecutive horizons. Within each basis weight, the ordering of the production sets is random, as this ordering has no impact on Production. As sets are completed, they are cut into jobs and transferred to Distribution.

4.2 Distribution's Response

Distribution specifies its delivery schedule for each customer individually. Even though Production is indifferent to the order of sets within each basis weight, Distribution does not request a particular order because determining one that minimizes its cost is an NP-hard problem (equivalent to The Assignment Problem with Side Constraints (Fisher et al. 1986); see Appendix B).

Our client's current practice for loading jobs onto cars is a myopic greedy algorithm with no consideration of Production's schedule. Its key objective is to minimize the number of railcars used, as the

cars' cost dominates the handling and demurrage costs. Jobs are loaded into columns within cars per First-Fit protocol as they are received from Production (without ordering them by size before determining the loading). Inside storage is used only when a car's arrival is unexpectedly delayed, so Distribution currently plans neither for this mode nor for its cost. (In our computational study of Section 7, we assume that a railcar arrives at the plant on the first day that a job it will carry is produced.) If a car's load surpasses a known threshold at the end of the day, e.g., 70% of capacity, then that car is dispatched.

We propose Algorithm *BP_Net* to find a better solution to Distribution's problem. *BP_Net*, too, minimizes the number of cars used, but it does this while also minimizing the handling and demurrage costs by considering all of a customer's jobs in the horizon. Because Distribution knows Production's schedule in advance, *BP_Net* can determine exactly how each car is loaded before Production begins. Thus, this process does not fill car r completely before starting to fill car $r + 1$, then have the last car of the horizon only partially full (as current practice usually does). Rather, *BP_Net* may choose to have empty spaces strategically placed on earlier cars so that they can leave a day earlier in order to avoid a demurrage charge. Similarly, it can store a job in the loading facility overnight, rather than loading it immediately onto a car. This could allow Distribution to delay the arrival of a car, which also reduces demurrage charges.

Since *BP_Net* can determine at the start of the planning horizon into which loading column of what car each job goes, the sequence in which jobs are placed into a car has no bearing. Thus, no benefit is gained by holding a job released early in the day in order to load it later in the day (we assume that cars arrive at the start of the business day). It follows that a job is stored in the facility only if it is to be kept overnight and the railcar to which it is assigned will not arrive until a later date.

Because the optimal assignment of jobs to cars for a customer is also a strongly NP-hard Bin-packing problem with multiple costs, we decompose it into two subproblems. Algorithm *BP_Net* first minimizes the number of cars used by minimizing the number of loading columns by running FFD with item sizes λ_j and bin size equal to the column height η . Second, these columns are assigned to railcars in a way that minimizes demurrage and handling costs.

The number of jobs input to FFD per run has a major effect on the solution. Inputting all of a customer's jobs for the planning horizon would minimize the number of columns created for this customer by FFD, but some columns and, consequently, some cars could have jobs with widely divergent production dates. In such a case, implementing the resulting plan might require holding some jobs for

most of the horizon, which would strain limited inside storage space or cause excessive demurrage charges. Conversely, executing FFD on smaller batches of jobs covering fewer days should require less storage (inside or on cars) but could also lead to less efficient packing and, hence, potentially require more railcars. (Obviously, each such batch contains jobs from consecutive days, e.g., if the planning horizon were one week, the batches could cover days 1 to 3, days 4 to 5, and days 6 to 7.) Therefore minimizing the number of columns required has two components:

1. Partition the days of the planning horizon into batches
2. For each batch, assign its jobs to loading columns by using FFD

Following these two tasks, *BP Net* minimizes handling and demurrage costs by focusing on the railcars:

3. Assign the resulting columns of each batch to railcars
4. Determine when each car should arrive to be loaded

Because of the dominance of the cost of railcars, *BP Net* in essence finds the smallest batches over which FFD can be run while still minimizing the number of cars used. The following subsections address the four tasks listed above in sequence. The sub-algorithms used for these tasks and the data that they exchange are summarized in Figure 4.

The high-level controlling algorithm can be stated simply as follows:

Algorithm BP_Net

```

For each customer  $k = 1$  to  $K$ 
  Call Create_Network( $k$ )
  Find the shortest path connecting node 0 to node  $D_k$ 
  Output the path and its length
Next customer
Calculate total cost

```

The subroutines used by Algorithm *BP_Net* perform the remaining tasks. *Create_Network* determines which arcs are added to the network (finds feasible partitions of days into batches, §4.2.1). *Calculate_Length* (§4.2.2), called by *Create_Network*, finds the length of each arc (cost of each batch) by assigning jobs to loading columns via FFD and then calling *Assign_Columns_to_Railcars* (§4.2.3) and *Storage_DP* (§4.2.4) to assign columns to railcars and to determine when they should arrive at the plant, respectively.

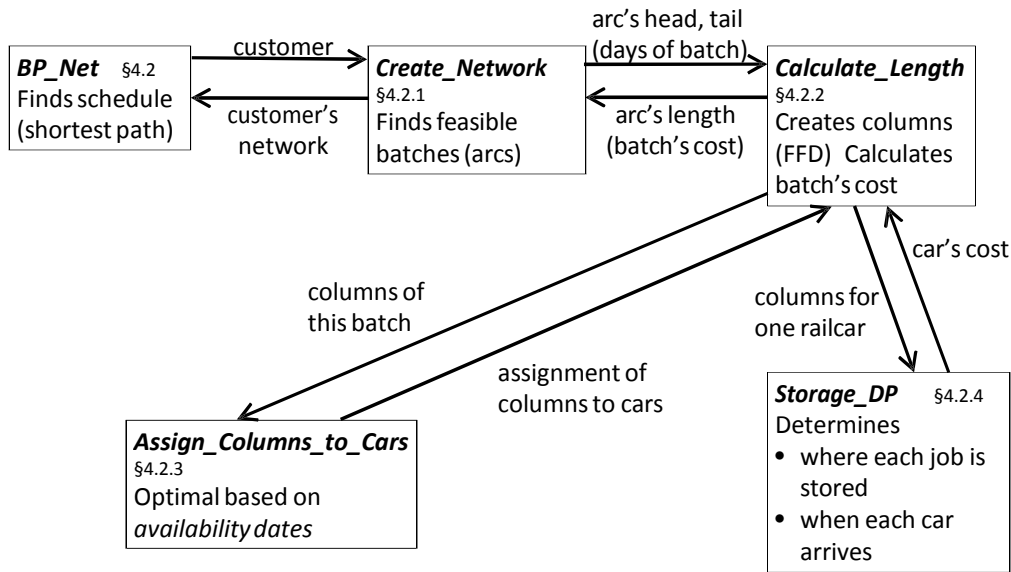


Figure 4: Logical flow of Algorithm *BP Net*, including data exchanged between subroutines

4.2.1 Partition Days into Batches

To partition the days into batches, Algorithm *BP Net* creates a directed acyclic network for each customer and finds a shortest path within that network. Each customer's network has nodes $0, 1, \dots, D_k$. Obviously, customer k 's last delivery should be on day D_k . Arc $(tail, head)$ represents the railcars that deliver the jobs that were produced between day $tail+1$ and day $head$, inclusive, to the current customer (cars may depart before day $head$ if they contain their full loads before then). These jobs constitute one batch that is assigned to columns by one run of FFD, i.e., there is a one-to-one correspondence between arcs and batches. The length of an arc is the cost of delivering and storing the jobs produced during these days (the method for finding these costs is described in the next subsection). Thus, a path from node 0 to node D_k represents a partition of the days of the planning horizon into batches, and the length of that path is the total cost of using that partition.

Subroutine *Create_Network* adds the arc $(tail, head)$ to the network for customer k either if the total amount of paper in the jobs produced for customer k on days $tail + 1, \dots, head$ is at least Y , i.e., enough to justify dispatching at least one railcar, or if $head = D_k$. The parameter Y is predetermined; for example, 70% of capacity, where capacity is $\mu\eta$. This lower bound on the amount of paper required to dispatch a car explains why nodes 1 and 2 in Figure 5 have no arcs: the total production for the

current customer on days 1 and 2 is less than Y . That neither can be the head of an arc implies that neither can be the tail of an arc, even if $head = D_k$.

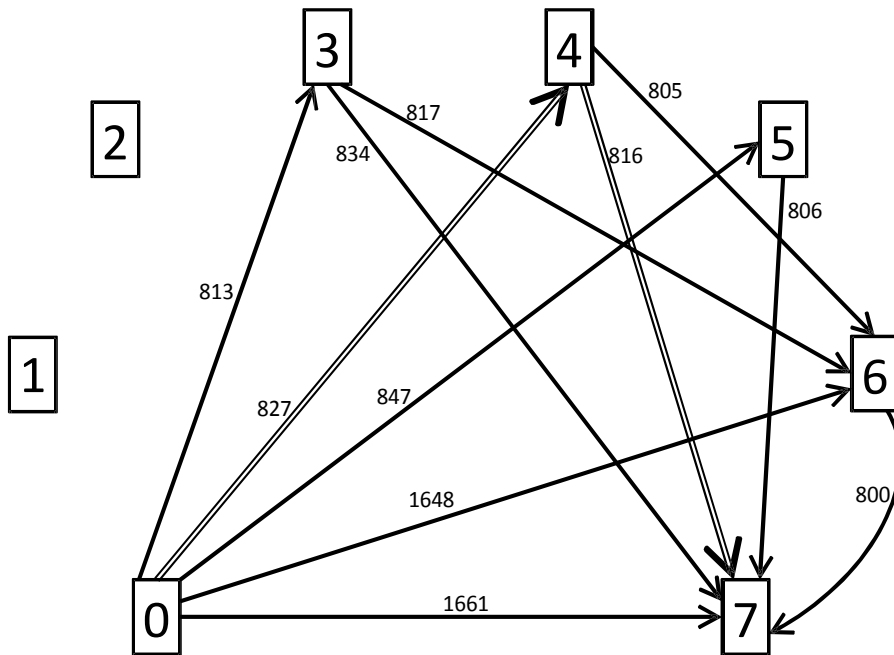


Figure 5: Example of network for scheduling a week's distribution for one customer. Total production for this customer on days 1 and 2 is not sufficient to justify dispatching a car. $\phi = 1, \chi = 30, \psi = 800$. The shortest path is $0 \rightarrow 4 \rightarrow 7$ (doubled-lines).

Clearly, if arc $(tail, head)$ is feasible, then so are $(tail, head+1), (tail, head+2), \dots, (tail, D_k)$. Hence, for each node $tail = 0, \dots, D_k - 1$, Subroutine *Create Network* finds the smallest node for which an arc originating at $tail$ is feasible (denoted $first\ head$), then adds arcs from $tail$ to this node and to all those beyond it. The length of an arc is determined by the number of cars used and the cumulative costs of storing the paper (handling and demurrage) over the nights of $tail + 1, \dots, head - 1$; this is calculated by Subroutine *Calculate Length*, which controls the remaining tasks. In Subroutine *Create Network*, $produced(d, k)$ is the amount produced (the sum of the jobs' widths λ_j) on day d for customer k .

Subroutine *Create Network(k)*

For $tail = 0$ to $D_k - 1$
 $first\ head = tail + 1$
 $total\ produced = produced(first\ head, k)$

Do Until $total_produced \geq Y$ or $first_head = D_k$
 $first_head = first_head + 1$
 $total_produced = total_produced + produced(first_head, k)$

Loop (End Do)

For $head = first_head$ to D_k

 Add arc $(tail, head)$ to graph

 Call Calculate_Length($tail, head$)

Next $head$

Next $tail$

4.2.2 Assign Jobs to Columns

Subroutine *Calculate_Length* first assigns the jobs produced for this customer during days $tail+1, \dots, head$ to loading columns by executing FFD using the height η of a railcar as the bin capacity and each job's width λ_j as its size. The number of columns created from this batch, denoted C^b , is divided by the number of columns per car (μ), then rounded up, to find the number of cars dispatched to this customer during days $tail + 1, \dots, head$. This number of cars is denoted R^b . (For both C^b and R^b , the superscripts b are merely labels to remind the reader that these quantities apply to the current batch. Indices that change with each batch are not needed because no two batches are ever considered concurrently.) After R^b is calculated, *Calculate_Length* calls two subroutines: Subroutine *Assign Columns to Railcars* assigns the columns to the cars (§4.2.3), and Function *Storage_DP* minimizes the sum of the costs of handling and demurrage for each car by determining when each railcar should arrive (§4.2.4). Subroutine *Calculate_Length* then concludes by computing the arc's length.

Subroutine Calculate_Length($tail, head$)

Pack jobs produced on days $tail + 1, \dots, head$ into C^b columns via FFD with item sizes λ_j
 and bin size η

$R^b = \lceil C^b/\mu \rceil$

Call *Assign Columns to Railcars*

$Total_Storage_Cost = 0$

For $car = 1$ to R^b

$Total_Storage_Cost = Total_Storage_Cost + Storage_DP(car)$

Length = $\psi R^b + Total_Storage_Cost$

4.2.3 Assign Columns to Railcars

A result of Subroutine *Calculate_Length*'s assignment of jobs to columns via FFD is that the production dates of the jobs within a column are randomly distributed among the dates $tail+1, \dots, head$. Assigning

these columns to cars to minimize demurrage is an NP-hard problem: it is equivalent to specifying the order in which sets are produced so that Distribution's cost is minimized (proven NP-hard in Appendix B). Therefore, we simplify this task by considering each column's availability dates. A column's *availability date* is the latest production date of its constituent jobs. The first step in assigning columns to cars for days $tail + 1, \dots, head$ is to order the columns ascending by availability dates. This task's updated objective then is to make each car as homogeneous by the columns' availability dates as possible. This serves as a proxy for minimizing demurrage and is equivalent to solving this problem for a system in which each column is homogeneous by its jobs' production dates.

Let c_d be the number of columns with availability date d . If $c_d \geq \mu$, then assign $\lfloor c_d/\mu \rfloor \mu$ of these columns to $\lfloor c_d/\mu \rfloor$ cars, and redefine $c_d = c_d - \lfloor c_d/\mu \rfloor \mu$, for $d = tail + 1, \dots, head$, and $R^b = R^b - \sum_{d=tail+1}^{head} \lfloor c_d/\mu \rfloor$. Hence, we may now assume that $0 \leq c_d < \mu$, for $d = tail + 1, \dots, head$; $C^b = \sum_{d=tail+1}^{head} c_d$; and $R^b = \lceil C^b/\mu \rceil$. If the number of dates for which $c_d > 0$ is now equal to R^b (it cannot be less than R^b), then finding an optimal loading is trivial (one date per car), so we assume that $head - tail > R^b$ and that $c_d > 0$ for $d = tail + 1, \dots, head$.

Example: Let $\mu = 4$, $tail = 0$, $head = 7$, $C^b = 17$, and $R^b = 5$. The vector of availability dates for columns is (1, 1, 2, 2, 2, 3, 3, 3, 4, 4, 4, 5, 6, 6, 6, 7, 7). These can be assigned to cars in various combinations (listed by availability dates):

Car 1: 1, 1, 2, 2

Car 2: 2, 3, 3, 3

Car 3: 4, 4, 4

Car 4: 5, 6, 6, 6

Car 5: 7, 7 Another

loading is Car 1:

1, 1

Car 2: 2, 2, 2

Car 3: 3, 3, 3, 4

Car 4: 4, 4, 5, 6

Car 5: 6, 6, 7, 7

Each loading has two cars that have only one availability date—Cars 3 and 5 in the first loading,

Cars 1 and 2 in the second. The first loading has three cars with two adjacent dates (Cars 1, 2, 4); the second has two cars with two dates (3, 5) and one with three (4). Therefore, the first loading has a cost of three nights' demurrage, which is calculated by summing the differences of the maximum availability date and the minimum availability date for the columns of each car: $\sum_{i=1}^{R^b} (Max_i - Min_i)\chi = [(2 - 1) + (3 - 2) + (4 - 4) + (6 - 5) + (7 - 7)]\chi = 3\chi$. The cost of the second is $[1 + 2 + 1]\chi = 4\chi$. \square

One of the facts guiding our assignment of columns to railcars is that moving all columns for a date from car $r - 1$ to car r may reduce the overall demurrage cost by allowing car $r - 1$ to leave earlier. Additionally, it creates extra space that may allow the columns of an earlier date to be consolidated onto one car, which would also reduce the demurrage cost. Obviously, these movements are restricted so that no additional railcars are allowed, since that would cause a significant increase in expense.

Before presenting the subroutine for this assignment, we state two structural results that help us find optimal loadings (based on availability dates) by limiting the number of solutions that we need to consider. These may allow some reduction in cost because how the columns of date d are placed into cars $r - 1$, r , or $r + 1$ directly affects how those of date $d - 1$ are placed into cars $r - 1$ or r and how those of date $d + 1$ are placed into cars r or $r + 1$. They are presented formally as Lemmas 1 and 2 and proven in Appendix C. All other lemmas in this study are also proven in Appendix C.

Lemma 1 asserts that if some of date d 's columns are placed into car r , then placing the remaining columns for date d into car r cannot increase the total cost. This is because placing all the columns for date d into car r could remove the need for those jobs to be stored overnight and may reduce demurrage by allowing car $r + 1$ to arrive a day later or by allowing car $r - 1$ to leave a day earlier. Even if all the columns for date d cannot fit into car r , moving as many as possible into r may be beneficial because it also increases the number of options for loading columns for other dates onto other cars.

Lemma 2 states that moving all of one day's columns from one car to another cannot raise the total cost. This follows directly from using the minimum number of railcars: the total amount of empty floor space across all cars ($\mu R^b - C^b$) is less than the capacity of a car, so moving all of one day's columns from one car to another cannot leave the source car empty, nor can it increase demurrage charges.

Subroutine *Assign Columns to Railcars*' initial assignment loads the first μ columns onto the first car, the next μ onto the second car, ..., and the last $C^b - \mu(R^b - 1)$ onto the last car. Because it may be possible to reduce storage costs by dispatching a car without a full load, rather than having it wait

extra days for its last columns, this subroutine then pushes forward as many columns as possible from car $r - 1$ to car r , $r = R^b, \dots, 2$, if doing so does not increase overall demurrage charges. First, columns from car $r - 1$ whose availability dates are the same as the earliest date on car r are moved forward, as the space on car r allows. Lemma 1 asserts that this cannot increase the demurrage cost, and if all such columns are moved, then this action will reduce demurrage.

Following that, columns of what is now the latest availability date on car $r - 1$, say \bar{d} are moved forward only if they *all* can fit on car r , i.e., if $c_{\bar{d}} \leq v_r$, where v_r is the number of columns that can be added to car r . Incidentally, $c_{\bar{d}} \leq v_r$ implies that \bar{d} is not the smallest date on car $r - 1$: if it were, car $r - 1$ would now be empty, which contradicts $R^b = \lceil C^b/\mu \rceil$. Lemma 2 states that this transfer of $c_{\bar{d}}$ columns cannot increase the demurrage cost. This movement creates a new latest date on car $r - 1$, so the process is repeated until either the columns on car $r - 1$ with the latest date cannot fit onto car r or date $r - 1$ is the latest availability date on car $r - 1$.

Subroutine Assign Columns to Railcars

Order columns non-decreasing by *availability date* and renumber them to reflect this order

For $r = 1$ to $R^b - 1$

 Assign columns $(r - 1)\mu + 1$ through $r\mu$ to $car(r)$

$v_r = 0$

Next r

Assign the last $[C^b - (R^b - 1)\mu]$ columns to $car(R^b)$

$v_{R^b} = R^b\mu - C^b$

For $r = R^b$ to 2, Step -1 /* unify columns of same date on same car, if possible */

 Let d^* be the earliest *availability date* among columns in $car(r)$

 Let n^* be the number of columns in $car(r - 1)$ with *availability date* = d^*

 Let $m^* = \min\{n^*, v_r\}$

 If $m^* > 0$ Then

 Move the last m^* columns from $car(r - 1)$ to $car(r)$

$v_r = v_r - m^*$

$v_{r-1} = v_{r-1} + m^*$

 Else

 Exit For /* no more movements can occur for any car */

 End If

Do /* move all columns for a date, if possible */

 Let \bar{d} be the latest *availability date* among columns in $car(r - 1)$

 If $c_{\bar{d}} \leq v_r$ Then

 Move the $c_{\bar{d}}$ columns of date \bar{d} from $car(r - 1)$ to $car(r)$


```

     $v_r = v_r - c_{\bar{d}}$ 
     $v_{r-1} = v_{r-1} + c_{\bar{d}}$ 
Else
    Exit Loop /* no more movements into this car can occur */
End If
Until  $\bar{d} = r - 1$ 
Next  $r$ 

```

Lemma 3 *Subroutine Assign Columns to Railcars finds an optimal loading of columns to railcars for a system that is based on availability dates (equivalently, with homogeneous columns).*

4.2.4 Determine When Each Car Should Arrive

We now calculate the total cost of storing paper (inside the facility or on a car) over the nights of $tail + 1$ through $head - 1$ (inclusive) for a given car and determine when it should arrive. For each car, we label the consecutive days spanning the production delivered by that car by $1, 2, \dots, d'$, and denote the number of jobs produced for this customer on those days by $\pi^1, \pi^2, \dots, \pi^{d'}$. The cost of storing a job overnight in the loading area arises from the extra handling (ϕ per job), so it is charged only once, rather than for each night that the job is held. Conversely, the cost of holding a car (demurrage: χ) does accumulate from night to night, but does not depend on the number of jobs in the car. Hence, if the car arrives on day d , $1 \leq d \leq d'$, then the total storage cost is $\sum_{i=1}^{d-1} \phi \pi^i + (d' - d)\chi$. Dynamic program Function *Storage_DP* finds the d that minimizes this cost for each car. This calculation is independent of the assignment of jobs to columns.

Function Storage_DP

Input: π^d for $d = 1, \dots, d'$; d', ϕ, χ .

Value Function: $f^d =$ cost of storing those jobs (both inside and in cars) that are produced on days d through d' for the current car.

Boundary Condition: $f^{d'} = 0$

Optimal Solution Value: f^1

Recurrence Relation: $f^d = \min \{ \phi \pi^d + f^{d+1}, (d' - d)\chi \}$

Concerning the recurrence relation, consider the first argument. If Distribution elects to store the undelivered paper on day d within the loading facility (at cost $\phi \pi^d$), then on day $d + 1$ it may choose either to continue storing within the facility or to load and store all of this customer's paper on a railcar

(either choice costs f^{d+1}). The second argument represents that once the storing of paper on this car has begun, no paper will be stored for it in the loading facility.

Here is an illustration of this dynamic program's values:

$$\begin{aligned}
 f^{d-1} &= \min \{ \phi \pi^{d-1}, \chi \} \\
 f^{d-2} &= \min \{ \phi \pi^{d-2} + f^{d-1}, 2\chi \} \\
 f^{d-3} &= \min \{ \phi \pi^{d-3} + f^{d-2}, 3\chi \} \\
 &\vdots \\
 f^1 &= \min \{ \phi \pi^1 + f^2, (d-1)\chi \}
 \end{aligned}$$

Lemma 4 *Subroutine Storage DP finds an optimal schedule for the arrival of railcars.*

Function *Storage DP* can easily be updated to allow for limited internal storage. Let Π be the upper bound on the number of jobs that can be stored inside for this customer. Given $\pi^1, \pi^2, \dots, \pi^{d'}$, define h by $\sum_{d=1}^{h-1} \pi^d \leq \Pi < \sum_{d=1}^h \pi^d$. If such an h exists and $h < d'$, then jobs must be stored on a railcar starting on day h . Hence, the boundary condition becomes $f^h = (d' - h)\chi$.

The computational study of §7 evaluates the effectiveness of Algorithm *BP-Net* by comparing its results to those of current practice and to lower bounds. This is illuminating because the majority of theoretical results of this section have by necessity assumed homogeneous columns. Regarding the algorithm's computational complexity, the FFD portion of Subroutine *Calculate Length* executes in time $O(j' \log j')$, where j' is the number of jobs delivered to *customer* during days $tail + 1, \dots, head$. The worst case running time of Subroutine *Assign Columns to Railcars* is $O(D^2)$. It follows that Subroutine *Create Network's* execution time is bounded by $O(D^2(J \log J + D^2))$, where $J = \sum_{k=1}^K J_k$ (total number of jobs), so Algorithm *BP-Net's* execution time is bounded by $O(KD^2(J \log J + D^2))$.

5 General Problem 2: Minimize Total Cost

In the current process, Production has the first-mover advantage, i.e., it can choose its preferred schedule and force Distribution to respond as best as it can. Hence, reducing the two parties' combined cost beyond that achieved by *BP-Net* requires a sacrifice by Production, because decreasing Distribution's cost further would require an increase in Production's cost. Of course, this would be done only if the decrease in Distribution's cost is larger than the increase in Production's cost. Our method for doing

this is to divide the customers into batches. For example, if we use two batches, half of the customers are served in the first half of the planning horizon, and the rest are served in the second half. Production's cost will increase because it must traverse all the basis weights twice, going up then down (see Figure 6). This causes twice as many transitions, so there will be more wasted pulp. Additionally, the allocation of jobs to sets may generate more wasted paper: rather than pooling all jobs for a given basis weight, only those jobs for half the customers go into each pool for creating sets. Hence, each bin-packing may be less efficient, causing the production of extra sets within some basis weights.

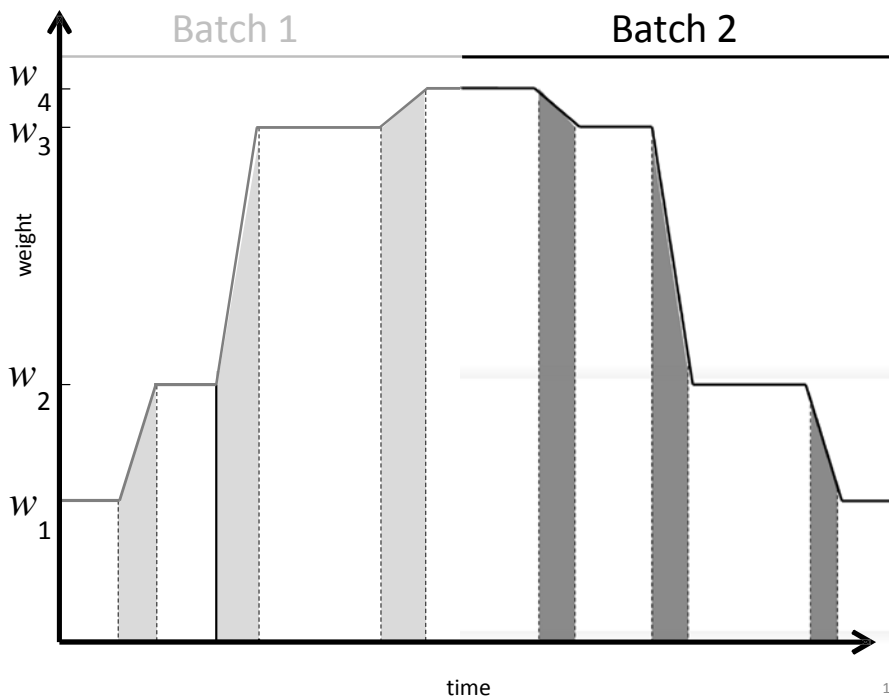


Figure 6: Schedule of basis weights produced for two batches

Compressing the time frame in which each customer is served reduces Distribution's cost by reducing the time over which it must store completed jobs. This allows Distribution to decrease its handling and demurrage expenses without using more cars. Thus, the proposed tradeoff is between Production's extra pulp usage (and the resulting wasted paper) and Distribution's reduced storage cost. We will evaluate this tradeoff through our computational study in §7.

Since our algorithm for solving Production's and Distribution's problems runs in polynomial time, running it twice for a particular instance will not unduly increase the calculation time. To generalize,

the number of batches into which the customers are separated can also be a decision variable, i.e., trying different numbers of batches and comparing the results is still a polynomial-time algorithm. Finding the optimal assignment of customers to batches, however, is NP-hard, since it can be shown to be equivalent to the Partition problem; see Appendix B.

To implement this scheme and to ensure Production's continued cooperation, Distribution must compensate Production for the additional cost it incurs from increasing its number of transitions. Let c_P and c_D be the original costs for Production and Distribution, respectively, and c'_P and c'_D be their costs in the cooperative solution. Clearly, a lump sum side payment paid by Distribution must be greater than Production's additional cost ($c'_P - c_P$) and less than Distribution's total gain ($c_D - c'_D$). This amount can be formulated as $c'_P - c_P + \beta[(c_D - c'_D) - (c'_P - c_P)]$, $0 < \beta < 1$, where β is a parameter that signifies the relative power between Production and Distribution. The value of β and, hence, the payment, would be determined by negotiations between the parties. Each party's reduction in cost provides it incentive to cooperate, and adherence to the agreed schedule is easily verified from Production's release of jobs to Distribution.

6 Plant-Specific Data

The jobs produced (based on demand) at our client's plant have widths 60, 72, 74, 75, 77, 78, 82, 86, 89, 90, 91.5, 94, 95, and 98 inches. Because these are each less than half the trim (252 inches), First Fit Decreasing is guaranteed to provide an approximation that is within $71/60 = 1.18\bar{3}$ of the optimum (Garey and Johnson 1985) when forming production sets. Regarding Distribution, the railcars used by this company are either fifty feet or sixty feet long and either standard height ($\eta = 127$ inches) or *high cube* ($\eta = 150$ inches). Hence, a column loaded onto a car can contain at most two jobs. This directs the development of this section, which we now outline.

For the general problem (§4.2), minimizing the number of loading columns is strongly NP-hard. For the current case, Lemma 5 proves that FFD solves the Bin-packing problem optimally. This minimum number of columns implies a minimum number of railcars. Assigning columns to cars so that demurrage is minimized is also intractable in the general problem, so this task was simplified by using availability dates. For plant-specific data, we minimize the differences in production dates between the two jobs of each column, subject to the constraint that the number of railcars be the minimum. Availability dates

may still be required, but with only two jobs per column in this case, they are more representative of production dates. The methods for loading columns onto cars (*Assign Columns to Railcars*) and for scheduling the cars' arrivals (*Storage DP*) are the same as for the general case.

Lemma 5 Consider an instance of the Bin-packing problem with a set U of n items, a size $\lambda_u \in (0, 1)$ for each $u \in U$, and bin capacity 1. If $\lambda_u > 1/3$ for all $u \in U$, then First Fit Decreasing finds an optimal solution to the Bin-packing problem.

Lemma 5 states that FFD finds the minimum number of loading columns that can be formed from customer k 's jobs in our client's environment. This number of columns C'_k tells us the minimum number of railcars R_k that can be used to deliver the current customer's jobs in the current planning horizon: $R_k = \lceil C'_k / \mu \rceil$. We now present an alternative method for assigning jobs to columns. It minimizes for each column the difference in the production dates for its two jobs (e.g., $|\delta_j - \delta_\ell|$), while still ensuring that all jobs fit into at most μR_k columns.

We minimize the sum of the differences between the production dates of the two jobs sharing each loading column by a maximum-weight matching problem on a non-bipartite graph (*MWMNB*): create a network with J_k nodes that represent the different jobs for customer k . Two nodes are connected by an edge if and only if they can be in the same column, i.e., edge (i, j) connecting nodes i and j exists if and only if $\lambda_i + \lambda_j \leq \eta$. The length of edge (i, j) is a large number minus the absolute difference in completion dates of jobs i and j : $M - |\delta_i - \delta_j|$, where $M = D_k = \max_{1 \leq j \leq J_k} \{\delta_j\}$. A maximum weight matching can be found by Edmonds' (1965) Blossom Algorithm in $O(J_k^4)$ time.

We cannot mandate a perfect matching (as is traditionally done for maximum weight matchings) because the number of large jobs could be too big for the amount of smaller jobs, i.e., the number of jobs larger than some $x > \eta/2$ could be greater than the number of jobs smaller than $\eta - x$. Moreover, there is no guarantee of an even number of jobs for each customer.

The number of columns generated by *MWMNB*, C_k , could exceed μR_k for the optimum R_k found by FFD. Consider the following example.

Example: Suppose $J_k = 4$, $\mu = 2$, and $R_k = 1$:

\mathbf{j}	λ_j	δ_j
1	0.8η	1
2	0.8η	1
3	0.2η	D_k
4	0.2η	D_k

The solution to *MWMNB* has three columns: {1}, {2}, and {3, 4}, with objective value $M - |\delta_3 - \delta_4| = M$, though these jobs obviously can fit into two columns; however, the objective value of solution {1, 3}, {2, 4} is $2M - |\delta_1 - \delta_3| - |\delta_2 - \delta_4| = 2$. Increasing the value for M reduces the number of columns by increasing the value of each match, but it allows there to be larger differences in the production dates within those columns. In fact, using $M = 2D_k - 1$ in this example gives the solution with two columns, but each column has a difference of $D_k - 1$ between its jobs' completion dates; the objective value for this solution is $2M - |\delta_1 - \delta_3| - |\delta_2 - \delta_4| = 2D_k = M + 1$. \square

In general, if $C_k > \mu R_k$, then we increase M by one (recall $M = D_k$ at initialization) and rerun the Blossom Algorithm. Each increase in M makes forming a column from two jobs with disparate production dates more attractive. This process can be repeated until $C_k \leq \mu R_k$, which will require at most D_k iterations because the greatest difference between two jobs' production dates is $D_k - 1$, so the columns can be formed optimally in $O(D_k J_k^4)$ time.

Once the columns have been formed, we use *Assign.Columns.to.Railcars* and *Storage DP* to load and schedule the railcars. Because *MWMNB*'s assignment of jobs to columns should generate far less dispersion of production dates within columns than does *BP_Net*, the total cost of *MWMNB* should be less than that of *BP_Net*. In fact, if the columns are all homogeneous by date, then Lemmas 3 and 4 imply that *MWMNB*'s solution is optimal. We compare *BP_Net* and *MWMNB* computationally in the next section.

7 Computational Study

We ran a computational study over twenty-four randomly-generated problem instances (sets of customers, their jobs, and the jobs' widths and basis weights), each with a wide variety of parameter values, to evaluate our solution strategies. These results are especially valuable because the problem's complexity status for general data makes analytical evaluation very difficult.

The test bed contains job widths that are randomly generated from a large range (between 20 and 90 inches) for generality to many environments. Each job's basis weight is also randomly generated from

a list of the eight distinct basis weights that are produced by the plant under study. Each problem has twenty customers, and each customer has sixty jobs. Each problem was run for three different numbers of columns per car (μ), five values for handling (ϕ), four for demurrage (χ), and three for car rental (ψ) costs. The variations in job characteristics, columns per car, and costs allow us to hold the trim size constant ($\tau = 252$) and use the two car heights (η) mentioned in Section 6 with no loss of generality. It follows that this data set with general job sizes had a total of $24 \times 3 \times 5 \times 4 \times 3 \times 2 = 8640$ runs. Where illuminating, we also present results for data sets with the job widths specific to the plant with which we have worked: five sets of jobs, two car lengths, two car heights, and three values each for handling and demurrage, for a total of 180 runs.

The goal of the computational study is to assess the value of our proposed new distribution process and new cooperation scheme. To understand the benefits that should be expected from these under different circumstances, we address the following questions:

- How does our solution for Distribution compare to current practice?
- What is the average improvement in the total cost realized by solving the combined problem?
- What is the effect of parameter values (handling, demurrage, cost per car, columns per car) on the size of the improvement realized by solving the combined problem?
- What is the value of choosing which customers are in which batches in the combined problem?

To compare our proposed solution to our client's current practice, we simulated the current distribution process described in the first two paragraphs of Subsection 4.2. Production for both current practice and our solution was simulated by the process described in Subsection 4.1. The improvement to the overall cost (Production and Distribution together, but using only one batch) realized by using *BP_Net* averaged 25.80%. Of course, this improvement is much larger (39.12%) if the reduction is calculated with regard only to the cost of distribution. Both Algorithm *BP_Net*'s (for general data) and Algorithm *MWMNB*'s (for plant-specific data) improvements decrease as the cost per car increases. This is expected because the cost per car is by far the largest of the three cost parameters, so all three schemes' (including current practice) first priority is to minimize the number of cars used. Thus, this number remains constant across all loading schemes as parameter values change, so increasing the per car cost moves the total costs closer together.

We also tested Algorithm *MWMNB* for plant specific data, as described in Section 6. It averaged an additional 3.29% improvement over the solution provided by *BP Net*. This improvement, too, is negatively correlated with the cost per car.

The relative percentage of the average improvement in the total cost realized by solving the combined problem is 4.40% above the improvement generated by the new distribution process. In only three runs (of a total of 8820) did solving the combined problem not reduce the overall cost. The parameters' influence on the size of the improvement from scheduling Production and Distribution together can be seen in Table 1. The improvement increases as either the handling cost or the demurrage cost increases. This happens because the use of these two storage methods is reduced by the use of batches. Hence, solving the combined problem leads to more savings when storage is more expensive. However, this effect peaks for handling when it reaches a cost of 4 per job, after which it declines. Inspection of solutions revealed that this represents a threshold beyond which the handling function is used very little because storage on the cars becomes more favorable.

handling	2	3	4	5	6
improvement	3.03%	4.61%	5.40%	4.35%	4.60%
demurrage	20	30	40	50	
improvement	2.58%	3.94%	5.10%	5.98%	
cost/car	300	400	500		
improvement	4.67%	4.41%	4.12%		
columns	6	10	14		
improvement	4.14%	3.99%	5.06%		

Table 1: Average percentage improvement realized from scheduling Production and Distribution together, analyzed by parameter values. *columns* indicates the number of loading columns per car.

That the size of the improvement decreases as the cost per car increases follows directly from the dominating nature of the cost per car, as noted earlier. Though the evidence is not strong, we suspect that the use of larger cars increases the improvement realized by solving the combined problem because using larger cars accentuates the value of the time required to fill a car: more jobs are required to fill them, and using batches compresses the time required to produce this larger number of jobs.

How customers are assigned to batches has minimal effect on the total cost. The best improvement realized by selecting specific combinations of customers for each batch, found by using a genetic algorithm to find favorable assignments, averaged 0.63%.

8 Conclusions and Suggestions for Future Study

We have studied the combined production and distribution problem for the paper industry. This sector is well-suited for this analysis because the size of the products severely limits the amount of finished goods inventory that can be held. First, for a general plant producing and delivering an unrestricted variety of job sizes, we developed a polynomial-time algorithm for scheduling Distribution's operations—a strongly NP-hard problem—that greatly reduces its costs (25.80%) for a given schedule of job releases from Production. Our theoretical results prove that specific portions of this algorithm produce optimal solutions to their subproblems. We have shown that the operational coordination of Production and Distribution via scheduling can also reduce costs significantly. More importantly, we have determined under which parameter value combinations such cooperation is more valuable, providing reductions that average 4.40% (given the size, output, and revenue of the paper industry, this percentage represents a large sum of money). Our method for minimizing overall costs requires very little additional computational time and can be easily understood and implemented. A computational study demonstrated our method's improvement over current practice.

Secondly, we considered the operations of a particular plant whose limited job sizes allowed us to derive more precise algorithms and additional theoretical results. We showed that First-Fit Decreasing produces an optimal solution to the Bin-Packing Problem if all jobs are larger than one-third of the bin size. After this fact was used to determine the minimum number of railcars needed for a given customer, we minimized the heterogeneity of dates within the loading columns without exceeding this number of cars. Combining this with our optimal algorithms for loading the columns onto cars and for scheduling the cars' arrivals minimizes the combined handling and demurrage costs. Hence, we minimize Distribution's overall cost for this restricted but practically-relevant setting. We have presented this to our client to propose that it incorporates this system for planning Production and Distribution.

The process of loading railcars—jobs are combined into columns, columns are loaded into cars—may be generalizable to other environments, such as palletizing products and then loading the pallets onto transporters (readers interested in studies that consider loading and transporting pallets may consult Iori et al., 2007, Fuellerer et al., 2009, and Zachariadis et al., 2009). Future research may consider our methods for this related problem. There are several directions in which additional studies of the paper industry may proceed:

- Rather than solving the problem for a fixed planning horizon through day D , how much more could be saved by solving it as a modified rolling horizon problem? If the first railcars depart after d days, the calculations could be performed again with the jobs originally scheduled for days $d + 1$ to D and those jobs that arrived in orders placed during days 1 through d .
- In practice, there may be uncertainty over railcars arrival dates, their usability when they arrive (they may have standing water or require additional cleaning), and whether the size ordered will be the size that arrives. Adding this stochasticity will make the problem very challenging.
- This manufacturer delivers to some of its clients via trucks. The characteristics of this mode of transportation are very different and require a completely new analysis.

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Online Appendix for “Balancing Production and Distribution in Paper Manufacturing”

Appendix A: The Bin-Packing Problem

Statement of the Bin-Packing Problem (Garey and Johnson 1979):

Assume we are given a finite set $U = \{u_1, \dots, u_N\}$ of items, a size $s(u_i) \in \mathbb{Z}^+$, $0 < s(u_i) < 1$, for each $i = 1, \dots, N$, and a positive integer $K < N$. Is there a partition of U into disjoint sets B_1, B_2, \dots, B_K such that the sum of the sizes of the items in each B_k , $k = 1, \dots, K$, is 1 or less?

First Fit Decreasing: The First Fit Decreasing (FFD) algorithm successively places each item into the first bin in which it can fit. Assume that we have unit-sized bins B_1, B_2, \dots, B_N , where N is the cardinality of set U . Let $r(B_k)$ be the space remaining in B_k , $k = 1, \dots, N$.

Arrange the items of U non-increasing by size

$r(B_k) = 1$, $k = 1, \dots, N$

$Bins\ Used = 0$

For $i = 1$ to N (items)

 For $k = 1$ to N (bins)

 If $s(u_i) \leq r(B_k)$ Then

 Assign item u_i to bin B_k

$r(B_k) = r(B_k) - s(u_i)$

$Bins\ Used = \max\{Bins\ Used, k\}$

 Exit For

 End If

 Next k

Next i

Output $Bins\ Used$

Appendix B: Complexity Results

Theorem 1 *Finding Distribution's preferred order of production sets is equivalent to Assignment Problem with Side Constraints.*

Proof: Given Production's assignment of jobs to sets, our task is to assign sets $s = 1, \dots, S$ to time slots $t = 1, \dots, S$ so that storage costs are minimized. Thus, each customer's jobs should be produced so that the number of periods between customer k 's first job and its last job is minimized, for $k = 1, \dots, K$, i.e., so that they can all be shipped as soon as possible. We use the following notation:

β_{js} : Parameter. $\beta_{js} = 1$ if job j belongs to production set s . $\beta_{js} = 0$ otherwise.

x_{st} : Variable. $x_{st} = 1$ if production set s is produced during time slot t . $x_{st} = 0$ otherwise.

u_j : Variable. The time at which the production set containing job j is produced.

C_k : Variable. The number of time periods between customer k 's first job and its last job.

\mathbf{J} : set of all jobs produced during the planning horizon.

\mathbf{J}_k : set of all jobs produced for customer k during the planning horizon.

$$\text{Minimize } \sum_{k=1}^K C_k \quad (1)$$

subject to

$$\sum_{t=1}^S x_{st} = 1, \quad s = 1, \dots, S \quad (2)$$

$$\sum_{s=1}^S x_{st} = 1, \quad t = 1, \dots, S \quad (3)$$

$$u_j = \sum_{t=1}^S \sum_{s=1}^S t \beta_{js} x_{st} \quad j \in \mathbf{J} \quad (4)$$

$$C_k \geq u_j - u_{j'}, \quad j \in \mathbf{J}_k; \quad j' \in \mathbf{J}_k; \quad j' \neq j; \quad k = 1, \dots, K \quad (5)$$

$$x_{st} \in \{0, 1\}, \quad s = 1, \dots, S; \quad t = 1, \dots, S \quad (6)$$

$$u_j, C_k \geq 0, \quad j \in \mathbf{J}; \quad k = 1, \dots, K \quad (7)$$

The objective (1) minimizes the total time that jobs are stored between their production and delivery. Constraints (2) and (3) ensure that all sets are produced and that exactly one set is produced in each time slot. Constraint (4) sets the value for u_j , the time at which job j is produced. Constraint (5) determines the total time between the production of customer k 's first job and the production of customer k 's last job. Constraints (6) and (7) require binary and non-negative values, respectively. ■

Theorem 2 *Finding an assignment of customer's to batches that minimizes total cost of Production and Distribution is NP-hard.*

Proof: We prove our problem's complexity by comparing it to Partition.

Partition (Garey and Johnson 1979): Given $B \in \mathbb{Z}^+$, a set $A = \{z_1, z_2, \dots, z_t\}$, $z_i \in \mathbb{Z}^+$, and $\sum_{i=1}^t z_i = 2B$, does there exist a partition of A into two disjoint subsets A_1, A_2 such that $\sum_{z_i \in A_1} z_i = B$?

Given an instance of Partition, we construct a specific instance of the decision problem for the paper manufacturer as follows: there are t customers, each with one job. The width of customer k 's job is $\lambda_k = z_k$, $k = 1, \dots, t$. It follows that the total of all job widths is $\sum_{k=1}^t \lambda_k = 2B$, so we let the trim be $\tau = B$. The Production cost of one set is larger than the worst-case total Distribution cost. Can the jobs of the t customers be partitioned into two production sets that will fit on the machine, i.e., each set has total width τ ? This is obviously equivalent to Partition. ■

Appendix C: Lemmas

Lemma 1 *Consider the set of loadings that minimize demurrage based on availability dates (equivalently, in which each column is homogeneous by production date). If some of date d 's columns are placed into car r , then, in at least one member of that set, the remaining columns for date d are placed into car r , as that car's space allows.*

Proof: Once a column for date d enters car r , adding additional columns for that date cannot increase the demurrage cost. ■

Lemma 2 *Consider the set of optimal loadings that minimize demurrage based on availability dates (equivalently, in which each column is homogeneous) in which d is the smallest (respectively, largest) availability date in car r . Suppose that car r now has room for v_r more columns. If $c_{d-1} \leq v_r$ (resp., $c_{d+1} \leq v_r$), then there is at least one member of this set for which all of date $d - 1$'s (resp., $d + 1$'s) columns are placed into car r .*

Proof: Suppose that the hypotheses of Lemma 2 hold. Consider an optimal solution in which all of date $d - 1$'s (resp., $d + 1$'s) columns reside in car $r - 1$ (resp., $r + 1$). Moving all columns for date $d - 1$ (resp., $d + 1$) into car r reduces $(Max_{r-1} - Min_{r-1})$ (resp., $(Max_{r+1} - Min_{r+1})$) by one and increases $(Max_r - Min_r)$ by one. Thus, the value of $(Max_r - Min_r) + (Max_{r-1} - Min_{r-1})$ (resp., $(Max_r - Min_r) + (Max_{r+1} - Min_{r+1})$) cannot be increased by moving all of the columns for date $d - 1$ (resp., $d + 1$) into car r . It follows that the new solution is optimal. ■

Lemma 3 *Subroutine Assign Columns to Railcars finds an optimal loading of columns to railcars for a system that is based on availability dates (equivalently, with homogeneous columns).*

Proof: For any optimal loading, all of the columns with availability date $head$ are in car R^b . Subroutine Assign-Columns to Railcars assigns the columns of date $head - 1$ to car R^b if they all fit, assigns the

columns of date $head - 2$ to car R^b if they all fit, ..., and assigns those of date R^b to car R^b if they all fit. This process is repeated for cars $R^b - 1, R^b - 2, \dots$, until no further movements can be made. The resulting loading minimizes the number of availability dates that are split across two cars. This fact and Lemmas 1 and 2 imply that the resulting loading is optimal for a system based on availability dates (equivalently, with homogeneous columns) because all potentially optimal solutions are considered. ■

Lemma 4 *Subroutine Storage DP finds an optimal schedule for the arrival of railcars.*

Proof: Clearly, if a car is present at the plant on day d and stays overnight, then all jobs produced on or before day d that will be delivered by that car should be stored on that car overnight. This implies that *Storage_DP* considers all potentially optimal schedules for the arrival of railcars and their costs. ■

Lemma 5 *Consider an instance of the Bin-packing problem with a set U of n items, a size $\lambda_u \in (0, 1)$ for each $u \in U$, and bin capacity 1. If $\lambda_u > 1/3$ for all $u \in U$, then First Fit Decreasing finds an optimal solution to the Bin-packing problem.*

Proof: Without loss of generality, we may assume that $\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_n$. Let j be the first item that FFD places into a bin (say, bin ℓ) that already has an item: $\ell \leq j - 1$. This implies that $j - 1$ is a lower bound on the number of bins used. Each of the next $j - \ell - 1$ items is placed into one of the remaining bins between 1 and $j - 1$. We know that this is possible because they can fit into bins $\ell + 1, \dots, j - 1$. In fact, if one of those items can fit into some bin $\ell' < \ell$, then each item in $\{j, \dots, 2j - \ell' - 1\}$ can be placed into one of the bins in $\{\ell', \dots, j - 1\}$. For clarity and with no loss of generality, we assume no such ℓ' exists, so bins $\ell, \dots, j - 1$ each have two items at this point if $n \geq 2j - \ell - 1$. If $n \leq 2j - \ell - 1$, then we have an optimal solution because $j - 1$ bins are used.

Next, items $2j - \ell, \dots, n$ are placed into bins $1, \dots, \ell - 1, j, j + 1, \dots, m$, where m is the total number of bins used. Suppose q of the items fit into bins among $1, \dots, \ell - 1$, and the remaining $n - 2j - \ell - q + 1$ are placed into bins $j, j + 1, \dots, m$. Since $\lambda_u \leq 1/2$ for $u \geq j$, no item is placed into bin $h + 1$, for any $h \geq j$, unless bin h has two items. Bin m has one item if $m = (n + \ell - q)/2$ (Figure 7(a)), and bin m has two items if $m = (n + \ell - q - 1)/2$ (Figure 7(b)).

Suppose there is a different solution with m' bins, where $m' < m$. To achieve this, at least one of the bins among $\{1, \dots, \ell - 1\}$, other than those already containing two items, must hold two items. However, the execution of FFD tried to place the smallest item(s), i.e., those that reside in bin m , into each of these bins and found that it could not happen. Thus, no such solution with m' bins can exist. ■

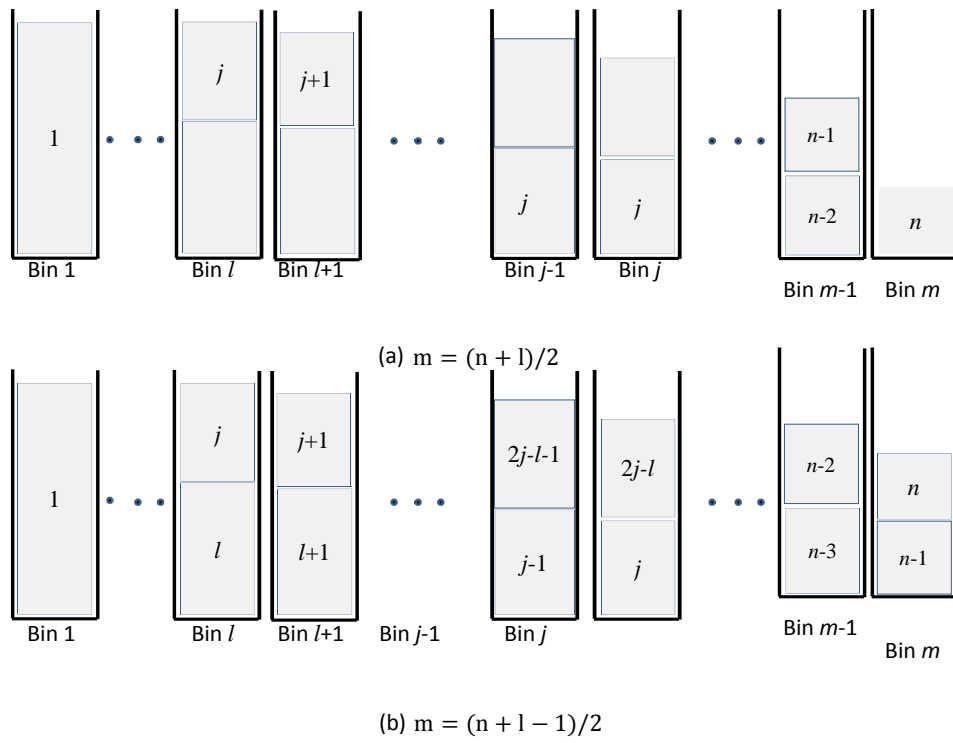


Figure 7: Configuration of bins for proof of Lemma 5 with $q = 0$ for clarity

Timing and Signaling Considerations for Recovery from Supply Chain Disruption

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Timing and Signaling Considerations for Recovery from Supply Chain Disruption

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Abstract

We study the interaction between a supplier's timing of recovery *ex post* a disruption in the face of a buyer that has a backup production option. After disruption, the supplier quotes a recovery due date and make recovery effort. We find that the supplier's quote of recovery time affects the buyer's use of the contingency option in two ways. First, when the supplier possesses the flexibility of quoting any recovery due date, the supplier may use the quote as a strategic subsidy to retain the buyer from invoking its backup option. As a result, the channel is pareto-improved. Second, when the supplier has private information about the severity of supply disruption, the supplier uses the quote of recovery due date to signal the disruption severity. The supplier may be unable to credibly convey the severity level of disruption to the buyer.

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1 Introduction

Supply chain disruptions are a major concern for firms because of the detrimental impact on their operational and financial performance. Natural disasters (e.g., earthquakes, hurricanes, tsunamis, volcanoes, floods), operational failures (e.g., fire hazards, information system failures), political instabilities, and labor strikes, among others have been known to cause severe disruption in supply chains of a variety of industries. Original Equipment Manufacturers (OEMs) in several industries have increased their reliance on a small number of key specialty suppliers for supplies of cutting edge materials, product modules, and components. There are several instances wherein a severe disruption at the only (or major) facility of a single-sourced component supplier has wreaked havoc in the supply chains of the entire industry (e.g., a major supply shortage of cell phone chips caused by a minor fire at Philips's facility in New Mexico in 2000; flooding of Seagate's two major factories in Thailand caused a major shortfall for the computer industry in 2012). Furthermore, as many supply chains have resorted to contract manufacturing for lowering cost and have got more far flung and geographically dispersed in their tiers, the OEMs have all too often lost visibility in the lower tiers of their supply chains. This has at times undermined their abilities to anticipate and withstand shock of supply chain disruption.

With the occurrence of many highly conspicuous disruptions in recent years, supply chain firms pay increased attention to supply risk mitigation and business continuity planning to reduce the detrimental impact of disruption. Under the menace of disruption, the supplier prepares itself for speedy recovery to normal operations once disruption occurs, and the buyer searches for backup options and defines in its continuity plan the contingencies that trigger the execution of such options. While it is quite plausible that certain parameters that govern post-disruption risk mitigation, such as penalty for supply delays or incentives for speedy recovery, are stipulated in the contingency clauses, the actual nature of severity of disruption, ensuing effort needed by the supplier to recover, and the detrimental impact on the buyer only become apparent after the disruption occurs. This leaves room for the supplier and the buyer to strategically plan their respective courses of action *ex post* disruption, such as the supplier's execution of recovery effort and the buyer's invocation of contingency actions.

Complicating this situation is that the supplier may have better information about the nature of disruption and its damage. The supplier is in a better position to assess its own condition *ex post* disruption than the buyer. For example, at the occurrence of disruption,

the supplier is in a unique position to make first-hand accurate, and timely assessment of the severity of damage to its capacity and operations, and keep it as private information if needed. However, it may be impractical for the buyer to do the same. This leads to information asymmetry about the severity of disruption between the two firms. Since the amount of effort required for full recovery increases as the severity of disruption heightens, information asymmetry reduces the buyer's visibility of the supplier's ability to make a speedy recovery and leaves the buyer in a disadvantageous position in managing its business continuity *ex post* a disruption.

In this study, we consider a scenario wherein a supplier experiences a disruption and ceases to produce, and consequently the buyer faces a disruption in supply. The supplier knows the severity of disruption, and defines and proposes a recovery plan in an effort to retain the buyer's business. Given the adverse impact due to the loss of supply, the buyer is faced with a choice to immediately switch to a backup source of supply (albeit by incurring a significant cost) or wait till the supplier recovers from disruption and resumes supply. But, the buyer's decision is hindered by a lack of information about the disruption's damage to the supplier. We want to explore the strategic interaction between the supplier and the buyer in the stage *ex post* supply chain disruption. Specifically, we aim to answer two research questions. First, after the occurrence of supply chain disruption, how does the supplier plan its recovery to retain the buyer, who is pressed to consider invoking the backup option for its business continuity? In this regard, we identify the value of strategically inserting tardiness (albeit counterintuitive) into the supplier's recovery schedule. Second, how does asymmetric information about the severity of disruption affect the supplier's recovery effort and its ability to retain the buyer's business, and affect the buyer's use of its contingency option? In this regard, we find that the supplier may strategically conceal disruption's damage by distorting its recovery plan that is visible to the buyer, thus hindering the buyer's abilities to accurately assess disruption's damage and reckon its contingency action.

2 Literature Review

Our work is related to the literature on supply chain risk management. For excellent surveys on this literature, please refer to Tomlin and Wang (2011) and Aydin et al. (2011). A majority of research in this literature is concerned with strategies for proactively mitigating risk of supply chain disruption. These strategies include multi-sourcing (e.g., Anupindi and

Akella, 1993; Tomlin, 2006; Babich et al., 2007; Yang et al., 2012), alternative or backup production plan (e.g., Yang et al., 2009), and reliability and process improvement (e.g., Wang et al., 2010). In deviation, we study the supply chain members' strategic interactions after the occurrence of disruption.

One of the prominent features of our model is information asymmetry in the supply chain. A stream of research in supply chain risk management addresses the challenge of managing supply disruption risk in the presence of information asymmetry (e.g., Gurnani and Shi, 2006; Yang et al., 2009, 2012; Gümüř et al., 2012). Most research in this stream assumes the supplier has private information about the disruption risk. This occurs when the supplier has better information on the nature and likelihood of disruption and its ability to withstand disruption, and would like to withhold that information from buyers for opportunistic reasons. In comparison, focusing the buyer and supplier's reactions to disruption, we assume the supplier has private information about the severity of disruption.

In analyzing asymmetric information in supply chain risk management, Yang et al. (2009, 2012) invoke mechanism design and model a screening game, where the buyer moves first to offer contracts. We model the buyer-supplier interaction after disruption as a signaling game, where the supplier's quote of recovery due date signals the severity of disruption. Gümüř et al. (2012) also model a signaling game in their study. However, their research is concerned with contract design prior to disruption, and leads to different insights.

In our model, we analyze supply recovery as the supplier's contingency response to disruption. There is sparse literature on the issue of supply recovery after occurrence of disruption (i.e., restoration of supply or production capacity). A few recent models feature supply recovery (e.g., Iyer et al., 2005; Hu et al., 2012; Kim and Tomlin, 2012). Hu et al. (2012) analyze a scenario wherein the buyer provides *ex ante* incentive for investing in capacity restoration capability before disruption, wherein the incentive is implemented by order quantity or unit purchase price. However, they assume no information asymmetry in the supply chain, and focus on contract design in anticipation of supplier disruption. Kim and Tomlin (2012) studies a situation where the system's disruption is caused by the failure of a subsystem and the culprit cannot be timely determined. Hence, the cost of disruption must be allocated between the subsystem providers. The authors study the role of predetermined allocation rule on the suppliers' provision of the reliability of the subsystems. In comparison, we are interested in the supply chain members' reactions to disruption and how the supplier's choice of restoration timing affects the buyer's choice of contingency actions.

Similar to our model, Iyer et al. (2005) also study a model wherein after disruption the supplier can choose the speed of recovery and there is asymmetric information in the supply chain. Our model setting is distinctly different in two aspects. First, they assume the buyer has private information about its cost of supply disruption. In our model, the supplier has private information about the severity of disruption. Second, in our model the supplier decides not only the speed of supply recovery (in term of the supply recovery completion time), but also the due date quoted to the buyer. We show the latter strategically affects the buyer's choice between waiting for recovery and invoking the backup option, and leads to interesting insights.

3 Model Setup

We model a stylized supply chain of one buyer and one supplier who pre-committed one unit of indivisible supply to the buyer. In this research, we shall focus on the buyer and supplier's interactions after the occurrence of the supplier's disruption. We assume that disruption strikes the supplier's facility at time zero, when the supplier suppose to deliver to the buyer, and the supplier loses the supply for the buyer instantly. We can extend the model to the case where the pre-determined delivery time does not coincide with the time of disruption, but, without changing the insights we will derive.

We will consider two models. One model features perfect information in the supply chain—both the supplier and the buyer know perfectly the severity of the supplier's disruption. The other model features asymmetric information—the supplier knows perfectly the severity of its disruption, but the buyer does not. In the rest of this section, we introduce the setup for the model of the perfect information. In §5, we shall extend the setup in this section to the model of asymmetric information.

In the face of disruption, the supplier has two options: to make a costly effort to recovery the lost supply or to terminate the contract with the buyer with a one-time cost. If the supplier opts to recover the supply, it posts a due date for full recovery, denoted as $d < \infty$. We assume that the supply is indivisible, and thus the supplier does not deliver the supply until it is fully recovered. The completion time of recovery, denoted as t , need not be the same as the due date, d . We assume that the supplier's recovery completion time, t , is deterministic, and the supplier has full control of the completion time by scaling its costly recovery effort. We define the supplier's cost of fully recovering the lost supply by time t to

be function $\Psi(t)$ for $t \in [0, \infty)$, with $\Psi(0) = \infty$. We assume $\Psi(t)$ is decreasing and convex in t . Intuitively, the more time the supplier has to make recovery, the less costly it is. As the recovery completion time is further relaxed, the marginal benefit from having more time diminishes. For technical convenience, we assume $\Psi(t)$ is continuous and twice-differentiable and denote its first derivative as $\psi(t)$. We formalize these assumptions as follows.

Assumption 1. $\Psi(t)$ is continuous, increasing, convex and twice differentiable; $\Psi(0) = \infty$.

If the supplier opts to terminate the contract with the buyer, the supplier pays the buyer x , and the buyer will invoke its backup option. We use $d = \infty$ to denote the supplier's choice of terminating the contract.

Given a due date $d < \infty$ posted by the supplier, the buyer responds with one of the following two options: to wait for supply recovery or to invoke the buyer's backup option. We assume that if the buyer accepts the due date and commits to waiting for recovery, it will not renege. The buyer incurs a cost of c per unit of waiting time. This cost is incurred, for example, from the buyer's loss of sales in the duration of disruption. We can think of c as the external disruption cost of the supply chain.

The supplier pays penalties to the buyer for the duration of recovery. First, the contract between the buyer and the supplier specifies a penalty clause for late delivery in the event of supplier disruption. Specifically, for every unit of the buyer's waiting time due to the supplier's delay of delivery, the supplier pays the buyer a penalty, p_0 . We refer to p_0 as the *delivery delay penalty*. Furthermore, if the supply is recovered after the posted due date, that is, $t > d$, then the penalty rate is boosted to a higher level, p_1 , where $p_1 \geq p_0$, for amount of time that the supply recovery is tardy. We refer to p_1 as the *recovery tardiness penalty*. In this model, p_1 is exogenously determined, based on a commonly agreed level in the industry. We assume $p_1 \leq c$, because the supplier's share of responsibility should not exceed the buyer's actual loss, in order to be enforceable by a court. We assume that p_1 are exogenously given. The supplier's total cost for recovering the supply includes its cost of recovery effort, $\Psi(t)$, and the penalties paid to the buyer:

$$\pi_S(t, d) \stackrel{\text{def}}{=} \Psi(t) + p_0 t + (p_1 - p_0)(t - d)^+, \quad (1)$$

where the operation of $(z)^+$ denotes $\max\{0, z\}$. The supplier's total penalties comprises of two parts. First, the supplier pays delivery delay penalty, $p_0 t$, for the entire duration before the supply is fully recovered and delivered. The second part, $(p_1 - p_0)(t - d)^+$, is the excessive penalty due to the tardiness in supply recovery at rate $p_1 - p_0$. We defi the second penalty

term as follows.

Definition 1. *The supplier's total excessive penalty due to tardiness in supply recovery is*

$$\Delta_p(t, d) \stackrel{\text{def}}{=} (p_1 - p_0)(t - d)^+. \quad (2)$$

The buyer's total cost of waiting for recovery is its cost of delay, $c t$, deducting the penalties received from the supplier:

$$\pi_B(t, d) \stackrel{\text{def}}{=} c t - p_0 t - \Delta_p(t, d). \quad (3)$$

The second option of the buyer is to invoke the backup option. Doing this, the buyer terminates the supply contract, receives a one-time refund from the supplier, x , and incurs the cost of searching for and exercising the backup option, b . We shall focus on the non-trivial case of $b \geq x$. We assume that the buyer has only one opportunity to terminate the contract for backup supply, which occurs at time zero. This assumption is reasonable, as an industry-wide disruption typically results in scarcity of backup supply capacities. A hesitation in booking the backup capacity may cause the buyer to permanently lose it. Such is the case with Ericsson, when its key supplier, Philips, was disrupted by a fire. While Ericsson was pondering whether to seek backup production capacity or to wait for the supplier's recovery, Nokia, another customer of Philips, swiftly exhausted all available backup capacities. As Ericsson finally realized that supply recovery was beyond reachable timeframe and hence decided to find alternative sources of supply, all backup supply capacities had been booked by Nokia. We further assume that the backup supply is instantly available when the buyer terminates the contract with the supplier.

As prescribed in the contract before disruption, the supplier repays the buyer an amount of x at the termination of the contract following the supplier's disruption. This payment may, for example, take the form of a refund of the buyer's down-payment for the product. Under the contingency choice of backup option, the supplier's total cost is x , and the buyer's total cost is $b - x$.

The timing of events is illustrated in Figure 1.

4 Model of Perfect Information

We first analyze the model under perfect information. With this model, we want to understand the supplier's optimal due date quoted to the buyer and the optimal recovery completion time. We shall derive insights about the buyer and supplier's responses to supply

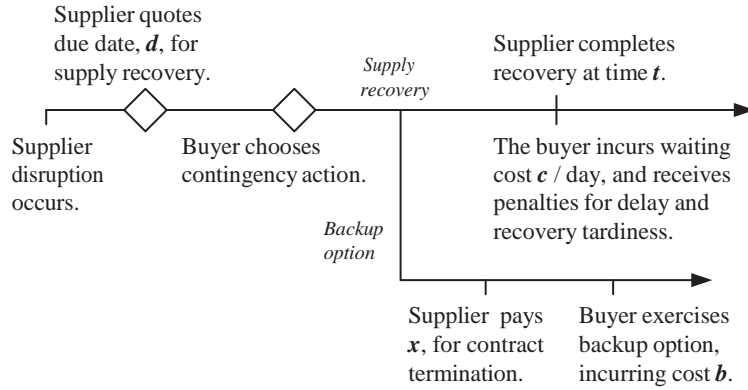


Figure 1: Time of events.

disruption, and use these results as a benchmark for the analysis of the effects of information asymmetry in §5. We solve this problem backward, starting with the supplier’s optimal recovery completion time in stage 3.

4.1 The supplier’s Optimal Recovery Completion Time

In stage 3, given that the buyer agrees to wait for supply recovery with due date d , the supplier chooses the completion time t to minimize its total costs of supply recovery:

$$\max_{t \geq 0} \pi_S(t, d) = \Psi(t) + p_0 t + \Delta_p(t, d) \quad (4)$$

Because both $\Psi(t)$ and $\Delta_p(t, d)$ are convex in t , the objective function is convex. Let $t^*(d)$ be the optimal completion time for a given due date d . We present the supplier’s the optimal completion time for recovery in Lemma 1, and is illustrated on the right panel of Figure 2. The three cases defined in Lemma 1 correspond to the three intervals in the figure.

Lemma 1. *The supplier’s optimal recovery completion time is*

$$t^*(d) = \begin{cases} \psi^{-1}(-p_1), & (5.A): d < \psi^{-1}(-p_1) \\ d, & (5.B): \psi^{-1}(-p_1) \leq d < \psi^{-1}(-p_0). \\ \psi^{-1}(-p_0), & (5.C): d \geq \psi^{-1}(-p_0) \end{cases} \quad (5)$$

Depending on the value of the due date d , there are three cases of the optimal completion time. When the due date d is very early (i.e., case (5.A)), the supplier finds it too costly to make sufficient recovery effort to meet the due date. Supply recovery will be tardy, so the supplier pays the recovery tardiness penalty at rate p_1 . Under this penalty, the supplier’s total costs of recovery is minimized at $t = \psi^{-1}(-p_1)$, at which the marginal cost of the

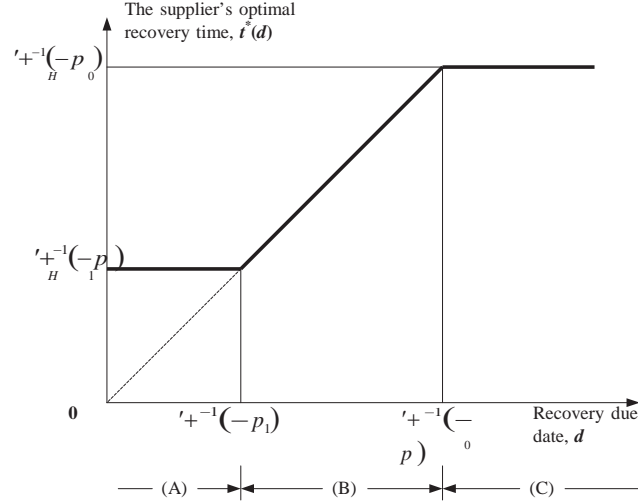


Figure 2: The optimal recovery completion time in relation to the due date d , $t^*(d)$. Intervals A, B and C along the horizontal axes correspond to the three cases defined in equation (5).

Recovery effort breaks even with the penalty rate p_1 . At the other extreme (i.e., case (5.C)), the due date d is so late that the supplier will always be on time even if the recovery effort is low. The supplier will pay only the delivery delay penalty at rate p_0 . The supplier's total costs of recovery is minimized at $t = \psi^{-1}(-p_0)$. In between the two extremes of d (i.e., case (5.B)), the supplier finds it more costly to pay penalty p_1 for tardiness than accelerating the recovery to make it on time. On the other hand, the supplier finds it more costly to make effort to be early than paying penalty p_0 for delaying the delivery. Therefore, the supplier completes recovery on the due date d .

It follows from Lemma 1 that the supplier's optimal recovery completion time falls in interval $[\psi^{-1}(-p_1), \psi^{-1}(-p_0)]$. Therefore, $\psi^{-1}(p_1)$ sets the *earliest possible recovery completion time* that the supplier will accomplish, and $\psi^{-1}(p_0)$ sets the *latest possible recovery completion time* of the supplier.

We define the supplier's and the buyer's total costs for using supply recovery under the optimal recovery completion time to be $\pi_S(d) = \pi_S(t^*(d), d)$ and $\pi_B(d) = \pi_B(t^*(d), d)$. We substitute $t^*(d)$ (in (5)) into (1) and (3) to obtain the expressions for $\pi_S(d)$ and $\pi_B(d)$:

$$\pi_S(d) = \begin{cases} \Psi(\psi^{-1}(-p_1)) + p_0\psi^{-1}(-p_1) + \Delta_p(d), & \text{(5.A): } d < \psi^{-1}(-p_1) \\ \Psi(d) + p_0d, & \text{(5.B): } \psi^{-1}(-p_1) \leq d \leq \psi^{-1}(-p_0) \\ \Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0), & \text{(5.C): } d > \psi^{-1}(-p_0) \end{cases} \quad (6)$$

and

$$\pi_B(d) = \begin{cases} (c - p_0)\psi^{-1}(-p_1) - \Delta_p(d), & \text{(5.A): } d < \psi^{-1}(-p_1) \\ (c - p_0)d, & \text{(5.B): } \psi^{-1}(-p_1) \leq d \leq \psi^{-1}(-p_0), \\ (c - p_0)\psi^{-1}(-p_0), & \text{(5.C): } d > \psi^{-1}(-p_0) \end{cases} \quad (7)$$

where function

$$\Delta_p(d) \stackrel{\text{def}}{=} \Delta_p(t^*(d), d) = (p_1 - p_0)[\psi^{-1}(-p_1) - d]. \quad (8)$$

is the extra penalty paid for tardiness of recovery at the optimal recovery completion time. Note that the supplier incurs the extra penalty $\Delta_p(d)$ only if the due date is earlier than the earliest possible completion time, $\psi^{-1}(-p_1)$ (i.e., case (5.A)), when recovery tardiness occurs. When the due date is moderate or very late (cases (B) and (C)), the supplier completes recovery on time or early, and no tardiness penalty is incurred. We illustrate the supplier and buyer's total cost for using supply recovery in Figure 3.

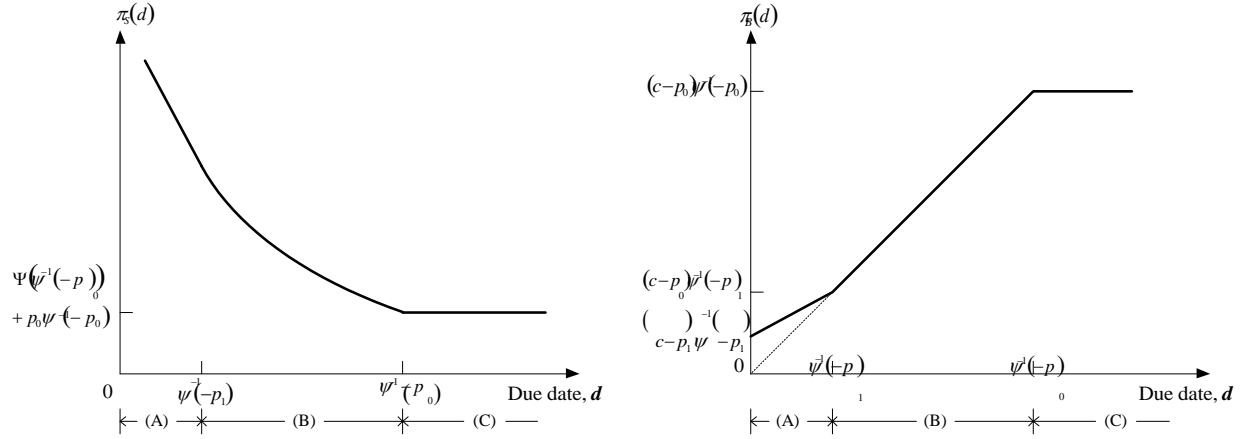


Figure 3: The supplier's total cost (the left panel) and the buyer's total cost (the right panel) for using supply recovery under the optimal completion $t^*(d)$.

Intuitively, as the due date d is relaxed, the supplier's total cost of supply recovery decreases, because it requires less effort for the supplier to recover the lost supply. In contrast, the buyer's total costs of recovery increases in d , because it incurs higher cost for waiting until the lost supply is recovered. We formalize these observations in Lemma 2.

Lemma 2. *The buyer's total cost of making supply recovery, $\pi_B(d)$, decreases in d . The supplier's total cost of waiting for supply recovery, $\pi_S(d)$, increases in d .*

4.2 The Buyer's Maximum Acceptable Due Date for Recovery

We now analyze the buyer's decision in stage 2. Given that in stage 1 the supplier offers to make supply recovery with due date d , the buyer has two contingency options: waiting for

supply recovery and invoking the backup option. If the buyer opts for supply recovery, then it anticipates the supplier will complete recovery at its optimal completion time $t^*(d)$, and the buyer's total costs of waiting for supply recovery is $\pi_B(d)$, given in (7). If the buyer opts for the backup option, then the contract with the supplier is terminated. The buyer receives the exit payment x , but incurs a cost of b for the backup option. The supplier's costs for invoking the backup option are totaled to be $b - x$.

The buyer waits for supply recovery, if the total cost for using the backup option exceeds that for waiting for recovery, that is, $\pi_B(d) \leq b - x$. Because the buyer's cost for waiting for recovery, $\pi_B(d)$, increases in the due date d (see Lemma 2), there exists a maximum due date that the supplier can quote, denoted as \bar{d} , without pushing the buyer to invoke the backup option. By solving $b - x = \pi_B(d)$, we obtain

$$\bar{d} \begin{cases} < 0 \\ = \Gamma \\ = \frac{b-x}{c-p_0} \\ = \infty \end{cases} \begin{cases} \text{(9.I)} : b - x < (c - p_1)\psi^{-1}(-p_1) \\ \text{(9.II)} : (c - p_1)\psi^{-1}(-p_1) \leq b - x \leq (c - p_0)\psi^{-1}(-p_1) \\ \text{(9.III)} : (c - p_0)\psi^{-1}(-p_1) < b - x \leq (c - p_0)\psi^{-1}(-p_0) \\ \text{(9.IV)} : b - x > (c - p_0)\psi^{-1}(-p_0), \end{cases} \quad (9)$$

where

$$\Gamma \stackrel{\text{def}}{=} \frac{(b - x) - (c - p_1)\psi^{-1}(-p_1)}{(p_1 - p_0)}. \quad (10)$$

One can verify from (9) that \bar{d} increases as $b - x$ increases. As the buyer's cost of using the backup option increases, the buyer gradually becomes more willing to wait for supply recovery and accept a long due date. In case (9.I), the buyer's net cost of using backup, $b - x$, is less than its cost of waiting for recovery, even if the supplier quotes zero due date. The buyer never waits for recovery. As the backup option becomes more costly, in case (9.II), the buyer waits for supply only if the supplier quotes a short due date, $\bar{d} = \Gamma$. As the cost of the backup option continues to increase into case (9.III), the buyer is now willing to wait for supply recovery, even if the supplier quotes a due date higher than before, that is, $\bar{d} = \frac{b-x}{c-p_0} > \Gamma$. It is clear that under $b - x \leq (c - p_0)\psi^{-1}(-p_0)$ (cases I, III and III) we have $\bar{d} \leq \psi^{-1}(-p_0)$.

In case (9.IV), the buyer's cost for using the backup option is greater than its cost for recovery, at any due date that the supplier may post. The buyer always chooses recovery over the backup option. We denote the buyer's choice as $\bar{d} = \infty$.

Substituting the optimal due date $d = \bar{d}$ into (6), we obtain the supplier's total cost for

supply recovery at due date $d = \bar{d}$:

$$\pi_S(\bar{d}) = \begin{cases} \text{N/A. The buyer chooses the backup option} & \text{under (9.I)} \\ \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b-x) & \text{under (9.II)} \\ \Psi\left(\frac{b-x}{c-p_0}\right) + c\psi^{-1}(-p_0) - (b-x) & \text{under (9.III)} \\ \Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0) & \text{under (9.IV)}. \end{cases} \quad (11)$$

Note that the four cases in (11) corresponds to the four cases defined in (9).

4.3 The Supplier's Optimal Response to Disruption

We now analyze the supplier optimal decision in stage 1 in reaction to supply disruption. The supplier has two contingency options: to pay the buyer the amount of x to terminate the contract; and to commit to supply recovery with the due date d that minimizes the supplier's cost for recovery, $\pi_S(d)$ (see equation (7)). The supplier prefers supply recovery over terminating the contract, if and only if $\pi_S(d) \leq x$. Because $\pi_S(d)$ decreases in the due date d , there exists minimum value of d for the supplier to choose supply recovery over terminating the contract. Setting $\pi_S(d) = x$, we obtain the minimum acceptable due dates for the supplier to commit to supply recovery:

$$d = \begin{cases} \infty, & x < \Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0), \\ \zeta^1, & \Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0) \leq x < \Psi(\psi^{-1}(-p_1)) + p_0\psi^{-1}(-p_1) \\ \zeta^{11}, & \Psi(\psi^{-1}(-p_1)) + p_0\psi^{-1}(-p_1) \leq x \leq \Psi(\psi^{-1}(-p_1)) + p_1\psi^{-1}(-p_1) \\ < 0 & x > \Psi(\psi^{-1}(-p_1)) + p_1\psi^{-1}(-p_1), \end{cases} \quad (12)$$

where ζ^1 and ζ^{11} are such that:

$$\zeta^1 = \text{the value of } d \leq \psi^{-1}(-p_0) \text{ that satisfies } \Psi(d) + p_0d = x \quad (13)$$

$$\zeta^{11} = \frac{\Psi(\psi^{-1}(-p_1)) + p_1\psi^{-1}(-p_1) - x}{p_1 - p_0} \quad (14)$$

One can verify that as x increases, \underline{d} decreases.

Supply recovery will be executed only if the due date is not too early, i.e., $d \geq \underline{d}$, and at the same time the due date is sufficiently early so that the buyer will agree to wait for recovery, i.e., $d \leq \bar{d}$. We further assume that when $\bar{d} = \infty$, the supplier will post a due date no later than $\psi^{-1}(-p_0)$, because the supplier will not benefit from posting a due date later than $\psi^{-1}(-p_0)$. The feasible set of due dates for supply recovery to occur is $[\underline{d}, \min\{\bar{d}, \psi^{-1}(-p_0)\}]$. We characterize the condition under which this set is non-empty in Lemma 3.

Lemma 3. Interval $[\underline{d}, \min\{\bar{d}, \psi^{-1}(-p_0)\}]$ is non-empty, if one of the following three mutually exclusive conditions are satisfied:

- $(c-p_1)\psi^{-1}(-p_1) \leq b-x < (c-p_0)\psi^{-1}(-p_1)$ and $x \geq \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b-x)$
- $(c-p_0)\psi^{-1}(-p_1) \leq b-x < (c-p_0)\psi^{-1}(-p_0)$ and $x \geq \Psi\left(\frac{b-x}{c-p_0}\right) + c\left(\frac{b-x}{c-p_0}\right) - (b-x)$
- $b-x \geq (c-p_0)\psi^{-1}(-p_0)$ and $x \geq \Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0)$

Because the supplier's cost for making supply recovery, $\pi_s(d)$, decreases in the due date, the supplier optimally set the due date to be the upper bound. Therefore, the supplier's optimal due date, denoted as d^* , is $d^* = \min\{\bar{d}, \psi^{-1}(-p_0)\}$. We summarize the supplier's and the buyer's equilibrium responses to disruption in Proposition 1.

Proposition 1. In equilibrium, the buyer's risk mitigation action and the supplier's recovery due date and completion time are

I. When $b-x < (c-p_1)\psi^{-1}(-p_1)$ (condition 9.I), the buyer invokes the backup option.

II. When $(c-p_1)\psi^{-1}(-p_1) \leq b-x < (c-p_0)\psi^{-1}(-p_1)$ (condition 9.II),

- If $x \geq \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b-x)$, the buyer waits for supply recovery; the supplier makes supply recovery, posts the due date $d^* = \Gamma$, and completes recovery at time $t^* = \psi^{-1}(-p_1)$; the supplier's cost for recovery is $\pi_s(d^*) = \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b-x)$
- Otherwise, the buyer and supplier do not agree on a recovery due date.

III. When $(c-p_0)\psi^{-1}(-p_1) \leq b-x \leq (c-p_0)\psi^{-1}(-p_0)$ (condition 9.III),

- If $x \geq \Psi\left(\frac{b-x}{c-p_0}\right) + c\left(\frac{b-x}{c-p_0}\right) - (b-x)$, the buyer waits for supply recovery; the supplier makes supply recovery and posts the due date to be equal to the completion time of recovery, $d^* = t^* = \frac{b-x}{c-p_0}$; the supplier's cost for supply recovery is $\pi_s(d^*) = \Psi\left(\frac{b-x}{c-p_0}\right) + c\left(\frac{b-x}{c-p_0}\right) - (b-x)$.
- Otherwise, the buyer and supplier do not agree on a recovery due date.

IV. When $b-x > (c-p_0)\psi^{-1}(-p_0)$ (condition 9.IV),

- If $x \geq \Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0)$, the buyer waits for supply recovery; the supplier makes supply recovery post the due date to be equal to the completion time of recovery, $d^* = t^* = \psi^{-1}(-p_0)$; the supplier's cost for supply recovery is $\pi_s(d^*) = \Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0)$.

- Otherwise, the buyer and supplier do not agree on a recovery due date.

On the left panel of Figure 4, we illustrate the supply chain firms equilibrium response to disruption in relation to $(b - x, x)$ and the equilibrium due date of supply recovery when it is used. In region (a), where the buyer's cost for using the backup option $b - x$ and the supplier's cost for terminating the contract x are both large, the buyer and the supplier agree on using supply recovery. In region (b), where the buyer's cost for using the backup option or the supplier's cost for terminating the contract is small, the buyer or the supplier prefers not to use supply recovery. In equilibrium, supply recovery is not used, and the buyer invokes the backup option.

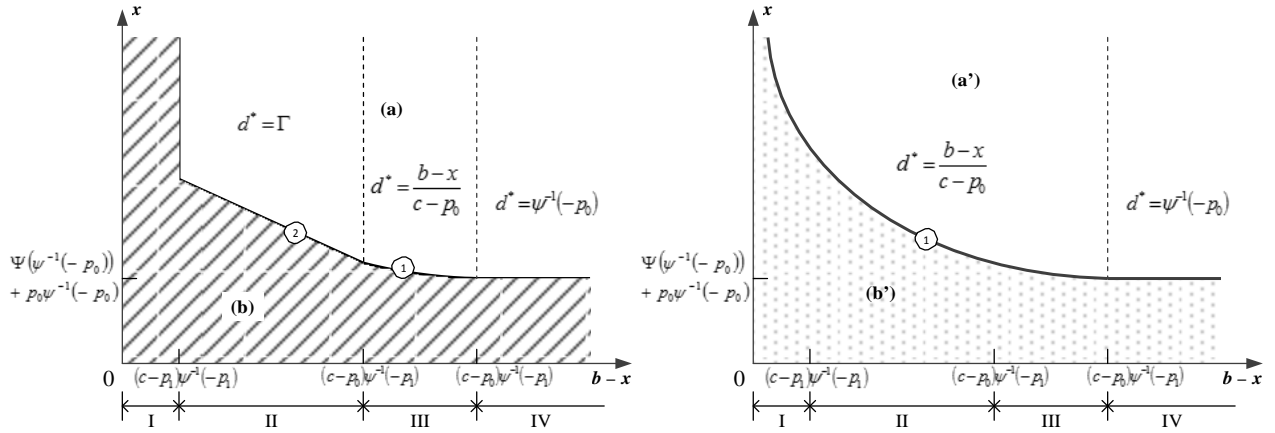


Figure 4 The left panel: The supply chain firms responses to disruption in equilibrium. The right panel: the supply chain's response to disruption in equilibrium when supplier procrastination is disallowed. Regions (a) and (a'): the buyer and supplier agree to use supply recovery with due date d^* . Regions (b) and (b'): the buyer and supplier disagree on supply recovery; the buyer invokes the backup option. Line segment 1: $x = \Psi \frac{b-x}{c-p_0} + c \frac{b-x}{c-p_0} - (b-x)$. Line segment 2: $x = \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b-x)$.

4.4 The Effects of Supplier Procrastination

We start this discussion by making an observation about the supplier's optimal due date versus the completion time for recovery. We find that in case (II) of Proposition 1, when supply recovery is the equilibrium response to disruption, the recovery completion time is strictly later than the due date. That is, it may be optimal for the supplier to procrastinate in the recovery process. We formalize this observation in Corollary 1.

Corollary 1. *At equilibrium, $t^* > d^*$ under $(c - p_1)\psi^{-1}(-p_1) \leq b - x < (c - p_0)\psi^{-1}(-p_1)$ and $x \geq \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b - x)$.*

Because the supplier can choose the recovery completion time without being restricted by the due date posted, the supplier enjoys flexibility in planning supply recovery, but it creates room for procrastination and tardiness in recovery process. Simply intuition suggests that allowing the supplier to procrastinate is to the buyer's disadvantage, and thus makes supply recovery less favored and less used by the buyer.

To evaluate the effects of supplier procrastination on the two firms' contingency responses to disruption and on their costs, we analyze a benchmark model that is a variant of the main model—the supplier must choose the recovery completion time to be $t \leq d$ in stage 3. Intuitively, this extra restriction can be implemented by setting the tardiness penalty to be extremely large, e.g., $p_1 = \infty$, so recovery tardiness is prohibitively costly for the supplier to use as a strategy. Therefore, to derive the result for this variant model, one can apply $p_1 = \infty$ to Proposition 1. Specifically, when $p_1 = \infty$, we have $\psi^{-1}(-p_1) < 0$, so cases (I) and (II) in Proposition 1 vanishes. We solve the benchmark model and present the equilibrium in Lemma 4:

Lemma 4. *Under constraint $t \leq d$, the buyer and supplier's contingency responses to disruption are: when $0 \leq b - x < (c - p_0)\psi^{-1}(-p_0)$,*

- *If $x \geq \Psi \frac{b-x}{c-p_0} + c \frac{b-x}{c-p_0} - (b - x)$, the buyer waits for supply recovery; the supplier makes supply recovery and posts the due date to be equal to the completion time of recovery, $d^* = t^* = \frac{b-x}{c-p_0}$; the supplier's cost for supply recovery is $\pi_s(d^*) = \Psi \frac{b-x}{c-p_0} + c \frac{b-x}{c-p_0} - (b - x)$.*
- *Otherwise, the buyer and supplier do not agree on a recovery due date.*

When $b - x \geq (c - p_0)\psi^{-1}(-p_0)$,

- *If $x \geq \Psi \psi^{-1}(-p_0) + p_0\psi^{-1}(-p_0)$, the buyer waits for supply recovery; the supplier makes supply recovery post the due date to be equal to the completion time of recovery, $d^* = t^* = \psi^{-1}(-p_0)$; the supplier's cost for supply recovery is $\pi_s(d^*) = \Psi \psi^{-1}(-p_0) + p_0\psi^{-1}(-p_0)$.*
- *Otherwise, the buyer and supplier do not agree on a recovery due date.*

On the right panel of Figure 4, we illustrate the supply chain's equilibrium response to supply disruption in relation to x and b and the equilibrium due date of supply recovery,

if used. Intuitively, the buyer and supplier agree to use supply recovery only if the cost of the backup option and the buyer's cost of terminating the contract are both high, that is, $(b - x, x)$ falls in region (a').

To identify the effects of allowing supplier procrastination on the supply chain's equilibrium response to disruption, we compare the equilibrium in Lemma 4 with that in Proposition 1. We illustrate the differences in Figure 5, which is derived by comparing the left and right panels of Figure 4.

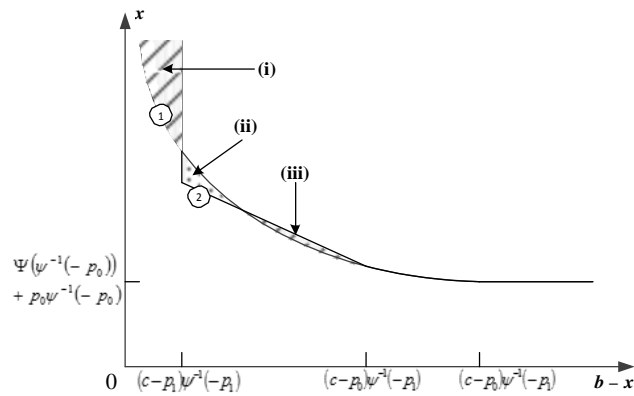


Figure 5: The effects of allowing supplier procrastination. In regions (i) and (iii), supply recovery is used if supplier procrastination is allowed, but is not used if supplier procrastination is disallowed. Line segment 1 and 2 are defined in Figure 4.

We identify three regions where supplier procrastination causes a difference in the supply chain's equilibrium response to disruption. In regions (i) and (iii), if supplier procrastination is disallowed, the buyer and supplier agree to use supply recovery, but the buyer will forego waiting for recovery if the supplier is allowed to procrastinate. Allowing supplier procrastination causes supply recovery to be less used, even if the buyer compensated by the tardiness penalty from the supplier. The main reason is that allowing supplier procrastination increases the buyer's cost of waiting for supply recovery.

Interestingly, there may exist a non-empty region (ii), in which if supplier procrastination is disallowed the buyer and supplier disagree on supply recovery, but they agree to use supply recovery if the supplier is allowed to procrastinate. Allowing supplier procrastination may increase the use of supply recovery. Technically, region (ii) is the following set of $(b - x, x)$:

$$\Omega \stackrel{\text{def}}{=} (b - x, x) : \Psi \frac{b - x}{c - p_0} + c \frac{b - x}{c - p_0} \leq x < \Psi \left(\psi^{-1} \left(\frac{p}{-1} \right) \right) + c \psi^{-1} \left(\frac{p}{-1} \right), \quad (15)$$

for every $b - x \in (c - p_1) \psi^{-1}(-p_1), b^1 - x)$,

where b^1 is such that

$$\begin{aligned} & \square \Psi \frac{b^1 - x}{c - p_0} + c \frac{b^1 - x}{c - p_0} = \Psi(\psi^{-1}(p_1)) + c\psi^{-1}(p_1) \quad \text{and} \\ & \square (c - p_1)\psi^{-1}(-p_1) < b^1 - x < (c - p_0)\psi^{-1}(-c) \end{aligned} \quad (16)$$

In Proposition 2, we characterize the condition under which region (ii) is non-empty.

Proposition 2. *There exists p_1^1 , such that, for all $p_1 \in (p_1^1, c]$, there exists a b^1 that satisfies conditions (16) and Ω is non-empty.*

Proposition 2 establishes that allowing supplier procrastination increases the use of supply recovery if the tardiness penalty, p_1 , is close to the supply chain's external disruption cost, c . To understand this result, we begin with the case where supplier procrastination is disallowed. Under a low backup cost (i.e., $b - x < (c - p_0)\psi^{-1}(-c)$), the buyer will prefer supplier recovery over the backup option only if the recovery due date is earlier than that is optimal for the channel, cause channel inefficiency. To complete recovery by this short due date the supplier will incur a prohibitively large cost for supply recovery, so it chooses to terminate the contract but not to make supply recovery. In the case where supplier is allowed to procrastinate, a high tardiness penalty (i.e., p_1 close c) improves the channel efficiency because it aligns the supplier's interest with that of the whole channel, reducing the cost of supply recovery effort. The supplier now finds supply recovery less costly than terminating the contract.

It follows that in region (ii), allowing supplier procrastination benefits both the supplier and buyer. We formalize this result in Corollary 2.

Corollary 2. *For any $(b - x, x) \in \Omega$, in the case where supplier procrastination is allowed both the buyer and the supplier's costs are lower than in case where supplier procrastination is disallowed.*

In summary, our findings have two practical implications. First, we show that allowing the supplier to procrastinate may increase the use of supply recovery and benefit both the buyer and supplier. Therefore, a savvy buyer may choose to tolerate tardiness in supply recovery. Second, uncertainty in the recovery process is typically blamed for tardiness in supply recovery. Our findings show that the buyer and supplier may have an incentive to allow procrastination, even when there is no uncertainty in recovery.

4.5 The Effects of Recovery Tardiness Penalty

In supply-risk management, penalties play the role of transferring risk from the buyer to supplier and aligning the supplier's actions. One may think that a larger recovery tardiness penalty is to the buyer's benefit, but to the supplier's disadvantage. We will now analyze how the supplier's cost is affected by p_1 .

To understand the effects of p_1 , we plot the equilibrium outcome in relation to $b - x$ and p_1 in Figure 6, which is constructed from Proposition 1. To facilitate the construction of the figure we use $\psi^{-1}(-p_1)$ as the proxy for p_1 . Recall that $\Psi(\cdot)$ is a convex function; its derivative $\psi(\cdot)$ is a monotone, increasing function. As p_1 increases from its lower bound p_0 to the upper bound c , $\psi^{-1}(-p_1)$ decreases from $\psi^{-1}(-p_0)$ to $\psi^{-1}(-c)$. Corresponding to the four cases defined in Proposition 1, there are four regions, labelled as (I), (II), (III) and (IV). These four regions are separated by lines 1, 2 and 3, which correspond to the boundary conditions that define the four cases in Proposition 1. For illustration purpose, we choose the value of x that satisfies $\Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0) \leq x < \Psi(\psi^{-1}(-c)) + p_0\psi^{-1}(-c)$. Lines 4 and 7 specify the minimum $b - x$ for the supplier to be able to reach an agreement with the buyer for using supply recovery. The shaded regions indicate the set of $(\psi^{-1}(-p_0), b - x)$ at which the buyer and the supplier agree to use supply recovery.

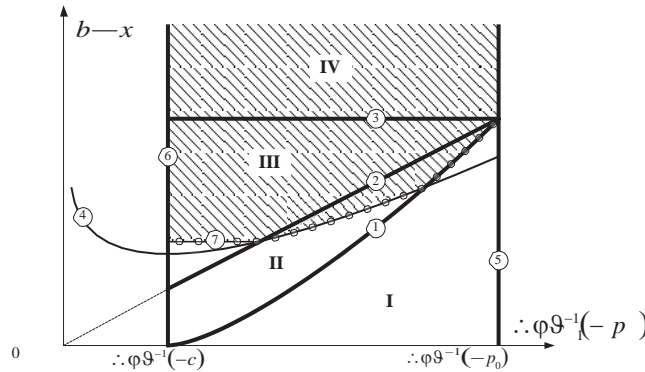


Figure 6: The supply chain's equilibrium response to disruption by the four cases defined in Proposition 1, when x satisfies $\Psi(\psi^{-1}(-p_0)) + p_0\psi^{-1}(-p_0) \leq x < \Psi(\psi^{-1}(-c)) + p_0\psi^{-1}(-c)$. In the shaded regions, the supply chain's equilibrium response is supply recovery, and in the unshaded regions, the supply chain's response is to use the backup option.

Line 1: $b - x = (c - p_1)\psi^{-1}(-p_1)$; line 2: $b - x = (c - p_0)\psi^{-1}(-p_1)$; line 3: $b - x = (c - p_0)\psi^{-1}(-p_0)$;
line 4: $b - x = \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - x$; line 5: $\psi^{-1}(-p_1) = \psi^{-1}(p_0)$; line 6: $\psi^{-1}(p_1) = \psi^{-1}(c)$;
line 7: $b - x = \Psi\left(\frac{b-x}{c-p_0}\right) + c\left(\frac{b-x}{c-p_0}\right) - x$.

To see how the equilibrium outcome and the supplier's cost change in p_1 , we fix $b - x$ to

be a value between lines 3 and 7 in Figure 6. As p_1 increases from p_0 to c , $(\psi^{-1}(p_0), b - x)$ goes from right to left through regions (I), (II) and (III) in order, and the expression for the supplier's cost can be extracted from the respective cases in Proposition 1. We find that as $\psi^{-1}(-p_1)$ decreases (i.e., p_1 increases) the supplier's cost decreases. We generalize this observation to a broader range of values of $b - x$ and x in Corollary 3.

Corollary 3. *Under $(x, b - x)$ such that $x \geq \Psi(\psi^{-1}(-p_0)) + p_0 \psi^{-1}(-p_0)$ and $\Psi \frac{b-x}{c-p_0} + \frac{c-b-x}{c-p_0} - x \leq b - x < (c - p_0)\psi^{-1}(-p_0)$, the supplier's cost in equilibrium decreases in p_1 .*

Surprisingly, Corollary 3 shows that the supplier benefits from an increase in the tardiness penalty. This result is driven by the role of the tardiness penalty, p_1 , on the supplier's use of supply recovery and the channel efficiency. When the penalty is small (in region (I) and unshaded part of region (II)), the supplier has no incentive to make supply recovery but terminates the contract, paying the termination cost x . The tardiness penalty p_1 is irrelevant. As p_1 increases to be moderate (in the shaded part of region (II)), the supplier makes supply recovery but will procrastinate, incurring penalties for tardiness. The tardiness penalty becomes relevant. In fact, as p_1 increases, the supplier's recovery effort is better aligned with the centralized supply chain, and the channel efficiency improves. The supplier benefits from the improvement in the channel efficiency. Finally, as p_1 becomes very large (in region (III)), the supplier makes supply recovery without procrastination. The tardiness penalty has no effect on the supplier's cost.

5 The Model of Asymmetric Information

In the analysis in §4, we have focused on the situation in which the disruption severity is perfectly known by the buyer as well. We now turn to the model of asymmetric information—the buyer does not know the severity of the supplier's disruption.

Under information asymmetry, the buyer does not have perfect visibility of the supplier's condition after disruption. To compensate for the lack of information, the buyer can better assess the supplier's ability of making a timely recovery and improve its decision making, by collecting information from the supplier from its communication with the supplier *ex post* disruption and inferring the severity of disruption. Specifically, in this model we assume that the buyer assesses the severity of disruption by reading the recovery due date posted by the supplier. For example, the buyer can interpret a late recovery due date posted by the supplier as a sign of high severity disruption and, thus, considers invoking its backup option;

and the buyer may do it conversely, if the supplier posts an early due date.

However, privileged with private information, the supplier can manipulate the buyer's expectation of supply recovery and its response to disruption by twisting the recovery due date. For example, a supplier that suffers severe damage from disruption may pretend to be only frivolously affected by posting an early due date. This may make the buyer believe that backup production is less necessary, and the supplier has a better chance to retain the buyer's business.

It is not clear *a priori* whether the buyer can reliably infer the severity of the supplier's disruption by interpreting the due date posted by the supplier and how the supply chain firms responses to disruption are effected by information asymmetry. We shall explore these questions in this section by modeling the interaction between the buyer and the supplier *ex post* as a signaling game, in which the supplier has private information and moves fi

5.1 Setting of the Signaling Game

We now extend the model setting of perfect information in §4 to the model of the signaling game, in which the severity of disruption is the supplier's private information. We assume the severity of disruption, denoted as θ , is "high" (i.e., $\theta = H$) with probability α or "low" (i.e., $\theta = L$) with probability $1 - \alpha$. Immediately after the occurrence of disruption, the supplier perfectly observes the severity of disruption. The buyer does not observe the severity of disruption, but only knows the prior probability distribution of the severity, θ .

The supplier's cost of recovering supply depends on the severity of disruption. Under severity θ , the supplier incurs a cost of $\Psi_\theta(t)$ for completing supply recovery by time t . Similar to $\Psi(t)$, $\Psi_\theta(t)$ is decreasing, convex, continuous and twice diff tiable. Since a more severe disruption causes greater damage and thus is more costly to remedy, we assume that when faced with the high level severity of disruption the supplier's cost of recovering the supply is larger than under the low level of severity. That is, $\Psi_H(t) > \Psi_L(t)$. Denoting the first derivatives of the recovery cost under the two severity levels as $\psi_H(t)$ and $\psi_L(t)$, we assume $\psi_H(t) < \psi_L(t)$. In words, if the recovery completion time t is relaxed, under the high level of the severity disruption the supplier's recovery cost is reduced by a greater amount than under the low level of the severity disruption. This reflects the fact that under a more severe disruption the supplier's recovery cost is more sensitive to recovery time. We formalize these two assumptions in Assumption 2.

Assumption 2. $\Psi_H(t) > \Psi_L(t)$ and $\psi_H(t) < \psi_L(t)$.

The timing of events in the signaling game is as follows. Nature moves first to draw the severity of the supplier's disruption to be $\theta = H$ with probability α or $\theta = L$ with probability $1 - \alpha$. This is also the buyer's prior belief about the severity of disruption. Knowing the true value of θ , the supplier decides whether or not to recover the lost supply or pay x to the buyer for terminating the contract. If the supplier chooses supply recovery, it posts a recovery due date, $d < \infty$, and promises paying penalties for delay of delivery and tardiness of recovery at rate p_0 or p_1 . Seeing the due date, the buyer updates its belief about the severity of disruption. Then, based on its posterior belief, the buyer decides whether to wait for supply recovery or to invoke its backup option. If the buyer chooses supply recovery, then the supplier makes the recovery effort and pays penalties for delay and tardiness; otherwise, the buyer collects x from the supplier and invokes the backup option.

5.2 The Effects of the Severity of Disruption and the Supplier's Incentive

To prepare for the analysis of the signaling game, we shall analyze the supplier's and the buyer's costs under the two disruption severity levels and the supplier's incentive of misreporting the severity of disruption under asymmetric information.

The supplier's optimal completion time of recovery. We first analyze the supplier's optimal recovery completion times at the two disruption severity levels. From Assumption 2, we prove the following property in Lemma 5.

Lemma 5. $\psi_H^{-1}(-p) > \psi_L^{-1}(-p)$.

Lemma 5 shows that, given all other factors the same, the supplier's optimal completion time is longer under high severity disruption than under low severity disruption. Setting $p = p_1$ and p_0 , respectively, we conclude that under high severity disruption the supplier's *earliest* and *latest possible recovery completion times*, $\psi_H^{-1}(-p_1)$ and $\psi_H^{-1}(-p_0)$, are longer than under low severity disruption, $\psi_L^{-1}(-p_1)$ and $\psi_L^{-1}(-p_0)$, respectively.

The supplier's cost for supply recovery. To derive the supplier's costs for supply recovery at the severity level θ , denoted as $\pi_S^\theta(d)$, we substitute $\Psi(\cdot)$ and $\psi(\cdot)$ in (6) with $\Psi_\theta(\cdot)$ and $\psi_\theta(\cdot)$, for $\theta = H$ and L . The left panel of Figure 7 illustrates an instance of $\pi_S^H(d)$ and $\pi_S^L(d)$. Similarly, we derive the supplier's maximum acceptable due date at the severity level θ , denoted as \underline{d}_θ , from equation (12). From (12), we learn that, when the cost for terminating the contract is very low $x < \Psi_\theta(\psi_\theta^{-1}(-p_0)) + p_0\psi_\theta^{-1}(-p_0)$, for $\theta = H$ or L , we have $\underline{d}_H = \infty$ or $\underline{d}_L = \infty$. That is, the supplier may not want to make supply recovery. The equilibrium under

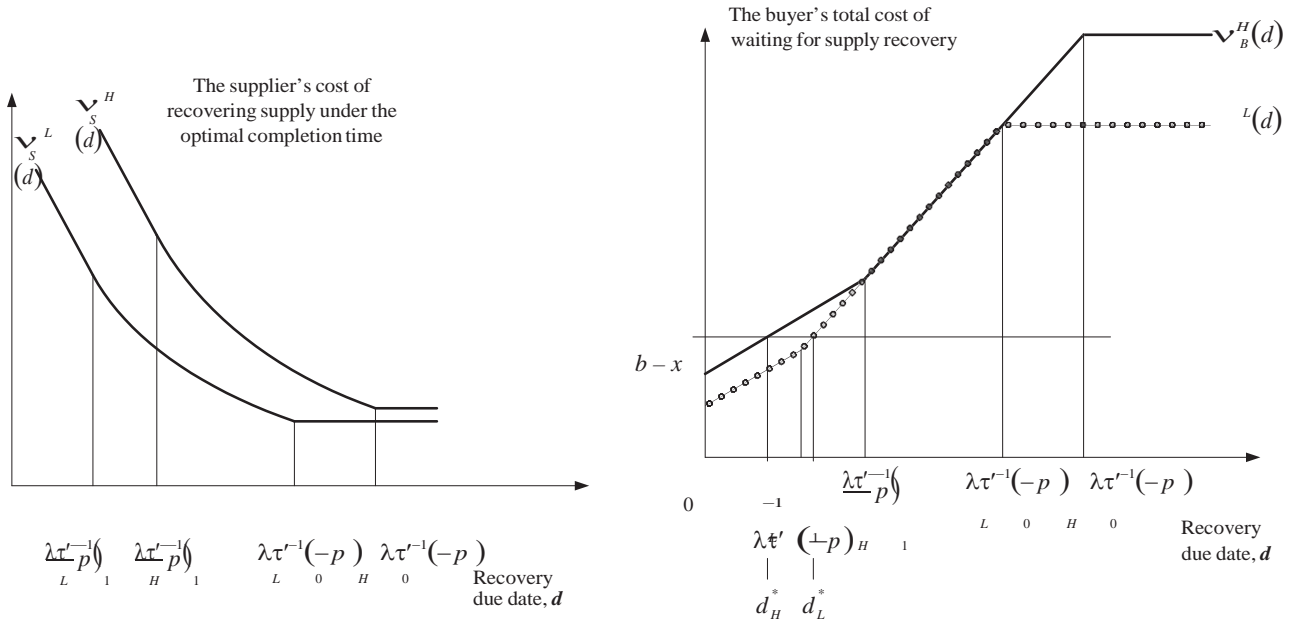


Figure 7: The supplier's cost (the left panel) and the buyer's cost (the right panel) for using supply recovery at the supplier's optimal recovery competition time at the high and low disruption severity levels.

such extreme \underline{d}_H and \underline{d}_L degenerates to that in the perfect information model, either because the buyer can perfectly distinguish the severity level (when either $\underline{d}_H = \infty$ or $\underline{d}_L = \infty$, but not both), or because supply recovery is irrelevant (when $\underline{d}_H = \underline{d}_L = \infty$). In the rest of this section, we shall focus on the nontrivial case where $x \geq \Psi_\theta(\psi_\theta^{-1}(-p_0)) + p_0\psi_\theta^{-1}(-p_0)$, for both $\theta = H$ and L , under which $\underline{d}_H < \infty$ and $\underline{d}_L < \infty$. Under such x , we identify the following relationship between \underline{d}_H and \underline{d}_L in Lemma 6.

Lemma 6. *If $x \geq \Psi_\theta(\psi_\theta^{-1}(-p_0)) + p_0\psi_\theta^{-1}(-p_0)$ for both $\theta = H$ and L , then we have $\underline{d}_L < \underline{d}_H < \infty$.*

Lemma 6 implies that the supplier accepts an earlier due date under the low disruption severity than under the high severity.

The buyer's cost for using supply recovery. To derive the buyer's total costs for using supply recovery under the severity θ , denoted as $\pi_B^\theta(d)$, we substitute $\psi(\cdot)$ in (7) with $\psi_\theta(\cdot)$. We illustrate an instance of $\pi_B^H(d)$ and $\pi_B^L(d)$ on the right panel of Figure 7. Note that, in this illustration, $\psi_L^{-1}(p_0) \geq \psi_H^{-1}(p_1)$. When p_0 and p_1 approximates each other, $\psi_L^{-1}(p_0) > \psi_H^{-1}(p_1)$ may be true. In this section, focus on the more general case of $\psi_L^{-1}(p_0) \geq \psi_H^{-1}(p_1)$. The insights we develop under this condition will carry over to the case of $\psi_L^{-1}(p_0) < \psi_H^{-1}(p_1)$.

The expression of \bar{d}_θ can be obtained from (9) by substituting $\psi^{-1}(\cdot)$ in equation (9)

with $\psi_\theta^{-1}(\cdot)$. Corresponding to Γ in equation (9), we define $\Gamma_\theta \stackrel{\text{def}}{=} \frac{(b-x)-(c-p_1)\psi_\theta^{-1}(-p_1)}{(p_1-p_0)}$, for $\theta \in \{H, L\}$. We find that $\bar{d}_H \leq \bar{d}_L$ is always true. We summarize our findings in Lemma 7.

Lemma 7. *The break-even due date of the buyer is larger under low-severity disruption than high-severity disruption, that is, $\bar{d}_H \leq \bar{d}_L$. Specifically,*

$$\begin{aligned} \square \bar{d}_H &< \bar{d}_L, & (c-p)\psi^{-1}(-p) &\leq b-x < (c-p)\psi^{-1}(p) \\ \square \bar{d}_H &= \bar{d}_L, & (c-p_0)\psi_H^{-1}(p_1) &\leq b-x \leq (c-p_0)\psi_L^{-1}(p_0) \\ \square \bar{d}_H &< \bar{d}_L, & (c-p_0)\psi_L^{-1}(p_0) &< b-x < (c-p_0)\psi_H^{-1}(p_0) \\ \square \bar{d}_H &= \bar{d}_L = \infty, & b-x &\geq (c-p_0)\psi_H^{-1}(p_0) \end{aligned} \quad (17)$$

For $b-x < (c-p_1)\psi_L^{-1}(-p_1)$, both \bar{d}_H and \bar{d}_L are irrelevant.

Lemma 7 shows that, if the disruption severity is known to high, the buyer will accept a shorter recovery due date than low severity disruption. To see why, we note that the buyer is equipped with the backup option. Because the cost of waiting for recovery is larger under high-severity disruption than under low-severity disruption, the buyer is less tolerant of a lengthy recovery under high-severity disruption than under low-severity disruption.

Furthermore, we define \hat{d} to be the maximum acceptable due date under its prior belief. That is,

$$\alpha\pi_B^H(\hat{d}) + (1-\alpha)\pi_B^L(\hat{d}) = b-x. \quad (18)$$

It is straightforward to see that for the same $b-x$, we have $\bar{d}_H \leq \hat{d} \leq \bar{d}_L$. We derive the following properties of \hat{d} .

- $\hat{d} \leq \psi_H^{-1}(-p_0)$ if $b-x \leq \alpha\psi_H^{-1}(-p_0) + (1-\alpha)\psi_L^{-1}(-p_0)$;
- $\hat{d} = \infty$ if $b-x > \alpha\psi_H^{-1}(-p_0) + (1-\alpha)\psi_L^{-1}(-p_0)$;
- \hat{d} increases in $b-x$.

The supplier's incentive to misrepresent the severity of disruption. If the buyer acts as if it has perfect information about the severity of disruption, then the supplier will take advantage of its better information. For example, suppose the disruption severity is high, but the buyer believes the severity is low and, thus, accepts any due date that is no later than \bar{d}_L . The supplier will take advantages to report due date \bar{d}_L to enjoy a longer due date (than \bar{d}_L) and reduced costs for supply recovery.

In the next subsection, we shall analyze how the buyer will respond to the due date posted by the supplier in the face of supplier's strategic behavior.

5.3 The Equilibrium of the Signaling Game

We now analyze the equilibrium of the signaling game under asymmetric information. In general, a signaling game may have pooling and separating equilibria. In a pooling equilibrium the supplier's strategy at the two disruption severity levels are identical, while at a separating equilibrium the supplier's strategy diff between the two severity levels. Specifically, the equilibrium of the signaling game will be in one of the following fi e forms, defi as follows:

Definition 2. *The possible forms of equilibrium under asymmetric information are:*

- $P(d^e)$, where $d^e < \infty$: pooling equilibrium at which the supply chain's response to disruption is to make supply recovery with due date d^e at both disruption severity levels.
- $P(\infty)$: pooling equilibrium at which the supply chain's response to disruption is to use the backup option at both disruption severity levels.
- $S(d^e_H, d^e_L)$, where $d^e_H \neq d^e_L$, $d^e_H < \infty$ and $d^e_L < \infty$: separating equilibrium at which the supply chain's response to disruption is to make supply recovery with due date d^e_θ at the disruption severity level of $\theta \in \{H, L\}$.
- $S(\infty_H, d^e_L)$, where $d^e_L < \infty$: separating equilibrium at which the supply chain's response to disruption is to use the backup option under high severity disruption and to make supply recovery with due date d^e_L under low severity disruption.
- $S(d^e_H, \infty_L)$, where $d^e_H < \infty$: the separating equilibrium at which the supply chain's response to disruption is to make supply recovery with due date d^e_H under high severity disruption and to use the backup option under low severity disruption.

In the above definitions, notation $d^e_\theta < \infty$ (or $d^e < \infty$) indicates that the supply chain will use supply recovery with due date d^e_θ (or d^e) in response to disruption of the severity θ (or at both severity levels)—the supplier will make supply recovery with due date d^e_θ (or d^e), and the buyer will wait for recovery. Notation $d^e_\theta = \infty$ (or $d^e = \infty$) indicates that the supply chain will use the backup option in response to disruption of the severity θ (or at both severity levels), because the supplier does not make supply recovery or the buyer invokes the backup option, or both.

The equilibrium strategies of the supply chain players depend on the value of $b - x$, which determines the buyer's maximum acceptable recovery due date \bar{d}_H and \bar{d}_L , and the value of x , which determines the supplier's minimum acceptable due date \underline{d}_H and \underline{d}_L . We

present the supply chain's equilibrium response to disruption under asymmetric information in Proposition 3. We shall organize the result in two cases of $b - x$. Within each case, the result is organized by the value of $(\underline{d}_H, \underline{d}_L)$, which depends on the value of x .

Proposition 3. *Under $b - x \leq (c - p_0)\psi_L^{-1}(-p_0)$, the buyer and supplier's equilibrium response to disruption under asymmetric information is*

- *If $\underline{d}_H \leq \hat{d}$, then there exists a pooling equilibrium $P(d^e)$, where $d^e \in [\max\{\underline{d}_H, \bar{d}_H\}, \hat{d}$;*
- *If $\underline{d}_H > \bar{d}_H$ and $\underline{d}_L \leq \bar{d}_L$, then there exists a separating equilibrium $S(\infty, \min\{\underline{d}_H, \bar{d}_L\})$;*
- *If $\underline{d}_H > \bar{d}_H$ and $\underline{d}_L > \bar{d}_L$, then there exists a separating equilibrium $P(\infty)$;*
- *If $\underline{d}_H \leq \bar{d}_H$ and $\underline{d}_L > \bar{d}_L$, then there exists a separating equilibrium $S(\bar{d}_H, \infty)$.*

Under $b - x > (c - p_0)\psi_L^{-1}(-p_0)$, the buyer and supplier's equilibrium response to disruption under asymmetric information is:

- *If $\underline{d}_H \leq \min\{\bar{d}_H, \psi_H^{-1}(-p_0)\}$ and $\underline{d}_L \leq \psi_L^{-1}(-p_0)$, then there exists a separating equilibrium $S(\bar{d}_H, \psi_L^{-1}(-p_0))$;*
- *If $\underline{d}_H > \min\{\bar{d}_H, \psi_H^{-1}(-p_0)\}$ and $\underline{d}_L \leq \psi_L^{-1}(-p_0)$, then there exists a separating equilibrium $S(\infty, \psi_L^{-1}(-p_0))$;*
- *$\underline{d}_H \leq \min\{\bar{d}_H, \psi_H^{-1}(-p_0)\}$ and $\underline{d}_L > \psi_L^{-1}(-p_0)$, then there exists a separating equilibrium $S(\bar{d}_H, \infty)$;*
- *If $\underline{d}_H > \min\{\bar{d}_H, \psi_H^{-1}(-p_0)\}$ and $\underline{d}_L > \psi_L^{-1}(-p_0)$, then there exists a pooling equilibrium $P(\infty)$.*

To understand these results, we shall compare the equilibrium under asymmetric information versus perfect information.

5.4 Effects of Information Asymmetry

In this section, we will compare the equilibrium outcomes under asymmetric information versus those under perfect information to identify the effects of information asymmetry on supply recovery and the supply chain members' costs. Proposition 3 indicates that the signaling-game equilibrium depends on the buyer's maximum acceptable due date of recovery, \bar{d}_H and \bar{d}_L , versus the supplier's minimum feasible recovery due dates, \underline{d}_H and \underline{d}_L . Since \bar{d}_H and \bar{d}_L increase simultaneously in the buyer's total cost of using the backup option $b - x$

(please see Lemma ...), we will organize the discussion in the increasing order of $b - x$ (as well as \bar{d}_H and \bar{d}_L).

For convenience, we recapitulate the supply chain firms' equilibrium responses to disruption under perfect information in the following lemma.

Lemma 8. *Under perfect information at the disruption severity $\theta \in \{H, L\}$, the supply chain firms' equilibrium responses to disruption are to make supply recovery with due date $\min\{\bar{d}_\theta, \psi_\theta^{-1}(-p_0)\}$, if $\underline{d}_\theta \leq \min\{\bar{d}_\theta, \psi_\theta^{-1}(-p_0)\}$, otherwise, the equilibrium response is no recovery (i.e., to invoke the backup option).*

5.4.1 When $b - x < \pi_B^H(\psi_H^{-1}(-p_1))$

We begin with the case where the buyer's cost of using the back, $b - x$, is so low that $\bar{d}_H < \bar{d}_L \leq \psi_H^{-1}(-p_1)$. This condition has two implications. First, the buyer's maximum acceptable due dates under both disruption severity levels are finite, indicating that the supplier will conditionally wait for recovery only if the due date is sufficiently early. Second, the buyer's maximum acceptable due date under high severity disruption is strictly earlier than that under low severity disruption. Therefore, under perfect information the equilibrium recovery due dates at the two disruption severity levels will be different, if supply recovery is also feasible for the supplier. This enables the existence of a separating equilibrium, at which supply recovery is used regardless of the disruption severity, under perfect information.

We illustrate the equilibrium under asymmetric information in Figure 8 and the accompanying table. (Note that for every $\underline{d}_L \leq \psi_L^{-1}(-p_0)$, inequality $\underline{d}_L < \underline{d}_H$ must hold.) In the table, we also present the equilibrium under perfect information.

We compare the equilibrium under asymmetric information versus perfect information to find that information asymmetry causes a difference in regions (a), (b) and (c).

In region (a), the supplier's contract termination cost, x , is so low that $\underline{d}_H \leq \bar{d}_H$ and $\underline{d}_L \leq \bar{d}_L$. Under both disruption severity levels, the supplier's minimum feasible recovery due date is earlier than the buyer maximum acceptable due date. Under perfect information, if the severity of disruption is known to be high, the supplier reports recovery due date \bar{d}_H and the buyer waits for recovery; if the severity is known to be low, recovery is also used but with due date \bar{d}_L , which is strictly greater than \bar{d}_H . In other words, the unique equilibrium under perfect information is a separating equilibrium, at which supply recovery is used regardless of the disruption severity and the recovery due date under high severity disruption is earlier than that under low severity disruption.

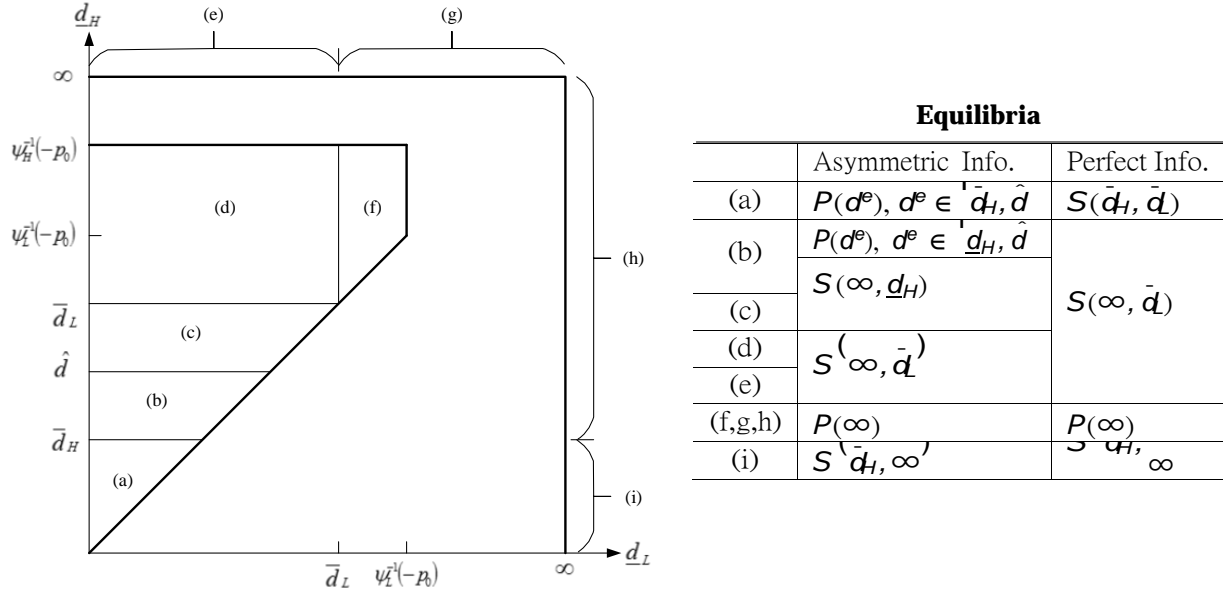


Figure 8: The equilibria under asymmetric information and perfect information in relation to \underline{d}_H and \underline{d}_L , when $\bar{d}_H < \bar{d}_L \leq \psi_H^{-1}(-p_1)$. Regions (e), (g), (h), and (i) represent the situations where $d_H = \infty$ or $d_L = \infty$.

Under asymmetric information in region (a), there exists a unique pooling equilibrium, at which recovery is used under both disruption severity levels with the same due date, but not a separating equilibrium. As a result, the buyer cannot distinguish the severity of disruption solely by reading the due date quoted by the supplier. The buyer's inability to resolve the disruption severity information is caused by the supplier's incentive of misrepresentation under high-severity disruption. Specifically, under high severity disruption, the supplier wants to set the recovery due date to be \bar{d}_L , which is later than \bar{d}_H , to decrease its cost of supply recovery.

At the pooling equilibrium, the recovery due date $d^e \in [\bar{d}_H, \hat{d}]$. In particular, d^e is bounded from above by \hat{d} (defined in ...), which is the buyer's maximum acceptable due date when it holds the prior belief about the severity of disruption. Because the buyer is unable to distinguish the disruption severity, the buyer holds the prior belief about the severity of disruption. If the due date is later than \hat{d} , the buyer's expected cost of recovery will exceed its cost of using the backup option, so the buyer will opt for the backup option. Moreover, because $\hat{d} < \bar{d}_L$, the equilibrium due date under asymmetric information, d^e , is strictly less than \bar{d}_L , which is the recovery due date under low severity disruption under perfect information. Therefore, information asymmetry pushes the supplier to quote an earlier recovery due date under low severity disruption. As a result, the supplier's cost of

recovery is higher than the perfect information case. To the opposite, under high severity disruption the equilibrium due date $d^e \geq \bar{d}_H$. Information asymmetry allows the supplier to relax the recovery due date and reduces its cost of recovery.

The above observation about the effects of information asymmetry on the recovery due date sheds light on how information interacts with the supplier's use of "strategic subsidy". Recall that when the buyer's cost of using backup, $b - x$, is small, the supplier strategically sets the due date to be earlier than its minimum completion time, and thus pays the buyer a "subsidy" to reduce its cost of waiting for recovery. Under high severity disruption, a longer due date enabled by information asymmetry reduces the amount of "subsidy" to the buyer, while under low severity disruption information asymmetry leads to an earlier recovery due date and may increase the amount of "subsidy".

Interestingly, we find that information asymmetry reduces the buyer's expected cost of waiting for recovery and present the finding in Corollary 4:

Corollary 4. *Under $\bar{d}_H < \bar{d}_L \leq \psi_H^{-1}(-p_1)$ and at $(\underline{d}_H, \underline{d}_L)$ in region (a), the supplier's expected cost under asymmetric information is smaller than that under perfect information.*

Under asymmetric information, the buyer's expected cost of recovery is $\alpha\pi_B^H(d^e) + (1 - \alpha)\pi_B^L(d^e)$. At the pooling equilibrium, because the due date, d^e , is earlier than \hat{d} , the buyer's expected cost of waiting for recovery is less than the cost of using the backup option, $b - x$. Under perfect information, the buyer's expected cost is $\alpha\pi_B^H(\bar{d}_H) + (1 - \alpha)\pi_B^L(\bar{d}_L)$. Under perfect information, the buyer's costs of using the recovery at the two disruption severity levels are equal to the cost of backup: $\pi_B(\bar{d}_H) = \pi_B(\bar{d}_L) = b - x$. So is the buyer's expected cost of recovery. Therefore, information asymmetry about the disruption severity can benefit the buyer.

In region (b), the supplier's contract termination cost, x , is such that \underline{d}_H satisfies $\bar{d}_H \leq \underline{d}_H < \hat{d}$ while $\underline{d}_L \leq \bar{d}_L$. Under perfect information, there exists a unique separating equilibrium where the backup option is used under high severity disruption but supply recovery is used under low severity disruption. Under asymmetric information, there exist two possible equilibria—a pooling equilibrium $P(d^e)$ with $d^e \in [\underline{d}_H, \hat{d}]$, at which supply recovery is used regardless of the disruption severity; and a separating equilibrium $S(\infty, \underline{d}_H)$, at which supply recovery is an equilibrium strategy only under low severity disruption. We will discuss the effects of information asymmetry at the two equilibria respectively.

First, suppose that in region (b) the system is in the pooling equilibrium $P(d^e)$ under asymmetric information. Similar to region (a), in region (b) under asymmetric information,

the buyer cannot resolve the disruption severity solely from the supplier's signal, because the supplier under high severity disruption wants to pretend to be low severity. Moreover, under asymmetric information the recovery due date is less than the buyer's maximum acceptable due date under the prior belief, \hat{d} , so the buyer's is better off in expectation under asymmetric information than under perfect information.

There are new and interesting effects of information asymmetry in region (b). Under perfect information, supply recovery will not occur if the disruption severity is high, but it will occur under asymmetric information. Therefore, information asymmetry increases the use of supply recovery. Under perfect information, if the disruption severity is low, the buyer's maximum acceptable due date is even earlier than the supplier's minimum acceptable due date. There does not exist a recovery due date that is simultaneously acceptable to both the buyer and the supplier. Under asymmetric information, because the buyer is unable to distinguish the disruption severity, it will wait for recovery as long as the due date is earlier than its expected maximum acceptable due date, \hat{d} . Because this allows the supplier to make supply recovery with a due date that is feasible even under high severity disruption. As a result, information asymmetry benefits the supplier if the disruption severity is high.

Next, suppose that in region (b) the system is in the separating equilibrium $S(\infty, \underline{d}_H)$. The buyer can distinguish the severity of disruption from the due date quoted by the supplier. Because there does not exist a jointly feasible due date for the buyer and the supplier under high severity disruption, under asymmetric information the buyer invokes the backup option in equilibrium. Information asymmetry has no effect on the equilibrium outcome under high severity disruption. Under low severity disruption, however, information asymmetry causes the supplier to post an earlier due date, \underline{d}_H , than that under perfect information, \bar{d}_L , to convince the buyer that disruption is truly of the low severity. Specifically, the supplier wants to credibly assure the buyer that, if the disruption severity is high, the supplier will have terminated the contract but not promise to recover the lost supply. To accomplish this goal, the supplier sets the recovery due date to be \underline{d}_H (or a value slightly smaller), so the supplier would have no interest to deviate from the strategy of terminating the contract if the disruption severity is high.

In region (c), where \underline{d}_H is slightly larger than that in region (b) (i.e., $\hat{d} < \underline{d}_H \leq \bar{d}_L$), under asymmetric information there exists a unique separating equilibrium, which is the same as the separating equilibrium in region (b). Moreover, under perfect information the equilibria in the two regions are identical as well. Therefore, all aforementioned observations

about the effects of information asymmetry in region (b) (when the separating equilibrium is selected) continue to hold in region (c).

In all other regions, where $\underline{d}_H > \bar{d}_L$ or $\underline{d}_L > \bar{d}_L$, the equilibrium under asymmetric information is identical to that under perfect information. Information asymmetry has no effect in these regions, because the supplier that experience high severity disruption has no incentive to mimic low severity disruption, for two reasons. First, when $\underline{d}_H > \bar{d}_L$, the latest recovery due date accepted by the buyer under low severity disruption \bar{d}_L is not acceptable for the supplier under high severity disruption. Therefore, under high severity disruption the supplier will not mimic low severity disruption for trick the buyer into waiting for recovery, even if recovery is the supplier's strategy under low severity disruption. Second, when $\underline{d}_L > \bar{d}_L$, under the low severity disruption the supplier will terminate the contract. Under high severity disruption, the supplier can only be worse off by mimicking low severity disruption.

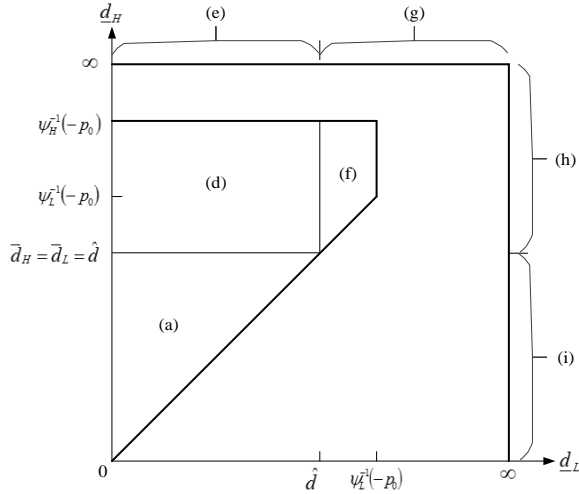
5.4.2 When $\pi_B^H(\psi_H^{-1}(-p_1)) \leq b - x \leq \pi_B^L(\psi_L^{-1}(-p_0))$

We (now) consider the case where the buyer's cost of using the backup option, $b - x$, is medium: $\pi_B^H(\psi_H^{-1}(-p_1)) \leq b - x \leq \pi_B^L(\psi_L^{-1}(-p_0))$. In such case, the buyer's maximum acceptable due dates are equal: $\bar{d}_H = \bar{d}_L = \hat{d}$, where $\psi_H^{-1}(-p_1) \leq \hat{d} \leq \psi_L^{-1}(-p_0)$. Therefore, under perfect information, when $\underline{d}_H \leq \hat{d}$ and $\underline{d}_L \leq \hat{d}$, the system has a unique pooling equilibrium where supply recovery is used with the same due date at the two disruption severity levels.

To derive the equilibrium under asymmetric information, we apply $\bar{d}_H = \bar{d}_L = \hat{d}$ to Proposition 3 and present the results in Figure 9. Note that because $\bar{d}_H = \bar{d}_L = \hat{d}$, regions (b) and (c) in Figure 8 vanish. We also provide the equilibrium under perfect information in all regions. From the table in Figure 9, we observe that in all regions the equilibrium under asymmetric information is the same as that under perfect information. Therefore, under moderate $b - x$ information asymmetry has no effects.

5.4.3 When $b - x > \pi_B^L(\psi_L^{-1}(-p_0))$

Finally, we consider the case where $b - x$ is high: $b - x > \pi_B^L(\psi_L^{-1}(-p_0))$. Under such $b - x$, the buyer's maximum acceptable due dates at the two disruption severity levels are $\bar{d}_L = \infty$ and $\bar{d}_H > \psi_L^{-1}(-p_0)$. The backup cost is so high that, if disruption is known to be of the low severity, the buyer is willing to wait for recovery with any due date.



Equilibria		
	Asymmetric Info.	Perfect Info.
(a)	$P(\hat{d})$	$P(\hat{d})$
(d)	$S(\infty, \hat{d})$	$S(\infty, \hat{d})$
(e)		
(f,g,h)	$P(\infty)$	$P(\infty)$
(i)	$S(\hat{d}_H, \infty)$	$S(\hat{d}_H, \infty)$

Figure 9: The equilibria under asymmetric information and perfect information in relation to \underline{d}_H and \underline{d}_L , when $\bar{d}_H = \bar{d}_L = \hat{d}$. Regions (e), (g), (h), and (i) represent the situations where $\underline{d}_H = \infty$ or $\underline{d}_L = \infty$.

The equilibrium under asymmetric information above is identical to that under perfect information. Therefore, information asymmetry has no effect on the supply chain's reaction to disruption. Under asymmetric information, if the disruption severity is low, to use supply recovery the supplier post the due date to be no later than $\psi_L^{-1}(-p_0)$. If the disruption severity is high, to use supply recovery the supplier can post a more relaxed due date $\bar{d}_H > \psi_L^{-1}(-p_0)$. Therefore, even if the severity of disruption is high the supplier has no incentive to pretend to be of the low severity.

6 Conclusion

In this paper, we study the supply chain's recovery from disruption that disables the supplier from meeting the buyer's requirement. After disruption, the buyer has two options: to use backup production capacity as an alternative source, and to wait for the supplier to recover and resume supply. In the face of disruption and the buyer's right to terminate the business with the supplier, the supplier makes an effort to recover supply to minimize its loss due to disruption. The supplier quotes a due date for recovery under a mutually agreed two-part penalty scheme: a penalty for delay of delivery due to disruption and an increased penalty for tardiness of recovery.

We find that under the two-part penalty structure, the supplier may quote a due date that is earlier than the earliest completion time of recovery that the supplier is able to

achieve, deliberately causing a tardiness in supply recovery. To compensate the buyer for this tardiness, the supplier pays extra penalty to the buyer, *de facto* decreasing the buyer's cost of waiting for supply recovery. Consequently, the buyer is more willing to wait for recovery, and the supplier avoids losing the buyer's business. Both supply chain firms are better off, compared to the case where the supplier restricts itself to on-time completion of recovery. Interestingly, this result is attained under the setting where the recovery process is deterministic. Hence, our finding provides an alternative explanation of the cause of tardiness in supply chain recovery, other than randomness of the recovery process.

After disruption, the supplier typically has better information about the severity of damage that disruption had done to the supplier. The severity level of disruption affects the supplier's ability and cost of making swift recovery. Taking advantage of asymmetric information, the supplier can influence the buyer's choice between the backup option and supply recovery, by quoting a due date that suggests a swift recovery.

We analyze the situation where the supplier has private information about the severity level of disruption. We model this problem as a signaling game, in which the supplier's quote of due date is received by the buyer as a signal of the severity of disruption. Asymmetric information in the supply chain reduces the buyer's visibility of the length of disruption and makes it difficult for the buyer to decide its contingency action. The supplier that experiences a high-severity disruption tends to quote a long due date, mimicking the behavior as if disruption's severity is low. As a result of such behavior, in situations where the buyer tends to wait for recovery regardless of the severity of disruption, under low-severity disruption the supplier's quote of due date cannot convincingly inform the buyer the severity of disruption. Conversely, the buyer cannot reliably distinguish the severity of disruption by observing the supplier's quote of the due date. These results hold, even if the buyer's cost of using the backup option is sufficiently low, when the supplier would quote different due dates under different severity levels of disruption, if the severity level were commonly known in the supply chain.

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Appendix: Proofs

Proof of Lemma 3. HINT: fi go by the cases of $b - x$, which determines the value of \bar{d} ; next, for each case of \bar{d} , write down $x > \pi_S(\bar{d})$. •

Proof of Proposition 1. Case (I) follows from applying condition (9.I) to equation (11).

We now focus on Case (II). We compare the supplier's cost of recovering supply under condition (9.II), $\pi_S(d) = \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b - x)$, with the supplier's cost of terminating the contract, x . The former is less than the latter, if and only if $b \geq \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1)$. Applying condition (9.II) to equation (9), we obtain the buyer's maximum due date, $\bar{d} = \Gamma$. Note that $\Gamma < \psi^{-1}(-p_1)$. We then apply $\bar{d} < \psi^{-1}(-p_1)$ (i.e., condition 5.A) to equation (5), obtaining $t^*(\bar{d}) = \psi^{-1}(-p_1)$.

Following the same procedure, we can prove cases (III) and (IV). The details are skipped for brevity. •

Proof of Corollary 3. We will prove the case illustrated in fi The other cases are similar.

In region (I) and unshaded part of region (II), the supplier's cost is constant, x . As $(\psi^{-1}(p_0), b - x)$ enters the shaded part of region (II), supply recovery is used, and the supplier's cost becomes $\pi_S(d^*) = \Psi(\psi^{-1}(-p_1)) + c\psi^{-1}(-p_1) - (b - x)$; and as $\psi^{-1}(-p_1)$ decreases (i.e., p_1 increases), $\pi_S(d^*)$ decreases. As $(\psi^{-1}(p_0), b - x)$ enters region (III), the supplier's cost becomes $\Psi\left(\frac{b-x}{c-p_0}\right) + c\frac{b-x}{c-p_0} - (b - x)$, which is constant again in $\psi^{-1}(-p_1)$. •

Proof of Lemma 7. In general, $\bar{d}_H \leq \bar{d}_L$, because $\pi_B^H(d)$ and $\pi_B^L(d)$ are both increasing in d and $\pi^H(d) \geq \pi^L(d)$ for all $d \geq 0$. The result follows from the expressions of \bar{d}_H and \bar{d}_L .

Immediate versus Delayed Price Discounts

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Immediate versus Delayed Price Discounts

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Abstract

Sellers commonly offer an immediate discount percentage off the regular price. In contrast, some sellers apply a credit toward a future purchase, based on the customer's prior purchase. We contrast the efficacy of these two discounting strategies to better understand conditions under which prior-purchase based discounts may outperform immediate discounts.

1 Introduction

A pricing strategy that some sellers employ is to assess a fixed percentage of a customer's current order as a discount off the same customer's next order. We refer to this policy as the Delayed Discount Strategy (DDS). For example, assuming a discount percentage of 20%, if a customer were to place two \$100 orders in succession, then the net amounts paid would be \$100 and \$80, and that customer would carry forward \$16 (20% of \$80) in credit. Successive purchases of the same size would ultimately lead to the customer paying \$83.33 out-of-pocket for each \$100 order, with a credit-carryover of $\$83.33 \times 20\% = \16.67 accounting for the difference. Thus, in equilibrium, we see in this simple example that the DDS with a 20% credit carryover is equivalent to the seller offering a 16.67% discount off each order. Such an equivalence is not necessarily possible in more complex scenarios, such as when valuations vary across customers and customers' purchase quantities vary. Applying a percentage discount off each order is the more typical approach that sellers follow to enact a price-change or sale; we refer

to this traditional tactic as the Immediate Discount Strategy (IDS). In this paper, we contrast the DDS and IDS alternatives when customers differ in their relative valuations (willingness to pay) and can alternate between high and low order sizes.

An obvious DDS benefit to the seller is that no discount is paid out at the time of a customer's first purchase. That benefit is fleeting, however, given that the seller provides discounts on all subsequent orders. Moreover, in a scenario where a customer purchases only once, delayed credits impact neither seller nor customer and the customer pays full price. Therefore, in this paper we consider a repeat purchasing context and focus on the difference between delayed and immediate discounts in equilibrium.

Studies on discounts given by retailers in the form of "gift cards" have shown that customers quite frequently fail to make use of those cards. The failure to invoke such credit could be due there being no subsequent purchases as already discussed, but other possible reasons are that the credit could either expire or otherwise be lost (e.g., losing a physical gift card), or that the transactional inconvenience of using the credit outweighs its value. Our interest is in understanding the efficacy of delayed vs. immediate credit as a discounting mechanism, as opposed to considering impediments to customers utilizing credits, and therefore we assume that the credits will be faithfully recorded and subsequently applied by the seller to the customer's account. A customer's credits will neither expire nor otherwise be lost. Naturally, if customers were to assign significant value to discounts that they would either lose, let expire, or not invoke (due to transactions costs), that would benefit the seller; but, it is also questionable whether rational customers would assign value to such discounts. By assuming that all credits—whether immediate or delayed—are consistently applied, we can make a fair contrast between the impact of the delayed and immediate tactics.

In the most simplistic of scenarios as described above where the customer has the same order size over time, the resulting equilibrium cash flows are stable over time and therefore the issue of how the customer contrasts future vs. present flows (i.e., time discounting) does not arise. In more complex scenarios, however, such as when a customer's purchase choice today may impact their purchase tomorrow, then the customer's time-discount factor is relevant and must be accounted for when analyzing the

customer decision problem. We assume in this paper that customers are fully rational, forward looking, and act to maximize their expected discount net present value. We assume that in each period, a customer's order size is probabilistic and either large or small. Thus, over time, a customer wishes to place a series of small and large orders, each with known probability. If the seller's (after-discount) prices are too high, or, equivalently, a customer's valuation is too low, then the customer may optimally opt to make no purchase in any period.

Under the IDS option, there is no carryover between periods, making the customer's decision problem easy to analyze. For the DDS option, however, the credit carryover between periods implies that today's purchase decision may impact future decisions, and so solving the customer problem requires analyzing the interdependence between possible future realizable states. For example, a customer may optimally make their large order today because the resulting high credit level in the next period may generate (discounted) value by supporting a subsequent order that would not otherwise be possible.

We will assume that customers are heterogeneous with respect to their valuations of both small and large order sizes. For customers with high valuations, it may be optimal to purchase both small and large orders with low (or even no) credit. In contrast, for customers with low valuations, it may be optimal to purchase only small orders, in which case they will always have the correspondingly low credit carryover. As a second source of customer heterogeneity, we later permit customers to have distinct per-period budget limits. When considering both types of heterogeneity, customers differ not only how much they would be willing to pay for the large (and small) orders, but also how much they are able to pay. We treat the seller's pre-discount prices corresponding to the small and large orders as exogenous.

Initially, we will assume that any given customer has the same valuation for both small and large order sizes, which could reflect a scenario where the "small order size" corresponds to a temporary (and exogenous) sale event—i.e., the product values do not change but the final price lowers. Our analysis of the DDS shows that a stratification of optimal state-dependent buying policies results. These four policies correspond to how

favorable the customer's state must be in order for a purchase to be optimal for that customer. The most favorable state is when the customer has high credit coupled with the small order state. The next most favorable state occurs whenever the customer has low credit coupled with the small order state. The third most favorable state is if the customer has high credit coupled with the large order state. The least favorable state is if the customer has low credit coupled with the large order state. In equilibrium, customers who would opt to purchase only in the most favorable of these four states cannot occur and therefore the resulting demands to the seller correspond to derived customer segments corresponding to the latter of the three states. We show that the seller's expected profits are a simple linear function of these equilibrium demand states, for both the DDS and IDS options.

For the case when the small and large order sizes have identical valuation for a given customer, our numerical results show that the IDS option yields higher equilibrium (expected) profits than the DDS alternative. The finding is intuitive because in this case a customer's pre-discount surplus is large at the small order size and small at the large order size. Therefore, to induce purchasing, large discounts are needed at large order sizes and small (or no) discounts are needed at small order sizes, which is precisely what the IDS provides. In contrast, the DDS will sometimes provide a low discount (carryover) in periods where a customer's demand is high, and a high discount in periods where a customer's demand is low, which is inefficient.

We therefore expect the DDS option to perform better in contexts where customers' surpluses do not correlate with order size. For example, at baseline pricing (i.e., before discounts), if customer surplus for small orders is small (or even negative), and customer surplus for large orders is higher, then the DDS option may increase profitability. Potentially, profits and customer surplus may both increase. Although the formal analytics and most of the numeric results in the paper focus on the aforementioned case where customer pre-discount surplus is higher for small orders (yielding IDS profit dominance for the seller), we conclude our analysis by considering a scenario where customer pre-discount surplus is higher for large orders. In that case, we show that indeed the DDS option can generate higher expected profits for the seller—yielding a 23% profit increase

in our final example.

In the next section, we formally define our assumptions, notation, and analytic model for the customers' problem. We first define each customer's four alternative optimal purchasing policies. Then, for each of those policies we derive the resulting equilibrium states via Markov Chain analysis and determine customers segment themselves within those four policy alternatives. We next show how we can incorporate customers' budget constraints into the analysis. After describing how to derive the resulting equilibrium demands, we formally show the seller's expected profit maximization problem. We then present the results of our series of numeric comparisons of the IDS and DDS options.

2 Related Literature

This paper relates to the literature on behavioral-based pricing and research on rewards programs. Our study focuses specifically on the equilibrium effects of delayed versus instantaneous discounts. Conceptual papers such that those by Dowling and Uncles (1997) and Shugan (2005) emphasize that rewards programs should be employed carefully, or their expected resulting benefits may fail to materialize. To the extent that delayed rewards are similar to rewards programs, our analytic results support this finding, as we find that delayed rewards reduce the seller's equilibrium profits except in particular problem settings.

The empirical literature provides similarly mixed or qualified support for the efficacy of rewards programs. Using data from an online grocer, Lewis (2004) found that this seller's loyalty program did increase annual purchasing for a substantial proportion of customers. Keh and Lee (2006) studied both the timing (immediate vs. delayed) and the type (direct vs. indirect) of rewards in two service conditions (satisfied vs. dissatisfied) and observed that in particular delayed "direct" rewards appeared to be effective specifically with "satisfied" customers.

In addition to our paper, there are several papers that have analyzed reward schemes analytically. Gandomi and Zolfaghari (2013) studied a two period monopoly problem where the loyalty reward r given to returning customers in the second period. Others have looked at duopoly competition within a two-period context with either an exoge-

nous reward level (Singh et al. (2008)) or endogenous reward level (Kim et al. (2001)) in the second period. In contrast, our paper focuses on endogenizing the reward percentage and consider the equilibrium state with an infinite horizon problem. Caillaud and Nijs (2011) also considers an infinite horizon problem, but focuses on duopoly competition for overlapping generations of customers, each of whom lives for two periods. In contrast, our study is restricted to a single seller, but an important aspect of our analysis is that customers consider the effects of today's purchase decision on their ongoing sequence of orders, which informs a customer's optimal equilibrium purchase policy.

3 The Model

Consider a market of customers that repeatedly purchase from the seller over a succession of periods. We are interested in studying how delayed versus immediate discounts impact a customer's optimal ordering policy, while permitting their order size to vary from period to period. We assume the seller's discount will be a fixed percentage of the customer's order size (measured in \$-terms), and will be applied either immediately (the IDS case) or to the customer's next order (the DDS case). Because the discount will apply to the entire order "basket" for the customer, we will keep our analysis at that "basket" or order-size level, rather than attempt to track individual items within an order. We thus need to consider only the total \$-amount of an order. For simplicity, we consider only two order sizes, which we refer to as $\{low, high\}$, each with a corresponding pre-discount dollar amounts $\{p_l, p_h\}$. For each individual customer, the small and large order sizes apply with probabilities $\{1 - \gamma, \gamma\}$, respectively, in each period.

We permit customers to be heterogeneous with respect to the utility v they associate with an order. Initially, we assume that valuation v for a single customer is the same for both small and large orders. Without loss of generality we normalize the market size to one, assume that the range of feasible v values within the range $[0, 1]$. Later, we will consider distinct respective valuations v_l and v_h with $v_l < v_h$ for a single customer.

The seller is interested in comparing the influence of the two possible reward strategies on the expected demand that each customer will generate over time, and therefore we must analyze each customer's optimal purchase policy. Under IDS, the customer is

awarded an immediate cash discount as a percentage of his current purchase amount. The one period surplus from purchasing the product will be $(v - p_i + \alpha p_i - F)$ where $i \in \{l, h\}$ and F denotes a possible fixed cost associated with ordering (we will assume $F = 0$ in our later discussions).

Under DDS, the customer is rewarded points as a percentage of his current purchase amount redeemable in the next period. To express the customer's surplus for this case, we introduce the notation k to represent the customer's credit carryover from the prior period. We also can introduce an additional cost parameter w to reflect the possibility that the customer associates a cost (a physic "overhead" cost) with carrying forward unused credit from one period to the next; later, as with F , we will likewise set this cost parameter to zero when contrasting the DDS and IDS alternatives. Given this notation, the customer's surplus expression for the DDS case is $(v - p_i + k - F - wap_i)$.

3.1 Customer Problem for Delayed Discount Strategy (DDS)

If the seller enacts the DDS alternative, the customer's purchase decision in any given period can impact their future purchasing, due to a possible change in the credit carryover. Therefore, to determine their optimal purchasing policy, the customer must solve a decision problem that we can formulate via dynamic programming techniques over an infinite horizon. In each period, a given customer will have a potential desire to purchase either a small or large order (i.e., the low/high order sizes with respective probabilities $\{1 - \gamma, \gamma\}$), and the only decision a customer makes is whether to purchase or not. Therefore, in dynamic programming terms, the control variable for the customer's problem is a binary variable. Note that customer's preference for large or small order size is random and exogenous. At the start of each period, the customer knows his reward level accumulated from the last period purchase (the state variable we denote as k), and he realizes his preference for large or small order size (i). In the below table, all the remaining key notations are summarized.

β	customer discount factor
k	available credit at the start of the current period
k^t	available credit at the start of the next period
$i \in \{l, h\}$	this period order size
$i^t \in \{l, h\}$	next period order size
$x_i \in \{0, 1\}$	whether or not to place an order
γ	Probability of a large order size preference = $\Pr(i^t = h)$
$1 - \gamma$	Probability of a small order size preference = $\Pr(i^t = l)$

The general stochastic DP problem for the customer can be formulated via the Bellman equation:

$$V(k, i) = \max_{x_i} \{ U(x_i, k, i) + \beta EV(k^t, i^t) \} \quad (1)$$

where

$$U(x_i, k, i) = x_i(v - p_i - F + k - w\alpha p_i) \quad (2)$$

and

$$k^t = \begin{cases} \square \\ \square \\ \square \end{cases} \begin{cases} k & \text{if } x_i = 0 \\ \alpha p_i & \text{if } x_i = 1 \end{cases} \quad (3)$$

We can express the Bellman as an expectation over the two possible order-size states:

$$EV(k) = \gamma \max_{x_h} \{ U(x_h, k, h) + \beta EV(k^h) \} + (1 - \gamma) \max_{x_l} \{ U(x_l, k, l) + \beta EV(k^l) \}$$

In equilibrium the carryover credit level k must correspond to either the low or high order size. Thus, there are two possible values for the credit carryover, implying $k \in \{\alpha p_h, \alpha p_l\}$. Exploiting this fact, we can further expand the Bellman by explicitly detailing the two possible alternatives:

$$EV(\alpha p_l) = \gamma \max_{x_{lh}} \{ U(x_{lh}, \alpha p_l, h) + \beta EV(k^h) \} + (1 - \gamma) \max_{x_{ll}} \{ U(x_{ll}, \alpha p_l, l) + \beta EV(k^l) \}$$

$$EV(\alpha p_h) = \gamma \max_{x_{hh}} \{ U(x_{hh}, \alpha p_h, h) + \beta EV(k^h) \} + (1 - \gamma) \max_{x_{hl}} \{ U(x_{hl}, \alpha p_h, l) + \beta EV(k^l) \}$$

Note that we modified our original control variable from x_i to x_{ji} , where $i, j \in \{l, h\}$. For example, x_{lh} represents the decision when having low credit (resulted from last period's small order size) and purchasing a large order size today. For the sake of notation simplicity, hereafter we write $EV(\alpha p_l) = z_l$ and $EV(\alpha p_h) = z_h$. Remember that if the customer decides not to place an order, the current reward level will carry forward to the next period; otherwise, he will use all of it to reduce his out-of-pocket expense at the current period. We can therefore rewrite the two Bellman equations as:

$$\begin{aligned} z_h &= \gamma \max_{x_{hh}} \{x_{hh}(U(x_{hh}, \alpha p_h, h) + \beta z_h) + (1 - x_{hh})\beta z_h\} + \\ &\quad (1 - \gamma) \max_{x_{hl}} \{x_{hl}(U(x_{hl}, \alpha p_h, l) + \beta z_l) + (1 - x_{hl})\beta z_h\}, \text{ and} \\ z_l &= \gamma \max_{x_{lh}} \{x_{lh}(U(x_{lh}, \alpha p_l, h) + \beta z_h) + (1 - x_{lh})\beta z_l\} + \\ &\quad (1 - \gamma) \max_{x_{ll}} \{x_{ll}(U(x_{ll}, \alpha p_l, l) + \beta z_l) + (1 - x_{ll})\beta z_l\}. \end{aligned}$$

3.2 Optimal purchase policies under DDS

Under the DDS option, the four possible states denoted by hl , ll , hh and lh yield progressively lower immediate surplus for the customer. Therefore, a customer who is willing to purchase even in state lh must have a relatively high order valuation (utility), whereas a much lower valuation may be sufficient to induce purchasing in state hl . We next elaborate on this basic idea to define four potential optimal purchasing strategies that customers with distinct valuations may follow.

Those customers who deem it optimal to purchase in state lh are willing to purchase in the most adverse state and therefore will optimally also purchase in states hl , ll , and hh . We refer to this purchase policy as OPP1. Customers who do not follow OPP1 yet deem it optimal to purchase in state hh will optimally also purchase in states hl and ll ; we refer to this purchase policy as OPP2. Customers who follow neither OPP1 nor OPP2 yet deem it optimal to purchase in state ll will optimally also purchase in state hl ; we refer to this purchase policy as OPP3. And finally, we denote as OPP4 the purchase policy under which a customer is only willing to purchase in state hl —these customers thus have the lowest valuation range.

We next derive the related pairs of Bellman's equations for the purchase policies OPP1, OPP2, OPP3, and OPP4.

OPP1: Always Purchasing. If a customer optimally chooses to always purchase, he sets $x_{hl} = x_{hh} = x_{ll} = x_{lh} = 1$.

$$\begin{aligned} z_h &= \gamma(U(1, \alpha p_h, h) + \beta z_h) + (1 - \gamma)(U(1, \alpha p_h, l) + \beta z_l) \\ z_l &= \gamma(U(1, \alpha p_l, h) + \beta z_h) + (1 - \gamma)(U(1, \alpha p_l, l) + \beta z_l) \end{aligned}$$

After solving this system of two equations for the two unknowns z_h and z_l (the real value of our value function V at two corresponding credit levels), we denote the solutions as z_h^1 and z_l^1 , given by:

$$\begin{aligned} z_h^1 &= \frac{F + p_h(\gamma - \alpha) + \alpha p_h(-\gamma\beta + \beta + \gamma w) - (\gamma - 1)p_l(-\alpha\beta + \alpha w + 1) - \gamma v_h + (\gamma - 1)v_l}{\beta - 1} \\ z_l^1 &= \frac{F + \gamma p_h + \gamma(\alpha p_h(w - \beta) - v_h + v_l) - p_l(\gamma + \alpha(-\gamma\beta + (\gamma - 1)w + 1) - 1) - v_l}{\beta - 1} \end{aligned}$$

OPP2: Not purchasing at lh . If a customer optimally chooses to always purchase but not at the worst state (lh), he sets $x_{hl} = x_{hh} = x_{ll} = 1$ and $x_{lh} = 0$.

$$\begin{aligned} z_h &= \gamma(U(1, \alpha p_h, h) + \beta z_h) + (1 - \gamma)(U(1, \alpha p_h, l) + \beta z_l) \\ z_l &= \gamma(\beta z_l) + (1 - \gamma)(U(1, \alpha p_l, l) + \beta z_l) \end{aligned}$$

After solving this system of two equations for the two unknowns z_h and z_l , we denote the solutions as z_h^2 and z_l^2 , given by:

$$\begin{aligned} z_h^2 &= \frac{\gamma(F + \alpha p_h w + p_h - \alpha p_l - v_h) + \alpha(p_l - p_h)}{\gamma\beta - 1} - \frac{(\gamma - 1)(F + \alpha p_l(w - 1) + p_l - v_l)}{\beta - 1} \\ z_l^2 &= \frac{(\gamma - 1)(F + \alpha p_l(w - 1) + p_l - v_l)}{\beta - 1} \end{aligned}$$

OPP3: Not Purchasing at lh and hh . If a customer optimally chooses to purchase when preferring a small order size (hl and ll) but not when preferring a large order size (lh and hh), he sets $x_{hl} = x_{ll} = 1$ and $x_{lh} = x_{hh} = 0$.

$$\begin{aligned} z_h &= \gamma(\beta z_h) + (1 - \gamma)(U(1, \alpha p_h, l) + \beta z_l) \\ z_l &= \gamma(\beta z_l) + (1 - \gamma)(U(1, \alpha p_l, l) + \beta z_l) \end{aligned}$$

Solving this system yields the following solutions z_h^3 and z_l^3 :

$$\begin{aligned} z_h^3 &= \frac{(\gamma - 1)(-\gamma F\beta + F + \alpha p_h(\beta - 1) + p_l(-\beta(\alpha + \gamma + \alpha\gamma(w - 1)) + \alpha w + 1) + v_l(\gamma\beta - 1))}{(\beta - 1)(\gamma\beta - 1)} \\ z_l^3 &= \frac{(\gamma - 1)(F + \alpha p_l(w - 1) + p_l - v_l)}{\beta - 1} \end{aligned}$$

OPP4: Not Purchasing at lh and hh and ll . If a customer optimally chooses to just purchase at the best state (hl), he sets $x_{hl} = 1$ and $x_{lh} = x_{hh} = x_{ll} = 0$.

$$\begin{aligned} z_h &= \gamma(\beta z_h) + (1 - \gamma)(U(1, \alpha p_h, l) + \beta z_l) \\ z_l &= \gamma(\beta z_l) + (1 - \gamma)(\beta z_l). \end{aligned}$$

And finally, solving this system yields the solutions z_h^4 and z_l^4 :

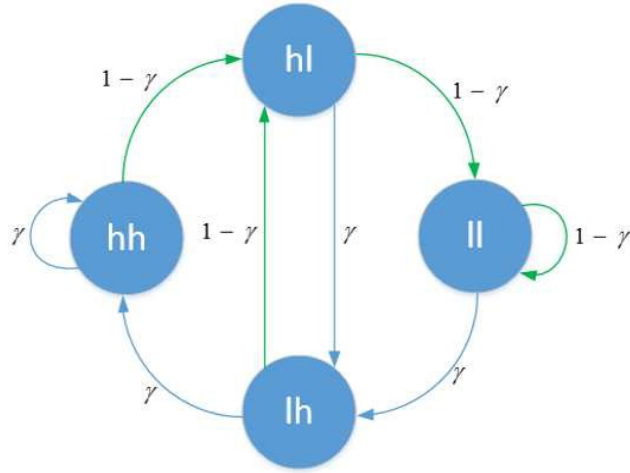


Figure 1: Markov Chain when following OPP1

$$z_h^A = -\frac{(v-1)(F-\alpha p_h + \alpha p_l w + \rho_l - v_l)}{\gamma \beta - 1}, \text{ and } z_l^A = 0.$$

3.3 Steady-state purchase probabilities under DDS

We next analyze what fraction of customers are in each of the four possible purchasing states $\{hl, ll, hh, lh\}$ at equilibrium. For that we should analyze four Markov Chains, one for each of the feasible optimal purchase policies defined in the prior subsection. Since each of these Markov Chains can be described by a single, time-independent matrix P , each resulting stationary-distribution vector π will be found by solving the following system:

$$\pi P = \pi$$

$$\pi_{hl} + \pi_{ll} + \pi_{hh} + \pi_{lh} = 1$$

$$0 \leq \pi_{ij} \leq 1 \text{ for } i \& j \in \{l, h\}$$

Equilibrium state probabilities for OPP1. Customers following OPP1 always purchase. Figure 1 shows the corresponding Markov chain and we next show the associated probability transition matrix P^1 .

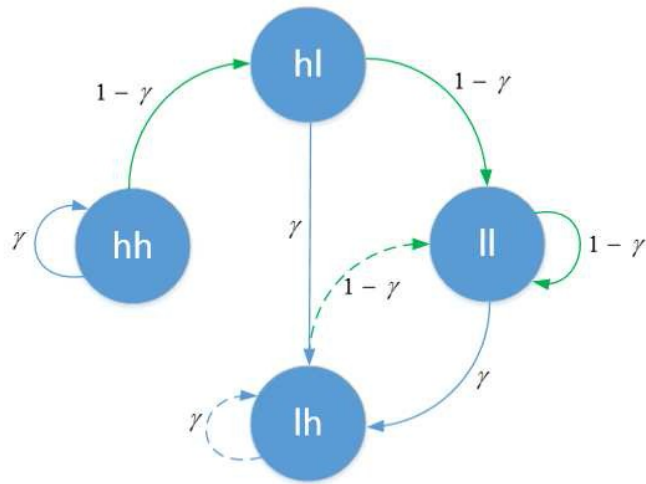


Figure 2: Markov Chain when following OPP2

$$P^1 = \begin{bmatrix} 0 & 1 - \gamma & 0 & \gamma \\ 0 & 1 - \gamma & 0 & \gamma \\ 1 - \gamma & 0 & \gamma & 0 \\ 1 - \gamma & 0 & \gamma & 0 \end{bmatrix}$$

The stationary probability vector for customers following OPP1 is:

$$(\pi_{hl}^1, \pi_{ll}^1, \pi_{hh}^1, \pi_{lh}^1) = (\gamma(1 - \gamma), (1 - \gamma)^2, \gamma^2, (1 - \gamma)\gamma)$$

Equilibrium state probabilities for OPP2. Customers following OPP2 purchase in all states but *lh*. Figure 2 shows the corresponding Markov chain and we next show the associated probability transition matrix P^2 . In the Markov chain figure, note that dashed flows represent the customers who move out of a state without purchasing in that state.

$$P^2 = \begin{bmatrix} 0 & 1 - \gamma & 0 & \gamma \\ 0 & 1 - \gamma & 0 & \gamma \\ 1 - \gamma & 0 & \gamma & 0 \\ 0 & 1 - \gamma & 0 & \gamma \end{bmatrix}$$

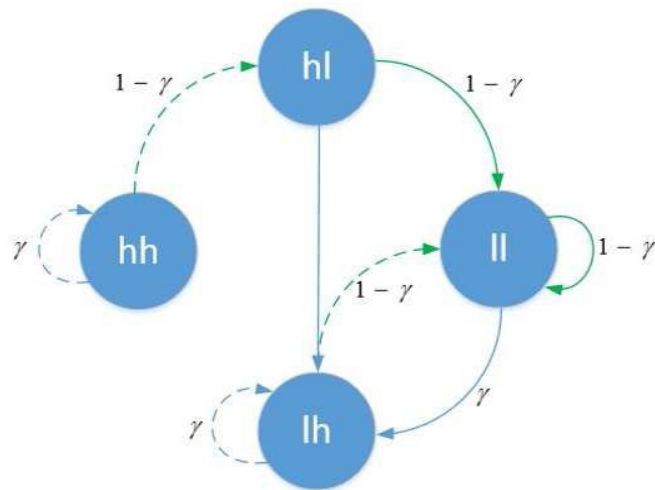


Figure 3: Markov Chain when following OPP3

The stationary probability vector for customers following OPP2 is:

$$(\pi_{hl}^2, \pi_{ll}^2, \pi_{hh}^2, \pi_{lh}^2) = (0, 1 - \gamma, 0, \gamma)$$

Thus, in equilibrium the OPP2 policy results in customers spending some proportion of their time in each of states *ll* and *lh*, but purchasing occurs only in state *ll*.

Equilibrium state probabilities for OPP3. Customers following OPP3 do not purchase in *hh* and *lh*. Figure 3 shows the corresponding Markov chain and we next show the associated probability transition matrix P^3 . In the figure, recall that dashed flows represent the customers who move out of a state without purchasing in that state.

$$P^3 = \begin{pmatrix} 0 & 1 - \gamma & 0 & \gamma \\ 0 & 1 - \gamma & 0 & \gamma \\ 1 - \gamma & 0 & \gamma & 0 \\ 0 & 1 - \gamma & 0 & \gamma \end{pmatrix}$$

The stationary probability vector for customers following OPP3 is:

$$(\pi_{hl}^3, \pi_{ll}^3, \pi_{hh}^3, \pi_{lh}^3) = (0, 1 - \gamma, 0, \gamma)$$

We see that, paralleling the above result for OPP2, in equilibrium the OPP3 policy

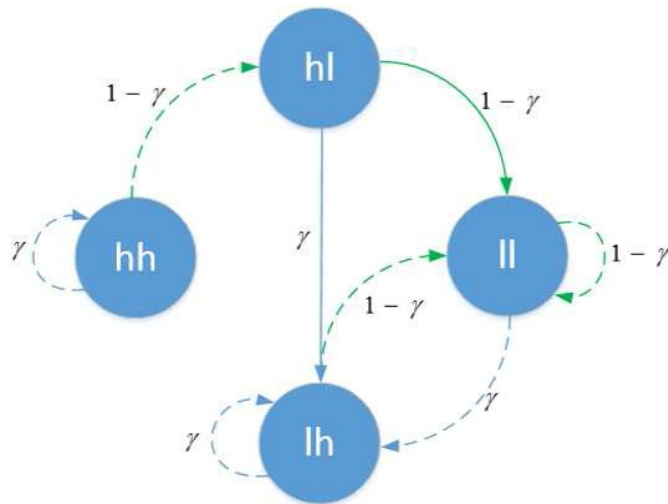


Figure 4: Markov Chain when following OPP4

results in customers spending some proportion of their time in each of states *ll* and *lh*, but purchasing occurs only in state *ll*.

Equilibrium state probabilities for OPP4. Customers following OPP4 only purchase in *hl*. Figure 4 shows the corresponding Markov chain and we next show the associated probability transition matrix P^A .

$$P^A = \begin{pmatrix} 0 & 1-\gamma & 0 & \gamma \\ 0 & 1-\gamma & 0 & \gamma \\ 1-\gamma & 0 & \gamma & 0 \\ 0 & 1-\gamma & 0 & \gamma \end{pmatrix}$$

The stationary probability vector for customers following OPP4 is:

$$(\pi_{hl}^A, \pi_{ll}^A, \pi_{hh}^A, \pi_{lh}^A) = (0, 1-\gamma, 0, \gamma)$$

Notice that in equilibrium, OPP4 yields no purchasing since customers will only buy in state *hl* but that state has a steady-state probability of zero.

4 Deriving demands and profits under DDS and IDS

4.1 Expected demands under DDS

To derive the portion of customers who optimally prefer to always purchase (following OPP1), we need to compare the expected NPV of surplus they receive from acting under OPP1 compared to acting under OPP2. By the same token, we need to compare OPP2 with OPP3, OPP3 with OPP4, and OPP4 with the fallback option of not participating in the market. The expected NPV of surplus for a customer following a particular OPP depends on the stationary probabilities of each OPP and it is equal to z^k for $k=1,2,3$ and 4:

$$\begin{aligned} z^1 &= (\gamma^2 + \gamma(1 - \gamma))z_h^1 + ((1 - \gamma)^2 + \gamma(1 - \gamma))z_l^1 \\ z^2 &= \gamma z_h^2 + (1 - \gamma)z_l^2 \\ z^3 &= \gamma z_h^3 + (1 - \gamma)z_l^3 \\ z^4 &= \gamma z_h^4 + (1 - \gamma)z_l^4 \end{aligned}$$

The size of customer mass who optimally follow OPP1 is determined by:

$$z^1 \geq z^2 \rightarrow F + \alpha p_h w + p_h + \alpha \beta (p_l - p_h) - \alpha p_l \leq v \rightarrow v^1 \leq v$$

The size of customer mass who optimally follow OPP2 is determined by:

$$z^2 \geq z^3 \rightarrow F + \alpha p_h (w - 1) + p_h \leq v \rightarrow v^2 \leq v$$

The size of customer mass who optimally follow OPP3 is determined by:

$$z^3 \geq z^4 \rightarrow F + \alpha p_l (w - 1) + p_l \leq v \rightarrow v^3 \leq v$$

The size of customer mass who optimally follow OPP4 is determined by:

$$z^4 \geq 0 \rightarrow F + \alpha p_l w + p_l - \alpha p_h \leq v \rightarrow v^4 \leq v$$

The thresholds on the valuations axis represent the indifferent customer between any two adjacent policies.

$$\text{OPP1 market size} = d_1 = \int_{v^1}^1 dv$$

$$\text{OPP2 market size} = d_2 = \int_{v^2}^{v^1} dv$$

$$\text{OPP3 market size} = d_3 = \int_{v^3}^{v^2} dv$$

$$\text{OPP4 market size} = d_4 = \int_{v^4}^{v^3} dv$$

4.2 Expected demands under DDS incorporating budget constraints

We can permit, without much added complexity, customers to be heterogeneous not only in their valuations but also in their per-period spending limits. We refer to such limits budget constraints. We assume customers' budget constraints fall within the range $[0, B]$, where B therefore denotes the highest budget limit.

Customers following OPP1 gain positive surplus from purchasing in all states and thus such customers would hope to have a budget in excess of $p_h - \alpha p_l + F$, which is the net post-discount order amount for the most expensive state (lh). However, if the budget constraint does not support this level of expense, the customer can still hope to follow OPP2 if the budget supports an expense $p_h - \alpha p_h + F$, corresponding to state hh . If this amount is also beyond the budget constraint, the customer can hope to follow OPP3 at expense $p_l - \alpha p_l + F$, corresponding to state ll . If even this is beyond the customer's budget, then following OPP4 requires only that the budget support an expense of $p_l - \alpha p_h + F$. Otherwise, if the budget is below even this threshold, then the customer cannot purchase at all.

The same line of reasoning applies to the customers who would follow OPP2, OPP3 and OPP4 when not budget-restricted. In particular, customers who would follow OPP2, OPP3, OPP4 must have budgets that can support the respective purchase amounts of $p_h - \alpha p_h + F$, $p_l - \alpha p_l + F$ and $p_l - \alpha p_h + F$; otherwise, these customers will optimally follow the next policy in this sequence that their budget can support. Figure 5 illustrates the demand segmentation that results from the interaction of valuation and budget-level heterogeneity across the continuum of customers along these two dimensions. Thus, the resulting demand functions are:

$$\begin{aligned}
 D_1 &= d_1 \int_0^B \frac{1}{B} db \\
 D_2 &= d_2 \int_0^{\frac{p_h - \alpha p_l + F}{B}} \frac{1}{B} db + d_1 \int_{\frac{p_h - \alpha p_l + F}{B}}^{\frac{p_h - \alpha p_h + F}{B}} \frac{1}{B} db \\
 D_3 &= d_3 \int_0^{\frac{p_h - \alpha p_h + F}{B}} \frac{1}{B} db + (d_2 + d_1) \int_{\frac{p_h - \alpha p_h + F}{B}}^{\frac{p_l - \alpha p_l + F}{B}} \frac{1}{B} db \\
 D_4 &= d_4 \int_0^{\frac{p_l - \alpha p_l + F}{B}} \frac{1}{B} db + (d_3 + d_2 + d_1) \int_{\frac{p_l - \alpha p_l + F}{B}}^{\frac{p_l - \alpha p_h + F}{B}} \frac{1}{B} db
 \end{aligned}$$

The equilibrium demands are:

$$\begin{aligned}
 D_{hl}^d &= \pi_{hl}^1 D_1 + \pi_{hl}^2 D_2 + \pi_{hl}^3 D_3 + \pi_{hl}^4 D_4 = \pi_{hl}^1 D_1 \\
 D_{ll}^d &= \pi_{ll}^1 D_1 + \pi_{ll}^2 D_2 + \pi_{ll}^3 D_3
 \end{aligned}$$

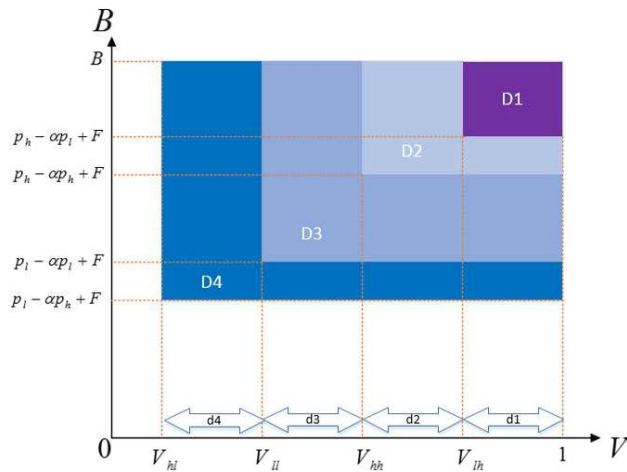


Figure 5: Justified demands after applying the budget constraint

$$D_{hh}^d = \pi_{hh}^1 D_1 + \pi_{hh}^2 D_2 = \pi_{hh}^1 D_1$$

$$D_{lh}^d = \pi_{lh}^1 D_1$$

Note that $D_{lh}^d = D_{hl}^d$ under all parameter settings. Only customers who follow OPP1 are buying in these two states in equilibrium. Also, recall that in equilibrium, all customers following OPP1 always purchase (in all four states). Also, as described above, even though surplus maximization allows customers following OPP2 (and OPP3) to purchase in hl , ll and hh , in equilibrium these customers jump between lh and ll and therefore will be only purchase in ll . Also as highlighted above, no demand results from customers following OPP4 because although they would purchase in state hl , the high credit level cannot result from a low order size and so that state cannot occur in equilibrium.

4.3 Expected demands under IDS

When the seller is offering an immediate discount, the customer problem reduces to a one-period surplus optimization. As illustrated in Figure 6, there are only two states in the Markov Chain: ll and hh .

$$d^l = \frac{p_h + F - \alpha p_h}{p_h + F - \alpha p_h} dv$$

$$d^h = \frac{p_l + F - \alpha p_l}{p_l + F - \alpha p_l} dv$$

Applying the range of budget constraints yields:

$$D^l = d_1 \frac{p_h + F - \alpha p_h}{p_h + F - \alpha p_h} db$$

$$D^h = d_2 \frac{p_l + F - \alpha p_l}{p_l + F - \alpha p_l} db + d_1 \frac{p_h + F - \alpha p_h}{p_l + F - \alpha p_l} db$$

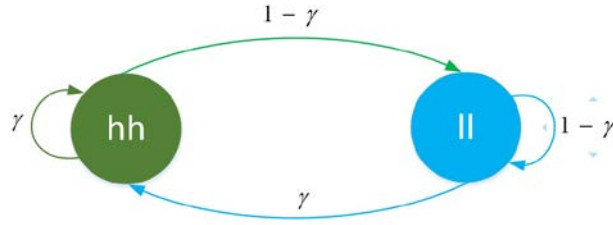


Figure 6: Markov Chain for Immediate Discount Strategy

Thus, the resulting equilibrium demands under budget-restricted spending are as follows:

$$D'_{hh} = \gamma D_1'$$

$$D'_{ll} = (1 - \gamma)(D_1' + D_2')$$

4.4 Expected seller profits under DDS and IDS

Let us define the profit margins at each state as:

$$R_{hl} = p_l + F - \alpha p_h - cp_l$$

$$R_{ll} = p_l + F - \alpha p_l - cp_l$$

$$R_{hh} = p_h + F - \alpha p_h - cp_h$$

$$R_{lh} = p_h + F - \alpha p_l - cp_h$$

The seller is maximizing its profit in the equilibrium.

$$\text{Profit}^{IDS} = D'_{hh} R_{hh} + D'_{ll} R_{ll}$$

$$\text{Profit}^{DDS} = D^d_{hl} R_{hl} + D^d_{ll} R_{ll} + D^d_{hh} R_{hh} + D^d_{lh} R_{lh}$$

We next consider a series of numeric results corresponding to baseline parameter values of: $\beta = 0.9$, $\gamma = 0.4$, $p_l = 0.5$, $p_h = 0.7$, $c = 0.5$, $F = 0$, $w = 0$, and $B = 1$. We vary the discount level α and consider the resulting equilibrium demands and expected profits for the IDS and DDS policies. We begin by plotting the demand segments resulting from the DDS and IDS options in Figures 7 and 8, and then in Figure 9 we combine those segment demands within a single graph. In Figure 10 we present the total demand

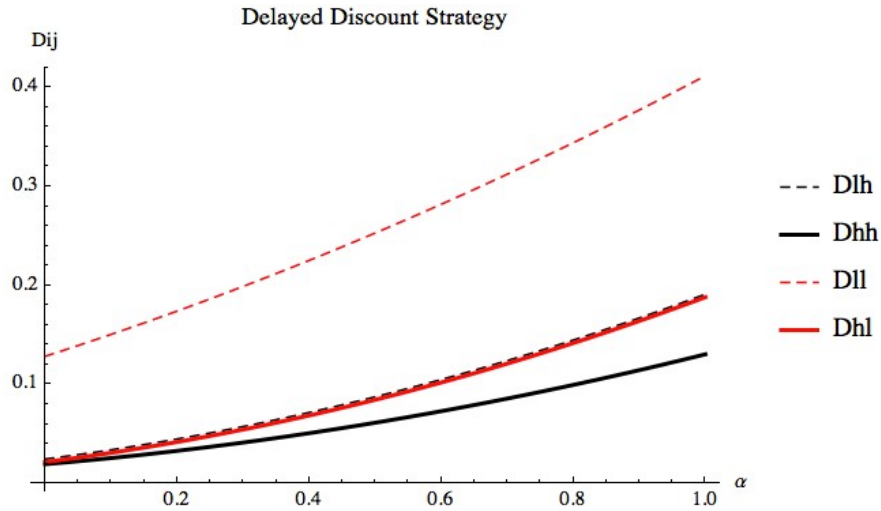


Figure 7: Demand under DDS

corresponding to the DDS and IDS solutions. This figure shows that the IDS option consistently yields higher demand, for any given level of α . Figures 11 and 12 show the corresponding profit levels, both at a segment-specific level (in Figure 11) and in the aggregate (in Figure 12). Figure 12 shows that at their respective optimal discount levels, which are approximately $\alpha = 10\%$ and $\alpha = 7.5\%$, the IDS option yields higher expected profits than the DDS option.

5 Allowing for distinct $\{low, high\}$ order-size valuations

We will now permit customers to have independent valuations v_l and v_h corresponding to the *low* and *high* order sizes. Although it is possible to extend our earlier analysis with heterogeneous customers to this case with valuations $\{v_l, v_h\}$, for brevity we will focus on a single customer type—a homogeneous market—and demonstrate that with distinct valuations $\{v_l, v_h\}$, the DDS option can be effective at increasing demand and the seller's profits.

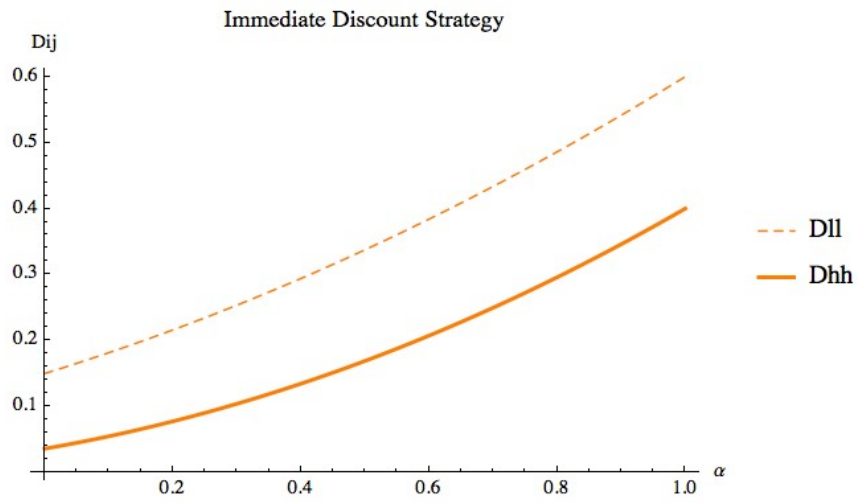


Figure 8: Demand under IDS

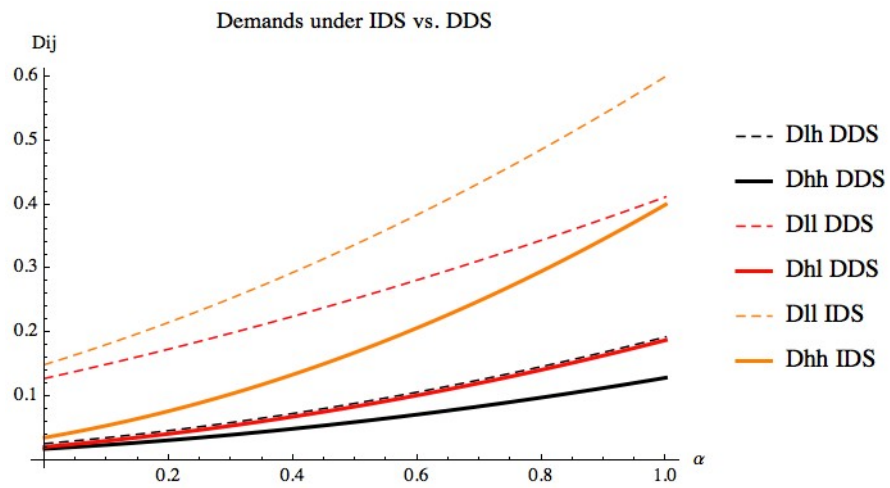


Figure 9: Demand under IDS

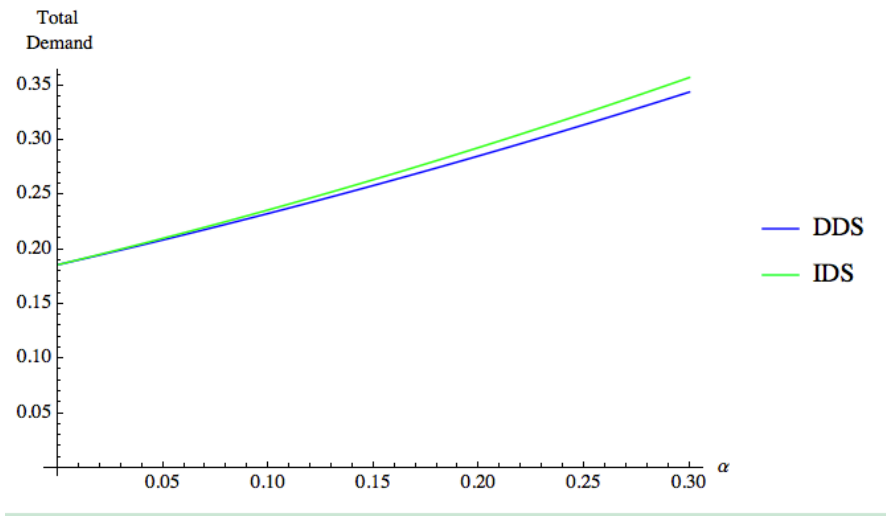


Figure 10: Demand under IDS

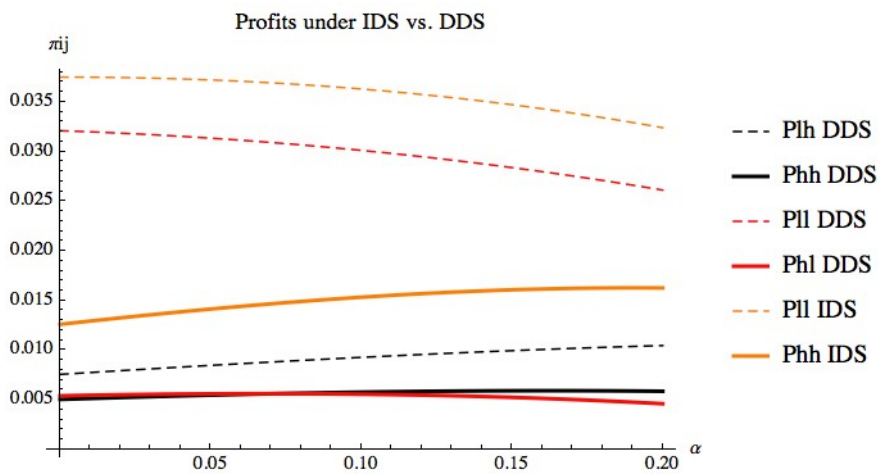


Figure 11: Profits streams

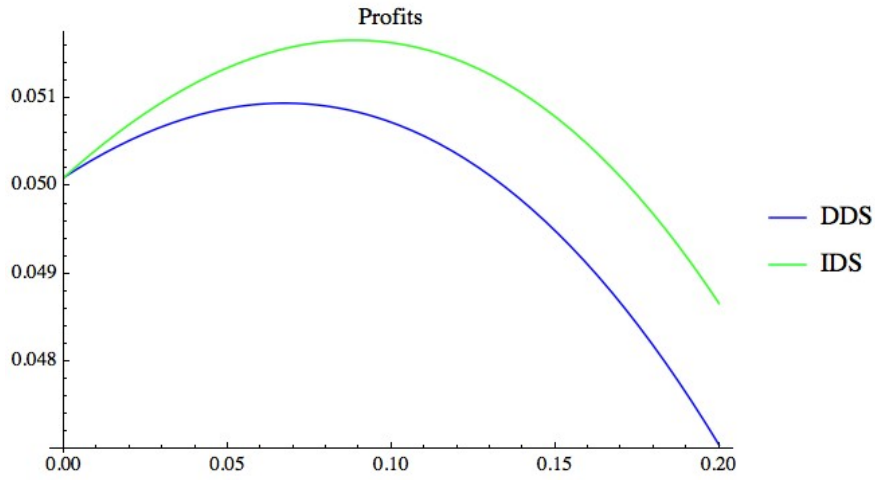


Figure 12: Aggregate Profits under IDS vs. DDS

5.1 DDS demands with distinct v_l and v_h

With the valuations for the two order sizes being independent, eight possible purchase policies result as shown in the table below. The ordering of the surpluses corresponding to these eight possible policies can vary depending upon the relative magnitudes of v_l , v_h , p_l and p_h .

OPP i	hl	ll	hh	lh
1	✓	✓	✓	✓
2	✓	✓	✓	✗
3	✓	✓	✗	✗
4	✓	✗	✓	✓
5	✓	✗	✓	✗
6	✓	✗	✗	✗
7	✗	✗	✓	✓
8	✗	✗	✓	✗

To solve the customer problem, we should follow the same steps in the identical valuation model: writing a system of two equations two unknowns for each OPP and solving for value function z_l and z_h . We have identified numeric examples in which the DDS outperforms IDS in terms of equilibrium profit. One such example, involving no budget constraint, is based on the parameter values: $\beta = 0.8, \gamma = 0.8, p_l = 0.5, p_h = 1, v_l = 0.35, v_h = 0.95, \alpha = 0.25, c = 0.6, F = 0$, and $w = 0$. The following table shows the surpluses corresponding to the eight possible customer purchase policies:

OPP i	hl	ll	hh	lh	z_h^i	z_l^i
1	✓	✓	✓	✓	0.8	0.675
2	✓	✓	✓	✗	0.48	-0.025
3	✓	✓	✗	✗	0.04	-0.025
4	✓	✗	✓	✓	0.804	0.684
5	✓	✗	✓	✗	0.5	0
6	✓	✗	✗	✗	0.05	0
7	✗	✗	✓	✓	0.8	0.680
8	✗	✗	✓	✗	0.8	0

The results in this table show that the market associated with the chosen parameters receives the highest NPV of surplus when following the fourth purchase-policy case: purchasing in hl, hh and lh . Therefore the profit in equilibrium for DDS is:

$$\text{Profit}^{DDS} = \gamma(1 - \gamma)R_{hl} + \gamma^2 R_{hh} + \gamma(1 - \gamma)R_{lh} = 0.132$$

5.2 IDS demands with distinct v_l and v_h

The customer problem for the IDS case is relatively easy to address even for the case where v_l and v_h are distinct. We can simply express whether it will be optimal for the customer to purchase in states l and h respectively as:

$$d_{hh} = \begin{cases} 1 & v_h \geq p_h - \alpha p_h + F \\ 0 & \text{otherwise} \end{cases}$$

$$d_{ll} = \begin{cases} 1 & v_l \geq p_l - \alpha p_l + F \\ 0 & \text{otherwise} \end{cases}$$

Applying our sample parameters from the subsection immediately above, we find $d_{hh} = 1$ and $d_{ll} = 0$ and the profit in equilibrium is:

$$\text{Profit}^{IDS} = \gamma R_{hh} = 0.12$$

Thus, we see that there is a $\frac{\text{Profit}^{DDS} - \text{Profit}^{IDS}}{\text{Profit}^{IDS}} 100\% = 10\%$ increase in profit if the seller follows the DDS option in this market.

We next show that if we allow a lower per-dollar unit cost (c) for the small order size, as would more likely be the case in practice, then the profit advantage further improves for the DDS option. For example, let us consider the same parameter values as in the prior scenario but rather than consider a single c , let $c_l = 0.4$ and $c_h = 0.6$. Then, we find that:

$$\text{Profit}^{DDS} = 0.148 \text{ and}$$

$$\text{Profit}^{IDS} = 0.12.$$

$$\text{For this example, we have } \frac{\text{Profit}^{DDS} - \text{Profit}^{IDS}}{\text{Profit}^{IDS}} 100\% = 23\%.$$

The larger DDS profit advantage in this scenario showcases the potential benefits from delayed discounts under favorable conditions. Further analysis is required to gain a deeper understanding of the conditions under which delayed discounts are favorable. The analysis approach we have presented provides the vehicle for undertaking such further study.

6 Conclusion

In this paper we have contrasted the impact of providing customers with either immediate or delayed price discounts. We have referred to these two alternatives as the Immediate Discount Strategy (IDS) and Delayed Discount Strategy (DDS), respectively. As we discussed in the Introduction, if customers' successive order amounts (in dollar terms) are stable over time, and if customers are homogeneous (and rational), then for a given DDS discount level, there exists a (higher) IDS discount level at which the two policies are equivalent. However, as we have analyzed, when customers' are heteroge-

neous and/or their order sizes can vary, there is no equivalence between the DDS and IDS options, even when both are set optimally. We have shown that when a given customer has equal valuation for both the low and high order sizes, as would be the case when the low and high orders represent sale and regular pricing on an identical basket of products, then the immediate discounts generate higher demand (and profits) than occur under delayed discounts. This follows from DDS sometimes offering large carried-forward discounts in the lower-price (sale) state, and small carried-forward discounts in the full-price state (the "high order size"). In contrast, the IDS option would offer large discounts in the full-price state, when larger discounts are needed to induce customer purchasing, and relatively small discounts in the low-price state, when either low or no discounts are needed to induce purchasing. Therefore, the simple IDS approach works perfectly well in such simple scenarios.

The potential for the DDS to be the more efficacious option becomes evident in scenarios where customer surpluses are positively (rather than negatively, as in the prior example) correlated with the order size, at pre-discount prices. For example, before any discounts, if customers associate higher surplus with large orders and lower surplus with small orders, then the IDS fixed %-off approach is not ideal in that it rewards customers with the largest (smallest) discount when the least (most) discount is required to induce purchasing. Therefore, there exists the potential for the DDS to increase the seller's profitability in the appropriate scenarios. To demonstrate this, near the end of the prior section we showed two related examples where the expected profits resulting from the DDS exceeded those of the IDS, by 10% and 23%, respectively. In both those examples, the setting was such that the customer's pre-discount surplus corresponding to the large order size was higher than for the small order size. The only difference between the two examples was that in the first example we assumed identical cost to the seller for both low and high orders; encouragingly, for the second example where the seller had higher cost for the larger order, as would be typical, the profit advantage from the DDS rose from 10% to 23%. We can thus see that there is indeed scope for the DDS option to improve the seller's profits.

Further study is required to more fully characterize the conditions under which—

and the extent to which—the DDS option can increase profitability. Two promising avenues of study that we have begun exploring are: (i) allowing for the possibility that customers may not return in each period (i.e., the probability of a customer returning in each subsequent period is less than one), and (ii) defining a structured positive or negative correlation between the pre-discount order amount and a customer's valuation of that order size, to enable a more systematic evaluation of how the correlation between customer surplus and order size relates to the relative profitability of the DDS option. The results at the end of the prior section indicate that the DDS may be effective when pre-discount surplus correlates with order size, but further and more comprehensive analysis is needed to better understand that relationship.

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Appendix C – Worksystems Inc.

Final Interview Report

Training Evaluation for Worksystems, Inc. by Pacific Research and Evaluation



PACIFIC
Research &
Evaluation

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Executive Summary and Recommendations

The goal of the evaluation conducted by Pacific Research and Evaluation for Work Systems Inc. (WSI) was to identify whether three trainings funded by the Department of Defense are likely to have a lasting effect on the defense contractors, resulting in continued process improvement. Specifically, WSI was interested in an evaluation that assessed the application of training skills and demonstrates that the applied principles learned in the training result in a process or manufacturing change within the organization.

Common themes emerged across the three trainings which included positive feedback from the trainings as well as areas for improvement. Positive feedback received across all training was related to the focus of training content on lean concepts. Results of the interviews showed that employees feel the content of the training and the six sigma principles are very relevant to the manufacturing industry. The instructors received positive feedback across all trainings as well, even when employees were unsure of how the training could be used on the job,. Finally, employees across all trainings responded positively to bringing multiple organizations together in the trainings.

Suggestions for improvement were related to a lack of resources to facilitate transfer of training concepts back to the job. Specifically, results showed that a lack of supervisor buy-in or knowledge of lean concepts inhibited transfer. Additional time allocated to applying the concepts on the job and the availability of software programs used in the training are other resources that could improve training transfer. Finally, when train the trainer courses were included in the training suite, it was difficult for interviewees to make the connection between this training and process improvement outcomes.

Overall recommendations for funding future trainings are provided below:

Recommendation #1: Future training efforts for manufacturing companies should continue to focus on lean principles. Interviewees consistently shared positive feedback about how lean manufacturing is leading to efficiency outcomes within their organization.

Recommendation #2: We recommend that trainings continue to bring together multiple organizations in the same industry. Feedback from this evaluation showed that employees valued the opinions and experiences of fellow trainees from different organizations.

Recommendation #3: It is recommended that future training efforts that are focused on lean manufacturing require a supervisor's attendance with his/her employees. In order for employees to feel supported in the application of lean concepts, supervisors and managers need to have an understanding of the concepts and the potential impact on the organization as well. These trainings often encourage employees to completely re-work processes within the organization and if the supervisor does not understand lean, it is less likely they will support these change efforts.

Recommendation #4: If training efforts are going to focus on specific software programs, we recommend that the organizations receive support to purchase these programs for the employees. The transfer of training is less likely to occur if employees do not have access to the software they were using during the training.

Recommendation #5: We suggest including time built into the trainings for application of training content. One of the three training programs included in this evaluation incorporated built in time to apply the knowledge and skills learned in the classroom to a real world project. This portion of the program received the most positive feedback and led to noticeable outcomes related to productivity and efficiency. Those trainings that assigned an application project but did not set aside actual course time to complete it saw less transfer of training to the organization.

Introduction

Worksystems, Inc. (WSI) is a nonprofit agency that accelerates economic growth in the City of Portland, Multnomah and Washington counties by pursuing and investing resources to improve the quality of the workforce. They design and coordinate workforce development programs such as the recent trainings that were provided by Mount Hood Community College, Clackamas Community College, and Clark College. WSI received training funds from the Department of Defense for the purposes of workforce training which were dispersed for the purposes of funding training for companies in Oregon that produce and sell products in the defense industry.

Pacific Research and Evaluation is an external company that was hired by Worksystems, Inc. (WSI) to evaluate training offered for these local companies by three local community colleges. The goal of the evaluation was to identify whether the funded training is likely to have a lasting effect on the defense contractors, resulting in continued process improvement. Specifically, WSI was interested in an evaluation that assessed the application of training skills and demonstrates that the applied principles learned in the training result in a process or manufacturing change within the organization.

The following report will summarize the overall methods for evaluating the training offered by the community colleges and provide more specific details about data collection at each site along with the results and specific recommendations for each training program in subsequent sections broken down by training.

Methods

The evaluation plan for this project was framed around Kirkpatrick's widely accepted model of training evaluation¹ which emphasizes the importance of measuring the success of a program not only in terms of a participant's *reaction* to or *knowledge* gained from training(s) but also in terms of subsequent *behavior* change and program *results* in the form of key student outcomes.

Kirkpatrick's framework for evaluating training programs includes the assessment at four key levels: 1) Reactions, 2) Learning, 3) Behavior, and 4) Results. Reactions refer to the basic feedback employees offer about training programs such as whether the training was relevant to them, how effective the instructor was, and the extent to which training materials were useful. The second level, learning, refers to the knowledge gained from the training and is often assessed with a pre- and post- knowledge test. The third level corresponds to behavior and focuses on assessing behavior change as a result of the training. This level refers to the actual transfer of training to the workplace and is often assessed through observations or behavioral self-monitoring. Finally, level four assesses the results or ultimate outcome of interest to the organization. The results assessment often focuses on the bottom line and answers the question, "what does success of this training look like to the organization?"

¹Kirkpatrick, Donald L. (1998). *Evaluating Training Programs: The Four Levels*. Berrett-Koehler Publishers.

Pacific Research and Evaluation conducted 41 interviews with various Oregon companies that produce products for the department of defense. Table 1 summarizes the number of interviews completed within each organization along with the associated training source.

Table 1. Interviews Completed

Organizations	# of Interviews	Training Source
Microchip Technology	4	Mt. Hood Community College
On Semiconductor	6	Mt. Hood Community College
Total Mt. Hood	10	
Selmet Inc.	4	Clark College
PECO Manufacturing	4	Clark College
InFocus	4	Clark College
Total Clark	12	
Benchmade Knife Co.	4	Clackamas Community College
Machine Sciences	3	Clackamas Community College
Sunstone Circuits	4	Clackamas Community College
Timbercon	5	Clackamas Community College
Grove Tec US	3	Clackamas Community College
Total Clackamas	19	
Total All Colleges	41	

Within each organization, the goal was to interview 2-3 employees who participated in the training and one supervisor of employee(s) who participated in the training. At some organizations supervisors went through the training with their employees and in these cases, they were asked to answer both employee and supervisor questions.

The purpose of both employee and supervisor interviews was to gather data at all four levels of evaluation including general reactions to the training, knowledge gained in the training, how knowledge from the training is being transferred into behaviors on the job, and if employees and supervisors are seeing changes in efficiency and productivity outcomes as a result of the trainings. Specifically with the supervisor interviews, the goal was to understand whether the information from the trainings was visually transferring to the job in terms of employee behaviors or efficiency outcomes.

Mt. Hood Community College

Mt. Hood Community College offered four trainings total and employees at Microchip and ON Semiconductor attended one or two of the trainings each, depending on interest and need. The trainings provided were called Problem Solving for Continuous Improvement, Project Management, JMP Software Training, and Skillful Trainer. These four trainings are summarized individually by level of evaluation below.

Problem Solving for Continuous Improvement

The Problem Solving for Continuous Improvement training was developed through the WIRED grant in 2009. The course was designed to train employee teams to effectively identify and solve problems and to reduce events, activities, and tasks that are considered unsafe, wasteful and/or redundant. This course was designed to prepare and assist team leaders to recognize and propose solutions to typical manufacturing problems. Microchip and ON Semiconductor employees attended the same, one day session covering specific modules in this course.

Level 1: Reactions

Problem Solving for Continuous Improvement received the least positive feedback of the four trainings from employees at both participating organizations. Employees said that it was difficult to remember details from the training because it took place over a year before the interview. The most common feedback from participants was that the training was not necessary. Interviewees stated that the trainings were redundant because their organizations provide similar trainings internally. Participants from one company completed the training offered by Mt. Hood Community College in order to compare it to the training offered by their institution and concluded that the two programs are quite similar.

- *The hard part for me with that class was that it was redundant with what we already teach.*
- *A lot of what I do here is problem solving, so it was really basic.*
- *The only thing they could have improved would be to not have condensed it down as much; there were other modules we didn't learn. I would have really liked to pursue the whole package.*

With regard to what went well within the Problem Solving training, employees mentioned that they were impressed with the presentation of the training. They reported having learned to approach work differently and that they are now able to identify steps that are potentially skipped in the problem solving process. It was also noted by participants that the offsite training offered fewer distractions than internal trainings typically do.

- *Overall, the training helped me to prioritize and to not jump to conclusions.*
- *I remember it being good for a beginning problem solving class. The role playing activities were good.*

When asked about the presence of the other organization at the training, participant feedback was mixed. Some employees reported that it was beneficial to have participants from another organization present because they were able to learn new approaches for solving similar

problems. Conversely, one employee reported that they would have felt more comfortable sharing ideas if they would have been in a class with only their own coworkers.

- *I think it was very positive. It was good to see the continuity across the industry. It's good to step out and see we're not the only ones struggling with something.*
- *It would have been easier if employees from the other organization weren't there, because there were ideas we didn't want to share. If they hadn't been included, there would have been more discussion and we could have gotten feedback from the instructor.*

Supervisors were asked about their reactions to the Problem Solving training. Similar to the participants' reactions, supervisors found this course to be the least beneficial. One supervisor reported having his/her employees attend the training as an exercise in problem solving. This supervisor asked participants to determine whether or not they were approaching problemsolving correctly by comparing their approach with the material presented in the training. Upon completion of the course, participants felt that they were indeed approaching problem solving correctly. This supervisor felt that this course was the least useful of the four to his/her employees.

Level 2: Knowledge

When participants were asked about the most important thing they learned in the Problem Solving training, many of them responded that it was difficult to remember the content due to the lapse of time between the training and the interview. Participants who could remember the content of the training gave responses related to process implementation.

- *I'm always thinking with the end in mind but I tend to skip steps, so the training did help me to see that there are other people with different thought processes and my need for speed can push those people out of the loop.*
- *It gave me some ideas for streamlining my job. I learned a method for creating processes so you can't make mistakes. So, you are safeguarding or implementing a process that eliminates error/reduces behavior toward making errors.*

Supervisors were also asked to report on the most beneficial concepts learned by their employees during the Problem Solving training. Both supervisors had little to say about the knowledge gained by employees from this training.

Level 3: Behavior

Trainees were asked if and how they apply the content from the Problem Solving training to their job. While many employees responded that there was not a strong "need" for the training, some did report that they have implemented concepts learned in the training into their workplace. The following are examples of these responses:

- *We are already using the content in the work we do. If we have scrap material, we ask, what was the root cause and how do you find a solution?*
- *I tend to listen first now and I still assert what I see as the larger problem. There's more outside that 10 minute bubble, so it's helping to close that.*
- *We created a team to reduce the amount of product. We reviewed those items with the team and decided that some things don't need to go to that step. That's one way we've looked at continuous improvement.*

When asked about barriers for the implementation of concepts learned during the training, participants stated that because the course was designed to be completed over the course of one year, it was not feasible to cover all of the material in such a condensed time frame. One employee reported that it would have been useful to have the training tailored more toward teleconferencing.

- *I'd want to learn how I can do things through teleconferencing. With being a 24 hour, 360 day operation, reading people's body language doesn't always work with people in Korea.*

Neither supervisor could provide an example of a way in which their employees have applied what they learned from this training.

Level 4: Results

When asked about the effect of the training on ability to recognize and propose solutions to manufacturing problems, participants stated that they believe the training will increase the quality of their products and decrease production time.

- *Yes, I think I've come up with a lot of ideas based on the training, but it's just a matter of getting those implemented with the same resources.*
- *I believe so. I know for a fact, I've seen a great improvement and it has led to the job I have now (employee was promoted after the training).*

Project Management

The Project Management training was developed with WSI funds in 2009. This course approached project management from the standpoint of managing a single, stand-alone project. It took participants through the project life cycle and included an overview of project management software. Topics included initiating a project, defining scope, planning a project, executing and controlling a project, and doing closeout. Skills learned were designed to allow projection and development teams within the company to address and foster innovation and change with great efficiency. Microchip and ON Semiconductor employees attended separate courses. Microchip had a need for strategies to address very specific mini-projects and ON Semiconductor addressed larger department scale projects.

Level 1: Reaction

Feedback on the project management training was positive from all employees interviewed. Participants reported that the instructor was very experienced and that they enjoyed the hands-on nature of the class. Employees said that they would definitely recommend the training to other employees.

- *This class stuck out a lot for me, because the instructor was really good and his way of presenting was well paced. Without the training I think I would be doing my job differently.*
- *The instructor was really good. He had a lot of experience, so I trusted his answers. He used examples from his past experience that he could draw upon to teach us.*
- *I really enjoyed the hands-on nature. I was able to take a project I was currently working on and apply it in the class.*

Suggestions for improvement included tailoring the content to the semiconductor industry and allowing more time for instructor feedback. One employee said that his/her organization does not work with Microsoft project, and therefore he/she did not find this portion of the training helpful. Another employee suggested awarding a certification upon completion of the training so that participants would be able to demonstrate their accomplishment to future employers.

- *We didn't have the instructor looking at the details of each group. I would have liked more feedback for our group. It would have been better to pick a common problem and work it out. Beyond my immediate group I didn't get feedback.*
- *It was a very general class; I could have used the info in any industry. But, I would have liked it more geared toward the semiconductor industry. All that experience is excellent; I use it almost every day to create a timeline as well as the software we learned, but overall I would want the class to suit my every day activities better.*
- *During the course training, we were asked to install Microsoft Project on our computers. Our management requests that work submissions be in a certain format which doesn't require project management software, so I don't know if that was a necessary part of the training.*

The supervisors were also asked for their reactions to the Project Management course. One supervisor stated that overall he/she thought the course was “pretty good” but wished there had been more focus on software throughout the training.

Level 2: Knowledge

When asked about the most important concept learned in this training, risk management was a common response. Responses are illustrated by the quotes below:

- *Being able to identify risks and stakeholders and getting everyone on the same page with no communication errors. This allows me to prioritize with the entire stakeholder group and keep people accountable on deadlines.*
- *Risk management and overall timeline. Those were the major things I learned. I now use a totally new approach to evaluate the risk and decide the least risk or most profitable.*
- *I thought the instructor was really good at explaining the topic of communicating to all stake holders.*
- *I think for me it was realizing that projects are huge and need to be broken into smaller chunks. A lot of time we don't hire external project managers. This class made me consider the length of projects and the resources needed to complete them.*

Neither supervisor gave specific examples in response to the question of the most valuable concept learned. However, one supervisor did reiterate that his/her employees received a lot of valuable information during this part of the training.

Level 3: Behavior

When trainees were asked how they use project management training in their job, several reported that it has improved their communication. One employee described using the training for planning purposes.

- *Communicate, communicate, communicate. It definitely had an effect on how I manage projects.*
- *I use the timeline. I use the software very regularly. I learned how I can sell to the stakeholders and get them to buy into my idea. That was a very good part of the course that I use every day.*
- *This class taught the importance of planning out the project and really understanding your resources. To know where you got the time to do it was really valuable for me.*

The following are participant descriptions of barriers encountered when transferring skills learned in the project management training to the workplace:

- *I wish the training was a little more focused on persuading people who don't see eye to eye with you. The site philosophy in the past has been conservative (document everything). I wish the training could have been more revolved around getting those people on board and trying to keep everybody on the same goal.*
- *More interaction in the class and ideas for different approaches to the project would have been useful. So, more interaction and more feedback from the instructor. We had tiny groups and most of our feedback was within the group. We never had other groups evaluate our group or the instructor.*

Both supervisors reported that this training had an impact on their employees, but neither gave specific examples of the ways in which the participants are using their new knowledge on the job. One supervisor noted a potential barrier for implementation of concepts learned in the cultural differences between the approach of the training program and the companies themselves.

Level 4: Results

Interviewees were asked if the training has affected the way production and development teams in their company approach their work. One employee indicated that the training has decreased time spent on specific tasks and has allowed employees to focus on moving product and dealing with issues bigger than documentation. Responses were varied, as shown below:

- *It is hard to say how it impacted me but it has helped me streamline and achieve my goals; we had specific goals to meet before the end of the year and I met those goals. It has definitely helped me do work more efficiently.*
- *I think so. We looked at things that were easy to implement; from here on out it has to be a site philosophy change which I think is occurring. There has been a lot of continual review. We are looking at processes in a little more detail and are going back and looking at smaller detail stuff now.*
- *It helped me with my projects but I haven't seen a change in efficiency as a result of this class.*

One supervisor reported that projects are managed more effectively as a result of the training, which can be seen on the floor via faster and easier production process.

JMP Software Training

The JMP Software Training was designed to help with continuous improvement and experiments to improve products and production. The JMP family of products makes information more accessible by linking statistics with graphics. It is the standard for visual data analysis and is used closely with lean six sigma and performance excellence. This class was intended for Process Technology Development and Yield Enhancement Engineers and focused on renewing and extending the team's foundational skills and familiarity with the JMP products.

Level 1: Reactions

The JMP Software Training received very positive feedback from all participants that were interviewed. Employees indicated that the instructor was excellent, reporting that he had expert knowledge of the software and answered questions accurately and timely during the training and via email post-training.

All employees said the training was very useful and that they would recommend the class to others. One employee described it as the best training that he/she had ever attended.

- *The instructor was very good. He was very knowledgeable, answered our questions accurately, and allowed us to follow-up with a personal email. I would give the instructor 10 out of 10. I would recommend the class to someone else. The instructor had used the program for 10-15 years. He knows the shortcuts and he was open to showing us how to do things quickly.*
- *I think this should be an integral part of the training plan. I think this training should be a must. JMP has a lot of features; it would help engineers learn how to do things to save time and make them more productive.*

Interviewees offered the following suggestions for improving the JMP training:

- *The difficulty is that it was so long ago that I don't have distinct or specific memories of the class. It was 2.5 days. It should have been longer, maybe with a second 3-day session. It's hard to leave work for that long though.*
- *Access to a contact person after the training, because as you work with the software you realize there are questions and every time there is a new version we have to figure out what is new, so somebody we could get in touch/contact with that would be very helpful.*

When asked how the training differed from past trainings participants had attended, answers were largely positive. One individual reported having liked the training because it was designed by an engineer. Another employee said that the training was very helpful to those with a base knowledge of JMP, because they could get questions answered that they brought with them to the training.

- *I had some basic knowledge of the program already so that was very good. It was like a question and answer so I got all my questions answered. It was different from other trainings in that sense.*

When asked for their reaction to the JMP Software training, one supervisor described it as “excellent” and added that his/her employees raved about the instructor. Another supervisor noted that this training was especially helpful because it would be difficult to provide internally, as internal personnel often do not have the technical skills associated with the course.

Level 2: Knowledge

When asked about the most important concept learned in the training, employees reported that it gave them familiarity with basic functions of the software and helped them get answers to questions they had about using it.

- *I learned how to combine data tables. I can now spit out and tabulate data. The tabulate feature wasn't something I was using before and learning it made my life easier.*
- *It gave me a familiarity with basic functions. Instead of being a tool I used poorly, it became a tool I could use with success.*

The supervisors reported that this training was helpful because it allowed their employees to develop experiments and to determine how to create new products in the factory.

Level 3: Behavior

See below for interviewees' specific examples of how the JMP training is being used on the job.

- *It made my everyday use more simple. What I would have done over 10 mouse clicks he showed us how to do in two mouse clicks. I use this everyday.*
- *I've used it in experiments and created several graphs and selected the ones people would be interested in. It's absolutely efficient.*
- *I use it every day to make combined tables. I do a lot of data analysis; I'm interested in getting responses and graphically see it; what is statistically different. It's a great tool. I need to use the program; I've used two other software programs and of the three tools I've used, JMP is my favorite. Not because of the training, but because the training allowed me to use it better and make my life easier.*
- *I use the SASS data tool to extract data and then I export it into JMP. What I need to do from there is all done in JMP.*

When asked about barriers to implementation, interviewees described the following:

- *A weakness of the program is that it's hard to format the numbers.*
- *The intro class probably should have been two pieces maybe with a follow-up a few months later.*
- *It's expensive to get a license, so not everyone can use it.*
- *It's a very complicated program. If you know how to use it the help option is useful, but it assumes you have a lot of statistical knowledge.*

One supervisor reported that the JMP Software training allowed his/her engineering employee to do his work more quickly. Conversely, the other supervisor questioned whether the software is applicable to his/her company's needs.

Level 4: Results

With regard to the overall outcome of improving efficiency in the workplace, interviewees reported that the training has helped them use the software more efficiently, which allows them to get their work done much faster.

- *It has helped me analyze the results of experiments more quickly and easily with confidence in the method. Excel is odd because they change how they calculate things over time making you waste time figuring out how they calculated results. So, the training helped me in that regard— in giving me a better tool.*
- *Yes, it has definitely helped with efficiency.*

When the supervisors were asked about improved efficiency, one noted that knowledge of the JMP software allows employees to get their experiments completed more quickly. The other supervisor mentioned that the software allows employees to write better experiments, which saves time because quality experiments only need to be run once.

Skillful Trainer

The Skillful Trainer was developed through the WIRED grant in 2009. It was a three-day workshop facilitated by an experienced Skillful Trainer. Topics included adult learning styles, curriculum development, instructional strategies, and assessment. The goal was for participants from the previous three trainings to attend the Skillful Trainer so that instructional pilots could be developed to internally disseminate the training content to other departments. Employees from Microchip and ON Semiconductor attended this training together.

Level 1: Reaction

Reactions to the Skillful Trainer session were also generally positive. Employees were pleased with the quality of the instructor, the interactive nature of the session, and the relevancy of the content to their work.

- *It was a really good and engaging class. The instructor was considerate to everyone in the classroom. I thought it was worth my time.*
- *The instructor was ready to go when we got there. The room was comfortable. The time slot worked well; the length of the class worked well. Good ice breakers.*
- *I was extremely impressed with the trainer. The training was very interactive and brought in many people. Very animated groups. It focused on work problems and outside of work issues.*
- *It had four modules, two of which I thought were especially relevant to my position (adult learning principles, setting training objectives). The other two that were less relevant for me were characteristics of exceptional trainers, though I did like the training and it was a good review. The least useful to me was developing training courses, which wasn't relevant to what I do.*

Interviewees gave positive feedback about working with employees from another organization during the Skillful Trainer portion.

- *Their outlook on the training was a little bit different but it went well to have the two groups together.*
- *I enjoyed it. They seem to have fun. Nice to meet people from a different company. What they were doing was the exact same thing as me.*
- *Loved it. Good to see the consistency. Good to see we're not the only ones having particular issues. They were animated which was entertaining. Keeps you awake.*

Suggestions for improvement included more time and specialization to the semiconductor industry as illustrate below.

- *The training was over four weeks and it was in the middle of the day, so it was a little difficult to get all four trainers there (they all have different shifts).*
- *It was pretty condensed. There was homework given that maybe if we had had an extra week my group could have improved on. We are now developing a program from that class. It was three weeks, one day a week.*
- *None of the training modules were set up for the semiconductor industry, so it was generic in that respect. Not even necessarily for manufacturing...they could have been more specific for manufacturing.*

When asked how this training differed from others they had attended in the past, participants' most common response was that it was conducted by an external instructor rather than an internal training team.

- *Training is usually internal (75%). It was a way to learn different skills and validate what we're doing internally. We could use their icebreakers. It's good to see how my trainers were responding to it.*
- *Usually training is from someone internal. She brought material from outside the company. So, her notebook has been a good resource to review at times.*

Both supervisors gave positive feedback about this training. One described it as “awesome,” while the other reported that those who participated in the training are now better trainers themselves. One supervisor also noted that the scheduling of this training did not allow their company to send as many employees as they wanted to, which could have been improved.

Level 2: Knowledge

When asked about the most important concepts learned in the Skillful Trainer session, interviewees referred to the Adult Learning Styles and Teaching Styles sections, as well as the Techniques for Engaging Learners.

- *My trainers are always looking for ways to keep people engaged. For example, I let people have time to think rather than blurt out the answers when I'm doing trainings now. It was kind of fun to watch my trainers try to stop and allow employees to think about answers.*
- *The instructor also mentioned that people need to be doing something different every 15 minutes. We used a lot of ideas for trying to get people a little more engaged. Also taught us to ask more open-ended questions.*
- *Wants versus need as adults and generational differences were highlighted. I took that away as a huge learning point.*
- *The other one was adult learning principles; we get a big cross section of demographics and what I took away from that module is that everyone has a different style and there's more than one teaching style.*

The supervisors stated that this training reinforced for employees that no two people are the same and taught participants how to relate better to others. Furthermore, both supervisors reported having observed situations in which employees used what they learned during this training to problemsolve in their workspace.

Level 3: Behavior

When trainees were asked how they use the knowledge they gained in the Skillful Trainer course on the job, they offered the following specific examples:

- *I have a new trainee and based on what I learned in the class, I set up two-weeks of specific objectives. I also asked him what's best for him (to read alone or read together). So I have fine-tuned my training technique to his learning. In the past I would just train and hope they understood.*
- *I have seen my employees bring bits and pieces into their training techniques. Not long after the class, we brought in a new technology to train people on. The training was originally written by someone scientific and was thus difficult to understand. So the trainers created activities, got employees to move around, asked interactive questions. This helped ensure that people left with the knowledge they needed.*
- *I've recognized generational differences. I recognized who to give milestones to and who to stand back and recognize that if I reacted the same way for different people it could be a negative rather than a positive.*

Both supervisors offered specific examples of their employees using knowledge gained from the Skillful Trainer class. One supervisor noted that the trainers are visibly more effective in the classroom. The other trainer stated:

- *It helped them handle people in the past that have been labeled as difficult to train. So, he learned that maybe there was a reason they weren't learning. There are people still working here who might not have been in the past so that's good (meaning they may have been let go due to not learning from the training).*

Level 4: Results

The Train the Trainer course was not specific to the manufacturing industry, which made it difficult for interviewees to offer examples of how the class has produced efficiency outcomes. However, the main theme appearing in their responses was that improved training skills lead to more efficient training.

- *Ultimately, big picture, we can't take specialists off the floor for very long. So, while it seems like a really long stretch because we're not tied to the product, putting people in front of a class who aren't good at training is inefficient. That's why efficient training is important.*
- *I think it has made me an effective trainer. I am the primary trainer on my shift, so on that respect I would say yes.*

Supervisors added that the training has improved efficiency in that workers are trained faster and therefore can return to work more quickly. One supervisor also mentioned that the training allowed his/her trainers to successfully train 15 new operators, which he/she believes helps with overall efficiency.

Summary and Recommendations

The overall feedback about the trainings offered by Mt. Hood Community College was positive. Employees and supervisors gave positive feedback about the Project Management Training, JMP Training, and Skillful Trainer with regard to the content of the class and the instructors. The primary suggestion for improvement was the desire for a more direct application to the semiconductor industry. From an evaluation perspective, this was related to the difficulty in gathering data at level four. If the training was tailored to the industry, the production and efficiency results may have been more visible to employees and supervisors. Another area for improvement was the Problem Solving for Continuous Improvement training which received less positive feedback from both organizations. Interviewees mentioned that they did not feel like they needed to training or they already receive it internally.

Our primary recommendations for this training series include:

Recommendation #1: Tailor the training to the industry in order to see an increased transfer to training to the workplace and the desired results in terms of ultimate organizational outcomes (e.g. Efficiency & productivity).

Recommendation #2: Unless a need is expressed by the organization, avoid offering external training that has already been done internally. We suggest conducting a needs assessment with employees to gauge whether training is needed rather than depending solely on manager suggestions.

Clark College

Clark College partnered with the ETI Group in order to provide comprehensive process improvement training for five defense industry manufacturers. The program was comprised of an 8-hour Excel for Six Sigma class (Green Belt), 128-hour Black Belt class, and a 10 hour train the trainer program. Each of the five participating organizations sent 3-5 employees to participate in the training and certificates were awarded to participants who successfully completed each segment of the program.

For the external evaluation, PRE was only able to connect with three of the five organizations that participated in the training. Throughout our interviews with the three companies who did participate in the interviews, we heard that the black belt training was very difficult and many people in the program did not pass or receive a certificate. This may be a potential reason for the lack of response from the two nonresponsive organizations. Employees were interviewed at InFocus, Peco and Selmet and data were gathered with regard to reactions, knowledge, behavior, and results of the training. The majority of these employees participated in all three portions of the training. Participants also identified Process Improvement Project, in which employees applied skills learned during the course to a project of their choice back on the job. The project allowed them to implement their new skills and to improve a process in their workplace.

The results below present the specific reactions and knowledge gained in the Excel for Six Sigma and black belt training and then summarizes the overall level three and level four data from the process improvement projects and other work applications within the organization.

Excel for Six Sigma

The Excel for Six Sigma course was a hands on program designed to equip the trainees with the skills necessary to use the MS Excel Analysis Toolpak add-in for statistical analysis. By the end of the 8 hour class, participants were expected to be able to use MS Excel to create and modify line and column charts and to use MS Excel to create and modify simple cell formulas.

Level 1: Reaction

At level one, employees offered positive feedback about the Excel for Six Sigma training. This feedback was related to the instructor or the course in general and included comments regarding the teaching materials, instructor and instruction methods, and the usefulness of the information provided in the training.

Instructor

- *The instructor had good examples, and displayed them on the screen so we could follow along.*
- *Overall he had a lot of good material. The spreadsheets already had formulas and that was handy. There was lots of repetition in class and that was good for making sure concepts were understood*
- *Russell's templates made it very obvious what we were trying to do...I liked his teaching method as well.*

Course in General

- *It was very well paced; it was a four-month course and it was nice that they inserted Excel right before Black Belt so we didn't forget it. There was a lot of stuff that I had no idea about for Excel... Without that intro I would have been lost.*
- *If you didn't know Excel really well, you really needed to know it for the class so it did have value.*
- *The training was well laid-out, so the concepts seemed to make sense as applied to the Black Belt course.*
- *I think I learned a lot from the Excel part.*
- *I think that the examples given and the templates were especially helpful. The tools helped us understand the statistical analysis tools.*

The employees also shared areas in which the Excel for Six Sigma portion of the training could have been improved. This feedback included comments about the course length and software programs used in the course. Furthermore, participants gave mixed reviews of the examples presented by the instructor and the instruction materials utilized.

- *We learned some statistics in Excel but I still do most of it in Minitab.*
- *I loved the examples and the situations we walked through, but it wasn't always clear why we were getting those examples. I could tell others may have been clueless as to why we were doing a certain equation.*
- *He gave examples up front and sometimes it was annoying, because I would have preferred for him to just let us do it. I would rather just try a task and then ask questions.*
- *It was a really hard course; probably one of the hardest I've ever taken. It wasn't long enough; it could have been longer.*
- *The PowerPoint training needed to be updated; a lot of things weren't correct anymore. It seemed like that happened a lot.*

Level 2: Knowledge

When asked what was the most important concept they learned in the Excel for Six Sigma training, many employees referenced their new knowledge of pivot tables. Additionally, some employees discussed the ability to use more software programs, skills for analyzing data, and proper techniques for solving problems.

- *It was helpful to learn the way Excel can link with JMP. We never had a course on JMP but it was done within the training; the way they integrated Excel and JMP and between the two you have 100% what you need. A lot of the formulas and short-cuts are useful for my day-to-day work and made my life easier.*
- *The use of pivot tables and how they are used to analyze data; that was a pretty general theme. We went over pivot tables for a long period of time. I could see how it could be applicable to data and how to visualize it.*
- *How to implement things with programs you can actually access today.*
- *The formula section. Square roots and cosines and the strength formulas. I had never done that in Excel. I had done Pivot Tables but not as extensively.*
- *To correctly analyze quality data. Also, learning the proper techniques depending on the kind of data you have or are trying to get. Reading the data correctly and interpreting it correctly.*

With regard to how the Excel for Six Sigma portion of the training helped prepare employees for the Black Belt training, participants had differing opinions. While some believed the first training helped prepare them for Black Belt through necessary instruction on Excel, others disagreed, noting that Black Belt focused on the use of JMP rather than Excel.

- *If you didn't have much experience in Excel, the training would be absolutely mandatory for the Black Belt training.*
- *Yes, it prepared me; I think it kind of went in two segments: learning basic stuff in Excel and then more difficult stuff for JMP.*
- *It didn't help prepare me for the Black Belt training because we used JMP instead of Excel. Maybe a small aspect of it was linked. You could use a table to reorganize data, but you could also do that in JMP.*

Black Belt

Six Sigma Black Belt program followed the classic six sigma Design, Measure, Analyze, Improve, and Control (DMAIC) process improvement cycle. Classroom training sessions were interspersed with periods of work on actual company-support process improvement projects. The Black Belt classes were held in a series of eight, two-day sessions between October 2011 and March 2012.

Level 1: Reaction

The second part of the training focused on Black Belt, to which some employees provided positive feedback regarding the instructor and the course in general include the class structure and the use of JMP.

Instructor

- *I thought Russ was a great instructor and related really well to all the industries. He had huge knowledge in casting and machining and manufacturing in general so that was all helpful.*
- *With all attendees being in the military industry, we have similar problems, so the instructor knowing that kind of stuff made the questions not so difficult to explain, which saved a lot of time. I think that would be true of any industry he taught in, because he was very open-minded. I think he did a good job of molding to companies.*
- *The trainer was a good explainer of the material. You could tell he had done it a lot, so he was good when he asked the questions. I thought it was good that other organizations were there. We got to hear some of their examples and application of the material.*
- *I really liked that he had the computers there and he made us do examples rather than us just listen to him talk. He also gave us the case studies to keep.*

Course in General

- *It was well organized. The documentation that was brought to the class was good (two books: one for Green Belt and one for Black Belt). The books were nice, because you could follow along and write in them.*
- *I'm glad we switched over to JMP. For me, I don't think it's going to be an issue but I'm not sure how well the training will be used by those who don't have JMP. How powerful you can get with it is a big thing. You can get lost doing one statistical analysis but when you know which application to use it's simple.*

Training participants also provided suggestions for ways in which the Black Belt portion of the training could be improved. Some suggested focusing less on JMP because the program is not used in their organizations. Additionally, employees provided negative feedback about the length of the program, the guidelines for the project, and the overall organization of the training

- *It was a continuation of Green Belt. It was too much of JMP since we don't use that here and I have to translate it to Minitab. Maybe it would have helped to let us do it on Minitab*
- *The class could have been more organized but other than that it was a good layout.*
- *It was too compressed. Even for people who work in it every day. The people who had already worked with JMP did fine. It was condensed and fast and then all of a sudden it was time for the test.*
- *When I think about the class, the only thing I thought was a negative was how much time we spent in class compared to applying what we were learning.*
- *JMP is interesting but we don't use it. It's so difficult to learn so that's what made it difficult for me. We got a temporary license and that has expired. It just happens that the instructor selected JMP to use to teach Black Belt.*
- *Getting the projects kicked off. At the very beginning it was suggested we do a project summary outline, but I would recommend that should be a commitment of companies involved. A lot of people go into it thinking of a project and then realized it's something they can't do. My recommendation would be to set stages where certain things should be completed at work.*

A common theme that surfaced during the interviews was related to the difficulty of the Black Belt training as illustrated in the quotes below. We heard from a few interviewees that there was a low passing rate in the Black Belt course.

- *It seemed like something you either understood or didn't, and you had to put time in to get it. But with Green Belt, if you were at class every day you would get it but with Black Belt you had to really pay attention in class.*
- *It (Black Belt) was good but it was way too fast. It was shorter than Green Belt section and required you to know JMP. You didn't go on to the Black Belt section if you didn't pass Green Belt.*

Level 2: Knowledge

Employees were asked to describe the most important concept they learned from the Black Belt training. Many referred to ways in which they plan to implement or have implemented what they learned in the training to their company.

- *Concentrating on areas of waste (e.g. time, energy, and resources). Being able to see what's not efficient and then to have the tools to improve it and also a plan in place to improve it.*
- *I thought that the design of experiments set-up was important. Also, it was important to learn sample size calculation. The basis of the statistical analysis process was well laid out and I could see it easily applied in our industry.*
- *Categorical data. In industrial engineering I see a lot of things I'm involved in and those are things I want to get projects going in. In this plant we're going to do it on the dryers for molding machines. I would like to do something with Black Belt with customers.*
- *Learning process capability. I've used it quite a few times. We need it here.*
- *Mainly the modeling. The different types of modeling and the best types of models to try first if you don't have something like JMP.*

Train the Trainer

The final component of Clark's training program was the train the trainer component. Each company sent three to five key employees to participate in a 10-hour train the trainer program in order to prepare them to become their companies' in house six sigma process improvement trainers. This program, combined with the skills and knowledge gained during the Black Belt program was designed to ensure post-grant sustainability of skill.

Level 1: Reaction

The employees interviewed reported that the last portion of the training was less useful and too idealistic for their everyday work, but some employees still gave positive feedback about the content of the training. Respondents noted that some aspects of what they learned could be transferred to their companies. The primary themes that emerged from the reactions were that employees felt they did not need the training for their job, they were unsure about the techniques presented, and that they enjoyed the training.

Did not need the training

- *We all left wondering why it was included in the six sigma. Maybe it was just our company, because we are all managers and have had it. It was nice and good info, but I didn't know why it was part of Black Belt. Unless it's for when you build your teams and give your team instruction*
- *This training could have been valuable if you do training in your job, which I don't do anymore. It just didn't apply to any of us. Otherwise, it was a really good class. It was the best Train the Trainer I've attended.*
- *I haven't actually done any training since I got that training but if I ever do training I will just use parts of what he taught.*

Did not buy into the training techniques presented

- *I thought the instruction was good. The class was interesting. The instructor did a lot of talking so it got boring. We did do some actual training. I think time will tell if his concepts are more right or if old-school ideas are more right.*
- *One thing I didn't like was that the training part taught us to be really extensive when you train, but I don't think anyone would actually do that. It didn't seem realistic. Maybe if you were training someone how to do something for 20 years but if you actually trained like that all you would do is train.*
- *It was alright. It's very idealistic in my opinion. It would be nice if training could be done in the way that was taught in the course but the reality is in the corporate environment in which you don't have time for the one-on-one.*

The training was good

- *I thought it was a good class and would suggest it for anyone who was going to teach someone. I do think I would use some aspects of it in my job.*
- *It went well. It was one that was pretty comfortable. We had a similar type of training here a couple of months before.*
- *It was useful. I had fun more so than I learned. As far as systemically breaking down how to train someone, it gave me insight into the importance of simplifying things for the trainee.*

Two employees also discussed ways in which the Train the Trainer portion could be improved. One suggested more focus on interpersonal skills and the other referred to the length of the training.

- *More focus on better interpersonal skills. It was easy for us to teach each other, but it would have maybe been better to help us with interpersonal stuff.*
- *Train the Trainer was two days but it could have been one. Just my own personal thing was that I didn't think it was as necessary. For me, this part of the training was just a refresher and it was over the course of two days spread out over four weeks, and I felt like the demonstration he had us put together was just for show rather than for applying it at work. We had to invent a 10-step process for training, which we shouldn't have done as it wasn't specific to the Black Belt program.*

Level 2: Knowledge

Participants were asked to describe the most important concept they learned during the Train the Trainer session. A reoccurring theme in many of their responses was the importance of repetition when training.

- *I learned to be repetitive when training. Also, it was useful to learn to make sure that the person you are training can do whatever you are training them on to completion; it defeats the purpose to leave someone before they understand what to do.*
- *Engraving the same concepts again and again. I think it would have been nice to look at how to Train the Trainer in Black Belt. It was more general about getting people to listen and to understand using eye contact and positioning and how to be effective. When you follow the steps and methodology in it it's really effective.*
- *Always have a meeting place and time. That is simple, but in the class there was a big emphasis in selecting a time and place and make it feel more important. I thought that was good.*
- *Don't combine too much material into each step; break it down into something the brain can take. Also, know exactly what you'll talk about when you start to train someone.*

Level 3: Behavior

Process Improvement Projects

An expected outcome of the six sigma process improvement training was that a black belt will apply what he or she has learned by leading or participating in an ongoing series of improvement projects prioritized by his or her organizations. The goal of these projects was to achieve outcomes such as enhanced customer satisfaction, reductions in cost, and improvements in productivity and efficiency.

During the interviews, employees were asked to discuss their Process Improvement Projects, which involved projects dealing with scrap reduction for two of the companies. Employees at the third company had issues implementing their project due to an inability to decide on a topic. Specific examples are described below.

- *We pour metal into a spinning mold and there are lots of issues of losing the metal...My project was on a family of parts; it's a large mold for us (374 pounds core), so we were getting 82 pounds of loss. Over a year, it was over \$400,000 of loss. My part of that was to give better tools to the operators to melt more precisely and not too much. If you don't pour enough you don't get the parts and that wouldn't be acceptable.*

- *We're actually going to do a couple of six sigma projects; the one we did for class is one in our molding department. The material dryers have issues; we have problems measuring and reporting scrap. Our plan is to get a better grasp on the scrap. It will help with process failures and help the process get better. It will give us more control. (A coworker then reiterated this plan and added that collecting data is an important step in determining their solution.)*
- *We never got into doing the project because the project itself kept changing. Halfway through the course the management team wanted to change it and then we didn't move forward. (A coworker echoed this statement by adding that management vetoed the first project due to the urgency of something else at the company.)*

With regard to how the Excel for Six Sigma training was used in the Process Improvement Project, employees noted that they use Excel to visually organize their data. Another employee reported that he did not use Excel for the project, but thought that the tricks learned during the course would eventually be useful. Finally, one employee commented that the Excel portion of the training was not useful because he already knew how to use the software program.

- *We currently have a database called Visual Manufacturing. The data goes in kind of unorganized and then you can pull it out and report. Those reports organize it in more of a column fashion. So, I use Excel to reorganize that data.*
- *It's kind of hard to say if what we use is from the training, but I'm sure I'll use some of the tricks.*
- *I haven't used the training, because it's stuff we already knew. We're using Excel but I didn't need the training to do so.*

Feedback about how employees are using the Black Belt training for Process Improvement Projects included the following:

- *We're using the JMP software to establish our current process. We haven't used it after our improvements but it gives us an idea of p values.*
- *Prior to the training we still solved problems and still went through steps. I would say I use more of the tools and more rigorously. I can't tell you how successful I've been with the tools but I can apply them.*
- *We're going to have to do some process capability on it; take measurements and run data.*

The last question about the Process Improvement Projects asked employees to discuss how they've used Train the Trainer in their project. The majority of employees reported that their use of this portion of the course has been limited.

- *I would have probably done it the same way, but I made sure the person I was training knew what to do before leaving them.*
- *I haven't used it well but I at least think about it when I do trainings. Sometimes the industry isn't like a classroom. Sometimes you're on the floor and you need to tell an employee what they're doing wrong. The classroom is too ideal.*
- *I'm probably not using Train the Trainer for Black Belt but more likely for how we teach people how to do manufacturing tasks.*
- *I don't think I will use it. My coworker might use it, but I don't think I will.*

Other Applications within the Organization

In addition to asking about process improvement projects, employees were asked to share other examples of ways in which they have used six sigma process improvement methodologies within their organization. Employees responded diversely, with most discussing the various ways in which they've used the methodologies. One reported that he has yet to utilize what was learned in the classroom.

- *It has mostly been on the project in which we use these trainings, but we have used Excel and JMP for other things. It would probably be on a project by project basis in which we would use Black Belt.*
- *I've used it for checking dimensions.*
- *There is a mask hose where we were having issues with the hardness of it, so I did a process capability on that.*
- *I used the Train the Trainer a few weeks ago to train someone. I prepared the night before and wrote out all the steps. The trainee and I have a lot of problems connecting when I try to teach him (I have been training him for 10 years) and using tools from the training helped.*
- *I haven't used it yet.*

When employees were asked if they experienced any barriers to applying the skills learned in the training to their workplace, many described a lack of time and their workload as obstacles. A few employees mentioned the lack of JMP software as a barrier to implementation and a couple of employees mentioned differing opinions about the six sigma processes from management within the organization.

Time as a barrier

- *My normal day-to-day work is a time barrier to implementing skills gained. I haven't run across any barriers as far as the company is concerned. I have access to as many people as I want; everyone is real supportive. Time and the scheduling of my own work that I have on top of this is a barrier.*
- *Just time barriers. The idea of Black Belt is to focus on a project. But we all have full-time jobs, so time is our biggest roadblock. We have the resources we need and some support from the organization (still get other tasks that keep us from projects). More time is needed.*
- *Workload. To implement a project is a barrier but we're getting real close to that. I think another thing was how long the class was. All of the classes together were 18 or 19 days total. I know it wasn't as spread out before (previous years), but we started in fall and ended in spring and fell behind at work every two weeks for a couple of months in a row. There has to be a happy medium where you do a segment and then try to implement something and then so on and so forth.*
- *Another barrier is that internally at our company there are different opinions on what Six Sigma should be. Some people think it should be a quick process; at some places I worked, Six Sigma meant saving \$100,000. But you can work all this time and not save money and then the project fails. So, we're trying to come away from stating a project that states we will save a certain amount of money.*
- *Time is the big crunch. Management would like to see it done but won't put the project before other things.*

- *Not having the software we were trained on. Time, resources and support from the organization. It's hard to have time especially with the move (the organization is moving to a new location). That's the biggest reason we haven't started the project.*

Level 4: Results for Entire Training Program

In order to understand the ultimate outcomes of the training, employees were asked to discuss how the trainings have impacted customer service, cost reduction, and led to improved efficiency within the organization. A discussion that took place within each company was that there had not been enough time to actually see changes in these outcomes as a result of the training which is consistent with training research. Thus, this portion of the interview was focused more on speculation about how the training may lead to these outcomes over time.

Customer Service

Employees were asked to discuss how the trainings have improved customer service within the organization. They speculated about how the training could improve their ability to meet customer needs through reducing prices, meeting deadlines, sharing a common language with customers, and training more people who work directly with customers.

- *Ideally, when it's done and we have certification, we will be able to train more people to give better customer service.*
- *If we're able to reduce our prices, I'm sure that would help with customer service. Without a doubt it reduces time and labor we need for finished product. We're using 70% on the wax portion and if we can reduce that it will have an impact on lead time to customers.*
- *I think the trainings will help improve customer service. I can say that so strongly because our other customers use the same concepts. The words we were taught and how to use them allows more dialog with people and you will feel more comfortably understanding what their issues are.*
- *If we have a stable process then the customer will get their parts on time. We have had issues where we've had to remake parts, so not doing that will help customers get deliveries faster. We can also make prices go down if we're more efficient.*

Cost Reduction

Employees were also asked explain how they have used Six Sigma tools and methods to reduce costs within their organization. Some participants responded by giving specific examples of how they expect to reduce costs.

- *Yes, with the justification for each process there would be a cost saving for each process. We've done smaller projects since the training where we've already seen cost savings.*
- *I've seen examples of it within our project; I expect there to be a cost reduction. Overall, we have made huge strides in cost reduction. I know that Six Sigma will reduce costs.*
- *Yes, kind of like with being able to accurately forecast the cost of warranties.*

Improve Efficiency

When asked how they've used Six Sigma tools to improve productivity and efficiency, participants responded diversely. Comments included the following:

- *Our project is looking at dimensional variation and our goal is to reduce variation, which makes a better product, which creates less re-work cycles.*
- *We're in the process of making improvements to efficiency with our project.*

- *I think I could see as far as productivity goes if we did things in a systematic way rather than fixing problems before they come up then you don't have to focus on it anymore.*

With regard to how the training has helped make improvements to processes that impact product quality, multiple employees referred to specific projects on which their company is working.

- *The only thing we're using it for right now is for the wax molds, but I think we can use it for different things.*
- *Designed experiments have been set up by some individuals that weren't in the class but work with one of the three of us who were. The experiments had to do with variability in the torque plates.*

Supervisor Feedback

Due to the fact that the supervisors did not attend the trainings offered by Clark College, a set of general interview questions were asked for each level of evaluation. These questions targeted the entire training including excel for Six Sigma, Black Belt, and Train the Trainer.

Level 1: Reaction

Supervisors were first asked if they were satisfied with the trainings offered by Clark College. For the most part, supervisor responses mirrored those of employees. However, one supervisor stated he has seen minimal effect from the training, which contrasted from what his employees stated previously.

- *The feedback I got was that the classes were beneficial and useful; some more so than others. It was a significant commitment of time. To date, I can't see a difference in how they do their work, but there may be a reason for that. We're looking for a project where we can see what the effects are but as of now there is minimal effect. I only heard them talk about the Six Sigma Black Belt training.*
- *I have heard feedback on the trainings. For the whole package, I heard just positive feedback. The trainer was great – very well prepared. The training was very relevant; the Black Belt training was the most relevant.*
- *Yes, one guy did very well. One guy passed Green Belt and didn't pass Black Belt. He was having a hard time with the concepts and asked instructors if he could go through again. The third guy didn't finish the second half of the course. It is all about understanding the Six Sigma process and how it can be used in the organization. It's a great class; I took it from Russell in previous years.*

Level 2: Knowledge

Supervisors were also asked about the most important concept learned by their employees in the training. One supervisor responded generally, while another mentioned specific sections of the training.

- *Organized thinking. How do you organize process and data to understand what you have and process issues.*
- *Speaking about the Black Belt training: There has been a skill change. The trainings provided a common set of tools; there's a lot of ways to get to the end result. In meetings we were*

explaining the methodology rather than the content. Now, the biggest benefit is that I can talk about different tools and they know what I'm talking about.

- *In Train the Trainer, the most important thing they learned was work flow and how to organize their thoughts. The training wasn't the most relevant for day-to-day use, but helped them come up with work instructions and broadened their horizons there.*

Level 3: Behavior

Two supervisors gave responses with regard to ways in which employees have used their training on the job, see below for comments.

- *I have one guy working on a project where he is looking on field failure rate information. We will re-evaluate how we calculated field failure rates based on what he learned.*
- *They're using it, but it's not really institutionalized yet. I actually have an internal Green Belt training that we're doing right now, and these guys (who went to the training) will be the go-to guys that will be running a lot of those projects, so I know they're using the methodologies now.*

When supervisors were asked if they had seen any barriers to implementing skills from the training on the job, the two who responded had very different opinions. One stated that there are no barriers, while the other listed multiple obstacles that his employees have faced.

- *There are no barriers that I know of that are preventing them from using what they learned.*
- *We have a lot of things that are driving for our attention (e.g. the company is moving buildings). I think, which is often the case, when you're in the training you are around subject matter experts but then when you come back to the work setting there are barriers to implementing change because it's an old pattern and hard to avoid getting back into that same rut. There is idealism of the classes, but I'm not very familiar with Six Sigma so I can't support them. Maybe in the future we should have the training be vertical and horizontal. With the amount of time that was invested, I was disappointed that there wasn't more of a groundwork for bringing back what they learned to the organization. I would have preferred if the trainings could have made the supervisor aware of what they are learning.*

Level 4: Results

Supervisors were also asked how they see the training affecting their organization's ability to make improvements to productivity and efficiency. The responses included the following:

- *It has the potential to do so. I'm looking forward to seeing how it all turns out. We're still trying to pick a process improvement project. I think we figured one out and will allocate it. The project we're looking at is putting a controlled process around our dryers.*
- *I haven't gotten feedback from them that said the trainings weren't worth their time, so I'm hoping that they will at some point transfer what they learned in the trainings.*
- *Too early to tell but in general more knowledge, better understanding, different thought process. Will grow over time.*
- *We've had a common problem with variability in our process. One person was able to apply what he learned and that was a significant reduction in time used...They are also much more efficient at making sure the measurement is proper for data collection, when to use the tools, how to use them, and charting options.*

Finally, supervisors were asked if there was anything else they wanted to add about the trainings. One supervisor shared suggestions a better location, while another demonstrated skepticism about the training.

- *It was a significant investment of time, and I would be hesitant in the future of investing that amount of time without seeing some positive benefit.*

Summary and Recommendations

The results of the training evaluation for Clark College showed that the Black Belt portion of the training received the most positive feedback from employees. Although some mentioned that it was a difficult class and they don't have the software to implement some of the techniques, employees reported that they are using the knowledge from the course on the job and anticipate applying it on future projects as well. The process improvement projects did not appear to be a huge success in two of the three organizations due to barriers such as time and resources. The Excel for Six Sigma training received positive feedback as well but employees referred to it as laying the ground work for Black Belt rather than being directly applied to their work. The train the trainer session received the least positive feedback from employees as they felt they did not have a use for it in their job.

Recommendation #1: It appears that employees did not understand how the train the trainer session was related to the rest of the training. We would suggest working to clarify this connection for future participants.

Recommendation #2: Although the Black Belt Training was well received, several employees mentioned that they do not use JMP in their organization and it would have been useful to learn the techniques through another application (e.g., Minitab). We encourage the organizations and trainers to brainstorm ways to make the program accessible to employees if they are going to invest in the training or to also include training on other applications.

Recommendation #3: Interviewees made several comments about the difficulty in passing the Black Belt course and suggested that this had led to decreased motivation to conduct process improvement projects. For purposes of workforce development, we would suggest considering the need for the program to be certification based. A less intense atmosphere may warrant a higher transfer of training.

Recommendation #4: When asked about barriers to implementation, we heard from both employees and supervisors that it would be helpful to have supervisors attend the training as well. We suggest inviting supervisors to participate with their employee in order to create buy-in for six sigma processes.

Clackamas Community College

Employees from five organizations participated in the Lean Leadership Academy at Clackamas Community College which consisted of three main parts: classroom instruction on Lean Manufacturing, Kaizen events, and the completion of a capstone project. Pacific Research and Evaluation visited each of the organizations and conducted interviews with 3-4 employees who participated in the training and one supervisor who either participated in the training or supervises an employee who participated. The organizations included: Benchmade, GrovTec, Machine Sciences, Sunstone, and Timbercon. Additionally, a small proportion of supervisors attended a mentor training.

This section of the report will summarize data from levels one through three separately for each component of the Lean Leadership Academy followed by an overall summary level four results for the entire Lean Leadership Academy.

Lean Classroom Instruction

Level 1: Reactions

The Lean Classroom Instruction received mostly positive feedback from participants. Almost all interviewees offered favorable comments about the instructor and instruction style. A majority of the employees also mentioned that they appreciated the opportunity to learn from participants from other organizations, as well as the use of group work during the training. Employees also spoke favorably about the opportunity to gain knowledge about lean manufacturing and specific skills that they have been able to implement in their workplace.

- *The teacher was good, was very clear on what he was talking about. I liked just about the whole thing because I learned a lot. Before I didn't understand why people did things a certain way here. Now I understand and I am way more organized, which saves time. I have corrected lots of stuff -- the class opened up my eyes to many safety issues, how to eliminate waste, etc.*
- *I like that it was a lot of hands-on training instead of lecturing. Getting put in groups with people from other companies was a valuable chance to learn from them and it opened your eyes to different ways of doing things.*
- *The instructors were well informed; very educated about the topic.*
- *The teachers were phenomenal and kept it interesting. I absolutely enjoyed having people from other organizations in the class.*

With regard to what could have been improved about the Lean Classroom Instruction, many participants reported that the class moved too quickly and that more time was needed to absorb the information presented. A few employees also specified that they would have appreciated more organization and more straightforward information about expectations and deadlines for assignments.

- *In the classroom we needed more time. I felt a little overwhelmed by all the information in such a short amount of time.*
- *As for the subject matter itself— it was too much information in not enough time (1/2 day). It seemed rushed, specifically during the leadership sessions.*
- *Giving out a syllabus at the beginning would have been helpful.*

Level 2: Knowledge

When asked about the most important concept learned during the Lean Classroom Instruction portion of the training, employees referred to the leadership skills, the 5S rules, value stream mapping, and the waste-reduction process.

- *The most important thing I learned was eliminating waste, through travel time especially. I saved time by creating a station at each sharpening assembly line, which made them much more efficient.*
- *The basic 5S rules were the most important thing that I learned. The key things that go into 5S are the main things that you need in a company. Everything from making processes shorter to what you need to look for in a good lead, how to get more organized, get rid of things we don't need.*
- *The overview of general leadership and the training techniques they offered were helpful (Mentor Training). How to train people was most important to me because that's my job. I'm trying to take a more lean approach.*

Level 3: Behavior

Employees were also asked to share behavioral examples of how they have applied Lean Classroom Instruction knowledge within their organization. Participants noted that as a result of the course they have organized tools, utilized visual management techniques, created smart goals, and created labeling systems.

- *The work place areas are now labeled. We made a specific place for each tool and solved safety issues (like knives hitting people's legs).*
- *I made tables with wheels and a peg board in order to organize tools and keep them available at all times. I used visual management – I made a card with daily goals for each person, where they can record what they have done each day. I labeled everything and keep close track of what each worker accomplishes so that I can show them their improvement at review time.*
- *Visual management tools; signs are up now regarding where things go and metrics are posted. I've used training information they gave us regarding clarifying with employees after giving instructions to make sure they are understanding them; I do that all the time now.*

Finally, with regard to the Lean Classroom Instruction, participants were asked if they have experienced any barriers to implementing the skills learned during the training in their workplace. A majority of those who responded affirmatively reported that resistance to change was the biggest obstacle for implementing lean techniques at work. Some of the participants who mentioned change as a barrier also discussed ways in which they solved the problem as summarized below.

- *People who have been here a long time are resistant to change; we learned about that and it was one of our better classes. One of the biggest hurdles is buy-in.*
- *Change is hard for everybody. One of the things we learned pertaining to our capstone is that we changed too fast. That would be the biggest barrier; if you move too fast people aren't going to embrace it. I gave a timeline and gave everyone a chance to change and only did subtle changes.*

Kaizen Events

Level 1: Reaction

Overall, employees gave favorable reviews of the Kaizen Events. The positive comments focused mainly on the opportunity to learn from how other companies operate and to implement concepts learned in the classroom.

- *What I liked most about the on-site kaizen event was that we got to start 5S in our soft goods area, and got lots of help. Instead of us trying to do it slowly ourselves, we got a whole day set aside to get the project started.*
- *I liked the Kaizen events because you got to see how other companies run. We can use their ideas here. You can also get feedback on what does and does not work in other companies from other participants.*
- *We were well prepared, so it went smoothly. In some of the other companies the Kaizen events were able to have a really big impact. It was good to learn that other companies were struggling as well, and how to help fix the problems.*
- *The Kaizen events went pretty well – they were one of the more beneficial parts of the class. It was good to not only talk about philosophies, but to also see them in action.*

Employees also noted some areas in which the Kaizen Events could be improved. One employee reported that it was hard for him/her to hear and suggested the inclusion of headsets in the future. A couple of other employees made negative comments about the group distributions.

- *There were a lot of 5S activities, which were too repetitive. People needed to be able to spend time in all groups and not get stuck in the same group every time (e.g., 5S).*
- *There should have been more organization in deciding where to place people for the events so that the activities felt more meaningful.*

Level 2: Knowledge

When asked about the most important concept learned at the Kaizen Events, employees responded diversely but with some overlap on the topics of value stream mapping, organization, and the importance of being open to change. Some of their responses included the following:

- *I learned to be open-minded and to take information from others. Be ready for change.*
- *The most important thing I learned was waste elimination – saving money, being more organized, knowing where things are so you don't waste time looking for them.*
- *The most important thing I learned was that everything has a place and that you need to keep it lean and get rid of junk.*
- *The most important thing I learned was that they have the same problems at other companies that we do here, and it's good to get a second opinion on how to do things.*
- *Regardless of the seniority of an individual, each person can add value.*

- *The most important thing I learned was the value stream mapping, because I had not had any exposure to it before.*

Level 3: Behavior

Employees were also asked to provide examples of how they have applied knowledge gained during the Kaizen Events. Some of their responses included the following:

- *The floor markings were one of the big things we brought back. The single piece flow, which we are not very good at, is another thing I took away from it.*
- *We brought back and implemented safety ideas from the Kaizen events. We used visual management at the work stations and on lines to make everything more clear.*
- *We saw the plush floor mats in another organization and ordered those for the people on the line here because they stand on cement all day long and it's really uncomfortable. Having a board at each station with every tool is something else we are working on implementing.*
- *We observed a visual representation for the "first responders" list at another organization and have now created one here. Now new people can put names to faces and will be able to find the right people quickly in an emergency.*

Lastly, participants were asked if they have experienced any barriers to implementing the skills learned during the Kaizen Events. One employee reported experiencing a barrier in people's attitude towards change.

- *It can be difficult to get others on board when you are trying to audit another department. People aren't always open to change.*

Capstone Project

Level 1: Reaction

Employees had very positive feedback about the Capstone Project portion of the training and discussed their project and the usefulness of it in detail.

- *Ours was awesome. It's still in place and we're still working on it. It's to reduce our over-build. It was a really fun project and a lot of people are involved in it. If it works we will save \$2 million and that's huge. It just went really well.*
- *For our capstone project we revamped the soft goods department. Everything was out of order and not in a single flow. People had to make triple the amounts of steps that they actually needed to. We moved all of the machines and tables into a single flow, re-labeled everything, and made specific sections for each step of the process. We also installed lights because the dye cutter was using a flash light before.*
- *I made value stream diagrams and charts that showed significant results in reduced labor (by about 20%).*

Many of the participants, even those who made positive remarks about the Capstone Project, mentioned that this portion of the training could have been improved by better communication regarding expectations and deadlines for assignments.

- *It was confusing. Instructions weren't specific enough.*

- *We didn't know what was expected of us for the project. We didn't understand when assignments were supposed to be turned in or graded. Teachers told us different things, and then we were scrambling at the end because the due date changed. But other than that, I thought that the project was great.*
- *The capstone project could have been improved by better communication of expectations. I didn't even know that it was getting graded until after, so obviously I did not know the grading criteria.*

Level 2: Knowledge

Participants also had varied responses to what they believe to be the most important concept they learned from the Capstone Project. The following include a few of their responses:

- *Realizing that our problems are not manufacturing problems, but assembly problems. Knowing when to check on the assembler and what to do when there is a problem is something I learned.*
- *Just going through the process was a good experience, but also seeing folks from the production floor, and learning to communicate better with others was very useful.*
- *How well my team (leadership) can work together to make something work.*
- *Probably that we have to take baby steps; not to move so fast. Just because everyone says that they are ready to implement doesn't mean they are; we need documentation that the training is done.*

Level 3: Behavior

Three employees shared the following examples of how they applied Lean Classroom knowledge into their Capstone Project:

- *Visual training concept had been applied; we do more of a visual training session with the finishing (deburring) department; having the pictures in addition to the written instructions is very helpful.*
- *I have applied safety, shadow board, signs (visual management stuff from the classroom) to the job as part of my capstone project. It gave me a different outlook on the work space.*
- *One of the things I did for my capstone was take three different forms, each that was based on the individual department utilizing it, and put them all into a one page audit checklist that could be used by all departments. I used information from class and my own research to make the form more efficient.*

Level 4: Results for Entire Lean Leadership Academy

Level four evaluation questions were asked with all component of the Lean Leadership Academy in mind. Employees were asked if the Lean Leadership Academy has increased their ability to recognize and propose solutions to manufacturing problems. Participants agreed that the training had a positive impact in this area because it has raised their awareness of problems and has resulted in employees making the necessary changes. Some participants described specifically areas in which they have recognized and subsequently solved problems. Some of their responses include the following:

- *Value stream gives me the tools to see what we are doing wrong and to fix the problems – I try to use the ideas constantly.*
- *Definitely. We went to more visual containers in soft goods department and use lots more labeling. A lot of time has been saved for certain employees. We still have a longway to go but there have definitely been improvements. We now know better how to deal with a mess.*
- *Yes. Looking back it seems common sense, but we wouldn't have done any of that stuff if we hadn't learned about it in class. I can supervise people easier because I can see what people are doing with their time more specifically.*

When asked if the training has led to improved efficiency in production and/or development at the workplace, many employees stated definitively that it has. Some described explicitly how the trainings have helped them improve in this area. The most common themes discussed included the reduction of travel time/steps and the reduction of scrap.

- *Training has definitely led to improved efficiency here. You don't have to walk around looking for tools.*
- *Yes, I know it has. Just by taking those steps out it has saved 2.5 hours to get the day's shipments done. We used to get done at 4:00 but now we get done at around 2:00. It has had an impact on our scrap (scrap rate went down) and we have time to do more thorough inspections.*
- *We have reduced travel time, the expense of sharpening belts has gone way down because I regulate how long they use the belts for (I have them use them for longer). Our scrap level has decreased a lot since I did a training on how to reduce scrap. I made a card with instructions for how to use a certain tool (I turned a 14 page manual into a 1 page instruction sheet) and people don't have to ask for help with that tool anymore.*
- *We reduced clean up time from 15 to 5 minutes, because it is so much more organized now. There used to be 5,000 unsharpened knives on the floor at any one time, waiting to be sharpened, and now there are no more than 100 on the floor each night. Tools that we use from the training include: 6S, the shadow box, and peg boards.*

Finally, participants were asked if there was anything else they wanted to mention about the training. Of those who opted to answer this question, many reiterated responses they had made previously. Several employees also stated that they would recommend this course to others and commented on how the course allowed them to learn.

- *I would absolutely recommend the training to someone else in an environment like this.*
- *I think that the training was a wonderful opportunity – we learned from each session. The books were interesting and the stories related well to work. The role playing and games in class were fun. I learned lots.*
- *I would recommend the training to anyone who has to make decisions/make things run. I learned a ton and realized that I have a ton more to learn. It makes a difference in how you react to situations – you have to do a lot of self-evaluation. We enjoyed the class. It was very stimulating, not boring.*

Supervisor Feedback

In addition to their experience with the three part training, supervisors were asked about their level of satisfaction with the program. Supervisors were asked to evaluate the impact the

trainings have had on their colleagues, as well as to give feedback regarding the half-day mentor training they attended.

The supervisors were asked if they were satisfied with the trainings offered by Clackamas Community College. Some supervisors discussed the mentor training they attended and some referred to the training their employees attended. The supervisors provided positive feedback for both sets of the trainings.

- *It was a great introduction to lean concepts and tools. The mentor class in the beginning covered a lot about communication styles, personality types, and how different personalities communicate. It was eye-opening because you realize what different personalities value, and that this can create conflict.*
- *It was good information. We talked a lot about different leadership styles, rules for what needs to be done with the participants, and our role as the mentor or mentee. I liked it. It also helped me apply the knowledge to the production floor.*

When asked for suggestions for improvements that could be made in the trainings, the supervisors echoed the statements of other employees by discussing the misunderstanding around deadlines and expectations, as well as the brief time-frame for the training.

- *There wasn't enough time to retain all of the information. There was a lot of information for half-day training.*
- *I do know there was some frustration about some deadlines and communications. (The supervisor was referring to comments made by employees who attended the three-part training.)*

The supervisors were also asked how the trainings differed from previous trainings their employees had participated in within the organization. Only one supervisor responded to this question, and in his/her response reiterated previous statements about the short amount of time allotted for the trainings.

- *The only difference between my training and this one is that mine was twice as long, so you had more time to think and process. I prefer the whole day vs. the half day set-up.*

Supervisors were asked to describe what they thought was the most important aspect of each of the three parts of the employee training. One supervisor discussed the ability to apply tools in order to create stability.

- *The importance of creating stability – how they can apply the tools learned to create stability. Without coaching they had familiarity with tools, but lack of understanding of how to use them. Now they know when to use the tool and why you use that specific one.*

Two supervisors responded to the question regarding the most important concept learned by employees during the Kaizen Events.

- *The most powerful part is that it was hands-on and having people who are passionate about it put their heart and soul into it.*
- *The leads really enjoyed the events at the other companies because it gave them a new perspective. Seeing a new environment helped them think outside the box here.*

One supervisor gave input on what he/she believed to be the most important concept learned by employees from the Capstone Project.

- *I was really proud of my team. They took it upon themselves to document everything. At the board meeting where they presented, it was neat to for the president and CEO to see what they have been working on and specifically the huge improvements that are visible. Everyone was very complimentary of the efforts that his team had put in.*

Supervisors discussed what they believed to be the most important concept learned during the mentor training. The majority of their comments referred to the skills presented for working with mentees.

- *The most important thing I learned was that different personalities can create such a different dynamic – people have a bias towards their own type of personality. Once people are able to recognize this, conflicts can be resolved. The coaching conversations with the leads were something else important. We learned how to apply tools we learned in order to coach them (the mentees) when they got stuck or thought that something was stupid.*
- *The most important thing that I learned were the ground rules for working with our mentee -- more specifically talking about what they learned and how to implement that knowledge. Also, process improvement.*

Supervisors were asked to give examples of how their employees have used knowledge learned during the training on the job. Because each of the employees they supervised had a different role at their respective company, the supervisors' responses varied greatly.

- *She took the whole supply cabinet and organized that. She put together a new process for incoming office supplies. She supports HR and helps streamline some of those forms by putting them on the Internet.*
- *There is often a problem with the intent behind 6S – it turns into a housekeeping/labeling activity that has nothing to do with elimination of waste or efficiency. We previously had to scrap all of the old 6s activities that were in place here because they were useless. My leads this year were able to re-identify where the lean tools should be used. They realized that audits and scores were not important, but using the tools to solve problems was very important.*
- *After the Capstone Project, one guy on one of the lines took the initiative to use tools from the class to reduce waste and production time.*

The supervisors were asked how the training has affected their organization's ability to provide cost-effective products in a time efficient manner. One supervisor responded by stating:

- *The training does seem to be affecting efficiency. We are trying to eliminate waste by looking at the current process and future processes.*

Furthermore, the supervisors were asked to give an example of something their employees can do more efficiently in their jobs because of the training. The supervisor who responded said:

- *Lead time has been reduced significantly, from six days of assembly to 2.5 days. Our scrap rate is 1/6 of what it was at the beginning of the training. Inventory levels have been reduced, and teams are better cross-trained.*

Finally, the supervisors were asked if there was anything else they wanted to report about the trainings. In response to this question, the supervisors made favorable comments about the trainings. One supervisor also gave constructive feedback about how the training could be improved with more focus on training the management team.

- *I am very proud of my team. This training made them feel much more valued and got them engaged and excited, which has cascaded down – they have shared a lot with their teams. The entire department is functioning as a more cohesive unit. It was a great experience.*
- *The mentee's capstone projects went well. Their development was clear and good, and they are implementing their new skills on the floor. More people should be trained; I would recommend the training to others.*
- *They are doing the training again so hopefully we can send more people and keep it alive. We are constantly improving.*
- *There is a real competitive advantage to this. We saved thousands of dollars just on one project that was addressed with a Capstone Project. However, another piece needs to be integrated into the training for the management team.*

Summary and Recommendations

The feedback received from employees who participated in the Lean Leadership Academy was overwhelmingly positive. Through the interviews, it was consistently apparent that employees not only gained knowledge of lean concepts but that they have implemented them in their workplace. The Kaizen events were the most popular aspect of the Lean Leadership Academy. Employees reported that they enjoyed working with other organizations and were able to generate ideas for lean processes that they can bring back to their own workplaces. Employees offered specific examples of how the training has less to efficiency outcomes in terms of hours saved and reduced scrap.

Recommendation #1: Employees mentioned the need for improved communication around expectations for the Capstone project. We suggest creating a communication that more clearly outlines these expectations (including dates) in future trainings.

Recommendation #2: With regard to the Kaizen events, a common theme was project repetition. For example, one person may have been assigned to a 5S task at every Kaizen event. We suggest creating a system to ensure that trainees are gaining experience in varying areas of lean production.

Recommendation #3: It was not apparent through our interviews that there were clear mentor-mentee pairings at each organization. We would suggest clarifying these roles for future trainings.

Recommendation #4: It was clear from our interviews that the Kaizen events were the most impactful part of this training and we strongly recommend continuing these in future trainings.