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DIGITIZING AMERICAN MANUFACTURING

DMDII FINAL PROJECT REPORT

FactBoard: Real-Time Data-Driven Visual Decision Support System for the Factory Floor

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I. EXECUTIVE SUMMARY

FactBoard application is a shop floor decision support system that converts thousands of existing real-time transactional data inputs from logistics and production systems into a collection of visual dashboards. Through industry implementation and test demos, **FactBoard** has shown the potential to improve productivity, to aid manufacturing operations in decision making, and provide new product markets for software companies.

FactBoard provides visualization capabilities of the shop floor environment with real time operation data. **FactBoard**'s decision support engine communicates much needed real-time information of plant status to enable effective factory-wide decision-making. The Dashboard module visualizes the current state and historical performance of the factory including cycle times and quality issues. The Sequencer module provides real time communication of schedule changes across production lines. Lastly, the Inventory Reconciler enables inventory modeling and predicted shortages which are communicated to the Sequencer. These three modules allows for early identification of possible problems, and enables decision makers to best redirect resources to minimize the impact of unexpected problems across the plant and ultimately reduce costly mistakes.

Early implementation of the tool is promising. Pilot studies of similar concepts deployed in isolated environments have demonstrated 98% reductions in line stoppages due to logistics issues, 86% reductions in on-site inventory, and 50% reductions in indirect material handling labor, all while simultaneously increasing productive throughput by nearly 10%. All of this contributes to reducing operational costs and increasing the ability of the factory and its supply chain to respond faster to changes in requirements.

FactBoard can bring the most value to markets with complex multi-line assemblies or complex supply chains. The light, web-based tool enables a high level digital network that can communicate problems between otherwise separate manufacturing lines. **FactBoard** makes information sharing easy whether between internal lines or between external suppliers. An additional future market could include extending the software to suppliers. The company can benefit from the digital network with real-time status of critical components. Real-time problems can easily be communicated which enables proactive solutions. This could be the future of supplier management.

The implementation of **FactBoard** requires only existing transactional data of manufacturing processes, access to a server, and a modern Windows computing system. **FactBoard** avoids the major cost of implementing new data collection capabilities by utilizing current capabilities to power the tool,

Our team consists of two large-scale vehicle-manufacturing firms (Boeing and Deere), along with two SME commercial manufacturing software development firms (Proplanner and FactoryRight) and a major engineering university (Iowa State University). Over the course of this project, **FactBoard** has been developed and modified to meet the needs of these large-scale manufacturers. During early implementation at our industry partners, **FactBoard** has been well received and identified as a tool that could add value to their operations.

II. PROJECT REVIEW

- **Problem Background and Technological Challenges**

Assembly and fabrication factories are universally challenged with the need to continually reduce costs and improve efficiency while simultaneously becoming increasingly flexible to meet ever-changing customer demand. By providing increased product options and allowing customers to lock in final order specifications close to actual production launch, companies provide customers additional value and improved service. For manufacturing, however, these increases in flexibility can lead to dynamic and frequent design configuration changes. It is often the case that operations on the production shop floor are using manufacturing Bills of Material (mBOMs) that were updated yesterday while receiving materials that were ordered by Enterprise Resource Planning (ERP) systems 30 or more days earlier.

Additional challenges come from variation with inbound material delivery, inconsistent material quality, shop floor equipment problems, and staffing issues. Collectively, these challenges form a landscape that shop floor coordinators must navigate to efficiently produce products every day. Discrepancies between the materials consumed on the shop floor for a customer order compared to the materials purchased for that specific customer order are costly to reconcile, track, and reduce for management, logistics, accounting, and the external supply base. In one case, it has been observed by one of the manufacturing team members that these discrepancies have driven increases in raw and work-in-process inventory levels of nearly $2.5 million on individual product lines. It is estimated that the potential reduction opportunity across an entire supply chain would be many times greater.

The ability to visualize and quickly react to the variance between actual shop floor production activity and the plans developed through manufacturing ERP systems is a challenge that many manufacturers face. To address this challenge, manufacturing personnel need access to real-time information in a mobile format that is meaningful and actionable. Although large volumes of real-time data are continuously being generated and stored, with significant information technology costs, the ability to turn this data into actionable information in real-time is lacking. In fact, in many complex production environments, such as in the manufacture of tractors, airplanes, excavators, and large trucks, the amount of available data is overwhelming. To be useful, it must be aggregated in a meaningful way and presented to personnel on the shop floor with realistic options for subsequent action.

- **Project Goal**

The goal of this project was to develop a software system, called FactBoard, which could process available data and convert it into actionable information in real time. We aimed to move away from a "sense and respond" environment to one where we provide "predictive" information at all levels of the manufacturing supply chain. Rather than searching through data to continually try to answer the question "What happened?", we want the system to automatically provide detail as to "What happened and why?" and allow us to model potential scenarios to understand "What might happen?" based on various response actions we could take. The tool developed in this project has the potential for broad application across manufacturing operations and can be tailored to meet the requirements of a wide range of decision makers.

The initial FactBoard proposal, as illustrated in Figure 1, was to combine real-time data and statistical models with analytical techniques to support business decision-making activities. By developing effective, mobile, and easy-to-deploy decision support technology, manufacturing enterprises of all sizes could increase their throughput and profitability providing a significant business advantage.

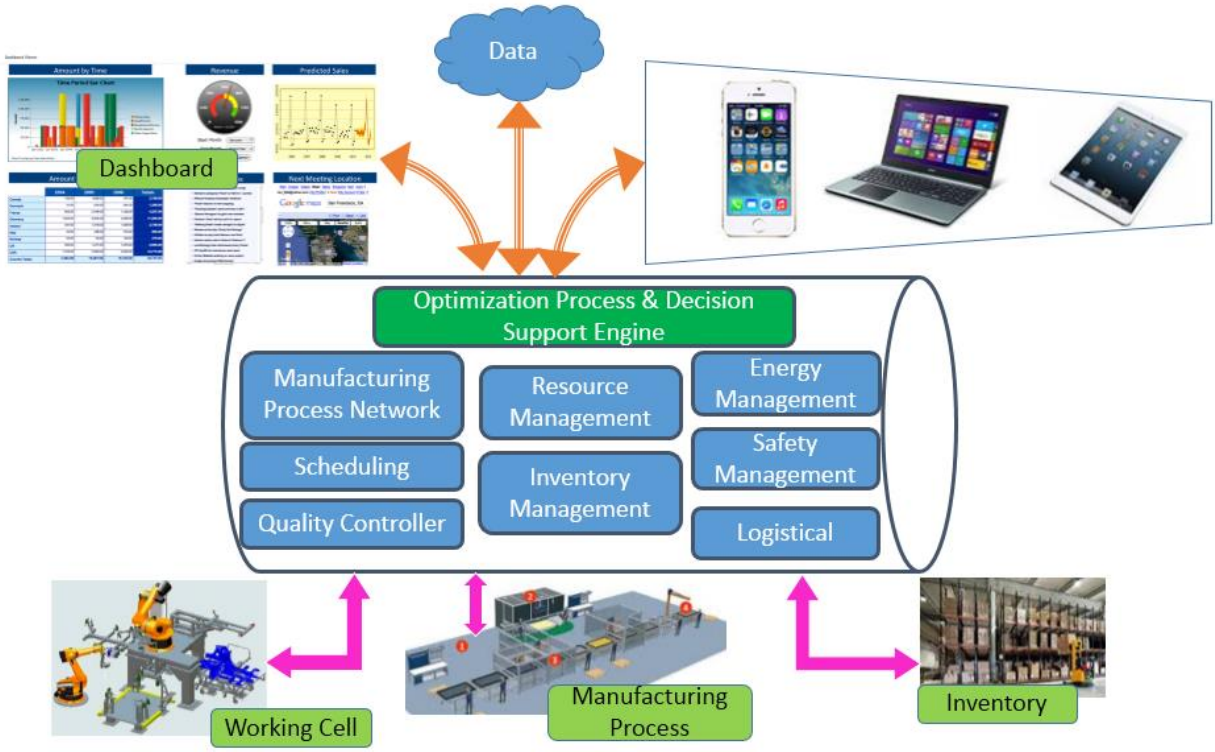

Figure 1. Overall View of the Proposed FactBoard Decision Support System

- **Technical Issues Addressed**

This project filled three technology gaps between real world data availability and decision making needs:

1. The disparities between existing real time transactional data collected from the shop floor and operational plans from ERP and PLM systems that define what should be happening. Particular issues include resolving differences between naming conventions, addressing holes in transactional data and handling temporal (time based) issues. This analytical mapping of "What is" vs "What should be" involves a level of analysis and problem solving not present in most manufacturing, or even software development, firms. On the other hand, the practical realities of the shop floor present substantial challenges to academics that require an in-depth understanding and team-based solution.
2. The gap between the results of the data collection and mapping phase just described and the needs of decision-makers. This gap can be bridged by defining a generalized series of analytical techniques to aggregate, analyze and probabilistically determine ideal outcomes for several unique personas. To enable globally optimal decisions, a set of key interactions between these personas must also be documented and developed.
3. The need for usable information displays, geared toward decision objectives, for major job personas that are critical to the successful coordination of production and logistics, such that those individuals achieve an increased efficiency and accuracy in their decision making.

- **Methodology of Software Development**

The original objective of the Factboard project was to enhance shop floor communications across managers and workers in an effort to increase production throughput, logistics and product quality for assembly operations.

The initial part of the Factboard project involved detailed factory shop floor Observations at Deere and Boeing in an effort to document the current communication methods being used, and the production TAKT cycles which were lost due to poor communications, quality and logistics problems.

Some of the key takeaways from that study are listed below:

- Cell phones are the dominant communication method for shop floor communication between workers in the plant and with external vendors.
- Quality problems involving internal manufacturing defects or external vendor shipments can take many hours to communicate to the necessary people. In the meantime, real-time production changes are made which are not communicated to the upstream suppliers in a timely manner. This creates shortages of needed parts and carts and results in operators taking parts from kits which were originally created for different units. This causes substantial inventory reporting problems for inventory management.
- Quality issues can take one or two days to be recorded as many inspectors write down issues by hand and enter them into the computer hours or days later.
- On-hand inventory requirements are difficult to reconcile with visual inventory when backflush points are several stations downstream and many key inventory items are used on specific product variants which depend on a sequenced production schedule.
- Each plant has different technology available for recording product and part movement as well as quality and logistics exceptions. A system must be able to "plug-and-play" in a very

diverse technology environment involving scanners (dumb and smart), RFID, PC/Tablet applications and smart phones.

- While many workstations scan vehicles upon entry and/or exit, and many part kits and containers are scanned upon delivery, this is not consistently followed, and thus "information holes" need to be resolved in any automated system.
- Workers, supervisors, inventory managers, external part kit suppliers and final assembly line schedulers have different needs for viewing stations and transactions. These views (called Personas in the report) can't be pre-defined for any particular user, so they need to be user-definable in the system.

Upon review of the field findings, the team determined a three phase approach involving:

1. Display of active products (serialized units) in selected stations on the assembly line with regards to Actual-vs-Planned cycle time, Logistics Issues, Quality Issues and Model Type. This includes the ability to view an aggregation of units over a period of time for a historical view. The historical view needs to be able to be generated for a date range of logged transactions or be read in from a data file which could have been generated by an external system such as a simulation application.
2. Viewing and Editing of the order sequence on sub-assembly, main-assembly and part kitting areas needs to be performed in a way that provided instant visibility by planners of upstream, downstream or parallel lines. Changes in the expected timing of a particular order needs to be instantly viewed and tagged for anyone supplying that production area/line. Production delays involving line shut-downs need to also be addressed such that the TAKT time start times can be moved.
3. Real-time computation and display is required of anticipated part shortages as a result of reconciling the on-hand inventory with the upcoming order (build) list and taking into account part consumption for downstream units which have not been backflushed by ERP.

Technologically, the team settled on a cloud-based design (initially specified in the project charter) that was based on extendable JSON transaction strings posted to a web service. The transaction manager was designed to accept encrypted JSON transactions at a frequency of several thousand per minute. Microsoft Azure was selected as the default cloud platform and the application was also designed to be installed on an internally hosted IIS.

The first phase Factboard Dashboard was available for testing in early 2017 and deployed into trial production at Deere by September 2017. Several iterations of the dashboard continued throughput June 2018. The second phase Factboard Scheduler was initially released in February 2018 and was revised twice during the Spring as a result of client feedback. Finally the Factboard Inventory Reconciler completed the third phase with an initial release in May 2018 which was reviewed in a group presentation which resulted in changes recommended for the final release in June 2018.

The application was developed in C# and used MS SQL Server for back-end database management.

Additionally, in May 2018, the Factboard Freshdesk support and Forums site was launched as a platform for distribution of the application code and documentation as well as hosted user feedback. During June 2018, additional documentation was created to assist with installing the application on

an in-house server as well as Microsoft Azure environment. As of this document, user and administrator videos are being created to assist with the transition and adoption of Factboard within the DMDII community.

III. TECHNOLOGY OUTCOMES

Business Problem Solved

Manufacturing organizations of all sizes are constantly looking for increased visibility into their production and logistics systems. Transforming the data from multiple sources and into meaningful insights is a common challenge throughout industry today. Making improper decisions due to incomplete or lack of data reduces a factory's throughput rate, can simultaneously drive excess inventory on some materials and shortages on others, leads to low overall equipment effectiveness, and will ultimately lead to product quality issues as process controls breakdown. The enhanced shop floor visibility provided through FactBoard enables more timely and accurate decision making across multiple factory personas. This could be tactical decisions made by supply chain personnel, operational decisions made by managers, or strategic decisions made by senior leaders. All of this contributes to reducing operational costs and increases the ability of the factory and its supply chain to respond faster to changes in requirements.

Our application consists of three main modules. First, the FactBoard Dashboard can be used in real-time mode to view active transactions on the shop floor. It can also display aggregated transaction statistics for any range of historical dates and times. Transactions can be view independently for production cycle time as well as logged quality and logistics issues. FactBoard can also play a pre-recorded or simulation-generated log file of transactions and provides an ANDON functionality to assist in reporting Actual vs Planned production targets to workers and management. This reporting can be via large display board or via any Internet-enabled device such as a tablet or smartphone.

Next, the FactBoard Sequencer module provides real-time viewing of the production sequence of a set of upstream, downstream or parallel assembly and kitting areas within any facility logging transactions to FactBoard. A production supervisor can author the sequence of one line while viewing the production sequence of any other line(s). Any changes to the authored production schedule are immediately and automatically communicated to all other production supervisors who have chosen to view the line being edited.

Lastly, the FactBoard Inventory Reconciler provides a real-time status of inventory availability at any production workstation for which inventory transactions are posted. Most importantly, the Inventory Reconciler will resolve the difference between physical inventory and reported inventory for production line where the inventory backflush point is located downstream of stations where accurate inventory reports are desired. Additionally, the Inventory Reconciler can logically assign Actual inventory to expected units in the future build schedule in order to anticipate and report part shortages. These part shortages are reported to the FactBoard Sequencer to aid the production supervisor in production sequence planning.

Support for Multiple Personas

The FactBoard application developed in this project leverages the knowledge base of PLM systems and provides visibility of real-time operations to the personnel who need it the most. Factboard can be used in many ways and can meet many customer needs. Below are some generic scenarios:

Case 1: If a user is working on a multi assembly environment and would like to monitor real time status of stations, **Dashboard: Current** should be used. Factboard allow users to input the plant information and create a custom view. In the following example the user can quickly identify the station performing bad and take appropriate measures.

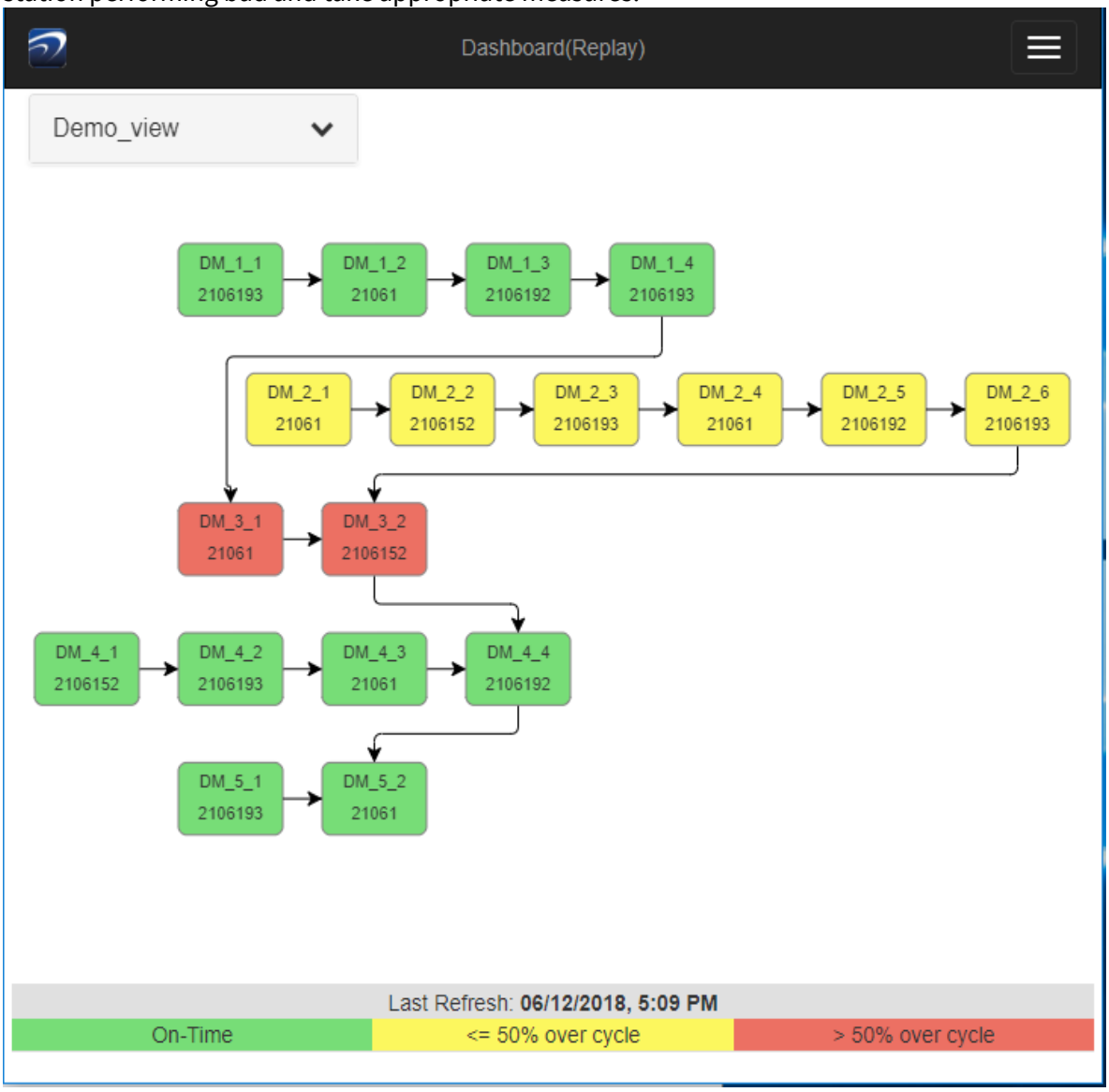

Figure 1Sample view for Dashboard

Case 2: If user want to review the station performance over time he can use **Dashboard: History** to quickly tally numbers. He can also use **Dashboard:Replay** feature to see transactions as if they were happening in real time.

Case 3: If a user is interested in finding out the stations where a unit was processed **Dashboard: Product Structure** provide the best solution. The user can select a unit number through the dropdown and the stations were highlighted according to appropriate status.

Case 4: The Sequencer allow a user to monitor the orders scheduled for the day and find any violations associated. If the user wants he can quickly unschedule and divert orders. The views in sequencer also allow user to select multiple lines and stations making the UI fully customizable. In the following view user can identify the orders being delayed. A more descriptive error is provided when the user hover his mouse over the violations. He can also see that Tractor 3B and Tractor 5B is lacking a resource required.

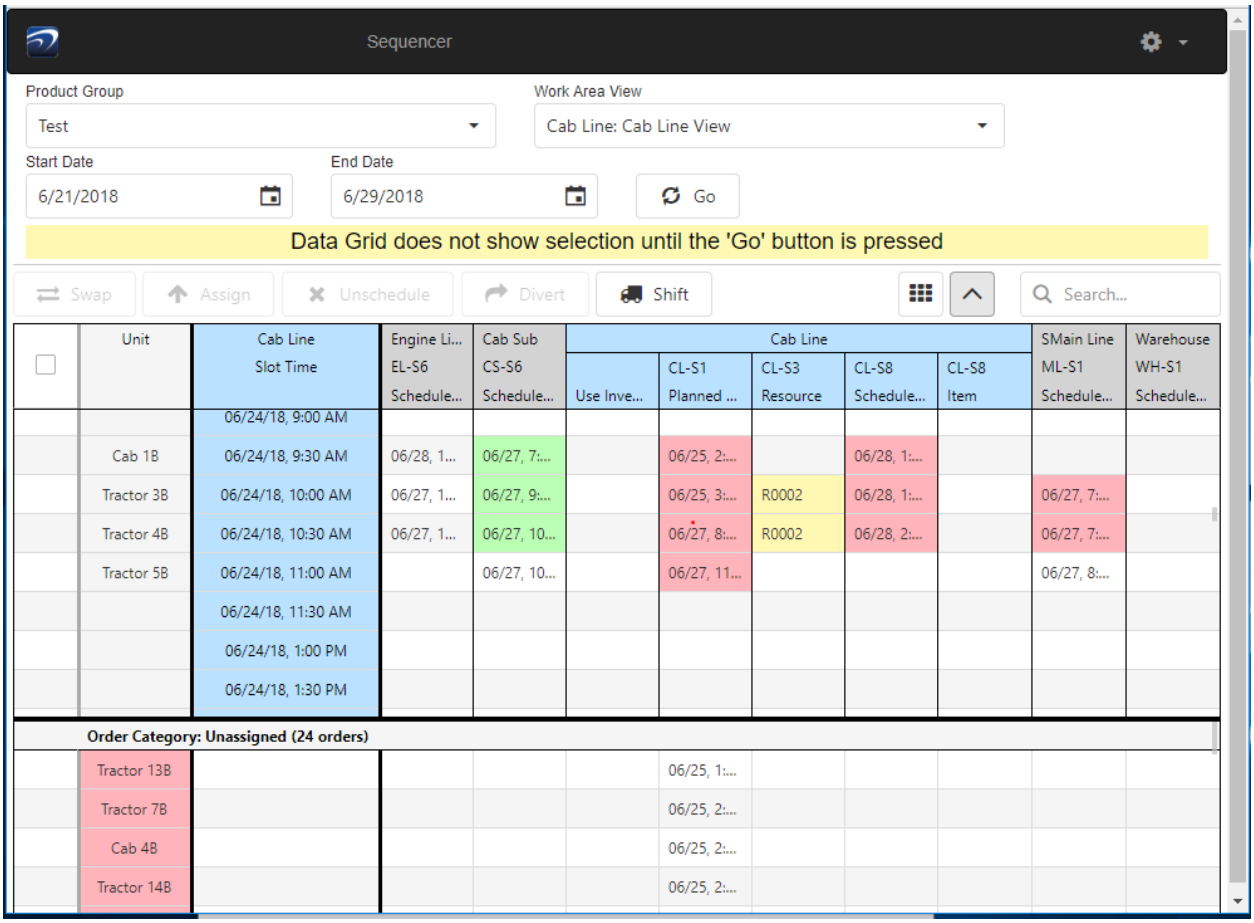

Figure 2 Sample view for Sequencer

Case 5: Keeping track of inventory is made easy through **Inventory Reconciler.** The inventory is automatically calculated according to scheduled orders. This helps user to foresee if he will fall short of some parts. The inventory is calculated from the current day to future end date. In the following example the user can see that Part P002 at storage area 3 will be required to fulfill the orders.

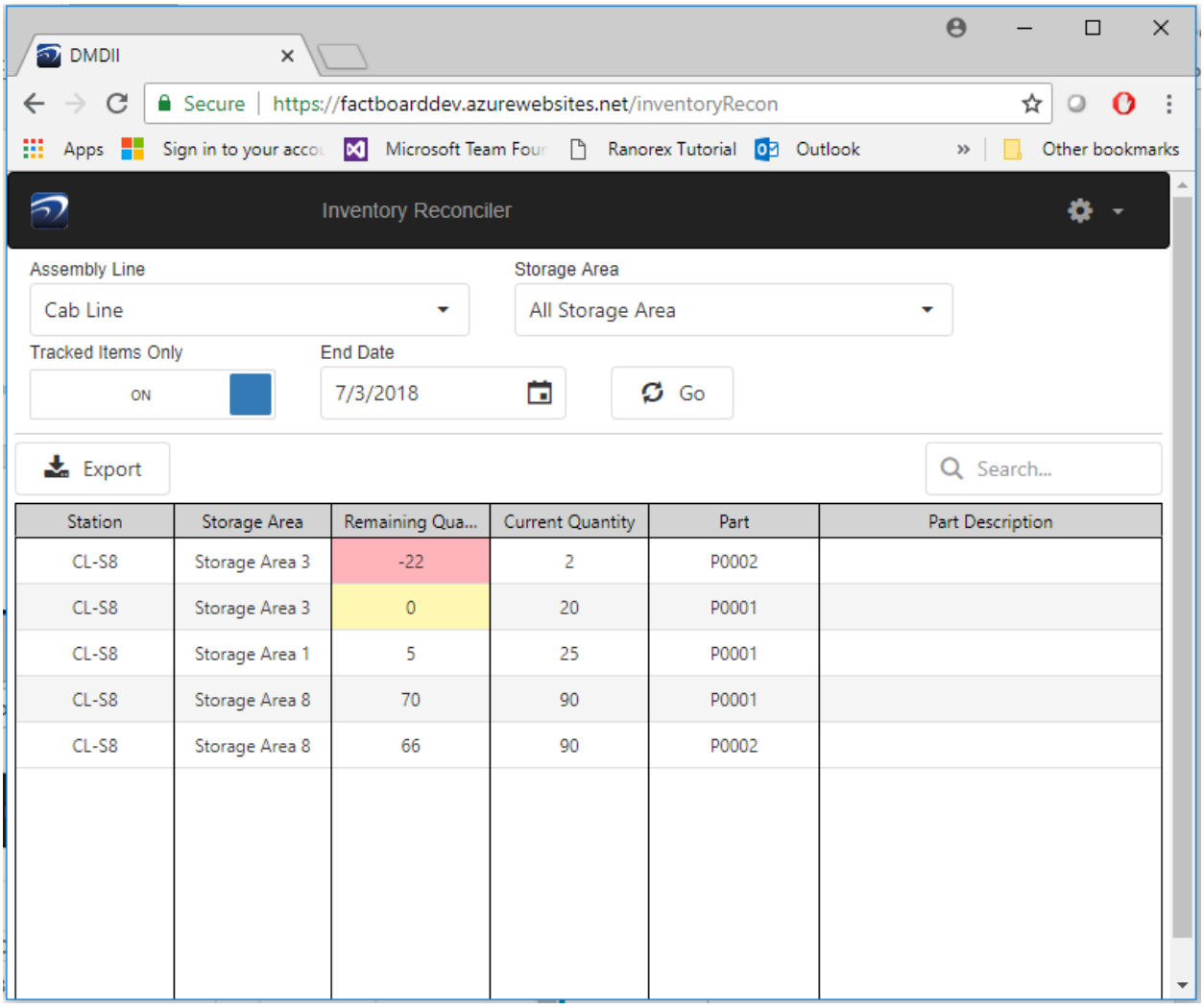

Figure 3 Sample view for Inventory Reconciler

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IV. KPI'S, INDUSTRY IMPACT & POTENTIAL

Table: Performance Improvement Metrics

Level	Unit of Measure	Metric	Frequency	Baseline	Future State
Product	Percent	Production Sequence Linearity	Rolling 12 months	~80%	~90%
Material	Total Count	RAW & WIP Inventory Days of Supply	FYTD + 6yr history	~30	~24
Factory	Parts per Million (PPM)	Material Shortage at Point of Use	FYTD + 6yr history	~60 PPM	~10 PPM
Factory	Percent	Overall Equipment Effectiveness	Rolling 12 months	~75%	~95%
Factory	Percent	Completed On Schedule	Rolling 12 months	~85%	~95%

The metrics shown above are representative of improvements seen in areas where the types of visibility and improved decision making capabilities provided by FactBoard have been implemented. Improved visibility to daily manufacturing variances and communication across functional groups to the response taken to address these variances drives significant impact not only within the manufacturing environment but also throughout the entire inbound and outbound supply chains.

Pilot studies of similar functionality deployed by proposal team members in isolated environments have demonstrated 98% reductions in line stoppages due to logistics issues, 86% reductions in on-site inventory, and 50% reductions in indirect material handling labor, all while simultaneously increasing productive throughput by nearly 10%. All of this contributes to reducing operational costs and increasing the ability of the factory and its supply chain to respond faster to changes in requirements.

FactBoard enables manufacturing companies of all sizes and resource levels to quickly and cost effectively bring together disparate data sources driving rapid improvements in operational business metrics through increased visibility, improved communication, and decision making.

This was seen at Boeing as the team had the opportunity to build a FactBoard demo within their internal system based on ProPlanner coding. The team presented this to Boeing manufacturing area leaders and industrial engineers. They believe that the tool can be useful and bring value to daily operation. We believe that if enhancements were made so this tool could reconfigure with location information and historical operation logs, it would bring even more value and become even more useful.

At Deere the FactBoard application was installed and connected to live data from one of their Construction and Forestry assembly lines. We tested the ability for dashboard creation and customization, JSON data connections, and all dashboard view functionality. Feedback from business process experts was used in development of the functional spec and UI development for the FactBoard Sequencer and Inventory Reconciler modules.

Due to the changes in business conditions at Deere from the start of the project we were not able to fully integrate and capture improvements as a results of utilizing FactBoard. We did receive feedback provided by the potential end users of this functionality after viewing demo data was very positive. Upwards of 72 hours per day are spent extracting and analyzing data, revising production schedules, and communicating changes across five assembly lines, one paint department, and multiple fabrication areas in the facility where FactBoard data was tested. This does not even include the additional time and effort spent by supporting departments like Supply Management and Logistics to adjust and respond to these changes. FactBoard has the potential reduce the time spent specifically on data analysis and communication down to single digit hours across these areas if fully implemented.

Deere also tested the Dashboard simulation capability provided by the application. Using data provided by one of their Turf and Utility product lines we tested the dashboard development and historical playback capabilities. Deere has a significant capability in this area and has a number of resources and tools available to help them with this type of analysis but many of their suppliers lack the resources, funding, and expertise required to undertaking this activity. FactBoard has shown the ability to easily ingest an historical data file in a simple to create .CSV format and quickly view a playback of workstation and assembly performance. This can be done with very little training and this simple visualization can be utilized to identify performance bottlenecks throughout the manufacturing environment. These visualizations can be made as simple or complex as the end user desires. Deere feels that could provide significant value to a number of companies within their Supply Base and plans to communicate this through their Supplier Development organization as another potential tool to help improve supply chain performance.

Based on what we learned and understanding the application, we believe:

a. Impact to the specific market the project was addressing and size of that market.

Based on the application as tested using data from two facilities at John Deere and as a build test case at Boeing that the application should be able to cover 80-90% of all complex assembly scenarios and can be used within both repetitive and discrete manufacturing environments.

In aerospace manufacturing, the ability to visualize the status of individual jobs within a complex assembly is incredibly valuable. It allows for fast troubleshooting and accurate staffing decisions. Additionally, the historical data allows for truly informed decision-making about where the most opportunity for process improvement exists to optimize scheduling and resources. The most valuable view in Aerospace application is by Unit Serial Number, also called line number. For large assemblies, the ability to track the line number across the plant is extremely valuable to ensure that all parts are complete.

FactBoard provides a low cost tool for visualizing transactions from the rapidly growing IOT (Internet of Things) production floor. Based entirely on extendible JSON transaction formats and communication standards, FactBoard addresses the need for low cost, quick and easy to deploy, production transaction visualization and reporting.

b. How could this technology be used in other industries

Primarily FactBoard was developed for use within Assembly plants, and in particular those which utilized sequenced sub-assemblies and part kits. Since FactBoard provides a quick and easy view of any transaction and since transaction attributes are extendable, FactBoard can serve as a communications and history tracking application for any production environment where it is difficult to view the current and historical activities on the shop floor.

c. Potential enhancements to increase functionality and value across more manufacturing use cases

For large manufacturing facilities with many stations and lines, the dashboard view of the plant can be overwhelming. There can be hundreds of stations (Installation Plan in Boeing) that makes the dashboard appear cluttered. Adding the ability to visualize lines would allow scalability to larger assembly systems. The ability to step back would allow management to better identify and investigate problem areas.

FactBoard currently has the ability to create different customized views for different segments of the plant. Switching between dashboards presents a scalability issue due to the large number of views required to capture an entire plant. Adding the capability to hyperlink to specific dashboards would make switching dashboards on the shop floor easier where tablets or phones are used. Additionally, this capability would allow FactBoard to act as an "add on" to company's current health monitoring tools.

FactBoard works well as a descriptive model. A possible next step would be to use data analytics and machine learning based on EVIR data to identify process inefficiency areas.

Easier reconfigurable for connecting with other reporting and monitoring systems.

Operation

1. If a unit is "signon" to a subsequent station prior to "signoff" from the existing station, the station will be automatically "signoff" even if the job did not complete. This creates a problem if there is travelled work.
2. Due to customization, there is a set of stations that are optional. It becomes a minor issue to show work progress with or without the optional stations.

Evaluation is currently underway to apply FactBoard to a machining environment and also to a batch assembly environment. Machining involves an infinite path through the resources whereby FactBoard is designed for a pre-defined path which is represented in the plant model. Currently this defined path is used by FactBoard to aid in resolving missing transactions. Without this path, FactBoard will only know the location of the part based upon the last transaction, and this can create difficulty if the transaction log implies that multiple parts are in the same machine. Batch assembly will be an easier new potential and one where the development team has anticipated. The biggest challenge with

batches, and also with machining is the lack of a pre-defined TAKT time with which to gauge completion. As such, FactBoard will need information about the expected processing time at a resource when it arrives to that resource. This information could be provided by attribute (tabular) data available to each resource (i.e. lookup expected processing time for Part "X") or it could be an attribute of the transaction. Both of these features will provide an extensive growth in the potential market size for FactBoard.

V. ACCESSING THE TECHNOLOGY

a. The FactBoard application is being offered as a full use, unencumbered, royalty free license, and is available for download on a cloud server that can be accessed by all DMDII partners.

b. System Overview:

The FactBoard system is a cloud-based real-time production visualization and sequencing solution that utilizes transactional information received from Internet enabled devices located on the shop floor. The main module is the Dashboard which displays current and historical production status involving cycle time, quality and logistics transactions. The Sequencer and Inventory reconciler are the other two modules which provide and enhance communications between production line supervisors to ensure a coordinated delivery of sequenced part kits and sub-assemblies to the main assembly line.

c. Background Intellectual Property:

None.

d. Technical and Systems Requirements:

SQL Server requirements

SQL Server 2012 SP2 or higher

Web Server requirements

IIS 8 or 10

Webserver Software Required:

.NET Core 2.0 Runtime (2.0.6 or higher)
.NET Core 2.0 Hosting Bundle Installer (2.0.6 or Higher)
IIS URL Rewrite2.1
Required IIS roles:

Web Server (IIS)

- Web Server
  - Common HTTP Features
    - Default Document
    - Directory Browsing
    - HTTP Errors
    - Static Content
    - HTTP Redirection
  - Health and Diagnostics *(all)*
  - Performance *(all)*
  - Security
    - Request Filtering
    - Basic Authentication
    - Digest Authentication
    - IP and Domain Restrictions
    - URL Authorization
    - Windows Authentication
  - Application Development
    - .NET Extensibility 4.5
    - ASP
    - ASP.NET 4.5
    - ISAPI Extensions
    - ISAPI Filters
    - Server Side Includes

e. Web browser requirements

Recommended

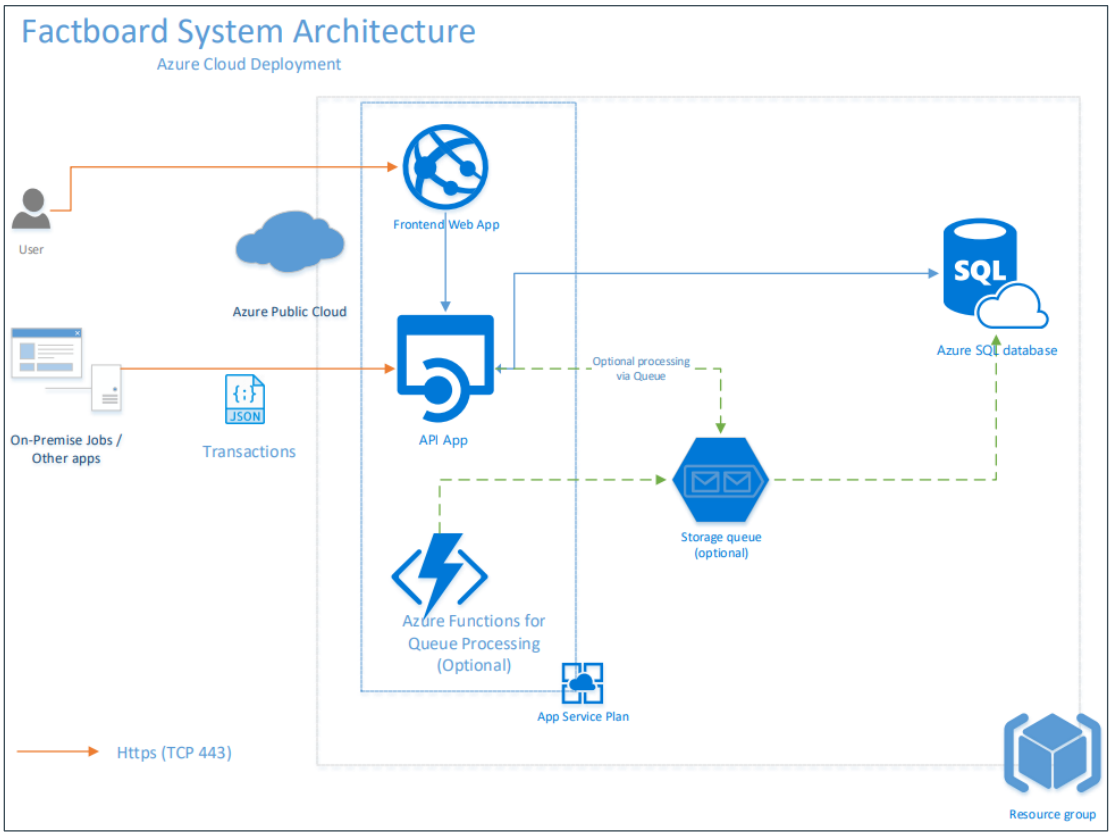
a. Google Chrome (latest public release)
b. Mozilla Firefox (latest public release)

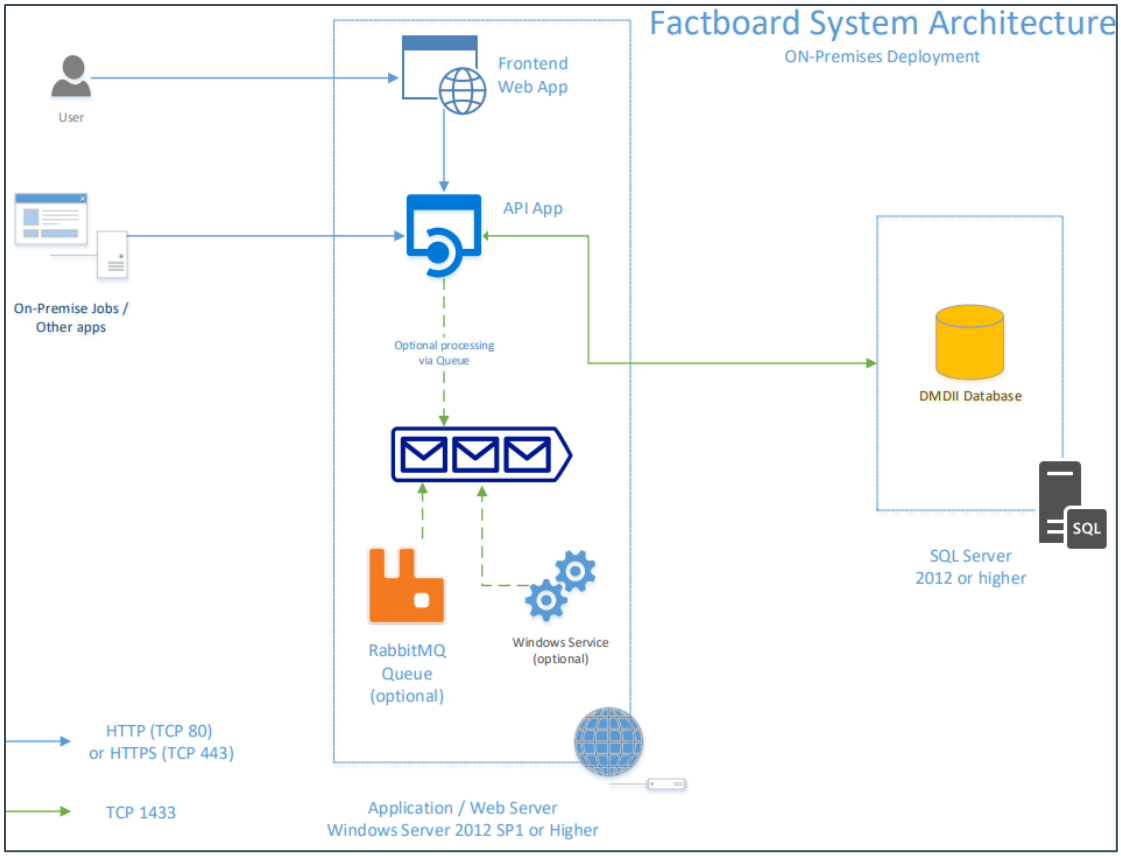
Minimum:

a. Google Chrome 49+
b. Mozilla Firefox 51+
c. Edge 25+

f. System Architecture

The software can be deployed on both cloud and premise. Once deployed it can be accessed like a usual website. We recommend using Chrome for best results. To post data on the website the user will need to send HTTP requests as explained in API guide. This can be done using Postman or other simillar applications. There are four main components to the architecure: The two web apps, a SQL server and a SQL database. The user sends transactions to the API app which then process it and saves it to the database. Some functions can also be performed through the User interface on the eb app and are descibed in the User guide. These operations also modify the data which is again sent to database through API app. The system architecture daigrams are described below. These architectures maychange according to the enviornment.





VI. TECH TRANSITION PLAN & COMMERCIALIZATION

a. Future Plans

Currently Proplanner has dedicated a resource to FactBoard development, documentation and support for the remainder of 2018 in order to evaluate the market potential and smooth the transition for new adopters. Proplanner has also launched a web-based support (forums, downloads, on-line help) site to assist with this effort. This site is planned to be supported indefinitely. During 2018, Proplanner will be launching a series of Transaction posting applications for Visual Basic, Excel, Raspberry, Android and IOS to aid in transaction posting availability.

b. Identified Barriers to Adoption

The largest barrier to FactBoard adoption appears to be manufacturing reluctance to utilized cloud hosting manufacturing transaction solutions. While FactBoard can be installed internal to a company's firewall, this does require extensive IT support which can be expensive and time consuming which takes a lot of the key value proposition away from FactBoard for many companies. Secondly, the availability of IOT transaction data which can be posted to a web location is a limiting factor in initial use.

Security can be another barrier to adoption. While FactBoard can use full credentialed encryption, this does increase the complexity for deployment and provides challentes for multi-vendor collaboration.

c. Additional Information to Consider

Providing the FactBoard dashboard as a free application to the marketplace is an idea worth considering. In this way, FactBoard may be adopted more frequently and provide upsell service and software opportunities for multi-company collaboration, security, scheduling and inventory reconciliation.

VII. CONCLUSIONS/RECOMMENDATIONS

Now that Factboard has been developed and tested with significant confidence that a positive return-on-investment (ROI) can be realized by a manufacturer, the ability to deploy, demonstrate and resell Factboard is needed.

Factboard's ability to provide value to manufactures lies in its capability to compile large amounts of complex and dynamic data into visualizations that show companies how to improve their production in the face of imperfect material availability. In order to communicate the benefits of Factboard's extensive power, a concise demonstration capability is needed. The demonstration should consist of a plant definition, sufficient data to exercise the plant through Factboard and the automation needed to conduct a demonstration using the data. This would be a very helpful tool for demonstrating and publicizing Factboard to potential users.

As a means to expand the distribution of Factboard software and services, a strategy to accomodate 3rd party vendors is needed. The strategy should consist of licensing parameters (e.g. ability to resell, modify and extend the code base), pricing models and profit margins, distribution methods, DMDII member rights and long term support responsibilities.

If the effort to deploy Factboard remains high, manufactures will be much less likely to implement Factboard and 3rd party vendors will be unlikely to resell Factboard services due to a low profit margin. Hence, efficient methods to deploy Factboard for a customer in the cloud or on premise is needed. Deploying a new version of Factboard in the cloud should take less than 15 minutes by experience developers and on-site deployment should require less than two hours and can be accomplished over a web-meeting application (e.g. WebEx, GoToMeeting or Bluejeans). This can be achieved by building the appropriate deployment automation. Techniques such Amazon Machine Images (AMI) for cloud deployment and Windows Installers for local installation could be used.

VIII. APPENDICES

a. Three different documents will be provided for FactBoard:

- **The User Guide**: This document will list all possible functionalities that a user can perform on the User Interface. It will also include all explanation for basic software components.
- **The API Guide:** This guide will target various HTTP requests that a user can send to the API website. This guide will assume the user understand the terminology in User Guide.
- **The Installation Guide:** This guide will provide brief instruction on how to install a instance of FactBoard on Azure Cloud.

b. Demos:

Many milestones were set over the course of project. Planned demos were delivered to FactBoard team when necessary. Extra demo sessions were also conducted on per request basis. A tutorial is also included in the API guide for future reference.

c. Validation & Testing:

1. Plans

Proplanner use comprehensive testing procedures to ensure the quality of our products. FactBoard was developed and tested in different modules. The API features were tested using Postman while all User Interface features were tested using manual tests. Google chrome Version 67.0.3396.87 (Official Build) (64-bit) was used to access and test the website features.

2. Results

FactBoard modules passed all tests successfully. The application was tested for complete functionality with valid inputs. Invalid inputs were tested where necessary but we expect the user to input expected formats and information.

3. Installation Reports

FactBoard application as successfully deployed at intended premise locations at Deere an Boeing. Proplanner maintained multiple instances on Azure Cloud.

4. Fact board User Guide and API manual

Fact board User Guide can be downloaded from the following link:
https://proplanner.freshdesk.com/support/discussions/topics/35000005829

Fact board API Manual can be downloaded from the following link:
https://proplanner.freshdesk.com/support/discussions/topics/35000005559

5. Additional Relevant Materials

Replay Study Formats can be found at:
https://proplanner.freshdesk.com/support/discussions/topics/35000005509

Sequencer Import Template file can be found at following URL:
https://proplanner.freshdesk.com/support/discussions/topics/35000005358

Proplanner help support forum for FactBoard:
This link can be used to browse frequently asked question and request a demo for Fact board.
All documents can also be found here:
https://proplanner.freshdesk.com/support/discussions