SPACE RANGE SCHEDULING AND THE LEAN AEROSPACE INITIATIVE

THESIS

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

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Alan M. Matuszak

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List of Acronyms

AF	Air Force
AFB	Air Force Base
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratories
AFSPC	Air Force Space Command
C&D	Control & Display
CIMPLEST	Cellular Intelligent Manufacturing Production and Labor Enterprise Tool
CCAS	Cape Canaveral Air Station
COTS	Commercial Off-the-Shelf
CSLRB	Current Launch Schedule Review Board
DLM	Depot-level Maintenance
DMCO	Delta Mission Checkout (Center)
EELV	Evolved Expendable Launch Vehicle
GCA	Ground Control Approach
GPS	Global Positioning System
IMVP	International Motor Vehicle Program
IPPD	Integrated Product and Process Development
IPPT	Integrated Product and Process Team
IPT	Integrated Product Team
LAI	Lean Aerospace Initiative
LEM	Lean Enterprise Model
LOD	Launch of Demand
MAJCOM	Major Command
MIT	Massachusetts Institute of Technology

MOTR	Multiple Object Tracking Radar
NASA	National Aeronautics and Space Administration
O&M	Operations and Maintenance
OD	Operations Directive
OR	Operations Requirements
ORD	Operational Requirements Document
P&S	Planning & Scheduling
P&W	Pratt & Whittney
PI	Program Introduction
PRD	Program Requirements Document
PSM	Program Support Manager
PSP	Program Support Plan
RLV	Reusable Launch Vehicle
RSA	Range Standardization and Automation Program
RSOR	Range Safety Operation Requirements
SC	Statement of Capability
SLR	Spacelift Range
SLRS	Spacelift Range System
SLRSC	Spacelift Range System Contract
SMC	Space and Missiles Systems Center, AFMC
STAR	Scheduling Toolset for Automated Ranges
TC&C	Telemetry Command and Control
TPM	Total Productive Maintenance
TQM	Total Quality Management
UDS	Universal Documentation System
USAF	United States Air Force
VAFB	Vandenberg Air Force Base
WPAFB	Wright-Patterson Air Force Base
XP	Wing Plans, Planning Office

Abstract

This study describes how lean principles and thinking can be applied to space range operations. The "lean" concepts of the right thing, right place, and the right time are applicable and relevant to this study. The basis for the lean concepts and principles considered is the Lean Aerospace Initiative (LAI). The LAI originated from the International Motor Vehicle Program (IMVP) that was conducted by a team from the Massachusetts Institute of Technology (MIT). The LAI is a collaborative research program involving government, industry, labor, and academia (primarily MIT). The partnership began in 1993 through support of the U.S. Air Force as the Lean Aircraft Initiative and was renamed in 1997 as the Lean Aerospace Initiative when it was realized that lean principles can and should be applied to test and space activities. The partnership allows the exchange of knowledge and research. As a result, it is expected that there will be fundamental improvements and added value in industry and government operations.

Thus, the Lean Aerospace Initiative (LAI) is an important part of the defense aerospace industry. It strives to understand and use lean practices that will, for example, improve turnaround times, reduce costs and improve the quality of the processes and operations involved in providing defense aerospace services and products. Consideration of lean principles and practices are facilitated through use of the Lean Enterprise Model (LEM). The model consists of research-based benchmarking data that help identify and assess leanness. The LEM is designed to tell users what lean is and not necessarily how to get lean.

This study on space range operations examines how the principles and processes associated with the Lean Aerospace Initiative (LAI) and the Lean Enterprise Model (LEM) can be applied toward scheduling activities and planning at the space launch ranges at Vandenberg Air Force Base, CA, and Cape Canaveral Air Station, FL. Current launch scheduling at both ranges is baselined as well as changes proposed under the U.S. Air Force's plans to upgrade and replace existing range infrastructure through the Range Standardization and Automation (RSA) Program. The existing and planned scheduling practices are then compared to lean concepts and principles. Value-added steps involved in the scheduling and planning practices are identified using the LEM principles.

This study focus on the space range operations such as telemetry, radar, command destruct, instrumentation, and infrastructure necessary to facilitate the actual launch itself, including the operators, maintenance personnel, and contractors. The organizational elements are considered along with the operational activities. The LEM enabling practices are used to identify suggested supporting practices and metrics to determine if current scheduling and planning processes are lean. Elements of the proposed RSA Program are considered in making recommendations for reducing waste and making current space range operations more lean. The RSA Program provides an excellent framework for incorporating new technologies and automation to enhance range operations.

While there are aspects of the current and proposed scheduling operations that were determined to follow lean concepts, areas are found that are considered *muda* or waste and do not add any value. Research conducted by MIT, LAI, and the Air Force

Research Laboratory at Wright-Patterson AFB, OH, on determining the benefits of lean practices currently employed by defense aerospace companies is used as a comparison to determine that there are potential benefits for modifying existing range scheduling methods and moving toward leaner operations.

SPACE RANGE SCHEDULING

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1 Introduction

You may delay, but time will not.

Ben Franklin

Much like the apprehensions felt by a graduate student setting out for the first time to write a thesis, so too were the feelings of many in roles of military and political leadership regarding the feasibility and impact of space in the future of warfare and society. In 1946, as the U.S. Air Force initially tackled the possibility of placing satellites in orbit around the Earth with its funding of Project Rand (Research and Development), naysayers and skeptics abounded, attacking potential costs as well as technical and military merits. The idea was too "fantastic [38:1]." Historically, this was not an unexpected response; nevertheless, the nation, as well as the world, pushed forward toward this new frontier. Only a year later, in 1947, in a follow on to the inaugural Project Rand study, the issues of satellite reconnaissance and communications platforms were detailed; the latter of which would become the inroad of private enterprise into space and the foundation of the commercial space industry [38:25].

The Communications Satellite Act of 1962 enabled the commercialization of space [9]. This new industry started out slowly, but is now projected to be worth a phenomenal $86 billion over the next 10 years [13]. As the value of the space market grew, the controversy over its development grew with it, specifically, there was the debate over the need for continued federal direction or a push to empower commercial industry putting the government in a role more like that of a customer than a provider [37].

The impetuous to increase commercial presence in space began in the 80s [36]. In 1984, the U.S. implemented its first space-commercialization policy [14]. This Reagan administration plan focused on developing a space station as a platform for future commercial activities and deregulation to encourage private commercial endeavors into space [14]. Also, under Reagan, the Commercial Space Launch Act of 1984 was enacted to eliminate some of the bureaucracy involved in the space launch process by centralizing control under the Department of Transportation [38:226]. Subsequent administrations followed suit, each providing its own vision for the future of the space industry and looking to expand opportunities available to the commercial sector [13]. The most recent thrust comes from the Commercial Space Act of 1997, which, among other things, calls upon NASA to continue to examine the possibilities and benefits for the private sector in space, forces the government to look to commercial industry when purchasing space transportation services, and streamlines licensing for commercial remote sensing projects [35].

As with any rapidly growing industry, the stake for labor and capital increase proportionally. Figure 1 shows the revenue from the space launch industry from 1996-98. Commercial space firms are now employing thousands of people and making investments in new research in space instruments and types of rockets. Remote sensing is expanding at rapid pace [35]. The benefits that have been realized are innumerable. But as growth in the space industry continues, the need for cheap access to space will be a driving force behind its future.

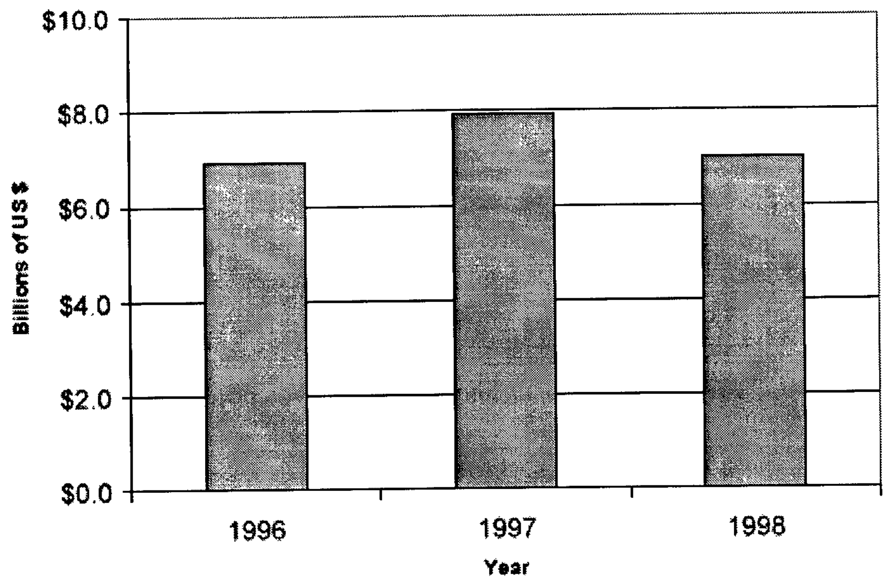


Figure 1 Space Industry Launch Revenue [25]

Continued elimination of bureaucratic barriers, incentives to increase private ventures into space, and competition in the space launch industry between various platforms and countries is providing the necessary incentive to provide inexpensive ways to place payloads into orbit. Right now, NASA is looking to drive down the $5,000 to $10,000 cost per pound for low earth orbit. Many of the obstacles to reaching these goals result from the use of varying types of expendable launch vehicles, launch platforms designed to meet mostly military needs, and complex, outdated systems requiring large investments in infrastructure as well as personnel [37]. To combat this, extensive research is being done in the areas of reusable launch vehicles (RLVs) and modernization of America's launch ranges. There is also interest in improving the methods used to prepare platforms for launch and reducing the manpower and hassle involved in those processes to create space transportation systems that work best for commercial industry which takes up a sizable chunk of U.S. range launch rates (see Figure 2).

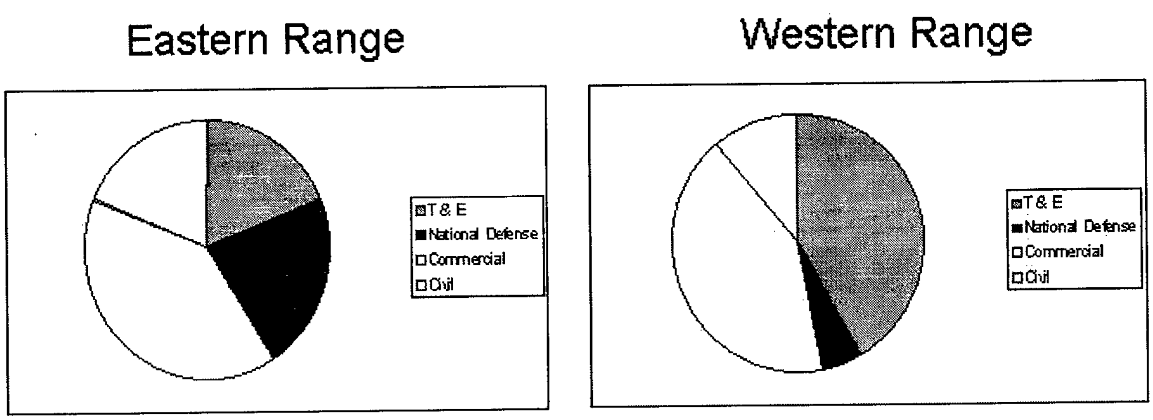


Figure 2 Launch Rates FY 98 [17: 16,19]

There is an addition push of late, from a military standpoint, for reduction of cycle-times and rapid turn around. From the summer of 1997 to the spring 1998, the National Space Security Space Architect and the National Reconnaissance Office conducted a study into the potential benefits of the capability to launch on demand (LOD). This is of particular concern for the military because it would reduce the number of on-orbital satellite spares necessary to maintain required operations, reducing post-mission downtimes, and eliminating unneeded launches [43].

The concepts "lean" and the Lean Aerospace Initiative (LAI) are at the forefront of changing the way many companies and organizations, such as the military, do business. The desire for "better, faster, cheaper" products and turn-around has been a constant fixture in industry, but today, the lean philosophy is proving itself as an effective way of reaching those goals [23]. It is a new way of doing business. Improvements in cost, performance, and cycle-time reduction have been seen not only in the auto industry, but also in defense aerospace. With the successes seen in these areas, it makes sense to examine where lean principles can be applied in the space launch arena, where cost and responsiveness are becoming so critical. From launch vehicle preparation and testing, to range and on-orbit operations, as well as in the operation of RLVs, space planes, and spaceports, "lean" is looking to assert itself as the best way of meeting future requirements.

1.1 Purpose of Thesis

While documentation of the implementation of "lean" philosophy in the auto industry and a few other areas including airplane manufacturing is extensive, only recently has focus been turned toward its application in space [23]. This thesis is meant to be a follow-on to research being done at the Air Force Institute of Technology and in conjunction with similar research at MIT to identify how "lean" can be applied to the space and spacelift industry. Whereas previous research has looked at the process of preparing a launch vehicle for deployment, this will look at the range support structure needed to make that deployment possible [16]. More specifically, it will examine the area of scheduling as it pertains to U.S. launch ranges.

The primary goal of this research is to identify how and where lean principles can be applied to current range scheduling operations. In addition to this, the U.S. Air Force's plan to modernize its ranges, the Range Standardization and Automation (RSA) Program, will be reviewed to determine how this will affect future scheduling. It will also be important to look at the influence of new technology on the aging U.S. ranges as part of RSA since the technological improvements to be employed as part of the program represent the foundation for the infrastructure of the future space range for the United States. The next step is to, with the help of the Lean Enterprise Model (LEM), identify tools and practices to make range operations "leaner."

In Chapter 2, the roots of the lean philosophy, LAI, and the RSA program will be identified as well as outlining the launch enterprise. Chapter 3 will take a closer look at range operations. Chapter 4 will examine scheduling practices that go on at U.S. space ranges as well as changes to be made under RSA and look at lean principles applicable to those activities. Finally, Chapters 5 and 6 will present recommendations and conclusions based upon those comparisons.

2 Lean, Launch Enterprise, and RSA

Few things are impossible to diligence and skill.

Brisbane

The United States' space and space launch industry, as well as "lean" have a relatively short, but rich history. Looking at that history, however briefly, is useful in examining the major concepts of each. The following chapter is intended to provide a better understanding of the development of "lean" and its principles, the lean enterprise, and U.S. range history, including the Range Standardization and Automation program.

2.1 Right Place, Right Time, Right Price

In 1985, American and European car manufacturers, still relying on mass-production techniques developed by Henry Ford, found themselves unable to stem the tide of increasing market share being taken away by Japanese companies[44:68]. Concerned about how this might affect the U.S. economy in the future, the Massachusetts Institute of Technology (MIT), through its International Motor Vehicle Program (IMVP), set out to examine current problems facing the world auto industry and specifically take a detailed look at auto manufacturing techniques [44:5]. What was discovered was an entirely different way of looking at the process of production. Different from the concepts of mass and craft production with which most people were familiar, this type was dubbed "lean" by the MIT researchers because it was able to do "more with less". It was their conclusion, that "lean thinking" was the driving force behind Japanese success.

2.1.1 What is "lean"?

"Lean is about getting the right things to the right place at the right time the first time while minimizing waste and being open to change [40]." "Lean" is a way of thinking that forces a producer to take a step back and look at the whole process of production. This does not just include the operations going on inside the factory itself, but also all levels of supply, distribution, development and even organization. This method of doing business starts with the customers. In lean thinking, they are the people who can best define *value* [45:16]. It is then the producer's responsibility to make or provide something that is valuable. Once value has been determined, the producer identifies all of the steps that are required in the process to bring that certain product about. With this done, it becomes possible to see what the essential, *value-added* steps are and adjust the production process so that products can *flow* from start to finish. As flow is developed, a tailoring of the process occurs so that no up-stream activity can start until it receives a cue from the activity directly down-stream. This is the idea of *pull.* When production is pulled along, impediments to flow are easily seen and opportunities for improvement can be identified, leading to the last fundamental idea of "lean" - *perfection* [44:19-25].

The advantages that were being realized by Japanese companies from "lean" production were a result of increased flexibility to consumer and environmental concerns, decreased inventories, and improved communications and quality. For example, in lean manufacturing, if something on the car didn't work at some point during assembly, then the whole process had to be halted – this was due to perfection [44:79].

As workers became more and more adept at eliminating problems, down times were reduced to nearly nothing and rework times dwindled to fix defects identified when the product had made it through the entire assembly line. American and European manufacturers were spending enormous amounts of time, manpower and money to fix problems that could have been dealt with more easily and cheaply if they had been discovered earlier in the production cycle [44:81].

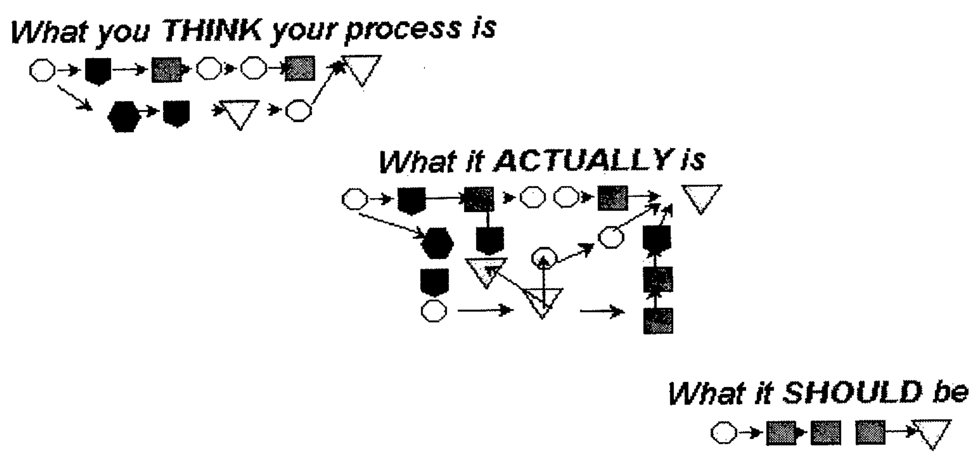


Figure 3 Work Flow Reality [24]

2.1.2 Lean and Quality Initiatives

Lean distances itself from other quality initiatives and Total Quality Management (TQM) in the respect that the entire process must be examined. Lean does not have a narrow focus. It does not limit itself to one department, one division, or even one company in the process of performing a service or getting a product to market because this leads to sub-optimization with each segment of the process attempting to maximize its own performance without respect to how it fits in with other segments [39]. This can potentially be a detriment to cycle times, impact customer satisfaction, and increase cost. It is essential in lean for everyone to know their role in the big picture. It is through this that it becomes easier to develop flow, pull, identify value and the value stream, and move more swiftly toward perfection (see Figure 3). Integrated product and process teams (IPPTs) also play an important role in defining the process as a whole, reducing cycle times and production and development lead times. Figure 4 describes the level of integration that "emerging lean" would like to have.

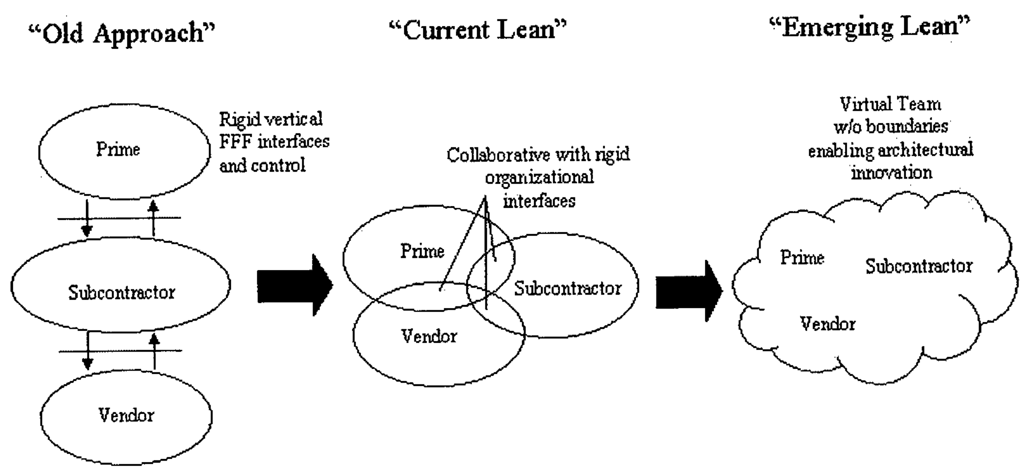


Figure 4 Lean Development [23:19]

2.1.3 Lean Aerospace Initiative

When MIT published its study in 1990 in the book, The Machine That Changed the World, interest in "lean" began to spread. Many people saw applications for it in their own businesses; the lean principles were not just limited to large-scale production, but could have a positive impact on any number of activities, including services, training and infrastructure [16:2-5]. These improvements and changes even caught the eyes of the Air Force.

In 1993, motivated by the IMVP study and interested in the application of lean in the defense aerospace industry, contractors, labor unions, MIT and the U.S. Air Force, formed the Lean Aircraft Initiative (LAI) to focus primarily on defense aircraft [16:2-5]. The intent was to benchmark the most effective industry practices as well a system for organizing and implementing lean research and principles. The LAI tailored lean practices, such as optimized product flow and integrated product and process development (IPPD), to fit its own specific industry. A Lean Enterprise Model (LEM) was also developed so that the effects of lean could be measured, shared, and applied [23:23]. Its architecture is shown (Figure 5) below and a copy of the LEM is attached as Appendix B.

In 1997, the name of the Lean Aircraft Initiative was changed to the Lean Aerospace Initiative [16:2-5]. The principles and practices of lean and the LEM were directed not only toward the aircraft industry, but also toward the space and spacelift industries. Collaborative participation was expanded and the focus shifted from benchmarking to cycle-time reductions and topics of mutual interest to both the aircraft and space industries. This constituted a second phase of LAI evolution [41].

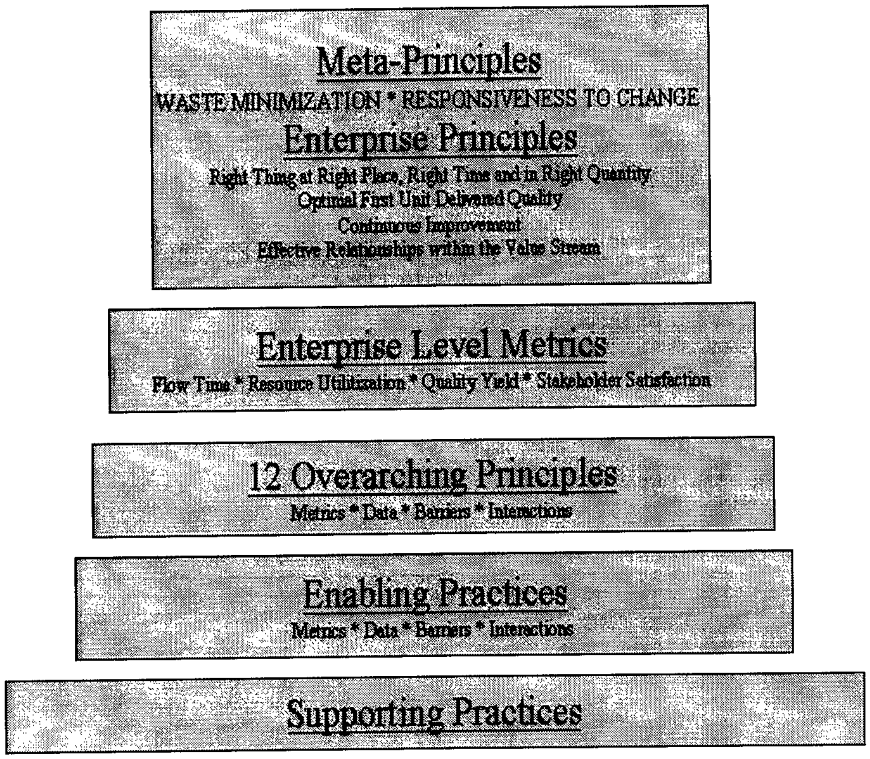


Figure 5 LEM Architecture [23:22]

Currently, emphasis within the Lean Aerospace Initiative consortium is on finding the best life-cycle value and the best methods for implementing lean and eliminating barriers and resistance to change. This is the third phase of LAI. It is now necessary for the Initiative to make the most of the cooperation, collaboration and research that has been developed, formed and produced [41].

2.1.3.1 Lean Aircraft Successes

Lean has already proven itself to be applicable in the aircraft industry. For example, Pratt & Whittney (P&W) began to make lean changes in its aircraft engine production in the 1990s after it found that it was unable to compete with other engine companies, such as Rolls-Royce and General Electric, in that industry. In the 1980s, P & W, with its mass production techniques in place since WWII, was unable to fix operational problems with its engines and had an unenviable record of mechanical problems. It was also sluggish in dealing with customer complaints, and could not react quickly enough to the changing engine markets, since long lead times for products required predicting where the market would go [45:162-3]. After pursuing a series of lean improvements, Pratt was able to reduce overdue parts from $80 million to zero, cut inventory in half, and doubled labor production. This occurred in only two years and began by constructing a value stream map of the process, and reconfiguring business units so value was properly channeled for each of their product families. They also rearranged machines in the assembly plants in the same order as the processing steps to force single-piece flow of products [45:175].

2.1.3.2 Push Toward Space Applications

As mentioned before, lean is in the process of being implemented in the space industry, the most recent example being the Boeing Delta II launch vehicle. The Delta team began in 1989 by analyzing its pad qualification and pre-launch procedures. By examining the total processing flow, a number of changes to eliminate impediments to flow were identified and implemented. Procedural changes, and better testing and floor space utilization in the Delta mission checkout center (DMCO), reduced the on-pad time necessary from 34 to 29 days. Additional changes to infrastructure, test facilities, and streamlining initiatives, as well as reexamining the launch processing flow after each change to identify additional improvement opportunities, have reduced the on-pad benchmark to 23 days, with some missions taking only 21. This was down from an original on-pad time of 40 days [16:3-25].

These results helped to propel research for application of lean into other areas of space operations. Range operations, on-orbit operations, infrastructure, maintenance, and satellite systems testing are all being examined for the possibilities of improvement through lean practices. With international competition driving continued growth of the commercial space sector, and the need for an ever-increasing presence in space, government and industry are searching for ways to keep themselves viable and relevant in this changing environment. The lean approach can provide this needed flexibility.

2.2 The Launch Enterprise

In his book, Lean Thinking, Womack mentions that the first problem when looking to make any process lean was being able to look at the process as a whole – being able step back and really look at what is going into producing your product or providing your service [45:276]. He asserts that there needs to be a mechanism created for doing this – the lean enterprise.

2.2.1 Why Examine The Whole Process

It becomes apparent, when one thinks about it, why it would be necessary to examine the entire process, especially when it pertains to the complicated, highly technical and highly expensive activity of launching a payload into space. The "launch enterprise" is made up of numerous processes and organizations each with an important role in the whole – materials suppliers providing composites for the payloads and launch vehicles, aerospace firms and their divisions testing and building the payloads, software companies designing the programs to be used for range operators to communicate, schedule and plan the launches, the range operators who will carry out the launch, and the list goes on. The usual tendency is for each organization is to optimize its operations to deliver something of value for the customer based on what it feels its role is in providing it [45:276]. When one pieces all of the operations for each firm which have been individually optimized along the value stream, one may end up with a process that is itself sub-optimized. Each piece is contributing what it feels is the necessary value, but it may not fit in with its role in the entire process. It is important for all organizations along the stream (the launch enterprise), including the customer, to coordinate so that there are no questions about how everything falls into place. For this reason, it is beneficial to provide a quick overview of the launch process in order to show how everything fits together in spite of the fact that this thesis will only be covering range aspects.

2.2.2 U.S. Space Launch Flow

The launch of a vehicle and payload into space is an involved process that includes numerous activities, many people, resources, and mountains of documentation (the purpose of lean being to reduce all of the above). Like any large process, it can be grouped into very broad areas to produce a good overview. The process starts with the organization wanting to place a payload into space. After doing its own studies to determine the feasibility of the payload and what it might require in the way of launch resources, that organization would contact the space wing plans division (XP) at the range they need to launch from (Vandenberg, Cape Canaveral for U.S.). XP works with the organization anywhere from 90 days to 5 years as the payload is designed and produced to determine what is required from the range and the base installation in the way of resources and support and if those requirements can be met. [21] Portions of the construction and integration of the payload take place at the ranges. The launch vehicle and payload are then mated, typically, for U.S. sites, at the pad. Testing of the complete system and launch dates must be scheduled and coordinated for range use.

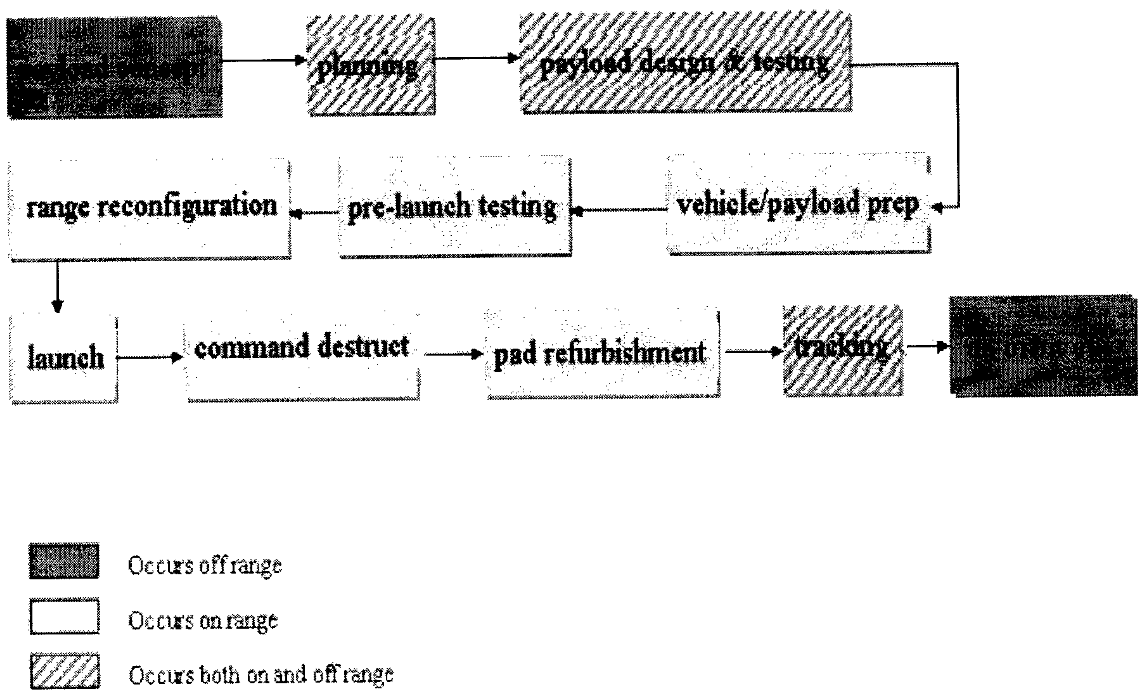


Figure 6 The Range and the Launch Enterprise

Prior to launch, the range must be reconfigured to support the new mission. This includes communications, radars, optics for recording the flight, telemetry and telemetry distribution. Safety and weather issues are addressed as the launch nears. Immediately after liftoff, the vehicle must be monitored in the event it is necessary to destroy it. Ground stations up and down range, and often around the world, track the vehicle. While this is going on, the launch pad is refurbished and made ready for another launch. Finally, on-orbit operations occur once the vehicle is in place. Figure 6 shows the flow of these activities as well as which ones may or do occur at the launch range itself. Throughout the process maintenance, upgrades, and training must also be scheduled and performed.

2.3 The Advent of RSA

Until Air Force restructuring created Air Force Space Command (AFSPC), the Air Force managed U.S. ranges at Vandenberg (VAFB) and Cape Canaveral (CCAS) had their own commanders, policies, procedures and equipment [42]. Essentially the two ranges were operating as two separate entities until being organized together under one unit in the early 1990s. Even today, there is little standardization between the two ranges, in spite of the fact that the two launch similar systems. This is partly because of the 40 years of independent evolution that the ranges have undergone and the geography of each range. For example, the fog at VAFB has driven a no optical visibility requirement there, but optics is a mandatory requirement at Cape Canaveral. Greater occurrence of storms cause a larger dependence on weather forecasting at CCAS, and on-shore flow at Vandenberg makes debris risk analysis more important there [27].

In addition, both ranges are still using equipment that was originally installed in the 1960s [18]. The low power command destruct used on John Glenn's shuttle flight in 1998 was the same one used on his Mercury-Redstone flight, for example. Additionally, until the 1980s when space commercial interests began to assert themselves, the ranges operated primarily to support military payloads. Concern about making U.S. ranges competitive in a global commercial launch market was never an issue. If the process worked well enough to meet necessary military requirements, then there was no need to change anything [19].

2.3.1 Need For Change

Today, almost half a century after space flight had become a reality, problems and concerns over U.S. launch ranges resulting from the environment in which they operated for so long (and other reasons which will be mentioned later in this section) have began to show up. Not only that, they have inserted themselves into a place of high national priority because of the ever-growing spacelift industry. The knowledge base is dwindling, requirements for specialized training needed to keep these obsolete systems running is expanding, and the Air Force estimates that there are in excess of 25,000 out-of-date range system components which cannot be fixed because there are no more spares [16:2-13]. Air Force Space Command has declared that "continued production, operation, and maintenance of [today's launch] vehicles are cost ineffective for two reasons: (1) escalating expenses associated with inefficient launch systems and their excessive infrastructure, and (2) outdated technologies, designs and manufacturing techniques [16:2-13]." These factors have led to supportability problems, reliability problems, and logistical support problems. All of this prompted the Air Force to undertake a major effort to overhaul the Spacelift Range System [4]. This was the genesis of the Range Standardization and Automation Program.

2.3.2 Development Falters

When development of the U.S. space program began, it was under the direction of some of the most brilliant scientists in America. Because of the fact that space was new ground, everything had to be state-of-the-art. They used the most advanced equipment of the day, and during the 1950s and 1960s due to the focus on the space race and on ballistic missiles, a great deal of money was being spent for Air Force, Army and Navy research and development in space [19]. In 1970, the Eastern range was considered to be the most modern of the two U.S. launch ranges, and at that time, it began to receive modifications to support the Space Shuttle. Prior to the Challenger disaster in early 1986, Cape Canaveral and Vandenberg were modernized only as they related to the Shuttle. The Western range at Vandenberg was given significant improvements since the Eastern range at CCAS was still fairly current due to the Apollo program [19]. After Challenger, the push was toward restoring the Shuttle to operational status and focusing more on the need for expendable launch vehicles that would have to be used in the mean time. The limited amount of funds available required prioritization of range needs and little was spent on range modernization. At the lower levels, money was spent only to keep systems functioning. It was decided that rather than make continuous improvements, the existing systems would continue to be kept in working order and little would be done to modernize [19].

2.3.3 *The Restructure Of Systems Command, Start Of RSA*

Prior to 1990, the operational portion of the Western Range was run by Strategic Air Command, with the Western Test Range falling under Air Force Systems Command and responsible for research and development. The Eastern Range was also under Systems Command as it, too, was considered a test range. In October 1990 all assets at both ranges were assigned to Air Force Space Command as part of Air Force realignment. Acquisitions for those ranges were moved to Air Force Materiel Command [19].

Because of outdated equipment and lack of spare parts for the systems that were currently being used, the Air Force wanted to update the communications backbone at Cape Canaveral, establish a new control center at Patrick AFB, and update the telemetry processing system at Vandenberg AFB. As different aspects of the ranges and parts of Systems Command were being reassigned, Space Command decided that it would like to standardize the two ranges as long as upgrades were being made anyway [22]. The idea was to save on design costs as well as have economy of scale; so all contracts were bundled together into a single project to bid to one contractor. What resulted was the Range Standardization and Automation Program Phase I (RSA I), to be carried out by the Harris Corporation.

In 1993, RSA I began, focusing primarily on the Eastern Range. The data, voice and video backbone at Cape Canaveral were upgraded, a dedicated wide area communications network was set up, as well as new networking systems and real-time and non real-time telemetry processing, display, and archival [19]. Harris tried to develop a unified tracking antenna for telemetry, communications, and radar, but was unable to make it work ($50 million overrun) [6].

2.3.4 RSA Today

In 1995, another phase of RSA was awarded to Lockheed Martin. While phase I was primarily intended to fix immediate and urgent needs for improvement at the Eastern Range, phase II was intended to be more proactive at fixing and identifying problems at both ranges. Specifically, RSA II is tasked with "architecting (sic) the first modern, automated and standardized range system, ever [18]." This new system, which is responsible for launch control over both ranges and public safety protection during the initial 5000 miles of flight, is called the SLRS or Spacelift Range System. The intent of the effort was to change the range launch operations concept and architecture to lead to a more efficient acquisition and presentation of information, centralize control of range operations, and automate range assets while maintaining an adequate level of safety [32].

RSA II is designed to rectify the following situations: unresponsive spacelift and costly, inflexible launch ranges. The following activities are planned: [16:4-6]

- Consolidate instrumentation using unified tracking antennas at remote tracking sites.
- Upgrade the Cape Canaveral communications backbone with a fiber optics network to allow redundant communications capability, increased data rate and bandwidth, and increased communications reliability.

- Build a centralized telemetry processing systems for both ranges, and upgrade the range operations control centers at the eastern (Cape Canaveral) and western (Vandenberg AFB) ranges.
- Upgrade imaging, surveillance, and weather systems.
- Upgrade debris tracking systems and multiple objects tracking radar (MOTR).

By making these adjustments, the Air Force is looking to reduce range configuration times, standardize range operations and architecture, eliminate in-house depot maintenance and fabrication, and update the 25,000 obsolete range components.

RSA IIA divides the SLRS into three main segments (Figure 7): control & display (C&D), instrumentation, and networking [16]. C&D provides for centralized archival of all data, control and display weather, infrastructure, planning and scheduling, range and flight operations and data product services. Main features of this segment include: common infrastructure, extensive use of commercial off-the-shelf (COTS) hardware, picture-in-picture video displays, standardized internal and external network interfaces, and a centralized network manager to enable operations from one console. The instrumentation segment deals with metrics, weather, telemetry, vehicle uplink, imaging and space objects. It will include GPS for metric tracking, mobile optics, standard imaging, and will balance the utilization of existing and emerging technologies. The final segment, networking, is responsible for data transmission, video, and network management. This segment will incorporate a synchronous optical network, data path redundancy, compressed real-time video, and modernized voice switching and communications panels. Under this new SLRS architecture, most operations personnel will reside in a centralized Operations Control Center and most maintenance personnel in a separate Maintenance Control Center [32].

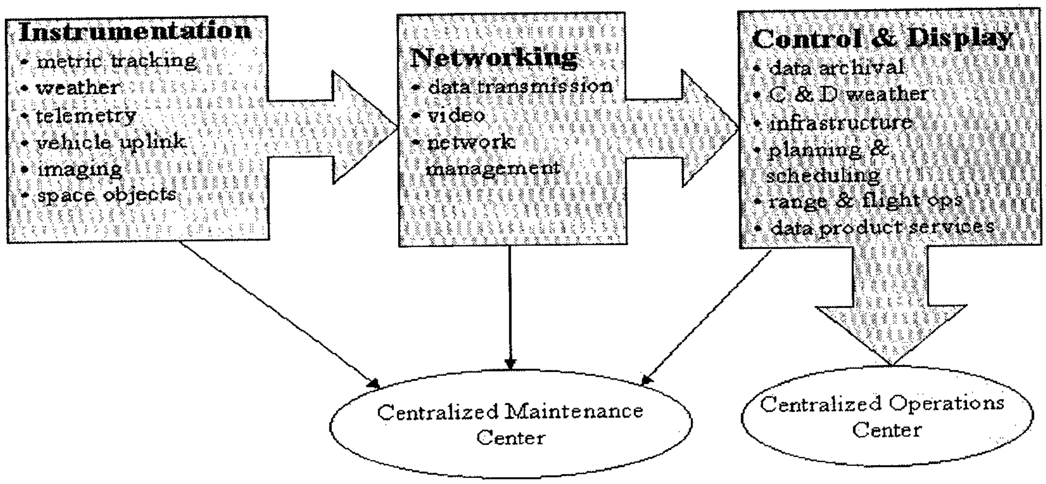


Figure 7 SLRS Basic Structure [32]

These improvements are to be delivered in six Range Delivery Increments each focusing on specific areas. The first two of which are in the process of being delivered as of the writing of this thesis [19].

2.3.5 Where Does Lean Fit In?

Since RSA is the future of the U.S. spacelift infrastructure, it is necessary to take care that it will be able to meet the ever-changing requirements of that industry. Not only should the technological improvements of American ranges be an important issue, but also the procedures for the launch process itself. Technological improvements and automation can, indeed, go a long way toward improving current cycle-times and infrastructure, but there may be fundamental problems in the process itself which need to examined and evaluated. Otherwise, the full potential of the ranges may never be reached. This could seriously impact the ability of the U.S. to compete in the spacelift industry internationally (world launch sites are shown in Figure 8) and continue to hamper initiatives to reduce costs per pound into space and turnaround times. Lean and the lean enterprise model can provide the necessary evaluation and implementation tools to enable perfection to be reached.

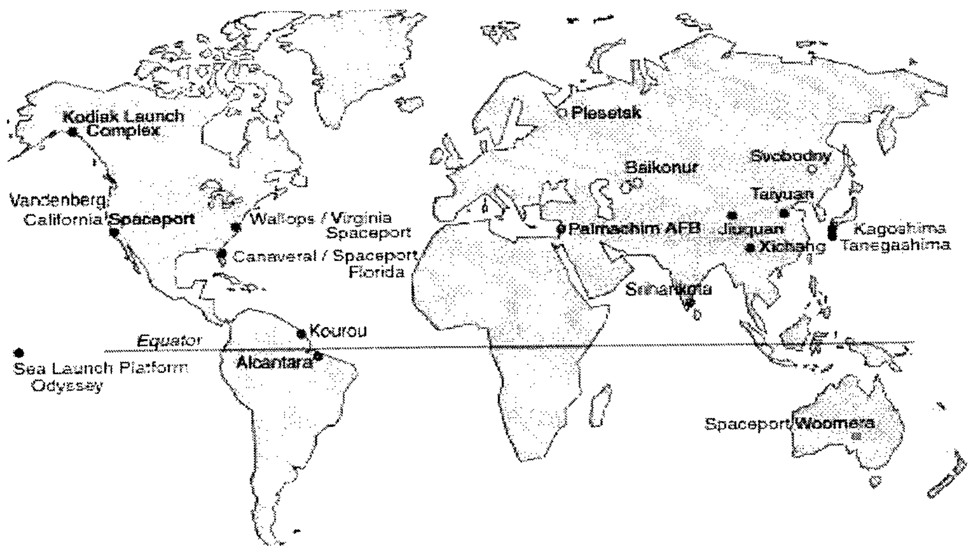


Figure 8 World Launch Sites [25]

3 Launch Operations

The effects of accelerated enemy research and development in preparation for war helped to create an opportunity for aggression which was promptly exploited. This lesson was the most expensive we ever had to learn. We must make certain that we do not forget it.

Agreement signed between National Advisory Committee for Aeronautics (NACA) and the U.S. services

It is important to examine the range itself before moving on. For the purpose of this thesis the term range or spacelift range (SLR) is not meant to refer to activities done on the range to prepare the vehicle itself for launch. It is meant to encompass the telemetry, radars, command destruct, instrumentation and infrastructure necessary to facilitate the actual launch itself and the operators, maintainers, and contractors that work in those areas.

3.1 Range Functions

The primary mission of the SLR is to facilitate spacelift operations [4:6]. It needs to support "sub-orbital launches, launch of vehicles into orbit and interplanetary space, test and evaluation of ballistic missiles, guided weapons, and aeronautical programs; space surveillance; and when requested, international launch activities [5]." In order to execute this mission the range must be able to protect the surrounding population, property, and for that matter, the environment from the hazards that are involved with launching a spacecraft. It also has to posses the ability to collect, process, and distribute necessary data to required areas within the range and to the customer. Essentially, the range provides launch facilities, safety for those facilities and during launch, command destruct, telemetry, optics, tracking and the maintenance of those systems [5].

3.2 Range Elements

The elements of the range consist of a range squadron, space launch squadrons, maintenance, and planning. Command destruct of the launch vehicle, radar and telemetry reconfiguration, and launch area safety are carried out by the military; for the most part, by the range squadron. The space launch squadrons provide oversight and engineering management for the preparation of the launch vehicles, which is carried out mostly by the contractor in charge of the mission. Maintenance, planning, scheduling, and training for the launch facilities and range operators are performed by a mix of military and government employees.

3.3 Space Launch Sequence

For a first-time mission, the flow of events through the SLR architecture for an expendable launch vehicle follows a particular path. This path consists of five main phases: planning, scheduling, pre-launch operations, launch operations, and post-launch operations [33:22]. Figure 9 depicts how those phases fit together.

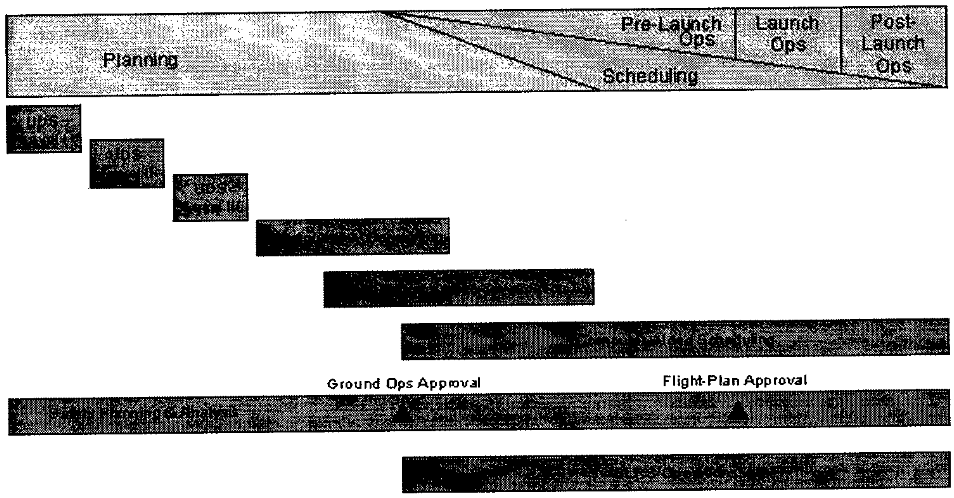


Figure 9 Expendable Space Launch Scenario [33:22]

3.3.1 Planning

Planning, in essence, is a matter of selecting enterprise objectives, and developing the policies and procedures and programs necessary to make them possible [20:519]. It involves decision-making and selecting between alternatives. If a project is not properly planned, it can be doomed from the start or lead to excessive time-consuming and expensive changes. At the space range, planning involves a number of activities and organizations both inside and outside of the range. It encompasses both broad and specific requirements for the execution of the mission. The typical lead time for missions performed at U.S. space launch ranges today for major programs involving range modification (such as Evolved Expendable Launch Vehicle) is from three to five years to around 60 to 90 days for some that are well established and that the range already has the capability to provide support [26].

The system used to provide the necessary paperwork and documentation for U.S. launch ranges is called the Universal Documentation System (UDS). UDS provides a common system for them to communicate requirements and determine capabilities in order for them to coordinate air, space, land, and sea efforts [26]. The UDS consists of three levels of documentation each composed of one part handled by the contractor and one part handled by the AF space wing.

Level 1 or the first series of documents involving a new launch program begins with a letter (not part of the UDS) submitted by the range user. This letter may not have a date, booster type, or payload specification. However, it serves to get the ball rolling on documentation as far as what might be needed in the way of systems or infrastructure and if the range can process the launch vehicle and meet those requirements [8]. This leads to a Program Introduction (PI) document, which is prepared by the range user [33:22]. This PI statement is then sent to XP for review and to enable the range to produce a Statement of Capability (SC) based upon basic requirements set forth in the PI [33:22]. This lets the user know if the range has the capability to provide the necessary services.

Approximately a year prior to launch, a Program Requirements Document (PRD) is prepared [8]. This is a detailed document that includes technical data and schematics [8]. The range user works in conjunction with a Program Support Manager (PSM) assigned to be their single point of contact with the range squadron [33:22]. The PSM is responsible for coordinating inputs from organizations around the range for the preparation of the other part of UDS level two, the Program Support Plan (PSP). This document is used by those range organizations for their own preparation and analysis [33:23].

The third level of the UDS is the most detailed. Operations Requirements (OR) documents are prepared by the user. This includes data on detailed vehicle design, trajectory data, on-board telemetry systems, and antenna patterns [33:23]. This information is the user input into the Range Safety Operation Requirements (RSOR) and establishes the necessary precautions and equipment needed to ensure a safe launch [33:24]. Finally, approximately thirty days prior to launch, an OD, or Operations Directive, is produced specific to each mission. This is done by the range squadron and serves, essentially, as the "launch bible" for that mission [8]. The entire UDS architecture is shown in Figure 10.

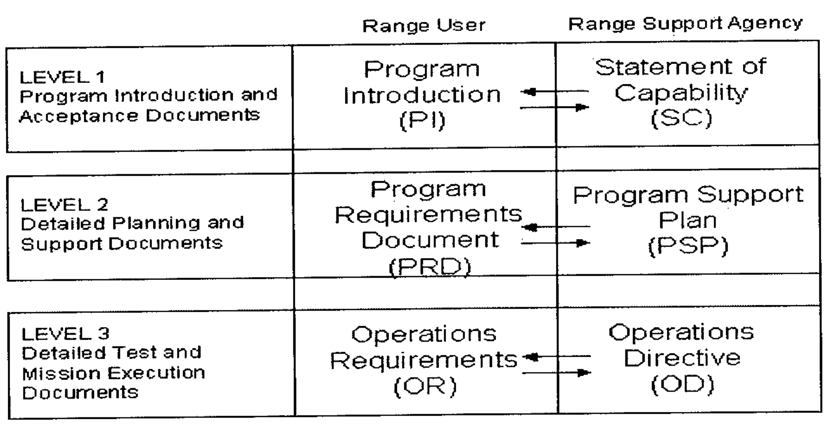


Figure 10 UDS Architecture [1:2-5]

3.3.2 Scheduling

As more and more specific details are provided, actual "operations" are scheduled based on the "pre-planned objectives, requirements, assets, configurations, and times" that are spelled out in the OD [33:25]. Scheduling is used by the range to control the operations that occur at the range and will be discussed further in the next chapter.

3.3.3 Operations Phases

Operations within the SLR occur in a series of three phases: pre-launch, launch, and post-launch [33:26]. These phases are described as generation, execution, and recovery in the Operational Requirements Document for the RSA program, and so this terminology will be used in this thesis. Figure 11 shows, in some detail, the launch operations process and how it fits in with planning and scheduling.

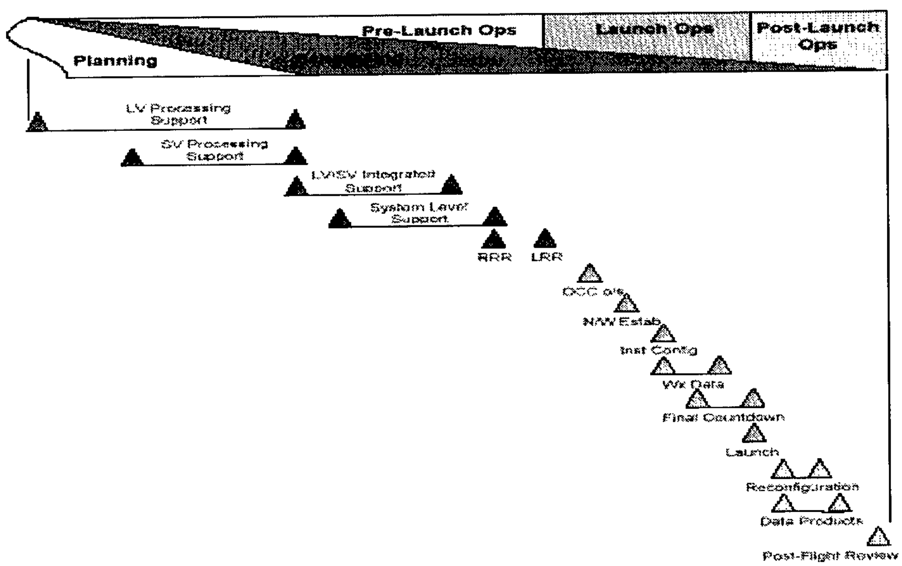


Figure 11 Launch Operations Process [33:27]

During the generation phase, planning and scheduling of launch activities, calibration and verification of the SLR and its subsystems for launch, and rehearsals and simulations for that launch occur. When the launch is executed, the range supports the necessary instrumentation, telemetry, launch countdown and tracking required for the particular mission. During recovery, securing and shutdown of the range is performed, launch data is archived as required, and post-operation analysis occur (see figure 12) [5].

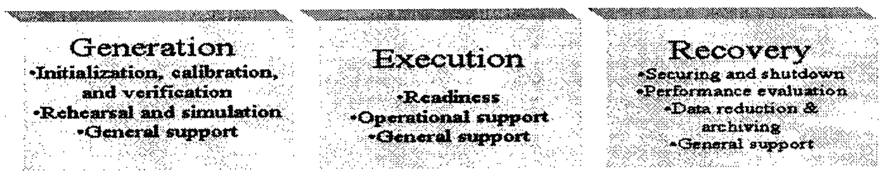


Figure 12 Range Operations Phases [5]

It is important to note the overall distribution of range needs for the entire launch cycle. Figure 13 displays the distribution of needs for U.S. ranges in the future. Planning and scheduling do not take up a relatively large piece of the chart shown in figure 13. They do, however, exert control, have effects on, or are affected by nearly all of the items mentioned.

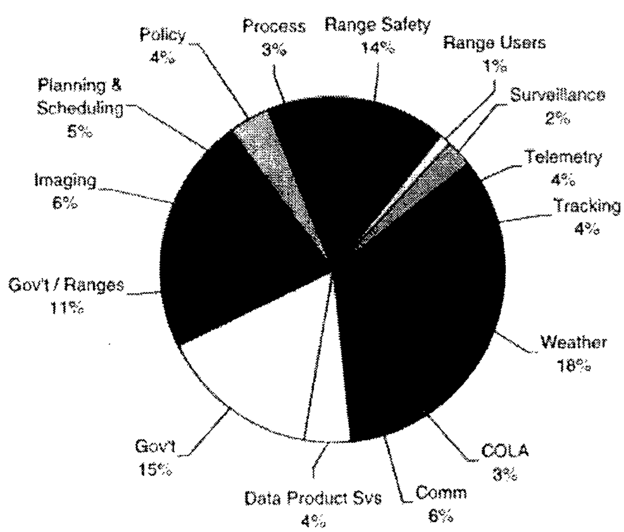


Figure 13 Distribution of New Range Needs [28]

4 Range Scheduling

We can lick gravity, but sometimes the paperwork is overwhelming.

Dr. Wernher von Braun

Utilization and effective management of resources in a process including time, people and materials is, understandably, an important issue for the success of that process. A good portion of that effective management is facilitated through proper scheduling, especially in today's changing and competitive commercial environments where it is necessary to continually seek "new and better control techniques to cope with the complexities, masses of data, and tight deadlines… [20:641]" Scheduling plays an important role in handling customer demand, controlling inventories, managing customer orders and requests, and enabling proper throughput through the process. All of these are areas where *muda* (waste) can occur and impede flow. These impediments will greatly affect the *takt* time, which sets the production pace to meet the demand of the customer. For example, if there is a demand for three launches each month from a given space range, the *takt* time is thirty days divided by three or ten days per launch. *Takt* time is the centerpiece of any lean system [45:310].

4.1 Why Look at Scheduling in Range Operations?

With regard to the operation of space ranges, scheduling also plays an important role. There are tests, training, maintenance and operations that must be tightly coordinated to ensure the most efficient use of range assets. Launch dates planned out and scheduled in advance may need to be changed for a number of reasons like weather, civilian traffic, technical delays and mechanical delays. The effects of these changes can have a cascading effect on any number of activities occurring at later dates. Because of this, process flow can suffer, as well as the schedule time for the system, thereby degrading capacity and responsiveness. Scheduling, as mentioned before, involves allocating resources and operations based on objectives, requirements, assets, and configurations determined to be necessary for various launch and training missions occurring throughout the range. Through the application of lean techniques, it may be possible to improve scheduling flexibility to better handle day-to-day operations and last minute changes.

4.2 Scheduling in General

We all know, just through what goes on in our daily lives, how difficult it is to coordinate a number of activities and responsibilities and get everything done that needs to be. One solution to this problem is to hire a private secretary to do all our scheduling and a chauffeur to whisk us around to all our appointments. For the majority of us, however, it is necessary to perform our own time management, prioritization, and transportation, and, if we're lucky, we may even get everything done and have an hour or two left over to fit in some sleep.

More often than not, something comes up that causes us to make changes in our plans. This typically results in a few phone calls to be made and a few eraser marks in our planners. When there is rearranging that must occur, this best case scenario is that we are able to talk directly to the person with whom we are changing our appointment to coordinate the necessary adjustments. Leaving a message on voice mail or e-mail or with someone else or talking to someone else who might not be completely "in the loop" can lead to problems, conflicts, or other complications. While effective scheduling may be difficult, it can be and has been done.

4.2.1 Berlin Airlift

A good example of lean scheduling, on the basis of continuous flow, delivery and production synchronization and using new technology to improve cycle times was the Berlin Airlift in 1948. After Russian forces effectively shut down all automobile and rail traffic to the Western sector of the city and refused to supply food to that area, U.S. military government in Europe and Great Britain decided that it would be necessary to mount an airlift of supplies [30].

On June 26, 32 USAF C-47s transported 80 tons of food from West Germany into Tempelhof Airport inside of Berlin. As the seriousness of the situation continued to escalate, additional aircraft (35 C-54 transports) from various locations in Alaska, Hawaii and the Caribbean were sent in to help out. This was effectively the beginning of the airlift. At that time it was code-named, Operation VITTLES. When it was obvious that the airlift would need to continue for some time the operation was renamed the Airlift Task Force and included both U.S. and British forces [30].

Five U.S. Air Force troop carrier groups, as well as U.S. Navy air transport groups and RAF transports were involved in the operations. The U.S. Military Air

Transport Service established ferry routes to fly air operations between Europe and repair depots in the United States. Daily totals of the tonnage transported by each group were published in newspapers distributed to airlift personnel in an effort to increase the levels of materials sent in [30].

A variety of planes were utilized, each according to its respective capability. The faster and larger C-54s were used exclusively in American sectors. C-82 “Flying Boxcars” from the U.S. were used to ship cargo too bulky for the 54s. The enormous C-74 “Globemasters” were used to bring in parts and engines for C-54s participating in the airlift to keep them up and running. Even B-24 Liberator bombers were converted and used to haul diesel fuel for English vehicles [30].

At Tempelhof Airport in Berlin, a Ground Controlled Approach (GCA) Radar system was installed to help better handle air operations. The new system made it possible to conduct all-weather operations. The led to the achievement of the world’s record (at the time) for GCA operations when in April 1949 during one six-hour period and average of one transport was brought in every four minutes [30].

Operations became more and more routine as the processes involved in the operation became well established. The flow of airplanes into the city was only hampered by icing in the clouds and other winter weather problems. Close scheduling of arriving and departing airplanes and the quick loading and unloading of cargo continued to improve. Unloading crews reduced the necessary time to service an aircraft from 17 minutes to 5 [3:6-3]. Turnaround time in Berlin was cut in half [3:6-3]. When the Russians finally ceased the blockade and the airlift officially ended in July of 1949, an unheard of 2,231,599.8 tons of supplies had been transported to the city over the course of less than a year [30].

The round-the-clock operations of the Berlin Airlift and the continuous flow of supplies that was achieve is an excellent example of what a "lean" scheduling operation might look like based on the Lean Enterprise Model. Delivery and production were synchronized throughout the value chain with the coordination of numerous organizations in different areas of the world. Continuous flow was orchestrated and coordinated through scheduling ground and air operations within Berlin. Ways to involve new technology to reduce cycle times and turnaround times were examined and implemented. Constant improvement was sought to make the airlift more successful and efficient. All of these are important aspects of the lean philosophy and way of getting things done.

4.2.2 Scheduling Addressed by Womack

Womack and Jones address scheduling in Lean Thinking, by illustrating a concept known to the Toyota company as "level scheduling [45:70]." This involves taking the orders for a certain part or product over a certain period of time and determining the *takt* times for each part and the changeover speeds necessary for the production of those parts. These figures are then used to produce a schedule for the time duration, which is then distributed to the areas involved in the production process.

Level scheduling can, however, find itself at the mercy of excessive inventories and unusual fluctuations in demand. The solution to this problem is to concentrate on keeping costs constant and produce only enough to meet actual need [45:82]. Long lead-times and flat demand can create a perceived volatility in a consumer market. There needs to be an elimination of lead-times so that "demand is instantly reflected in new supply... [45:88]."

4.3 Current Range Scheduling

Prior to the creation of AF Space Command and AF Materiel Command from Air Force Systems and Logistics Commands in the early 1990s, the two U.S. ranges at Vandenberg and Cape Canaveral were, in essence, autonomous units [34]. Thus scheduling, engineering, range operations, communications and all other range functions were under the control of the range itself. What made this desireable was that the scheduling department was able to talk directly to maintenance or operations or the customer to allocate range usage and make appropriate changes to the range schedule. It also made it possible to work conflicts out at lower levels of the chain-of-command [34]. Under Air Force Systems Command, the customer was able to come directly to scheduling with a conflict, which would then be able to provide the best solution and utilization of range resources [34]. What happened as a result of the Air Force reorganization was a fundamental change in the way scheduling was to operate and react to changes.

Under the new structure, AF Materiel Command, headquartered at Wright-Patterson AFB in Ohio, but with a space component (the Space and Missile Systems Center) at Los Angeles AFB, CA, was given control over the engineering and acquisitions aspects of the ranges. Air Force Space Command, headquartered at Peterson AFB, CO, was then responsible for the operations and maintenance and control of the range facilities themselves [26]. The ranges were restructured to mirror that of a "typical" Air Force wing. Maintenance was placed in the logistics group and the range squadron and scheduling were placed in the operations group all under the direction of a wing commander. As a result of this, scheduling operations became more involved.

In general, scheduling is done on a first-come-first-served basis, although scientific and national emergencies can take precedence. The WR range is typically running one shift, where two to three used to be used. This reduction was due to budget drawbacks. On the ER contacted work and unions place limits on shifts and work hours [11]. A master schedule for the ranges, the CSLRB, or Current Launch Schedule Review Board, is kept at Headquarters Air Force Space Command at Peterson AFB, CO. This schedule is user driven, but there can be problems getting on the schedule less than 90 days before launch [26]. It was initially necessary to go to HQ AFSPC to change launches, but that authority has come down to the wing commander level. After all the other ranges have been checked to approve a date and make sure they are available a request goes up to the respective wing commander for approval [34]. However, scheduling has already informally been committed for that launch before that approval.

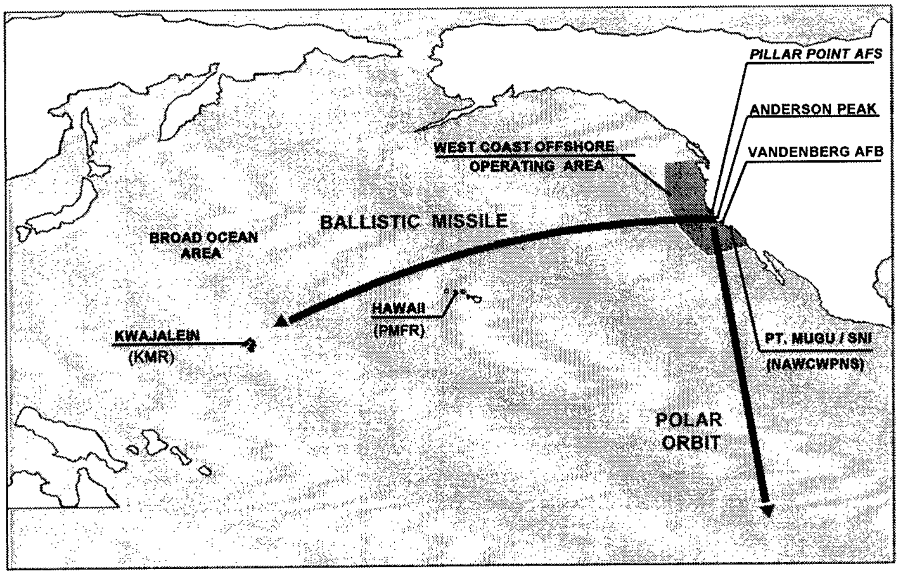


Figure 14 Western Range Geography [4:3]

4.3.1 Vandenberg AFB

The situation at Vandenberg AFB (see Figure 14) changed in a number of ways from the pre-AFSPC era. In order to get activities done, which used to be accomplished by coordinating between different organizations at the range, it now became necessary to go much higher up the chain of command. For maintenance, this meant going through the wing commander. For the customer, this meant going to the range commander, then to the maintenance commander and on up the chain until they could get the results they needed [34]. This type of action has been given the moniker "stovepiping." Much like the flame and smoke from a wood burning stove are forced to travel up through the stovepipe, so too were scheduling, maintenance, customers, and operators forced to travel up the stovepipe of the space wing chain-of-command.

With the increased difficulties in coordination and decrease in scheduling flexibility, a sort of "what if" scheduling procedure came about [34]. If maintenance personnel thought they might need to do some work on the range, they would schedule it. There might not need to be anything done, but it was easier to do that, than try to go up the "stovepipe" to get the necessary maintenance or upgrade time at the last minute. This also led to operations versus maintenance versus training time mentality within the range, each one looking to have priority over the other [23]. Giving operations priority can make it difficult to perform range upgrades and necessary maintenance. What has resulted is that there is an adversarial relationship between scheduling and maintenance, and built-in problems now exist with maintenance versus operational time [34]. In 1998 there were more than 60 days of dedicated downtime for maintenance [34]. Table 1 shows the maintenance summary for the WR in fiscal year 1998. Scheduling needs the flexibility to work around those downtimes and eliminate the need to close pads. That flexibility is no longer there [34]. Training takes its toll, too. Constant training requires three to four people to do the job of one person. You need a trainer, evaluator, someone to train, and, many times, the person who is being replaced. Range assets must be used and time must be blocked out where nothing else can be done [34].

Table 1 Western Range Maintenance Summary FY 98 [34]

Maintenance Action	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sept
Scheduled	394	372	319	339
Unscheduled	87	68	73	48
Modifications	26	23	19	35
Totals	507	463	411	422
Range Down Days For Maintenance	0	9	14	45

4.3.2 Cape Canaveral AS

Cape Canaveral has a slightly different role and situation in the U.S. range structure. There is a larger demand in the space industry market for equatorial launches and the Eastern Range at the Cape is where the United States performs those launches as shown in Figure 15. This places a greater burden on that range as far as resources and capacity are concerned. Cape Canaveral is busier than Vandenberg and therefore finds itself under tighter scrutiny and as the principle target for concern as part of the Space Launch Range System [17].

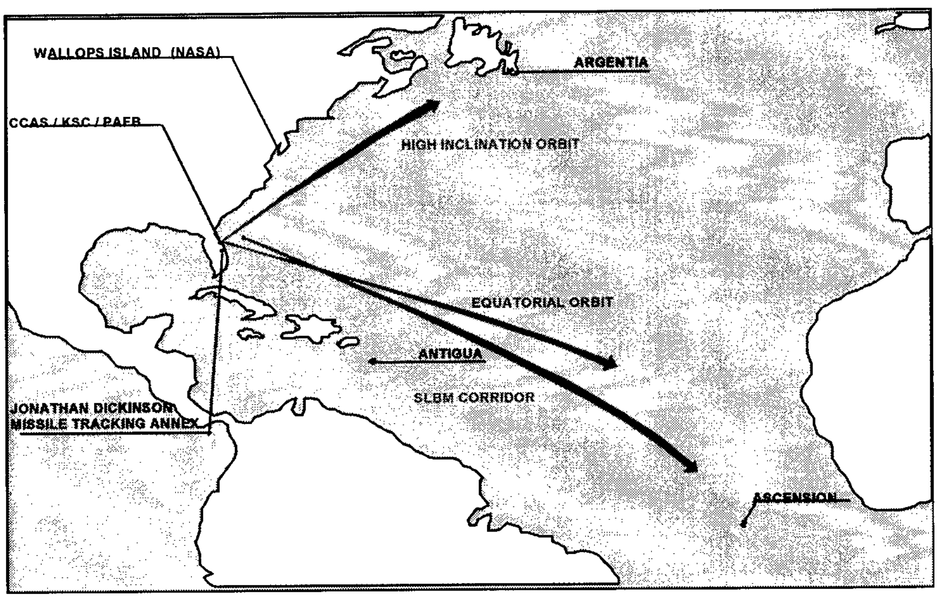
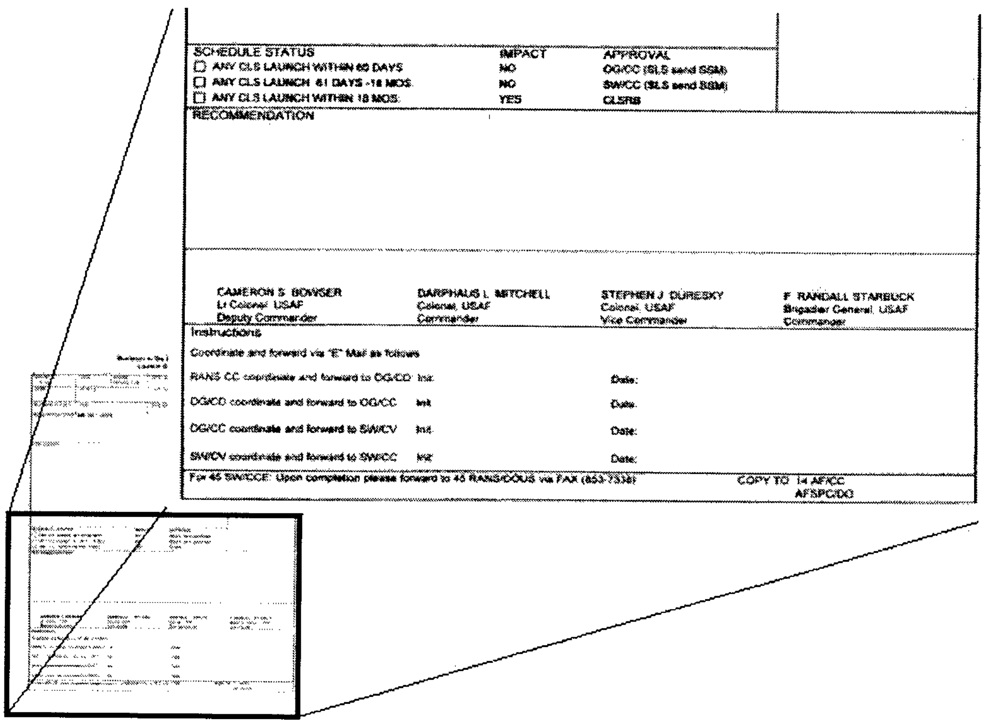


Figure 15 Eastern Range Geography [4:2]

Customer requests drive the scheduling process, and competitive urgency drives customers to stand firm on launch dates. The need for schedule and resource changes may arise on the range. When this occurs, the manual intervention of scheduling personnel is required to resolve these conflicts. In 1998, the Cape had 31 firings with 88 range calendar date changes [29]. A great deal of skill is required to handle these changes to maximize user access to resources and to persuade customers to trade off highly coveted launch dates [29]. Turbulence in the schedule can consume capacity and manpower. Routinely scheduled operations do not require approval outside of the scheduling organization. If the range is available, one can obtain a range requirement number and be placed on the schedule; however, launch date changes do result in a number of complications.



SCHEDULE STATUS	IMPACT	APPROVAL
☐ ANY CLS LAUNCH WITHIN 60 DAYS	NO	OG/CC (SLS send SSM)
☐ ANY CLS LAUNCH 61 DAYS -18 MOS.	NO	SW/CC (SLS send SSM)
☐ ANY CLS LAUNCH WITHIN 18 MOS.	YES	CLSRB

RECOMMENDATION

CAMERON S. BOWSER Lt Colonel, USAF Deputy Commander	DARPHAUS L. MITCHELL Colonel, USAF Commander	STEPHEN J. DURESKY Colonel, USAF Vice Commander	F. RANDALL STARBUCK Brigadier General, USAF Commander

Instructions

Coordinate and forward via "E" Mail as follows:

RANS CC coordinate and forward to OG/CD Init: Date:

OG/CD coordinate and forward to OG/CC Init: Date:

OG/CC coordinate and forward to SW/CV Init: Date:

SW/CV coordinate and forward to SW/CC Init: Date:

For 45 SW/CCE: Upon completion please forward to 45 RANS/DOUS via FAX (853-7336) COPY TO: 14 AF/CC AFSPC/DO

Figure 16 Form for Revision to ER Schedule [29]

Change requests must be submitted at least 30 calendar days prior to the launch date in question, or users run the risk of having their launch date made indefinite until approval can be obtained. Approvals must be coordinated through the Range Squadron Director of Operations, the squadron commander, the Operations Deputy Commander, the Operations Group Commander, and the Wing Commander (see Figure 16). The scheduling itself is done on the assumption that two launch attempts will be made available to the user, with the second attempt, if necessary, falling within a 24-hour period. Additional time can be taken and other accommodations made, but this must be negotiated with the range [2:7].

Typically at Cape Canaveral, launches occur on Thursdays, with preparation for launch (reconfiguration, setups, calibrations, certifications) completed on Monday, allowing crew rest on Wednesday; however, there is no date that cannot be a launch date. Sometimes preparation occurs on the day prior to launch. Checkouts and internal pad support are typically two days prior to launch. Training can also occur for missions other than the type currently being supported for launch [29]. The Range Operations Schedule is firm after a weekly scheduling conference normally held each Thursday morning [2:5].

Launch priorities are set up on a first-come-first-served basis. Operations priorities are usually set first. Planned maintenance typically is not considered critical enough that it cannot be rescheduled. However, equipment failures may take priority [29]. Inter-range support, worldwide communications, national urgency, space or scientific achievement and Department of Defense contingency exercises also figure heavily in the launch schedule [2:5]. Training occurs during the time remaining. Rehearsals for launch can also tie up a many range resources and involve a number of people. For most launches there are 2-3 significant rehearsals or combined system operations [29].

4.4 RSA Scheduling

The Range Standardization and Automation Program (both phases) is meant to build a system that is common at both ranges [34]. It also has the capability to automate a number of the tasks involved in the scheduling process. Planning and scheduling (P&S) is a subsystem of the RSA IIA architecture. This new architecture uses the NDI scheduling engine currently used by NASA to support Shuttle missions. As modified for RSA, it is known as the Scheduling Toolset for Automated Ranges (STAR) and incorporates additional commercial off-the-self packages to augment the basic engine currently in use [32:455].

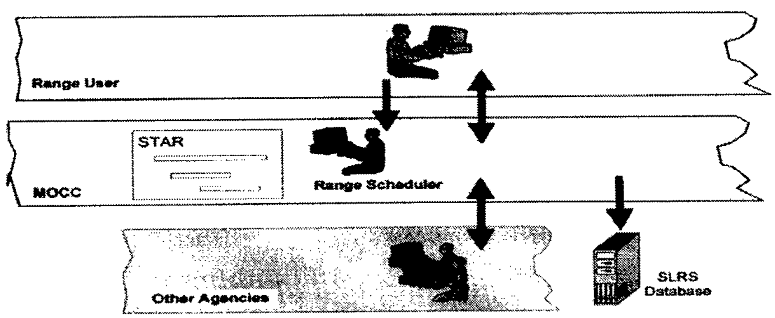


Figure 17 Computer-Aided Range Scheduling [33:25]

Planning data for each mission is fed into a common database for use by range users, planners, and schedulers as depicted in Figure 17. As each level of documentation is completed, the database provides that data, such as mission definition and requirements, to STAR. Weather information, range and flight operations information, and data from other analysis subsystems on the range are also fed into the STAR engine. The information and data are then used by STAR to automatically generate schedules, provide conflict resolution, and establish resource requirements. If a schedule change is needed, the database is updated and the Range Planner is notified [32:455]. Additionally, the programs used for user interface will be changed. This is to be a significant improvement on the Eastern Range [11].

The idea behind the changes and automation is to free up resources (people specifically) in order to better utilize existing manpower [29]. Standardization between the two ranges is also meant to reduce paperwork. For example, reports are currently unstandardized. Scheduling takes those reports from each range, looks them over, finds the differences, and then makes appropriate changes. Some of these differences between the ranges include how scheduling is approved, the roles of the various operations personnel, and variations between contractors and checklists that change from mission to mission [15]. Under the RSA architecture, STAR will be used at both Vandenberg and Cape Canaveral [34]. There will still be scheduled maintenance. Automated diagnostics and larger system pieces are meant to speed up repair. Regular and routine maintenance will be handled under operations, but repair of individual equipment items will still be performed by the maintenance squadrons under the logistics organizations [31]. Maintenance downtimes are to have the same priority as a launch [11].

As of right now, these changes to existing launch infrastructure are proposed. Seventy percent of the RSA IIA program has been officially contracted out. Most of RSA IIA has been re-scoped to a new contract, the Spacelift Range System Contract

(SLRSC). The new sustainment contract is to be let in March 2000 after the submission of this thesis, so it will continue to be referred to as RSA IIA here [27]. There is still some question as to what the actual modifications are going to be and what the new processes will look like once RSA is fully implemented. There is particular concern over how the transition between the current systems and the new architecture will be handled [15].

4.5 Range Scheduling From a Lean Perspective

We will now examine the process of range scheduling from a lean perspective. The first step toward making a process "lean" is to define the value stream. This, in turn, requires determining what is of value. The value of scheduling is for each organization or group being able to make use of range assets when required. Obviously, this is not always possible because another group may want to use the same resources at the same time, or some uncontrollable situation arises, such as interference in the launch area, bad weather, or some technical difficulty. At this point, it becomes valuable to be able to recoordinate schedules quickly to best utilize range resources and supply the user with the necessary resources.

The value stream in this process, which is essentially service oriented, flows between the customer and the scheduler in the range squadron. There must be open, two-way communication to establish what requirements are necessary for a mission and setting up and changing activities on the range. When conflicts arise between two organizations looking to use the same resource or time slot the value stream includes both parties involved.

In order to provide value to the range users, schedulers must have the ability to pull and allocate resources from the range. They must know what assets are necessary, who controls those assets, whether conflicts would arise by obligating those assets to a user, and who to go to resolve those conflicts. The schedulers should have that information at their disposal or be able to obtain it from the organization or person that does. It should then be possible to quickly reallocate those resources to the closest satisfaction of the users involved. It is this rapid reallocation or schedule rearranging that is the real measure of value in the range scheduling process. In its Range Integrated Product Team (IPT) report, Air Force Space Command mentions scheduling stabilization as part of a sensitivity analysis on range capacity. It proposes that a 30% reduction in schedule changes would result in a 5% increase in capacity [17:26]; however, applying this reduction would serve to limit customer flexibility and, therefore, customer value. The goal in improving the range scheduling process should not be to reduce the number of schedule date changes, but rather to reduce the time it takes to make those changes.

4.6 Are Current Processes and Procedures Lean?

The Lean Enterprise Model (LEM) provides the framework for moving organizations and processes in the defense aerospace industry toward becoming lean and consists of twelve key overarching practices. (A copy of the LEM in its graphical form is included as a fold-out in the appendix to this thesis) Since this is the benchmark used in making those processes lean, it is useful to examine some of those practices as they pertain to range scheduling. Three of the LEM's overarching principles will be examined along with some of their supporting practices. These three were chosen because they have the largest number of enabling practices that were easily identifiable and applicable to scheduling. Descriptions of how each of these practices pertain to range scheduling activities will be discussed along with current examples of their application in the defense aerospace industry. This is not to say that the remaining nine principles lack relevance in the area of range scheduling. Attention is given to them at the end of this chapter.

4.6.1 Identify and Optimize Enterprise Flow

This is the first overarching practice mentioned in the Lean Enterprise Model. The definition of this practice is to "optimize the flow of products and services either affecting or within the process, from concept design through point of use [12:9]."

4.6.1.1 Establish Models and/or Simulations

The first enabling practice under identification and optimizations of flow is the establishment of models and/or simulations to permit understanding and evaluation of the flow process. There appears to be little or no modeling at present or proposed under the RSA program to facilitate this. Currently, customers and users are able to view the schedule and are provided with documentation as to the processes and approvals involved in scheduling decisions and allocations. Under RSA and the new STAR system the customer does not have access to the system – only the schedulers have that access. The range operators and schedulers, and long time customers such as Boeing and Lockheed Martin seem to have a good understanding of the interrelationships between aspects of the range. New customers may find things very confusing. Flow charts and decision trees are available showing the requirements necessary to launch a payload from a given range, but the interactions and necessary relationships within that range are not clearly stated or visible. NASA has told range officials at Cape Canaveral that they would like to be able to send templates or scenarios to a knowledge engine that can let them know what can and cannot be done, and, what they must do to obtain range support [29]. There are no models or simulations in use to evaluate the effectiveness of this entire flow process.

Pratt & Whitney is currently making progress in this area within the defense aerospace industry by employing new software for finite capacity planning in its North Brunswick, Maine facility. The "Cellular Intelligent Manufacturing Production and Labor Enterprise Tool" (CIMPLEST) is used to evaluate capacity requirements according to labor, commodity code, and worker skills. This helps to quickly identify needs for resource reallocation, as well as calculate *takt* time [12:10]. This is similar to the resource allocation and deconfliction that the STAR system is to be used for under RSA.

4.6.1.2 Reduce the Number of Flow Paths

The number of flow paths in the scheduling process is kept to a minimum under current range structures. This enabling practice is, therefore, fairly well applied. Most of the scheduling deconfliction and allocation go directly through the scheduling department for customers and other range users. This should not change as RSA is brought on-line.

4.6.1.3 Reduce Setup Times

The next enabling practice is reduction of setup times. Actual turnaround time for pads, equipment, telemetry and other infrastructure at Cape Canaveral and Vandenberg is between 4 to 24 hours depending on the complexity of the systems being launched [7]. Different sizes of launch vehicles will have different specifications and reconfiguration times. This all has to be coordinated through scheduling for launches to occur. VAFB has approximately four tracking radars and a number of surveillance radars for safety reasons (to cover sea, land, and air space around the launch area). Radars can usually turn around in minutes to hours. Telemetry is slower (around 4 hours). In addition to radar and telemetry reconfiguration, new software and hardware needs to be up loaded. The consoles used by range operators are old and have links like the old-time operator switchboards. These links, too, have to be redirected for each launch because the contractor(s) specific to each mission will have its own control sites at different parts of the country, which may require different processors and different links [8].

Despite of the archaic equipment, the setup times are more than adequate for the demand, with plenty of capacity left over. What becomes a problem is the limit on the manpower available to perform these changes. With personnel draw downs, the range currently operates with one crew, and it is necessary for that crew to go on rest after each launch for a least eight hours because launches themselves last a number of hours. Then the crew can come back and reconfigure the range for the next launch. After that, another period of crew rest is necessary before the next launch preparation sequence can begin. The new "core crew" concept currently under consideration would have a smaller crew responsible for the launch and an additional crew which could do the reconfiguration while the core launch crew is on rest. That way, when they return a new launch sequence could start immediately [17]. The idea of the "core crew" and its purpose are lean improvements and are moving in the right direction. It offers a more effective use of time and manpower.

RSA also provides some relief in this area with the lean application of automation to the reconfiguration of equipment. A number of key automation initiatives will be utilized as follows:

- Automation of the range system initialization process and its inclusion into the range scheduling system
- Computer-aided configuration setup based on execution of predefined configuration control tables that establish required mission support
- Implementation of automatic fault detection/isolation
- Centralized planning and scheduling
- Automation of operational equipment initialization, configuration control, calibration, and testing that verifies establishment of a proper range/user mission support configuration [32:525]

These changes and automated improvements are expected to help the ranges do more with fewer people. They are a step in the direction of becoming lean, since they simplify the processes of reconfiguration and scheduling of range assets through the use of existing technology.

These improvements and automations should alleviate another impediment to flow at the ranges – "lockouts." A verification and validation is performed on each mission. Tests are scheduled 2-3 days before launch or major operation to make sure everything works. Verifications are then performed the day before. With some large or complicated vehicles, such as Titan, the launch agency will request the range to be "locked out" from that point until launch to make sure that nothing gets changed. This effectively shuts down the range for that period of time [11]. This is a serious impediment to the flow of the launch process and adds little or no value.

The major reason for the lockouts is that range configuration is a complicated process and equipment is very touchy. The user is concerned about breaking the configuration and having to perform re-verification [11]. This, in turn, could lead to launch delays. With the newer, automated equipment to be delivered with the RSA program, this problem should be alleviated. There will no longer be the need to manually switch cables, circuits or connections, and the equipment should not be as susceptible to failure. This increased robustness should eliminate the need to lock out the range.

There has been some concern expressed over the new STAR system for the automation of schedule allocation and deconfliction. The ability to reschedule is not expected to be as flexible with the new system. More steps are needed to do the same activities and the interface is not as user-friendly. The center where the changes are being developed is in Houston. There will be no real-time capability to change code in the software, whereas before, it took only a phone call [34]. With the manual intervention that is sometimes required in resolving conflicts between organizations looking to use the same launch date or resource, there may also be problems with using an automated conflict resolution system, especially in a service-oriented process such as launch scheduling [29]. Likely, the biggest advantage of using STAR will be the timely identification of conflicts, which would facilitate quicker solutions to those conflicts.

4.6.1.4 Maintain Equipment to Minimize Unplanned Stoppages

Another of the key enabling practices in identifying and optimizing enterprise flow is the proper maintenance of equipment to minimize downtimes and stoppages. Preventive maintenance of range equipment includes inspection, cleaning, mechanical adjustments and alignments, electronic/electrical adjustments, etc [31]. Older equipment requires constant "tweaking" to keep it running. These adjustments have driven the replacement of older systems with newer equipment possessing better operating capability and requiring fewer preventive maintenance actions. This will continue to be the case as more and more RSA systems are brought on-line. Currently, range equipment has few self-diagnostics and built-in test equipment [31]. This too, will begin to change. Preventive maintenance is performed by technicians on-site and by operator/maintainers [31]. These preventive maintenance requirements have decreased as more and more new equipment is introduced. These practices are similar to lean initiatives being used by Pratt & Whitney as part of its Total Productive Maintenance (TPM) program. TPM improves equipment performance and brings operators into the maintenance process. TPM involves initial cleaning and inspection, daily operator walkarounds and equipment checks, keeping records of down time, failure history, machine capability, and routine scheduled maintenance performed by either operators or maintenance personnel [12:19].

However, routine maintenance actions have been having a smaller and smaller effect on scheduling at the ranges, with very few occasions occurring where launches have been scrubbed due to an equipment failure just prior to launch. The main driver for those few scrubs is the redundancy of systems on the range [31]. Figure 18 shows how maintenance actions have decreased at Cape Canaveral as newer equipment has been introduced to the range. Depot-level maintenance (DLM) is where the largest amount of interaction happens [31].

Depot-level maintenance, for the most part, is a scheduled activity. It involves both preventive and corrective maintenance that is performed by an agency outside the range because of special skills, knowledge, or tools required. At Cape Canaveral, DLM is performed at the range. In the event that it cannot be handled at CCAS, the part must be handed over to maintenance, which in turn hands it over to another depot, located in Sacramento or Wright-Patterson AFB, OH [31].

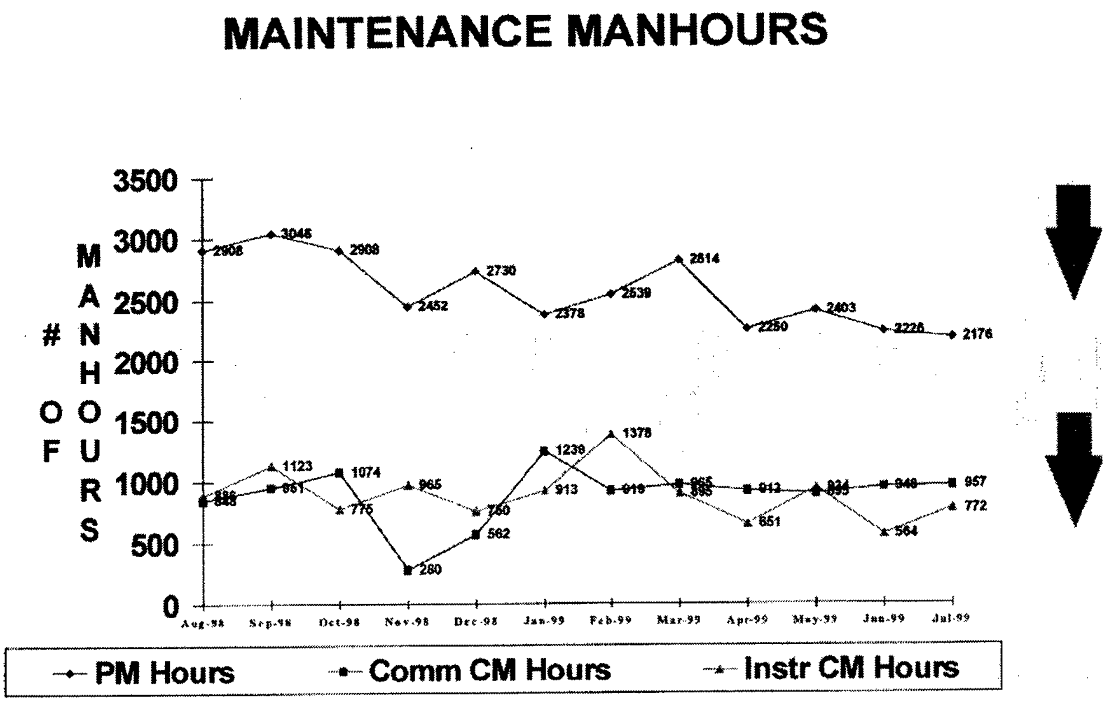


Figure 18 Eastern Range Maintenance Actions [31]

RSA will not fundamentally change the process of handing off equipment for major repairs. There will still be scheduled maintenance and all equipment will still fall primarily under the operations group. If a system has a failure, it will be troubleshooted by an operator/maintainer and performs necessary on-equipment maintenance activity. Any reparable part removed as part of these repair is sent to the vendor or depot for further action. To do serious repairs, the item will still have to be turned over to maintenance and so on [31]. In that sense, there still are problems with the process. Equipment that requires work beyond what can be repaired at the range can pass through a number of organizations and be taken to other areas of the country. These actions do not add value and should be looked at even though their occurrences are few.

RSA does make some strides, however, toward getting equipment repaired more quickly and back on-line for scheduling and operations. The items are going to be larger and replacements done on a sub-system level. The use of these larger parts is meant to speed up the repair process [31].

4.6.2 Assure Seamless Information Flow

Another important practice identified by the LEM is the assurance of seamless information flow. It is necessary to "provide processes for seamless and timely transfer of and access to pertinent information [12:21]."

4.6.2.1 Minimize Documentation While Ensuring Data Traceability and Availability

Progress has been made under the current range structure in reducing the approval times. Informing the various people throughout the wing at Cape Canaveral AS used to be performed through a staff summary sheet, containing the purpose, background, and other information regarding the change. The typical time taken in the process of contacting all of the people involved was approximately one week. The use of electronic forms has brought this down to 3 days [29]. It is much easier to receive and pass on responses from the parties involved using the computer, and the physical hand-off of paperwork is no longer there. This is definitely progress toward minimizing documentation while ensuring necessary data traceability and availability.

An example of a lean practice similar to this being preformed in the defense aerospace industry is Northrup Grumman's AutoBuy expert system. This system will automatically create requisitions for all requirements, check residual materials across all

Northrup Grumman sites, schedule deliveries based on build scheduling, approve requisitions based on set criteria, and create purchase orders for master agreement parts [12:28]. The expected benefits are reduced manpower requirements and reduced quote cycle time to "0" days with minimum documentation [12:28].

Opportunity for application of this enabling practice concerns the forms used by both ranges in the course of scheduling actions and launches. It was previously noted that differences in forms continually need be reconciled, even though they contain the same essential information. There is no value added to the process by continually having to take the time to resolve these differences. Standardization of the documentation and forms between Vandenberg and Cape Canaveral could eliminate that particular impediment to the process flow. RSA Phase IIA does take steps in that direction with its centralized documentation and database systems for the entire spacelift range structure.

4.6.2.2 Link Databases for Key Functions

Under the new RSA structure, centralized archival of data will be utilized, so that information will be more easily shared and accessed across the range [32:7]. Additionally, the optimum control and display solution calls for integration of information across all range functional areas necessary to perform and support the generation, execution, and recovery of missions [32:13]. STAR will allow the scripts associated with scheduled range operations to be automatically updated as the need arises and that information can be retrieved through a metadata search engine [32:15]. These changes go a long way toward linking databases for key functions throughout the value stream. Standard computing environments with proven commercial off-the-shelf (COTS) software are also to be facets of the new system [32:17].

Again, a current industry example of this practice is Northrup Grumman's Integrated Management Control System in Rolling Meadows, Illinois that incorporates planning and procurement systems, shop floor control, and quality systems. Shop support (engineers, planners, expediters, etc) have been reduced 48% in spite of a three times increase in shop orders and stock levels [12:26]. Textron Systems in Wilmington, Massachusetts has also been developing a company-wide database system, with common software standards to help increase the performance of its existing programs [12:26].

4.6.3 Make Decisions At Lowest Possible Level

This key overarching practice has particular application in scheduling where approvals are often necessary for changes. The objective of the lean philosophy is to "design the organizational structure and management systems to accelerate and enhance decision making at the point of knowledge, application, and need [12:37]."

Two of the main aspects of this overarching practice are empowering people to make decisions at the point of work and minimizing hand-offs and approvals (see Appendix). In the case of scheduling changes, there is a multitude of approving officials sandwiched between the scheduling department and the ultimate decision making authority, the wing commander. For initial placement on the schedule there is no long line of people necessary to sign-off. The scheduler is authorized to handle that.

Under an Air Force wing structure there are certain protocols and channels that must be used, so it is not hard to understand where the long list of approving officers comes from. Partially, there is the desire to limit any frivolous or excess paperwork ending up on the wing commander's desk. This is understandable. There are also times when conflicts exist which cannot be resolved satisfactorily by the scheduling department, and arbitration from a higher authority, such as the wing commander, may be needed.

From the perspective of lean, however, there is no value added by including many people in the approval chain for scheduling changes. If the range scheduler is able to identify and find an acceptable solution to the allocation and deconfliction of range assets, is it really necessary to involve the entire command authority at the range – especially when this authority is not needed for routine additions to the schedule?

The Air Force has recognized that these practices and approving actions are not benefiting the scheduling process or the cycle-times for launches. In its Range Integrated Product Team report on range user-friendliness the Air Force stated that "existing wing processes, used to schedule, reschedule, or cancel launches with the wing-delegated authority, are too slow." It mentions that the necessary actions can take weeks to become final even for routine requests [17:9]. Table 2 summarizes some of the enabling practices and suggested metrics for the LEM principles that have been mentioned in this thesis.

Table 2 LEM Practices and Metrics for Seamless Information Flow, Optimizing Enterprise Flow, and Making Decisions at the Lowest Level

Enabling Practices	Suggested Supporting Practices	Suggested Metrics
• Broaden jobs to facilitate the development of a flexible workforce	• Broaden jobs of range operators and other workers to include the ability to perform routine maintenance and turn around (this is currently being done)	• Output/employee • Certifications/qualifications per employee
• Build stable and cooperative relationships internally and externally	• Focus on relationships not only with well established customers, but also first-time customers	• # of new customers • # of years relationship with customers
• Provide for continuous information flow and feedback with stakeholders	• Provide for continuous information flow and feedback between scheduling, customer, range organizations, and range command authority	• Time for information retrieval • Stakeholder access to range information
• Assure consistency of enterprise strategy with "lean" principles and practices	• Assure scheduling strategy is consistent with lean principles and practices • Assure range strategy is consistent with lean principles and practices	• Lean metrics in scheduling • Lean metrics within the range
• Provide for an interchange of knowledge from and within the supplier network	• Provide for an interchange of knowledge between scheduling, customers, and range organizations • Provide a common location for stakeholders to access information (already being done and is planned for under RSA)	• Information database • Use of "lessons learned" system • Provision of training programs for new and existing customers
• Define and control processes throughout the value chain	• Define and control processes involved in range scheduling	• Software productivity • Employ lean practices in scheduling
• Level demand to enable continuous flow	• Level launch demand and need for scheduling actions to enable continuous flow	• Launches/time period
• Minimize cycle-time to limit susceptibility to externally imposed changes	• Minimize times required to perform scheduling changes and deconflict range assets	• Time required to make changes to schedule or deconflict assets
• Structure programs to absorb changes with minimal impact	• Structure range scheduling change and deconfliction mechanism to min. capacity loss	• # of scheduling restructures • Impact of changes on future launch dates

While these metrics cover, for the most part, the LEM practices of making decisions at the lowest level, assuring seamless information flow, and making decisions at the lowest level, there are certainly other aspects of the LEM that can be applied to range scheduling. Table 3 examines some of them.

Table 3 Other LEM Practices and Metrics

Enabling Practices	Suggested Supporting Practices	Suggested Metrics
• Establish models and/or simulations to permit understanding and evaluation of the flow process	• Develop templates and scenario generation for launch scheduling and resource allocation • Allow customers continuous access to scheduling system	• Model/simulation software • Online/available scheduling information
• Reduce number of flow paths	• Reduce the number of personal contacts necessary for the customer to get scheduling information and request changes	• # of people stakeholder must contact to get information/request changes
• Reduce setup times	• Reduce range setup times • Reduce range reconfiguration times • Eliminate range "lockouts" • Reduce deconfliction times	• Setup time, reconfiguration time • Automation of range configuration • Manpower usage • # of range "lockouts" • time from identification to deconfliction/resolution
• Maintain equipment to minimize unplanned stoppages	• Maintain range equipment to minimize unplanned stoppages	• Lost capacity due to unplanned depot level maintenance • # of maintenance actions
• Minimize documentation while ensuring necessary data traceability and availability	• Minimize paperwork necessary for scheduling changes • Automate form generation • Standardize paperwork for scheduling	• Use of electronic communication and documentation • Rework time for documentation conflicts
• Delegate or share responsibility for decisions throughout the value chain	• Delegate approval authority for routine scheduling changes • Allow stakeholders access to scheduling information and data archival	• # of approving officials for scheduling actions • stakeholder access to necessary information
• Minimize hand-offs and approvals within and between line and support activities	• Minimize hand-offs for scheduling actions • Allow scheduling authority to deconflict problems	• # of hand-off required for authorization • # of organizational levels

5 Recommendations

The voice of great events is proclaiming to us, Reform, that you may preserve.

Thomas Babington Macaulay

As evidenced in the previous chapter, there are a number of potential areas for the application of lean throughout the range scheduling process. The question now arises as to what should be changed or left the same in order for scheduling to become more lean and move toward perfection.

5.1 Organizational Structure

Operational problems, for the most part, are caused by the inherent organizational structure of the range system, and this is difficult to change. The typical Air Force wing structure is a vertical organization with a strict hierarchy. This is the nature of the military organization. With this structure come additional layers of management that can slow decision-making at times [10:76]. Downsizing in the military has not changed the fundamental way that the ranges do business in spite of the increased productivity required from remaining resources.

There are a number of commercial organizations that are looking to "flatten" their management structures. Not only does this have the intention of improving speed and efficiency (by reducing the need for managing relations between departments and relaying information up and down the hierarchy), it focuses more of the company's resources on the customer [10:77]. Ryder System, for example, had been organized as a vertical organization with divisions based on a specific product. The company wanted to organize itself in such a way that it could reduce overhead and improve its ability to respond to customer needs. At the time, to purchase a vehicle for leasing, it was sometimes necessary for 14 to 17 document handoffs from one functional department at one level of management to another. Ryder began viewing this paperwork flow as a single process starting with the actual purchase of a vehicle and ending with renting it to the customer. By eliminating unnecessary approvals, and moving authority to lower levels of the organization, Ryder was able to cut handoffs from five to two and reduce its purchasing cycle by one-third [10:79].

Other major corporations have also been making the move toward "flattening" their organizations in order to improve operations. General Electric's lighting division has eliminated its previous vertical management structure in favor of a horizontal design with over 100 processes and programs [10:78]. Their attempt to develop a "boundaryless" company has reduced cycle times and costs and increased responsiveness. Eastman Chemical, a division of Kodak eliminated senior vice-presidents for administration, manufacturing, and research and development and replaced them with self-directed teams. Lexmark International also moved toward cross-functional teams and reduced 60% of its managers in manufacturing and support [10:79].

The wing organization at each range should conduct a value stream analysis of its schedule modification approval process. It should be determined which approving officials actually add value. After this is performed, consideration should be given to approvals that can occur in parallel rather than in a series. It may also be possible that there could be a routing of necessary approvals to various officials on a case-by-case basis.

5.2 Automation

The Range Standardization and Automation Program provides an excellent framework for incorporating new technologies and automation to make information transfer, archival, and generation easier. This is necessary for becoming lean and for competing with newer launch ranges. Even though current, aging systems continue to provide adequate support for launches, they are gradually becoming increasingly problem prone and unresponsive. If demand continues to increase in the space launch industry, it is likely that users will go elsewhere to get the support and services they need. RSA is an essential upgrade and restructuring for the Spacelift Range System.

5.2.1 Information Management & Communications

Cape Canaveral and Vandenberg should use these technological upgrades, such as fiber optics, communications, computer, and data retrieval technologies, to make the launch process as easy and expedient as possible for the customer. Enabling the customers to have timely access to as much information as possible, should be a central focus. The concern should not be simply with the range functional areas. As previously mentioned, RSA does not give customers access to the system. It will be more beneficial to the customers to have the future systems web-based. This is an excellent place to start improvements. Continuous information flow and feedback with the customer regarding requirements generation, product development and solution-based problem solving is a must within a lean enterprise and new technologies are providing innumerable avenues to exploit this. Every possible effort should be taken in order to do so. The Internet, e-mail, and high-speed computer networking, for example, can provide almost instantaneous feedback and information transfer.

5.2.2 Equipment Reconfiguration

Range lockouts must be eliminated. They stick out prominently as *muda* and are a serious roadblock to the launch flow process. Because of this, it becomes a problem for scheduling of range assets. Unavailability of some communications, instrumentation or other equipment even when they are not being used is unacceptable. The RSA program should alleviate this with its improvements and upgrades to infrastructure. Equipment should be easier to reconfigure, it should be less "touchy" and more responsive. These enhancements must be exploited to eliminate unnecessary downtime to range assets and impediments to process flow. Activities that can be automated, such as radar and telemetry reconfiguration, must be automated in order to make them as lean as possible. The ability to remotely or electronically configure assets on the range is a significant "lean" advantage since it uses existing technology to reduce the times necessary to complete such activities. Additionally, the chances of errors in the configurations will be reduced. RSA can and should eliminate the need for lockouts.

5.2.3 Maintenance

Routine maintenance is continuing to improve, mostly because of new equipment being incorporated into the range. This new equipment will not require the adjustment that older equipment does, such as the switchboard style connections for older operator consoles. While replacing out-of-date systems is certainly a good thing, it is not a permanent fix. Eventually, even these new systems will become less robust to work with. It is important to make sure that the leanest system possible is in place for depot-level maintenance, whether it be programmed or due to equipment failure. The latter type of maintenance has the greatest effect on scheduling and range downtime. The new infrastructure under RSA is to have larger equipment items and, therefore, make replacement and diagnostics easier. The ability to perform depot-level maintenance at the range itself is "lean", since distances and times for transfers of equipment are minimized as opposed to having to send the part to another portion of the country. Multiple transfers and off-site DLM can occur, however and this should be examined as part of the maintenance value-stream. The use of larger equipment pieces is an also an excellent idea and should be continued as planned. The process involved in depot-level maintenance should be examined to determine the entire value stream. Once this is done, changes can be made to eliminate impediments to flow. As more areas of range operations become lean, and turnaround times and launch rates improve, a continuously operating range becomes even more critical.

Using operators as maintainers is another excellent lean tactic. The efficient use of manpower is a principle of lean thinking. Training operators to provide routine maintenance on equipment provides for this and is a practice that should be continued. Remote maintenance and self-diagnostics on range equipment will also save man-hours. This, too, should be considered when implementing automation in the new Spacelift Range System and made a part of any future launch infrastructure.

5.2.4 Automated Scheduling Systems

From the lean perspective, the STAR automated improvement makes sense. Recognizing conflicts automatically and providing possible solutions saves time and effort on the part of the schedulers and makes use of existing technology to improve flow. However, there are some aspects of STAR that might not improve the process. The system interfaces are not as friendly as before and the actual schedulers who would be using STAR were not consulted regarding the type of user interfaces that would make their job easier and provide them with the most value [34]. The ability to make real-time changes to the source code will also be missing, when previous types activities only required a phone call [34]. Conflict resolution between companies and organizations involving launch dates often requires face-to-face or other direct human intervention. Identification of these conflicts as early as possible can reduce subsequent problems in the scheduling process, and the STAR system is supposed to do that very well; however, deconfliction of range assets may not be the best candidate for automation. Automatic deconfliction can lead to more work for the schedulers to undo. This is part of the scheduling process may best be left to human intervention.

STAR is an excellent improvement and should be implemented, provided it is used primarily for identifying scheduling conflicts or fixing minor problems. Larger conflicts such as schedule date changes should not be automated. It is not necessary or desirable to have full automation, but partial automation is a definite improvement. There also needs to be the ability to make real-time changes to the source code in the STAR software. This is a capability that is not there. The addition of scenario generation software is an additional lean improvement to scheduling and should be a priority to enable more expedient deconfliction of range assets.

5.3 Integrated Product and Process Teams

Another important facet of lean is the use of integrated product and process teams. The use of these types of teams is not exploited in the scheduling process. Instead of allowing an adversarial relationship to develop between maintenance, operations, and even between contractors, teams could be used to help range schedulers allocate range assets. Not only would this facilitate more expedient resolution of conflicts, but it would provide more visibility to the entire scheduling operation to the stakeholders. IPPTs should be implemented in range scheduling operations.

5.4 Primary Value

Overall, the most important metric of the U.S. launch range scheduling process is the time it takes to recognize and resolve changes and conflicts. Changes to the range schedule and allocation of assets are inevitable. Trying to eliminate or limit the number alterations does not provide value to the range customer or user, especially with the complexity of the launch vehicles, payloads and infrastructures. The ability to quickly react to and implement these adjustments will be of the most value to the range and its customers. This is what range scheduling and the range itself needs to be striving for, and this involves open communications for all stakeholders and user access to necessary information. This needs to be a top priority.

5.5 Additional Topics For Study

In addition to range scheduling, there are a multitude of activities at the range and regarding range operations that lend themselves to lean examination.

1) *Planning.* Planning involves the coordination of range assets throughout the entire time the launch vehicle or payload is at the range. As mentioned before, prior to the move from Air Force Systems Command to Air Force Materiel Command and AF Space Command, the range had engineering, acquisition, and development as well as operations under its direction. After the split, the engineering, acquisition and development were placed under AFMC and the operation of the ranges was given to AF Space Command. Whereas the wing commander used to have operations and engineering working directly for him, they are now in different commands. If the range has a deficiency or can't provide some sort of support to the user, a deficiency statement must be written. It then has to be approved locally and at AFSPC even though the user might be the one paying for it. Once this is approved, an engineering statement is developed for AFMC who comes back with an estimate and requests the money. Logistics deals with the deficiency statements, so the range does not interact directly with AF Materiel Command. It is necessary for the range to go through maintenance. The range is no longer a whole entity and once again, there may be "stovepiping."

Another issue regarding turn around times is the OD. Because each mission and vehicle has unique requirements Directives can very greatly between successive launches. It takes time for the range operators to go over this document and become familiar with it so that they can control the launch. This can involve anywhere from one to two weeks and possibly affect cycle times. The use of a standard launch vehicle, such as the Evolved Expendable Launch Vehicle (EELV) may make strides toward improving this situation.

It may also be useful to examine the process involved in the interaction between the contractors and the wing or range when it comes to the planning of various missions, from the time the customer comes to wing plans with a requirement or need to the generation of the Operations Directive. How many different people does the customer have to contact over the course of the vehicle or mission lead-time, which can be around 3 years? This number should be minimized. How do changes in mission requirements affect lead times, especially with regard to documentation? A "one-stop shop" has recently been attempted at Cape Canaveral where the customer only needs to deal with a single person at the wing plans department to take care of questions and other needs. This is a significant "lean" improvement. The use of Integrated Product and Process Teams (IPPTs) could provide additional value to the customer and improve the process.

2) *Training*. Currently, most training for range operations requires dedicated range time. Vandenberg did recently install a training consol of its Range Control Officers and Range Operations Controllers that would not require shutting down the range. Also, there is the issue of how training will work between the two ranges as the equipment becomes standardized with the full implementation of RSA.

3) *Manpower Usage*. With personnel draw downs, the range currently operates with one crew and it's necessary for that crew to go on rest after each launch for a least eight hours because launches themselves last a number of hours. Then the crew can

come back and reconfigure the range for the next launch. After that another period of crew rest is necessary before the next launch is able to start. The new "core crew" concept currently under consideration would have a smaller crew responsible for the launch and an additional crew which could do the reconfiguration while that core crew is on rest. That way, when they come back and a new launch could start immediately. There is also the idea of having a maintenance crew that works maintenance most of the time, but could become operators during launch time. It would be useful to determine the use of launch personnel that adds the most value to the launch process.

4) *Maintenance and Safety.* Maintenance and safety procedures could be more closely examined to see where lean applies along with any increases inflexibility as a result of new communications, telemetry, tracking and control infrastructure.

5) *Launch on Demand.* There can often be long call-up times for replacement satellites. The launches of some of these satellites can be scheduled years in advance and may not be needed when they are launched. This can affect scheduling and cause pad crowding [43]. There may be a need to examine if these actions are lean. Also, the value-stream for the scheduling process may change should launch on demand become a reality.

6) *Schedule Modeling and Scenario Generation.* As mentioned in the previous chapter, a key enabling practice for the identification and optimization of enterprise flow is the use of models and simulations to evaluate flow. This is a key area for making lean improvements in scheduling operations. More research could be performed into developing scheduling flow models and scenario generators. It would be necessary to

determine what characteristics should be used and what information should be included to model the processes effectively.

6 Conclusions

I have but one lamp by which my feet are guided; and that is the lamp of experience. I know of no way of judging the future but by the past.

Patrick Henry

It is apparent that existing launch facilities in the U.S. with their aging infrastructure do not have the flexibility or cost effectiveness to remain competitive on into the future. Even if the competition among launch sites does not have an effect on the U.S. presence in the space launch industry, the enormous price per pound to get to space will still be an issue that must be dealt with. This is in addition to the desire for launch on demand capability. The Range Standardization and Automation Program is a necessity in this respect. But, even technology has its limits and obtaining perfection will require examining all of the processes and players involved in space launch.

This thesis examined the process of space range scheduling. It concluded that lean principles can be applied in the allocation and deconfliction of range assets, as well as the schedule change approval process. The Lean Enterprise Model's overarching practices of identifying and optimizing enterprise flow, assuring seamless information flow, and making decisions at the lowest possible level have particular importance. All of the LEM's practices, however, have some relevance in scheduling activities.

It was determined that there were many aspects of current range scheduling practices and upgrades to be made as part of the Range Standardization and Automation Program that would be considered "value-added" and not impede flow under the principles and philosophies of lean. Some of these were the use of electronic notification for range schedule change requests, improving the robustness of range infrastructure, allowing users easier access to scheduling information and databases, and automating the reconfiguration of range assets. These actions should be continued and improved upon.

There were other areas identified that did not follow the principles of the lean philosophy and they should be more closely examined to identify their value streams and value-added steps. Organizational and schedule approving structures was one such area. Avoiding excessive automation in range deconfliction, eliminating range "lockouts," and implementing integrated product and process teams were a few others. The ultimate goal of any "lean" endeavor into the scheduling process would be to reduce the time necessary to perform scheduling changes and adjustments while providing the greatest satisfaction to the stakeholders involved at the optimum cost.

With the potential applications of lean in space range scheduling identified, the question remained as to the potential impact of making those applications. Since specific benefits in time, money, and effort through the implementation of lean are difficult to quantify specifically because of the differences in situations, it was necessary to discuss examples of programs implemented in the defense aerospace industry that correlated with lean principles. In these examples, lean had a significant positive impact. By comparison, one would expect similar advantages to appear in range scheduling.

Even though there appears to be definite benefits through applying lean practices to range scheduling and operations, if you were to ask if the application of lean to the areas mentioned would be a driving force in reducing cycle times and cost in the launch process the answer would most likely be no. The majority of the cycle time is spent preparing the space vehicles and payloads for launch and very seldom are there delays due to range equipment failures. With launch cycles of anywhere from 25 days to a year and a half, a significant drop in range reconfiguration times, which are around 24 hours at Vandenberg, would not make a significant impact. There could, however, be a positive impact on range capacity as scheduling flexibility increases. It is also a good idea to investigate the range operations processes though, because cycle times will continue to decrease as lean is applied to launch vehicle preparation. As these cycle times drop, range reconfiguration and maintenance will become more and more influential. The earlier this is examined the better. That way the ranges will be prepared not to have to spend more time, money, or research later on or sub-optimize the launch process.

There is one additional concern, and that is over the implementation of lean changes within range scheduling – there could be difficulties in making them a reality. The problem that can arise is that the book answer may be this, but what's the operational answer? This is a question that deals not only with lean leadership, but also the nature of the military and its necessary organizational structure.

There has been a definite push toward lean in the defense aerospace industry since the inception of Lean Aerospace Initiative in 1992. In space, its presence is now being felt in the areas of spacecraft and payload testing and manufacturing. Its new push is toward range operations, whether it be on-orbit, launch, or pre-launch. The inclusion of these areas makes sense since lean thinking seeks to include the entire launch enterprise. Efforts to improve access to space and make it more affordable will continue to be an important part of the launch industry not just for the United States, but for the entire world as well, with its increasing dependency on satellites for communications and information. It appears that "lean" will persist in its efforts to place itself at the forefront of those improvements. With continued success in these endeavors, the goals of better, faster, cheaper may eventually be within reach.

Appendix: The Lean Enterprise Model

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Vita

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13. ABSTRACT *(Maximum 200 words)*
This study examined how the principles associated with Lean Aerospace Initiative and the Lean Enterprise Model could be applied toward scheduling activities at the United States' space launch ranges. Current launch scheduling at both ranges was baselined as well as changes under the Range Standardization and Automation Program. While there were aspects of the current and proposed scheduling operations that were determined to follow lean concepts, practices did surface that would be considered muda or waste when examined with those concepts in mind. Research conducted by the Air Force Research Laboratory at Wright-Patterson AFB on determining the benefits of lean practices currently used by defense aerospace companies was then used as a comparison to show that there were potential benefits in moving toward leaner operations

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