2010

Opportunities for Lean Enterprise in Public Regional Transportation

Levent Baykut
Cleveland State University

OPPORTUNITIES FOR LEAN ENTERPRISE IN PUBLIC REGIONAL TRANSPORTATION

LEVENT BAYKUT

Bachelor of Science in Physics

Kocaeli University, Kocaeli, Turkey

June, 2007

submitted in partial fulfillment of requirements for the degree

MASTER OF SCIENCE IN INDUSTRIAL ENGINEERING

at the

CLEVELAND STATE UNIVERSITY

July, 2010

This Thesis has been approved for the Department of Mechanical Engineering

and the college of Graduate Studies by

Thesis Chairperson, Professor M. Brian Thomas, P.E.

Mechanical Engineering /

Professor L. Ken Keys

Mechanical Engineering /

Professor Taysir H. Nayfeh

Mechanical Engineering /

Adjunct Professor John Van Blargan

Mechanical Engineering /

To my parents Kadir Turhan and Gülden Baykut, and my twin brother Mert Baykut.

ACKNOWLEDGEMENT

I am extending my most sincere appreciation to my thesis advisor Dr. M. Brian Thomas. Without his supervision and assistance, this thesis could never be completed. I am also thankful for my committee members', Dr. Taysir H. Nayfeh, Dr. L. Ken Keys, and Dr. John Van Blargan, guidance. Their assistance brought this thesis to a very good level.

RTA personnel were also very helpful throughout the implementation process. Rick Levi, Jose Clayton, and Kevin Stanley played a significant role at this thesis.

My office mates Dr. Sagar Gadgari and Dr. Renjun Bao were kind enough to let me benefit from their experience in industrial engineering.

Charles N. Berry guided me with his deep life experience at the frustrated times. He contributed this thesis in a very unique way.

My twin brother, Mert Baykut, always believed in me and supported me day and night. He sure is the best brother in the world.

Last but not least, my utmost gratitude goes to my parents. My father, Kadir Turhan Baykut, and mother, Gülden Baykut, supported me tremendously in every possible way. I am very thankful and lucky to have such a great family.

OPPORTUNITIES FOR LEAN ENTERPRISE IN PUBLIC REGIONAL TRANSPORTATION

LEVENT BAYKUT

ABSTRACT

This thesis demonstrates the application of Lean Enterprise principles in a unionized/government-subsidized environment. This study states that Lean cannot be fully implemented in such an environment. The work environment and organization's culture required a hybrid system to maximize the process efficiency. Lean production is a manufacturing philosophy that focuses on adding value for the customer. It is commonly accepted that Lean is applicable to almost any repetitive process in any kind of organization, including government agencies and unionized work environments.

The objective of this thesis was to research the opportunities and applicability for Lean Enterprise in public transportation. During the implementation a hybrid production system, consisting of Lean and systems engineering tools, is realized and integrated instead of a pure Lean system. This thesis details the implementation of Lean in the Greater Cleveland Regional Transit Authority's bus maintenance facility, and presents the results of the transformation. The possible future state is proposed by the aid of Arena simulation software and statistical analysis.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Motivation

This thesis researches opportunities for lean production system in Greater Cleveland Regional Transit Authority's (RTA) bus maintenance facility. RTA was founded in 1970 to provide reliable transportation to Cleveland residents. Currently RTA owns 620 busses and employs 2653 [4]. The Central Bus Maintenance Facility (CBMF), located in Cleveland, OH, performs major maintenance activities such as engine rebuild and brake and body overhauls.

The Lean transformation project described here was initiated from the engine rebuild department at the CBMF. After thorough observation of the engine rebuild activity, lean principles were implemented. Future implementation is supported by statistical analysis and simulation tools. Finally, a comparison of the before and after states is made. Results are discussed in the conclusion section.

1.2. History of Lean Production System

A good way to understand Lean Manufacturing's evolution, is understanding the history of car. In 1880s, there were no car dealers but machine-tool companies, which were operated by pure craftsmanship [13]. In 1887, Emile Lavassor started to manufacture Daimler's new "high speed" gasoline engine and, by the early 1890s, was manufacturing several hundred cars a year. However, the production system was still craftsmanship, which resulted in high price tags [13]. The real challenge in that time was making high quality and affordable cars. In 1908, Henry Ford found a way to overcome this long lasting problem with his famous car *Model T*. Ford's new technique dramatically reduced cost while increasing product quality. This new approach made cars affordable. Ford named this revolutionary system *mass production* [13].

In 1926, Saikichi Toyoda founded Toyoda Automatic Loom Works, Ltd. and started to manufacture his uniquely designed automated looms. In the late 1930s, the Japanese government urged Toyoda family to manufacture trucks for Japanese military. With government support and the money from selling its patents for looms, the Toyota Motor Company started truck production. They successfully supplied the Japanese military for almost twenty years. A big drop in sales at the end of 1949, however, forced Toyota to terminate a large portion of its workforce. This led to a lengthy strike, ultimately resulting resignation of President Kiichiro Toyoda [13]. This chain of events led the Toyoda family to consider better methods to produce goods. Much of the early work in developing Lean at Toyota was to car engine manufacturing during the 1950s.

In 1950 Eiji Toyoda assigned machine shop manager Taiichi Ohno with the task of determining how Toyota could match Ford's productivity within three years. Ohno's first action was to visit Ford's and General Motors' U.S. assembly plants to observe and understand their assembly practices. With this information and a study of Henry Ford's book [5], the basis of the Toyota Production System was formalized by Taiichi Ohno [9].

The Toyota Production System (TPS), from which Lean production system is derived, is a modified version of Ford's mass production. It can clearly be seen that mass production system has a great influence on TPS. In thirteen years of effort, the Toyota Motor Company had, by 1950, produced 2685 automobiles, compared with the 7000 Ford's Rouge was manufacturing in a single day [13]. According to Liker [9], Ford's mass production system in 1955 was designed to make large quantities of a limited number of models. In contrast, Toyota needed to produce low volumes of different models using the same assembly line, because consumer demand in the Japanese auto market was too low to support dedicated assembly lines for one vehicle.

Toyota started its philosophy out of necessity. The company did not have the space or capital to hold a lot of inventory. They could not afford to vertically integrate into all of their parts businesses, and they needed to build vehicles for a relatively small market demanding a large variety of vehicles. Under those conditions, it was simply impractical to blindly follow the lead of Henry Ford and make large volumes of single model such as the Model T [8].

This work later spread to vehicle assembly in the 1960s, and the wider supply chain in the 1970s. It was only at this point that supplier manuals were first produced and the "secrets" of Toyota's TPS approach were shared with companies outside Toyota. These manuals were written in Japanese; and it took almost another decade before the first English translations were available [17].

In the period of the 1960s through the 1980s, Lean manufacturing continued evolve and established a strong foundation to sustain the philosophy of continuous improvement.

In the early 1980s, James P. Womack and his collaborators founded the International Motor Vehicle Program at Massachusetts Institute of Technology, initiating a broad research effort focused on the Toyota Production System [9]. This incident was the first step for Lean production to enter automotive industry in United States of America. Womack's famous book, The Machine That Changed The World, coined the term Lean Manufacturing and introduced its principles to the American audience.

During 1990s, development of the concept of a value stream was seen to spread beyond manufacturing, or just a single company. By this evolution, Lean manufacturing became more visible to the world, and evolved rapidly with numerous academic research and professional applications, by a large spectrum of organizations varying from family businesses to publicly traded corporations [19]. Lean manufacturing's great success has impacted almost every sector of the economy including the service industry [17]. Because of the large spectrum of applicability for Lean manufacturing, a new name for this production system, Lean Enterprise, is starting to be used.

1.3. Lean Philosophy and Culture

Lean is a philosophy that, when implemented, reduces the time from customer order to delivery by eliminating sources of waste in the production flow [19]. According to James P. Womack and Daniel T. Jones, the term "Lean" is used for this production system because it uses less of everything compared with mass production – half the human effort in the factory, half the manufacturing space, half the investment tools, half the engineering hours to develop a new product in half the time. Also, it can reduce the necessary on-site inventory in half, result in many fewer defects, and produce a greater and ever growing variety of products [13].

TPS is not a toolkit, though; it is a sophisticated philosophy of production in which all of the parts contribute to a whole [9]. Implementing lean tools aggressively is not the way of true lean implementation. The starting point is, understanding the culture that forms the foundation for underlying Lean tools. One cultural shift is the active involvement of all employees in an organization. Traditionally, workers in mass-production plants were not involved in quality improvements. It was seen as more effective and expedient to have staff "experts" assigned to quality - workers worked, and the professional staff did the thinking. This runs counter to the philosophy of Lean manufacturing [22].

Muda, translated as "waste", is lean production system's main focus, and is defined as any activity that consumes resources but adds no value to the product or service for the customer. The recognition and elimination of waste is the heart of continuous improvement in Lean progress. *Muda* can be classified in two types. Type 1 *muda* is any avoidable non-value added activity. Type 2 *muda* is any activity that is non-value added, but unavoidable [11]. A good example to type 1 *muda* can be given as a machine running when there is no demand; on the other hand, keeping excess inventory in an ambulance for emergency purposes is an example to type 2 *muda*. A Lean philosophy is relentless in eliminating type 1 waste, relentlessly and attacks type 2 waste when there is no other waste left in the system.

Furthermore, Lean cannot be applied using "one size fits all" approach. Every situation requires a unique approach and determination of wastes present in the system. Wastes typically fall into one of seven categories first classified by Taiichi Ohno. These seven wastes are overproduction, waiting, transportation, over-processing, inventories, moving, and making defective parts and products [21]. Although the categories of waste are identified, it is often hard to recognize waste in a system due to different culture and circumstances.

The bottom-line target for Lean Enterprise is eliminating any kind of waste from the system. However the ultimate focus is providing value for the customer. Every action in a Lean organization should benefit the customer.

Lean Enterprise is a process-oriented philosophy. Many U.S. companies are result-oriented and tend to expect immediate gains, which leads them to base their decisions on short-term goals [22]. In contrast, Lean Enterprise focuses on basing decisions on a long-term philosophy, even at the expense of short-term financial goals [9].

There is no one-sentence definition of the lean production system or lean philosophy in the current literature. Womack *et al.* [11] defines Lean thinking as a five-step process: define customer value; define the value stream; making the value stream "flow"; "pull" material from the customer back, and; strive for excellence. Being a Lean Enterprise requires a mindset that focuses on making the product flow through value-adding processes without interruption, a "pull" system that replenishes only what the next operation takes away at short intervals, and a culture in which everyone strives for continuous improvement [9]. Relentlessly attacking muda is called *kaizen* or continuous improvement. Toyota production system's mindset is continuously looking for improvements by eliminating waste.

Muda is sometimes associated with *mura* (unevenness) and *muri* (overburdening people or equipment) in the literature. Overburdening is operating a machine or person beyond its capacity, leading to safety and quality problems. Unevenness results from an irregular production schedule and/or fluctuations in volume due to internal production problems. Both *mura* and *muri* can lead to waste in production [9].

1.4. Lean Tools

One of the best ways to understand the essence of the Lean production system is the "TPS house" (Figure 1). Other sources present different versions of the house, but the core principles remain same. Quality, low cost, and shorter lead-time – the roof – are the result of having a good foundation: Toyota Way philosophy (basing management decisions on a long-term philosophy); level production (*heijunka*); visual management, and; stable and standardized processes. Two outer columns, just in time, and *jidoka*, support the roof [9].

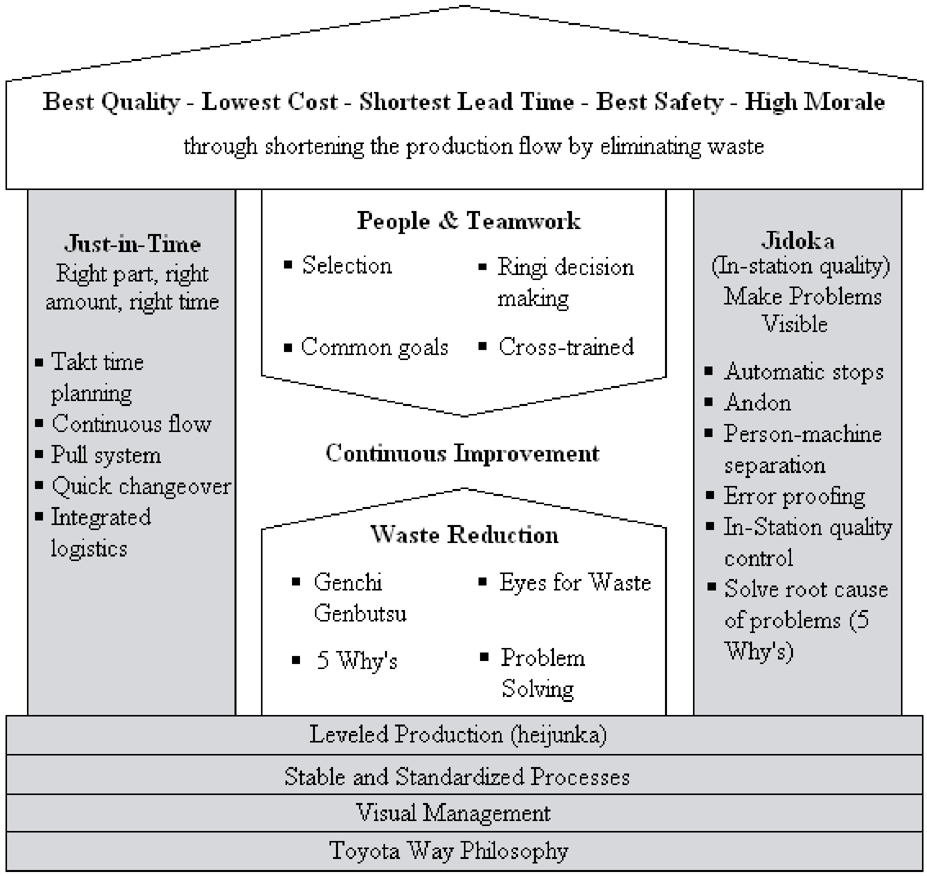

Figure 1: TPS house (The Toyota Way, 2004)

Toyota follows the mindset of machines working for people rather than people working for machines. *Jidoka* (built-in quality), or autonomation, refers a designing equipment and operations so that the operators are not tied to the machines with the operators being free, they can perform other value-added multiple tasks while a machine runs, improving their productivity [8].

Another useful tool under the Jidoka umbrella is *poka-yoke* (mistake proofing). This concept literally means a device, which prevents errors to from occurring [21]. The Toyota production system prefers using autonomation, over simple automation. The concept of autonomation was created by Toyoda Sakichi with the auto-activated loom invention. This invention has a mistake-proofing device that automatically and instantly stops the machine if the vertical or lateral threads broke or ran out. This concept is applied to the other equipment throughout the organization [21].

Some simple examples to poka-yoke include:

1) A machine that automatically stops running if a jam occurs.

2) An ATM machine that beeps to alert the user if he doesn't retrieve his card.

5S is a visual management tool consisting of elements developed to create a lean work environment [11]. The 5 "S" are:

1. *Seiri* (sort); separating needed materials from unneeded.
2. *Seiton* (set in order); setting the sorted material in order, often by color-coded storage bins for ease of use.
3. *Seiso* (shine); keep the workplace clean.
4. *Seiketsu* (standardize); conducting first three Ss daily intervals to maintain a workplace in the best condition for improvements.
5. *Shitsuke* (sustain); sustaining first four Ss all the time [11].

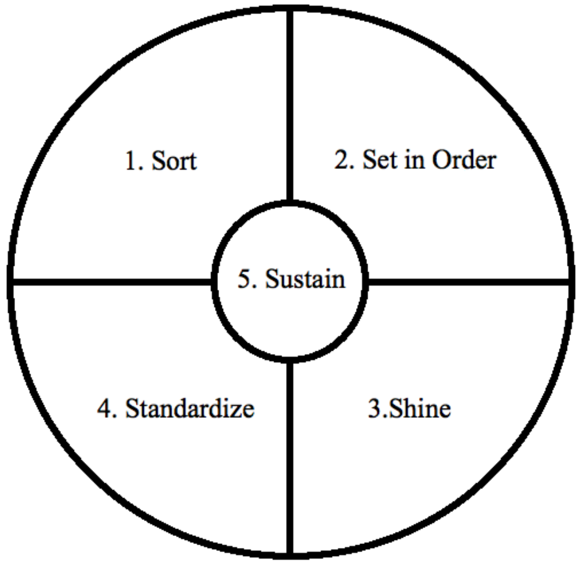

Figure 2: 5S diagram

The goal of 5S is to declutter the work environment and make it easier to recognize other forms of *muda*. 5S is a simple but effective tool. Even though some companies consider 5S as time-consuming, the potential gains in productivity outweigh its costs. Some U.S. manufacturers have added safety as a sixth "S". With proper implementation of 5S, though, safety is naturally sustained.

Value stream mapping (VSM) is a powerful tool used for seeing the whole process and identifying value-added and non-value added activities. When implementing Lean, a VSM should be drawn first to determine the path that a product follows during its production [9]. VSM is a paper-and- pencil tool that is used to map out not only how a process currently flows, but also what the process should look in the future after being improved to eliminate waste [11].

Five why is a problem-solving methodology which embraces asking "why?" until the root cause of a problem is reached. Repetition leads people to solve the root of a problem, instead of merely treating symptoms [9]. Five is chosen to emphasize the necessity of repeating inquiry to reach the root cause.

Heijunka is the leveling of production by demand and product mix. In many industries demand fluctuates, which makes an even production rate difficult to obtain. A *heijunka* implementation starts by taking the total demand for a product and dividing it by the time available for its production [9]. Often manufacturers have long lead times for orders, long changeover times, and limited capacity, regardless of the production system. These circumstances require necessity of *heijunka*. Lean manufacturers have a tendency for excessive production capacity when they free up resources and space to be fine if demand peaks up [11]. Even though leveling out sounds easy, it requires creativity and thorough understanding of demand and sometimes forecasting.

Just in time (JIT) is one of Toyota's most important principles. Some mistakenly consider JIT as a production system, but Toyota defines JIT simply as having the right parts at the right place and time, and in the right amount [8]. JIT was developed by Toyota to minimize inventories, but particularly work-in-process (WIP) inventory, which is one of Taiichi Ohno's seven wastes. At Toyota, JIT production extends out to its suppliers [8]. The following elements are necessary for JIT: a pull production system; reduced setup and changeover times, and; single-piece production [9]. Without these elements, JIT cannot be fully implemented.

A pull production system is one in which downstream demand triggers production in upstream work centers. A push system, on the other hand, produces goods independent of the demand. To avoid excessive production, order quantities are set with *kanbans* (card) [2]. A typical *kanban* system utilizes a set of standard containers, each having a description of what to produce and how many to produce. Production can only begin when there is an empty *kanban* to fill. Total WIP set by number of *kanbans* [2]. By implementing a *kanban* system, departments pull material from the previous sections of the line. This prevents the overproduction and build-to-stock in typical of push systems. A pull system and kanban implementation can eliminate much *muda* (waste) from production [7].

The second aspect of JIT is setup time reduction. Many times companies produce a variety of products requiring different machining processes. In this highly competitive market, companies cannot afford long periods for changeover. It is virtually impossible to level the production if the changeover time of a single machine is 2 days. In order to level a production, an organization must implement SMED (Single Minute Exchange of Dies) system [18]. SMED can be implemented two ways: (1) while machine is running, and (2) while machine is not running. Every machine requires a different set up time reduction approach and SMED's ultimate goal is reducing the setup time to 0 [20].

The third aspect of JIT is Single piece flow. Companies tend to build inventory to deal with an unpredictable demand; however this is a pure form of waste. Car dealers, stock incredible amount of cars and fail to sell them. JIT embraces producing single piece and on demand, therefore, there will be no inventory on hand. Single piece flow also incorporates with SMED. To sustain single piece flow and leveled production, SMED must take place. By establishing one-piece flow most of the waste is reduced. In essence, single piece flow means producing goods one at a time, through various operations, without interruptions, backflows or scrap [11].

Andon is a visual control system in a production area. It provides the current status of production, and alerts team members and supervisors when an error occurs [11]. *Andon* incorporates Total Productivity Maintenance (TPM), because any associate on the assembly line can interrupt production when there is a problem. Therefore, a quick response from maintenance is necessary for *andon* to be implemented throughout a plant. TPM is a productivity maintenance methodology originally pioneered by Nippondenso, a member of the Toyota group. TPM strives for zero unplanned down time for equipment so that production will not be interrupted due to machine failure [11].

Hoshin-Kanri, meaning "policy deployment," is Toyota's process of objective set up from the top of the company – including the president – down to the worker level [10]. Proper way to deploy the policy is determining what the company should pursue and establishing commitment to it. After the commitment is established, the objective should be deployed throughout the firm for sustainability [11].

1.5. Lean Metrics

Many Lean production tools have been presented in this section. However, metrics are more important than these quality tools. The success of lean can only be determined by a comparison of meaningful metrics before and after states. Ohno's statement, "don't tell me how you will do it, tell me how you will measure it", emphasizes that significance of having meaningful capstone metric [20]. RTA's current capstone metric is net cost per passenger, which is currently $3.45 [3]. RTA's quality improvement implementations should result in net cost per passenger reduction. This will satisfy executive level expectations and increase the level of commitment to Lean Enterprise within RTA.

1.6. Case studies

Lean philosophy has been implemented throughout different industries for over 20 years in USA. Each implementation harvested different but effective results. This section shows brief examples from Lean transformations.

Connecticut Department of Labor (CTDOL) implemented Lean techniques in 2005 to improve its internal operations processes. The most important aspect of CTDOL’s lean government initiative was the involvement and empowerment of line staff. Their program consisted of cross-functional teams participating in a series of classroom training and group work sessions [6].

In the pilot phase, four trained teams successfully applied lean philosophy to the customized job-training unit’s contract development and contract invoicing processes as well as the business management unit’s telephone work order initiation and procurement procedures. Teams automated processes and eliminated or modified reports, forms, approval processes, and worker process steps [6].

The following results show the impact of this project: 119 steps eliminated, redesigned, or automated; 1181 cycle time hours eliminated, redesigned, or automated; 33.5 staff hours eliminated, redesigned, or automated on a unit basis for four processes; more than $500,000 in staff time saved over the course of a year [6].

Merida, a Taiwan-based international bicycle manufacturer, implemented TPS in March 2003. The improvement project consisted of educational training courses, monthly instruction from a TPS consultant team, interactive learning forum, etc [16].

In three years, required time to input the material to bike frames has reduced from 6 to 2 days. Material stock has been cut by 1/5, and online stock has been reduced to 1/3. This in turn has been brought up 30% of the production efficiency [16].

Letterkenny Army Depot started to implement Lean philosophy in July 2005, after a brutal downsizing. Currently, the depot is fabricating HMMWV armor doors in 40 percent less time. Despite the insufficient resources caused by the downsizing, the depot crew delivered the door kits four weeks early, came in $1 million under budget, and worked into the process an annual savings of $1.4 million dollars [14].

Aggressive waste elimination and management with Lean process improvements netted Letterkenny Army Depot big savings in production time, impact on the environment and dollars. The Lean manufacturing production methods combined with environmental initiatives save the depot almost $15 million per year [14].

Case studies show that the Lean philosophy can be applied either to manufacturing or service industry with varying results. Each organization realized different improvement levels out of the transformation process.

CHAPTER II

WORK ENVIRONMENT AND PROJECT FOCUS AT RTA'S CENTRAL BUS MAINTENANCE FACILITY

2.1. Project Focus

This thesis' main focus is to research Lean principles' applicability to a unionized/government-subsidized organization via introducing Lean tools to a transit agency and observing the progress.

RTA has eight districts, or business units; Central Bus Maintenance Facility (CBMF) is the district responsible for bus fleet management. CBMF has six departments: the body shop, the unit rebuild department (repairs broken bus engines), the brakes department, the engine replacement department, the vehicle inspection department, and the electronic repair department. RTA's CBMF was selected as a pilot project for a Lean implementation because of its similarity to a manufacturing environment and performed repetitive processes in the facility. 113 mechanics and technicians work at the CBMF.

In the engine replacement department, a qualified mechanic will remove a failed engine from a bus and replace it with a new or rebuilt engine. This task is dependent on the engine rebuild department for its reliability. If a ready-to-install engine is defective, the engine replacement mechanic must spend extra time remediating the condition. This is an example of rework, a non-value added activity caused by defects. This relationship between the Engine Replacement Department and the Engine Rebuild Department is an example of an internal customer-supplier relationship.

A failed engine's journey starts in the field when a bus breaks down. The driver calls RTA headquarters and informs them about the problem, and the nearest available mobile repair truck is dispatched to fix the problem. If the field mechanic diagnoses the problem as an engine failure, the bus is towed to CBMF immediately. Upon arrival the bus is parked in the outside parking lot until a lift in the Engine Replacement Department becomes available. After putting the bus on the lift, the replacement mechanic prepares the engine for pull out. The failed engine is sent it to the engine rebuild department, and replaced with a rebuilt unit from the on-hand inventory. With this complete, the bus is ready to return to service.

2.2. Work Environment

CBMF belongs to Fleet Management module in the organization chart. Lean implementation project was under the equipment manager's supervision, who directly reports to CBMF director. CBMF has a grading system for its mechanics and first-level supervisors. Junior mechanics are classed as grade four while senior mechanics are graded as grade five. Assistant supervisors are first level managers with a grade number of six. CBMF performs maintenance tasks, which requires highly skilled labor. Promotion to upper grades is based on mechanic examinations held by RTA's training department.

RTA's managerial structure (Figure 3) is a vertical, top-to-bottom management system. At CBMF there are no horizontal interactions between the managers. This is in opposition to Lean manufacturing principles, which encourages more horizontal connections, both within and between departments.

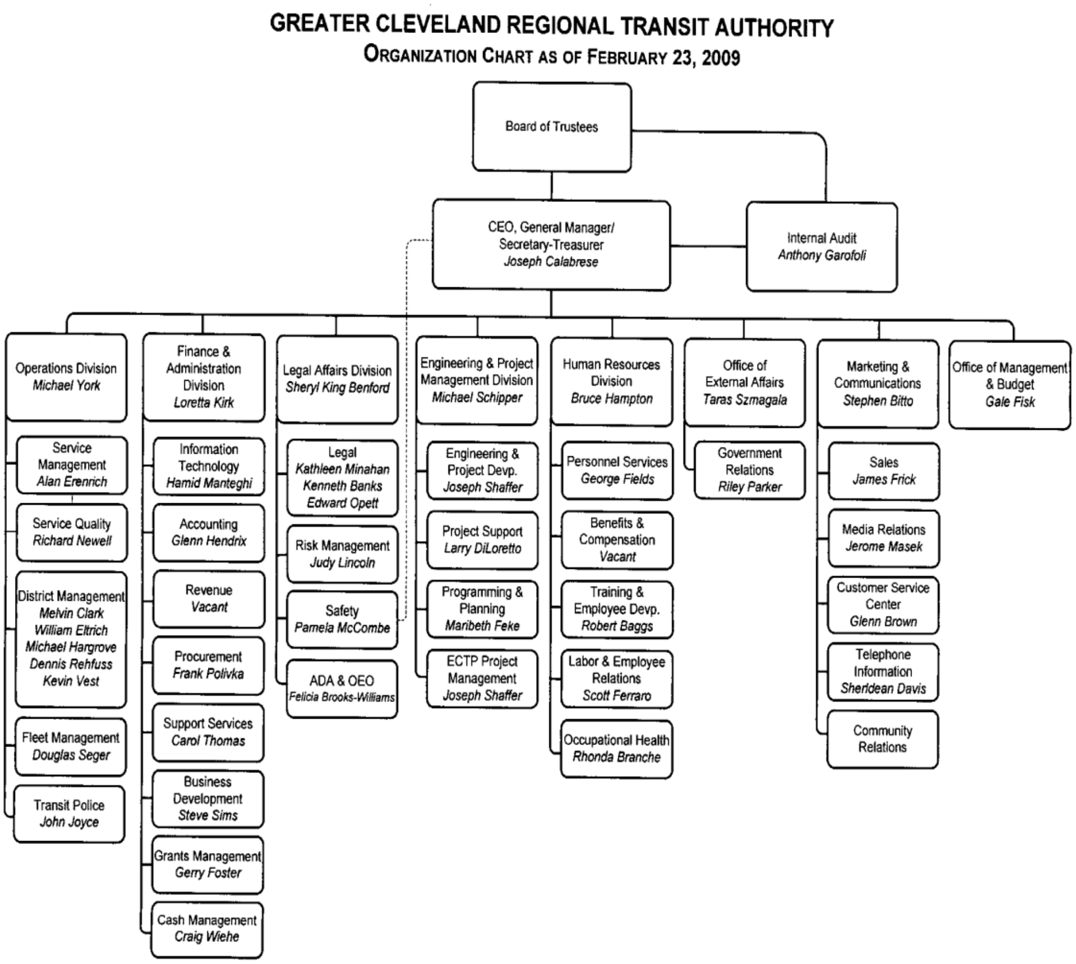

Figure 3: RTA's organization chart

This concept is called *yokoten* by Toyota Motor Company, meaning horizontal transfer of information and knowledge across an organization [12].

PROBLEM IDENTIFICATION/CORRECTIVE ACTION (PICA)

RTA INTRANET PICA FORM INSTRUCTIONS

You are encouraged to file Problem Identification/Corrective Action forms when deficient items/processes are observed. These items/processes can be purchased parts, products or services or RTA internally produced parts, products or services. **Only one form per item/process can be used**. PICA forms are also the venue for submitting your cost-saving ideas.

The PICA form does not supersede existing RTA standard operating procedures such as defect cards, inspection reports, safety hazard reporting, material return forms or the grievance procedure. **Employees shall alert RTA of deficient goods or services by using PICA forms**.

You shall complete as many of the fields below as possible. **Your name, badge number, job title, work location, work phone, the item, problem, solution, and a routing location are required.** The routing location will determine the specific Quality Assurance representative that receives your submission.

After receiving the completed form a Fleet Management Staff member may contact you to discuss the problem and alternative solutions. When the problem is resolved you will receive a completed response by interoffice mail.

PROBLEM IDENTIFICATION

Employee Name: ______ Employee #: ______ Date: **Tuesday, June 16, 2009**

Job Title: ______ Work Location: ______ Work Phone: ______ Item: ______

The problem is (please be specific):

Size

Recommended solution (if any):

Size

RTA Part #: ______ Vendor: ______ P.O. #: ______ OEM #: ______

NOTE: For help in filing PICA forms please contact your local QAC rep. The QAC reps are **Main Office - Flounsay Caver (X4704), Rail - Doug Schneider (X3841), CBM - Bob Stanko (X2547), Paratransit - Steve Yakowec (X6080), Triskett - Mark Brewer (X1208), Harvard - Bill Merryman (X3195)**, and **Hayden - Marty Albrecht (X2081).** Each member can also be contacted through their GroupWise mail.

- **1** - Main Office Area
- **2** - Rail District
- **3** - CBM District
- **4** - Paratransit/Revenue District
- **5** - Triskett District
- **6** - Harvard District
- **7** - Hayden District

Submit Clear

PROBLEMS ARE ONLY OPPORTUNITIES FOR SOLUTIONS!

Figure 4: PICA form

RTA uses a workplace suggestion tool called Problem Identification/Corrective Action (PICA) form (Figure 4) for improvement purposes. A mechanic with an innovative idea completes and submits out a PICA form. Management reviews and analyzes his suggestion(s). If the suggestion has merit, management implements it and the mechanic gets a dinner at a steak house of his choice.

Similar employee rewarding systems are wide spread over the United States. Honda organizes a lottery at the end of the year to reward three perfect attendees with brand-new Hondas. Toyota, on the other hand, uses the same suggestion reward system as RTA. Toyota's reward, though, is not as generous as RTA's. Workers get one to three dollars per suggestion at Toyota Motor Company. This is a reflection of cultural differences. In Japan, the employees take pride when their ideas are implemented by management. The feeling of being respected is a better prize than a steak dinner for Japanese workers. This relationship also demonstrates an important principle of Lean manufacturing: respect to the people.

RTA has a unionized work force. Some U.S. manufacturers believe that Lean principles cannot be implemented to a unionized job shop because of the union regulations. This statement however, has been shown to be false [8]. While unions have a considerable effect on the implementation and management processes, Lean it is still achievable. Transit Union Workers provide job security to all of the mechanics at RTA. This fact affects the productivity, improvement, and management decisions significantly. The mechanic truly believes that he will never lose his job unless there is a major downfall in the economy. Union regulations imposed various problems during implementation process, and will be described in the later sections of this thesis.

Lean production embraces job security as well. If layoffs occur during the lean project, Liker recommends that the organization should stop and review their transformation plan, because layoffs are toxic to the success of Lean [9]. If there is no way for an organization to survive other than laying off the employees, then it should be pursued. However, full commitment to the remaining employees should be established. This survival action is called lean layoff, which was exemplified by Toyota in 1949.

RTA executives and staff have a monthly TransitStat meeting, to discuss the last month's performance and problems. TransitStat is a measurement/evaluation system to improve RTA processes. Every employee, including the CBMF mechanics, earns raises based on their TransitStat score. From a Lean viewpoint, TransitStat is a good indicator for personnel evaluation and will be necessary to sustain continuous improvement within RTA. As it is determined above, RTA has a unionized work force, which promises job security. However when the current CEO, Joseph A. Calabrase was hired in February 2000, he laid off couple hundred workers and established full commitment to the remaining employees.

Part of RTA's management policy is striving for excellence. In essence, this statement corresponds to continuous improvement (*kaizen*), which is one of the most important aspects of Lean production system. This statement also determines the policy deployment (*hoshin kanri*) in RTA. The importance of policy deployment and continuous improvement is determined in the first chapter.

Also the union regulations affect the management philosophy and Lean implementation. Many of the managers at CBMF have difficulties with changes or process improvements because of the labor relations.

CHAPTER III

LEAN IMPLEMENTATION

3.1. Process Observation

The Lean transformation at CBMF started with a thorough observation of the engine replacement process. The Engine Replacement department had been chosen by CBMF management before this research was started, as engine replacement job is a repetitive process, performed by a single mechanic most of the times.

RTA does not use a Material Requirement Planning (MRP) system. They do, however, utilize the Ultramain Enterprise Resource Planning (ERP) system. This computer software is designed to track logistics and maintenance activities in the aerospace industry [23]. Ultramain keeps historical data, and includes separate modules, which are configurable to the customer's production environment.

According to the data gathered from Ultramain, the engine pull-out process takes between 8 and 12 hours. The entire replacement process takes 16 to 24 hours. As determined before, the time for engine replacement is largely dependent on the engine rebuild department. If the rebuild department can not supply the replacement department and deliver ready-to-install engines on time, then busses will be kept waiting on lifts. Other bus maintenance requiring the lifts will be delayed, ultimately costing RTA more money and affecting its service to Cleveland area residents.

Another constraint in an engine pull out job is the internal material shipment. This is a very big concern at every district in RTA, as the delivery performance by the inventory department is very poor. The engine replacement department is not only supplied by the engine rebuild department, but also the central warehouse within the CBMF. Inventory issues will be discussed thoroughly in the following sections of this chapter.

The three weeks spent at the engine replacement department for process observation allowed problems to become well-defined. The major problems were lack of standardization in rebuilt engines, and poor internal supplier performance. Because of these issues, both the task's time and its quality varied a lot from mechanic to mechanic.

The next step was to draw the value stream map for the engine replacement process. The VSM helps people to see the whole system data and identify non-value added activities. Combining Ultramain, process observations, and input from CBMF personnel, the VSM is drawn (Figure 5).

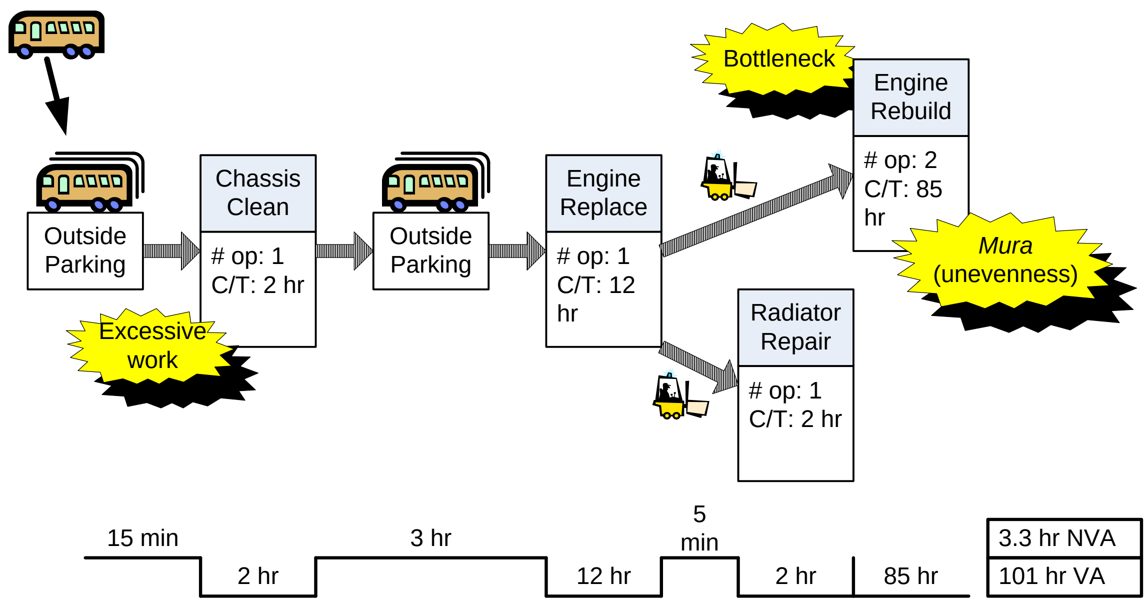

Figure 5: Value Stream Map of engine replacement

In addition to determining NVA activities & times, the VSM also identifies the process bottleneck and can guide changes to the process [1]. Figure 5 shows very little travel time, but this in fact is misleading. Mechanics don't transfer an engine if the next station is occupied, which creates an invisible waste. As seen in Figure 5, the time needed to pull an engine is 12 hours, while the cycle time for an engine rebuild is 85 hours. The tremendous difference between the cycle times creates a bottleneck at the engine repair department. With this discovery, the implementation area was shifted to the engine rebuild department from the engine replacement department.

3.2. Lean Implementation to Engine Rebuild Department

Lean production system values the input of the line workers and encourages their involvement in continuous improvement activities [9]. The engine rebuild process was observed for two weeks to gain an understanding of the dynamics and determine where waste was occurring. At the time of this project, there were four teams in the rebuild area each consisting of one grade four and one grade five mechanic. Total staffing in the engine rebuild department was eight. The layout and the set up was followed a craftsmanship model, with no form of automation, assembly line, or standard procedures employed, in the area.

The biggest problem at the engine rebuild department was not the layout nor the waste, but resistance to change by the work force. It is well known that, without the management and the mechanics' buy-in (Delphi method), Lean transformation can never be done [15].

Most people have a tendency to resist the idea of things changing. Employees can feel offended by someone telling them how to do their job in a better and more efficient way. This mindset is found in any kind of work environment [8]. In this case, the rebuild mechanics have been doing their jobs in the same way for more than fifteen years. The challenge here was convincing them to change. To do so, a policy of transparency was followed by the researcher. A one-hour meeting with the mechanics and management was arranged to discuss the current situation. In this meeting, information about this project and the Lean production system were distribution.

At the end of this meeting mechanics still had difficulties about how the researcher was going to implement Lean principles without any knowledge in bus maintenance. This argument was made many times during this project. Lean production, however, is a proven system and can be applied to any kind of repetitive process.

Another challenge faced by this researcher was mechanics seeing him as a threat and being skeptical about losing their jobs, even though RTA agreed that no job losses would come from this project. Since the mechanics were resistant to the project, they did not give their best effort towards any process improvement. Some tried to sabotage the project, and even talked about a minor strike. In this situation, Taiichi Ohno claims that the best action to take is sending the resistant worker to somewhere he cannot be harmful [9].

The best way to break resistance is to show positive results to the workers. If the Lean principles are implemented properly, very convincing and encouraging results will be gathered. To break the resistance at CBMF, the 5S tool was chosen.

There were two reasons why 5S was chosen as the first Lean tool to implement. First, the results from a 5S implementation are quick to appear, and will help in getting the mechanics' buy-in for future efforts [9]. Second, 5S address the cluttered, messy work environment. Figure 6 shows the layout of the engine rebuild department before the implementation process started. The lack of organization can lead to problems with quality, safety, and cost. Further, the clutter hides waste behind a veil of excess on-hand and non-value inventory items.

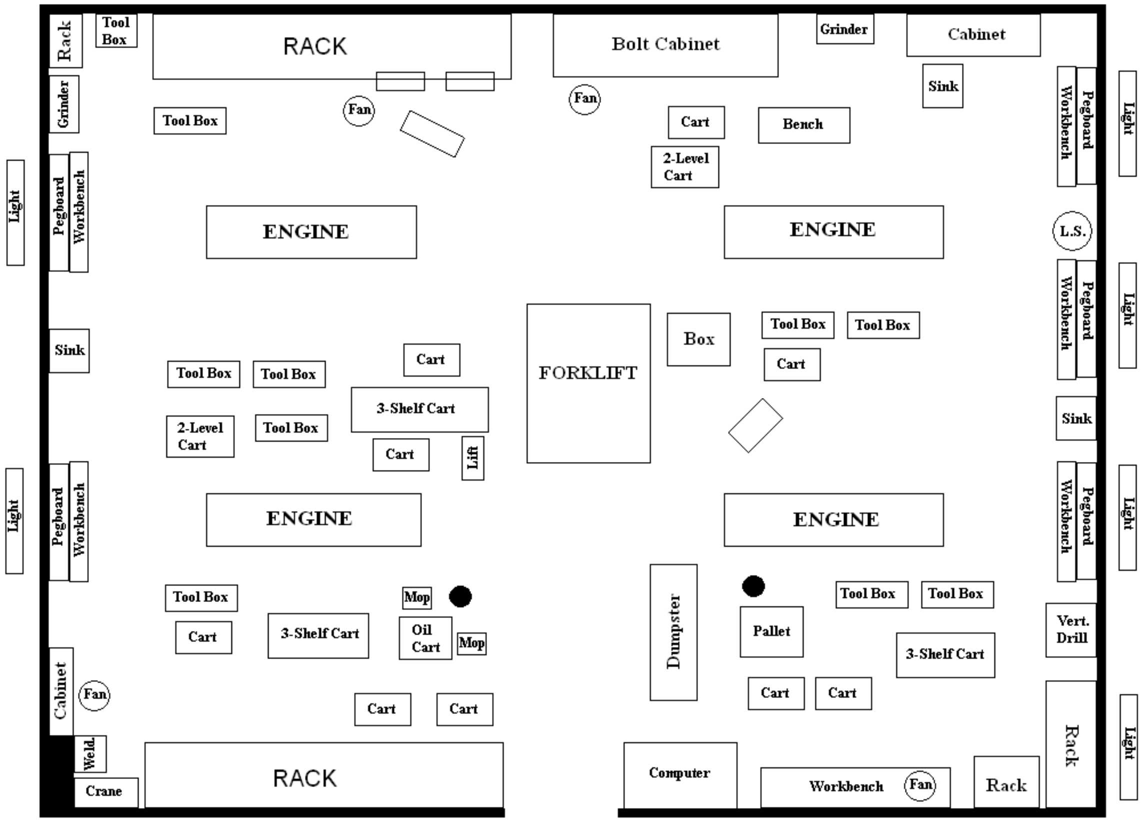

Figure 6: Engine rebuild department layout before the implementation

The first step was to sort the equipment and distinguish between necessary and unnecessary items. The forklift sat in the middle of the area all the time, but was only needed 10% of the time. It was moved to a designated parking place just outside of the work area. The second step was to separate the necessary equipment from the unnecessary. The Engine Rebuild department had five racks full of clutter and junk. Among those five were two larger racks for storing spare, used engine parts (Figure 7). While the racks were labeled, some labels did not match the material on the shelf. Another problem was the racks being blocked by ladders and carts. Mechanics had a hard time reaching and finding the parts that they were looking for. Each rebuild team had two mechanics, one grade four and one grade five, and RTA pushes hard to fully utilize their time. However, the mechanics were spending too much time for looking for the parts or walking around, which is a good example to waste classified as underutilized people.

Figure 7: Spare engine parts storage rack (large)

Removing unneeded inventory allowed CBMF to remove one of the two large five-shelf racks from the Engine Rebuild area. That rack was sent to the Central Rail Maintenance Facility (CRMF). This incident is a perfect example of synergistic Lean results. While there was no intention to help CRMF through this research project, CRMF had been waiting for such a rack to store its parts for over five months.

Initially, each team's work area was unique and there was no standardization. The excuse for a not-standardized work place was the variety in work. Mechanics simply thought that they should have their own personal system in order to repair the failed engines. The obvious action was taken and work place standardization was initiated as a part of the sorting phase. A complete engine repair job was studied and the mechanic's needs were determined. According to this study, an engine rebuild mechanic needs two carts, one multiple-shelf disassembly cart, and an organized peg board. The final state of the work cell is shown at Figure 8.

Figure 8: Standardized work cell

Before the 5S integration, mechanics' carts were often "jacked", or stolen, by mechanics from other departments in the CBMF, or even from other facilities. To solve this issue, two carts, painted red and identified with a number corresponding to the work cell, were assigned to each work cell. This discourages jacking because all CBMF personnel would see that a cart was being used without authorization.

After completing the sorting step, the next phase was straightening. The remaining inventory rack was color coded to match the frequency of the part usage: red for rarely used parts; yellow for sometimes used parts; and green for frequently used parts. In addition, containers on the shelves were labeled properly for the ease of use (Figure 9).

Figure 9: Color coded rack

The mechanics did not like the color-coding idea, and believed that color-coding the rack was unnecessary. Furthermore, they felt offended by this implementation. The mechanics said the following about the 5S implementation:

"This is unnecessary; I know exactly where everything is."

"Why are we sending these parts away, we may need it."

"It sure looks clean and organized, hope it will help us too."

"Why are you doing this, how will we benefit from housekeeping?"

"This must be a joke, everything will stay same, nothing will change!"

As it is understood from the quotations, mechanics resisted to the Lean transformation project and ignored the results. Using 5S is not only for housekeeping but also for equipment separation and making the waste visible. Lean production system's one of the most important principles is *kaizen* which promotes continuous improvement, the Lean champion should never be discouraged by the workers attitude.

The following step was shine. This stage of 5S is the simplest but yet most effective one. Because of union regulations, regular mechanics were not allowed to do cleaning and painting. Thus, the facilities maintenance mechanics were assigned to this task. Because of a backlog of work orders, the facilities maintenance department was unable to start cleaning or painting for two weeks. Shining stage was eventually completed with good feedback and results (Figure 10). This helped bring a full consensus to enable more rapid Lean improvements within the engine rebuild department.

Figure 10: Portion of Engine rebuild area after 5S

The fourth step of 5S is standardization. It is easy to mistake standardized work with standardization in 5S. They are two different aspects of Lean production system. Standardization in 5S embraces integrates a system of standardizing the workplace to sustain the implementation. To some extent, standardization is part of the sustaining stage. To implement this step, a standardization form and list of obligations were provided to CBMF (Figure 11). As it is seen from Figure 11, standardization step was completed successfully with the standard task handout.

To maintain the improvements made by incorporating some LEAN processes into the Engine Rebuild area, the following processes shall be enforced by the Assistant Section Supervisor.

- PPE should be worn at all times.
- 2 red carts and 1 blue "stacked cart" per area (no exceptions).
- No other cart allowed in the area.
- Metal Dumpster shall remain in its designated location.
- Used oil drum shall remain in its designated area (when not in use).
- Wall lights will be turned on everyday and turned off at the end of the shift.
- No engine stands used to transport the engines via fork lift shall be left in the area.
- Forklift shall always be parked in its designated area (when not in use).
- Designated employee toolbox locations shall not be changed. Should an employee wish to permanently relocate his toolbox, he/she shall consult with the Performance Supervisor.
- When processing cores, Batch core processing shall continue, however; no core parts shall be left out by the supervisor's work area. (cores will be processed immediately).
- Only use 1 red cart (1 per work station) for cores.
- All wash vat lids shall be closed nightly and radios, fans, and lights turned off.
- Non-work related books and magazines shall be removed from the area or kept in employee toolboxes during work hours.
- When it's necessary to discuss changes in work process, employees should bring their ideas/concerns to the Assistant Section Supervisor. The Assistant Section Supervisor should document the idea/concern and bring it to the Performance Supervisor for action or address the concern and inform the Performance Supervisor of the issue and resolution. This will eliminate unproductive time and, at the same time, provide a way for employees to submit valuable ideas for continuous improvement.

Figure 11: Lean guidelines

The most challenging stage of the 5S procedure was to sustain the new work environment and Lean philosophy. At first, mechanics were not willing to pursue 5S and other Lean tools. After seeing the dramatic results from the first steps, most of the mechanics started to commit to Lean philosophy and continuous improvement. At this point, ownership for this project can be sustained.

The final state of the engine rebuild department is shown in Figure 12. The number of engine stands was increased to 5 from 4. This capacity increase was not planned before the 5S implementation, but became possible as a side effect of it.

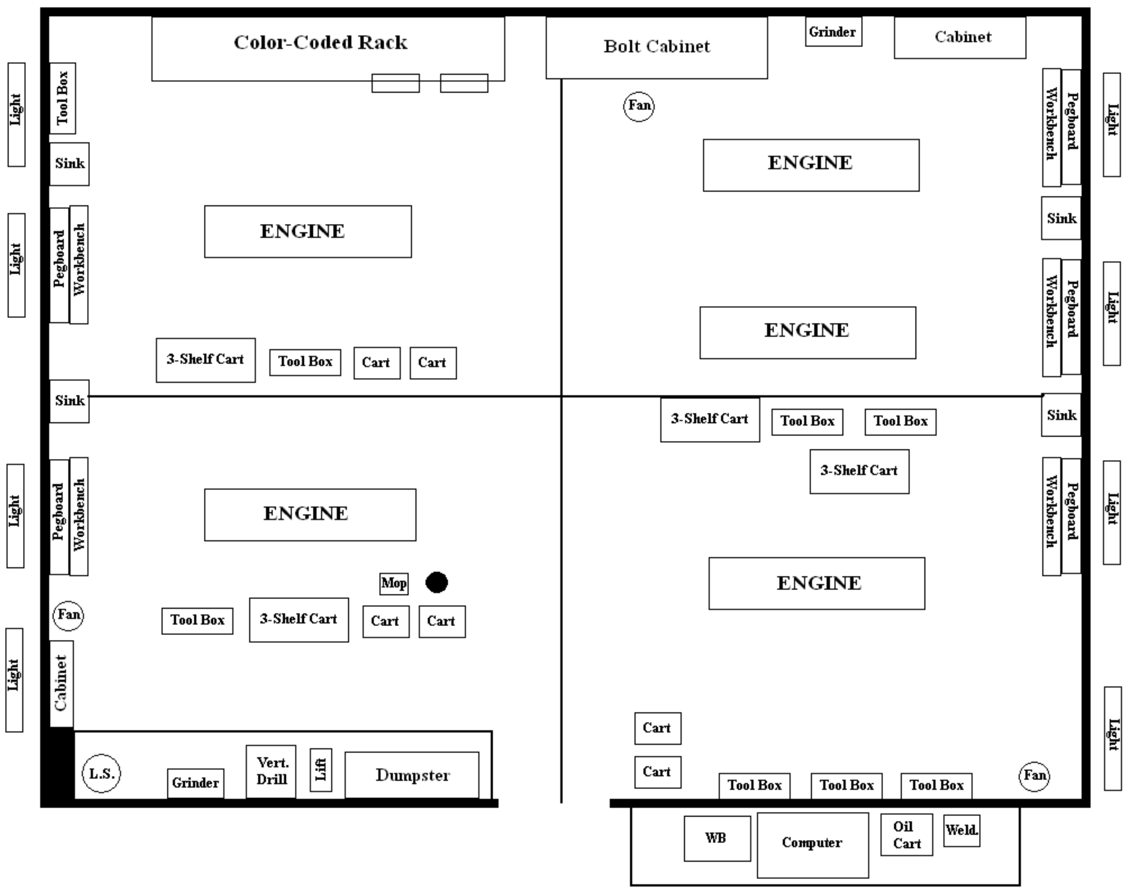

Figure 12: Engine rebuild lay out after the 5S implementation

An engine rebuild job requires removing and installing more than 400 bolts. Many of these are custom-designed for the engine and are not now manufactured by the vendors. A lost bolt forces RTA to order its replacement from a third-party vendor if they are lost. To prevent this from happening, the engine repair mechanics amassed their own private bolt inventories and held on to them. The informal, unwritten code between mechanics prevented one from asking for a replacement bolt from another's stash.

To overcome this issue and sustain reliable and quality engine repairs, Scott, an assistant supervisor, recommended having a common-access bolt stock. This could combine every mechanic's bolt inventory and make them accessible to everybody in the engine rebuild department. By combining every mechanic's inventory, the bolt bins on the five-shelf disassembly cart were emptied. This was a perfect opportunity to improve upon the bolt inventory idea by labeling all of the bolt bins and assigning specific places to them on the disassembly cart. The idea was to establish a method to avoid missing bolts when the engine rebuild job was complete. The bins would be empty before the job, and should be empty when the job is completed. If not, a label on the bin would guide the mechanic towards where that bolt should go on the engine (Figure 13). With help of this *poka-yoke* implementation, number of missing bolts and running out of bolts decreased to zero.

Figure 13: Special bolts bins (*poka-yoke* device)

RTA uses standard operation procedures (SOP) in many tasks. However, engine rebuild department did not have one, with the excuse was the job's unpredictable nature. Sometimes an engine rebuild is as simple as an engine head replacement, and sometimes as complicated as an overhaul of the entire engine. Hence, the common thinking was that, it was impossible to implement a standard procedure to the engine rebuild department.

The Lean production system, in contrast, embraces job standardization and recommends everybody's participation in the standardization [8]. Robert, an assistant supervisor at engine replacement department, took the initiative to develop a standard job procedure checklist showing the department's expectations from the engine rebuild department. Figure 14 shows a section of Engine Replacement Department's inspection sheet.

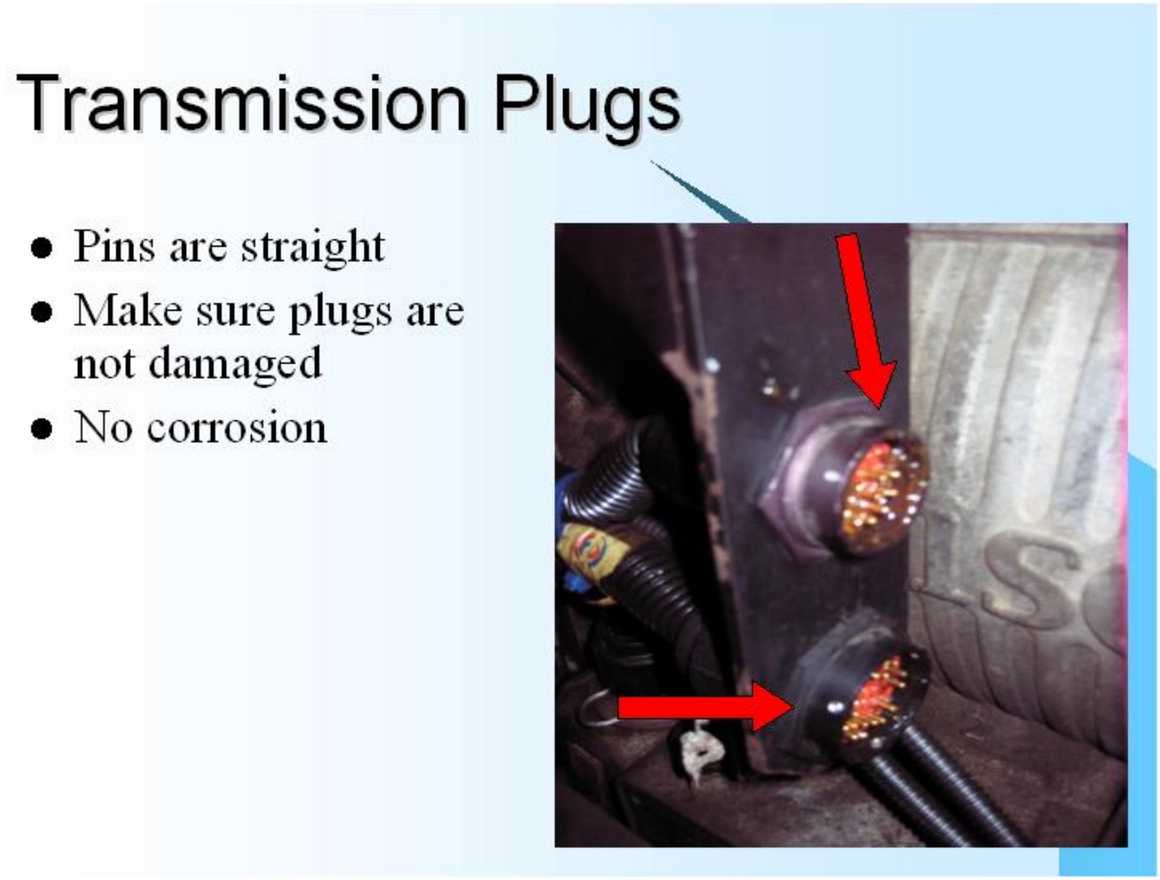

Figure 14: Screen shot from standard job procedure and checklist

Before Lean integration, engine replacement mechanics were fixing the defects created by the engine rebuild mechanics. This was taking a significant amount of time, resulting in long queues in the engine replacement department. To prevent those defects and maintain zero defects, a checklist was prepared and integrated into the engine rebuild activity. The engine rebuild assistant supervisor started to inspect the repaired engines by the checklist shown in Figure 15. This action dramatically reduced the defects reaching the engine replacement area. It is a good example of the Lean philosophy, in that it did not require a large cash investment yet yielded a satisfactory result was.

Detroit Diesel Series 50-EGR Engine Checklist

Engine Serial Number ______________________

Date Completed _______________ _______________

Technician ______________________________________

Item/Action	Inspected & Reused	or	New & Quantity
Starter			
Generator			
Engine Oil Cooler			
EGR Cooler			
V-Pod Modulator			
Transmission			
Trans Cooler			
Rear Crank Seal			
Tensioner			
Idler Gear Assembly			
Bull Gear Assembly			
Compressor Retro Kit			
Intake Rocker Arm			
Exhaust Rocker Arm			
Injector Rocker Arm			
Rocker Shafts			
SRS Sensor			
TRS Sensor			
Power Steering Pump			
Balance Shaft			
Thermostats			
Generator Belt			
Motor Mounts			
Oil Filters			
Primary Fuel Filter			
Secondary Fuel Filter			
Water Filter			

Kit Parts	New Parts Inpected & Installed
Cylinder Kits	
Head	
Head Bolts	
Turbo	
Injectors	
Cam Bearings	
Main Bearings	
Thrust Bearings	
Rod Bearings	
Cam Bolt	
Rocker Adjusters	
Gasket Set	
Front Seal	

Torque Verification

Item	Torque Value Ft Lbs	Verified with paint
Head Bolts	220	
Cam Bolt	50 then 90 degrees	
Main Caps	400	
Rod Caps	125-130	
Rockers	75	
Injector Crab	50	
Exhaust Manifold	50	
Intake Manifold	50	
Rocker Box	15-18	
Valve Cover	15	
Oil Pan	15	
Bull Gear	85-90	
Front Damper To Crank	130	

Figure 15: Series 50 EGR engine checklist

Both the procedure and final inspection checklists are integrated to the system to establish a better customer – supplier relationship within the CBMF, and more reliable product. Figure 16 shows the final process flow chart.

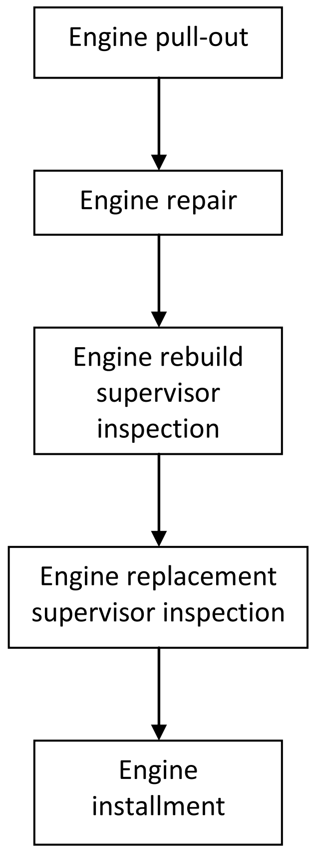

Figure 16: Process flow with integrated inspection

According to Taiichi Ohno, inspection is one of the seven forms of waste and should be eliminated from the system. However, in order to sustain reliability and better quality, integrating two steps of inspection was necessary. It is expected that after future improvements to the training and the process, these inspections may be eliminated.

CHAPTER IV

STATISTICAL ANALYSIS AND SIMULATION

The initial roadmap for this thesis did not have a statistical analysis nor a simulation component, but both contributed to the project tremendously. The purpose of this chapter is, to use these tools to determine the *takt* time and optimize the flow and resources. Many corporations such as, General Electric, Ford, and Boeing use statistical analysis tools to increase their productivity, reduce operation cost, and improve quality. Ultramain, RTA's ERP system, has a module for statistical analysis, but RTA staff does not use it.

4.1. Statistical Analysis

RTA's Engine Rebuild department used to follow an FIFO model, without any production scheduling. As a result, the Engine Rebuild Department either overproduced or was not able to meet the demand. Statistical analysis was used to determine the failed engine arrival rate, which in turn would determine the *takt* time for an engine rebuild. *Takt* time is the optimum production pace given by dividing total available work hour by the demand. Statistical tools were used in lieu of time studies as the latter was prohibited by the mechanics' union. Historical data for 313 engine failures, covering a span of 40 months, was obtained from Ultramain (Appendix A). Minitab was used to identify the statistical distribution of time-between-arrivals for this data. The best-fit distribution was found to be an exponential distribution having a mean of 3.88 days between arrival dates with a variance of 0.066 days (Figure 17).

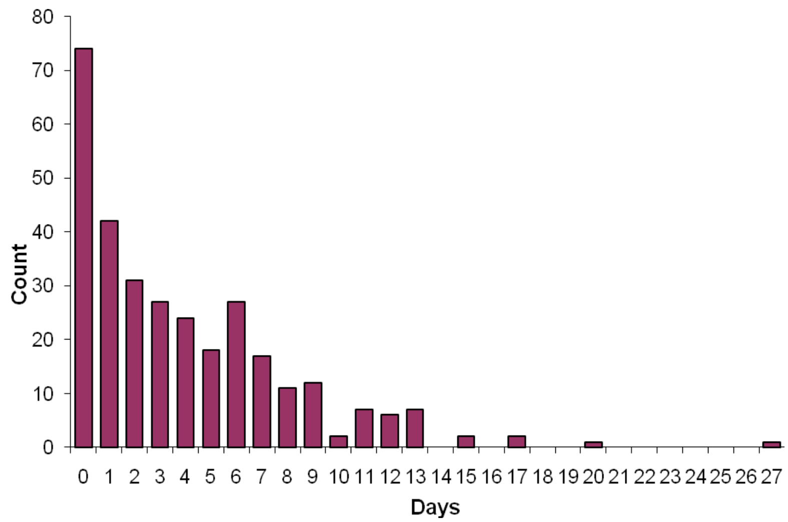

Figure 17. Historical distribution of days between engine failure

Because engine breakdowns are not scheduled events, RTA is required to have some number of engines on-hand for replacement; otherwise, busses will be kept waiting in the Engine Replacement area. It was proposed that RTA keep a specific number of ready-to-install engines for immediate use by the Engine Replacement, while matching the engine rebuild *takt* time of 3.88 days. The underlying goal was to prevent over-production and unnecessary inventory in the bottleneck operation, while at the same time preventing excessive waiting in the Engine Replacement area. Having the right number of engines on-hand and maintaining a steady repair pace will assist RTA in eliminating waste.

Another problem with the system is material flow. The Engine Rebuild Department's current production system follows craftsmanship model, in which an engine is serviced by a single mechanic, working at his own pace and his own procedures. In order to sustain single-piece flow, an assembly line idea was proposed to RTA. At this time, management is skeptical to implement a flow system because of the problematic inventory department (poor delivery performance), but yet excited to create the foundation to proceed to the single-piece implementation.

The Inventory Department contributes to problems in the Engine Rebuild Department caused by Ultramain. Ultramain software crashes very frequently and some of the software modules are not configured properly, which ultimately results in internal quality issues such as long lead times, reuse of worn parts rather than new ones, and jury-rigging of components to return busses to service. The author knows of one instance where duct tape was used to repair a leaking hose. This research's focus, however, did not include RTA's supply chain systems. Thus, inventory problems were not considered in the model.

Assuming an exponential distribution of engine arrival times, Arena software's process analyzer is used to simulate the process to determine the optimum on-hand inventory level. Table 1 lists the probability of meeting engine demand as a function of the on-hand inventory. After seeing these results, RTA executives decided to adopt a 6-engine inventory policy. With this, the Engine Replacement department will have an engine available 49% of the time, thus eliminating the bottleneck identified in the value stream map.

Number of Engines	Probability of Meeting Demand
1	0.073
2	0.178
3	0.272
4	0.358
5	0.440
6	0.494
7	0.526
8	0.564

Table I. Inventory and probability Correspondence

4.2. System Simulation

Beyond the Lean implementation discussed in Chapter 3, and the on-hand engine inventory optimization discussed in Section 4.1, it is hypothesized that a reorganization of how engines are processed in the Engine Rebuild area can improve engine availability and lower costs for RTA. Currently, an engine is serviced by a single mechanic as it is rebuilt. The proposed layout would consist of five work stations, in which each mechanic performs a portion of the work needed to rebuild an engine. It is thought that, by introducing flow, RTA would be able to avoid the overproduction of rebuilt engines.

At this time, RTA is unwilling to implement such a drastic change to the work environment. Instead, the proposed change is modeled in Arena. Arena is a simulation software for designing and optimizing any kind of system. The simulation found that three rebuild mechanics, instead of the five originally considered, would be able to meet the expected demand for rebuilt engines.

4.2.1. Simulation Model

The simulation model is based on the value stream map from Figure 5 and statistical analysis discussed in Section 3. The model consists of a five-station engine assembly line and the proposed safety buffer of five engines. Currently, the average time to rebuild an engine is 85 hours. Separating an engine rebuild into five workstations with balanced times allows the predicted rate of engine production (0.058 engine/hr) to match the time needed to reinstall an engine in Engine Replacement (12-16 hours).

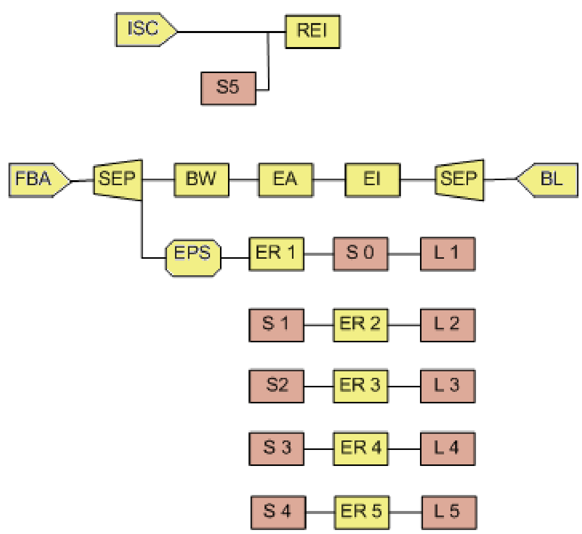

Figure 18. Simulation model (Appendix B)

Figure 18 shows the Arena model used in the simulation. The model uses the exponential distribution for failed engine arrivals; triangular time distributions for workstation processes, and; exponential time distributions for transportation of engines between workstations. The model accounts for the fact that RTA busses operate, and break down, seven days a week, while the mechanics only work five days a week. The model does not weight breakdowns by day, instead an average arrival rate was derived from the historical data (Appendix A). The number of workstations was treated as a variable, as was the number of mechanics in the Engine Replacement area. Both numbers were bounded between one and twenty with a suggested value of five. Details of the model are listed in Appendix B. Arena's OptQuest module was used to minimize cost, using the constraint that no more than three busses should wait on an engine at any given time. The simulation covers a three-year period of operations.

OptQuest is used to simulate various scenarios and select the optimum solution. There are three main components of the optimization program: constraints, controls, and the objective. A simulation can have several constraints and controls, but there can be only one objective.

Figure 19 shows the controls for number of install mechanics (NIM), number of repair mechanics (NRM), and on-hand engine inventory (OHE). In the main Arena model, these controls are assigned as variables so that OptQuest can recognize and change their values, within the established limits, in order to achieve the optimal solution.

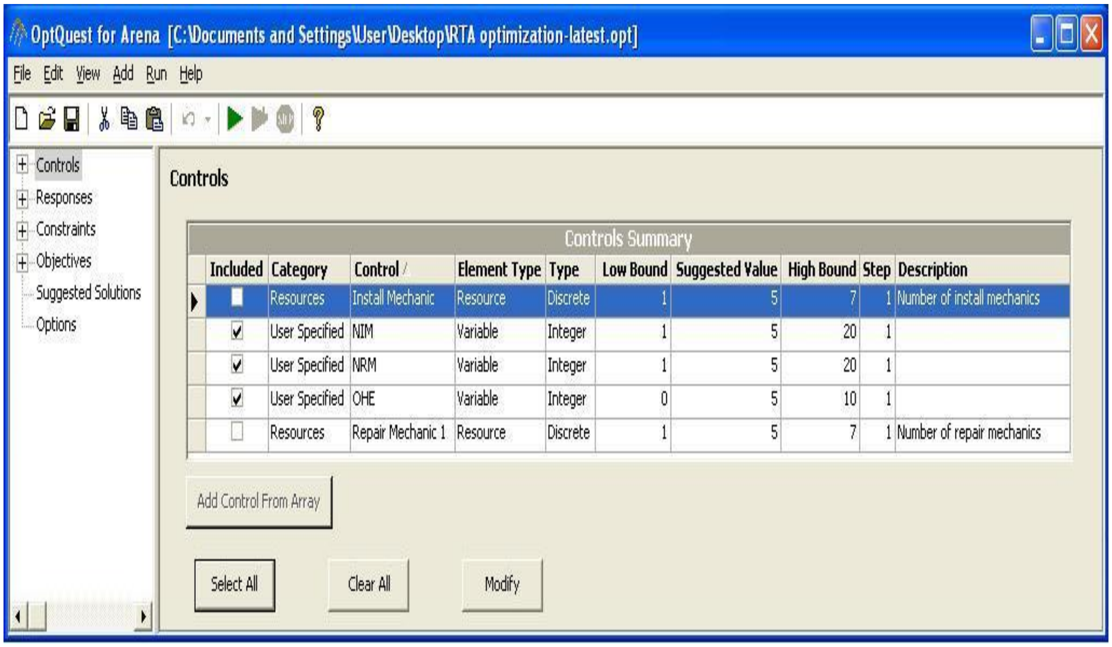

Figure 19. OptQuest's controls component

The number of idle busses is specified as the constraint. No more than three busses can be idle at any given time (Figure 20).

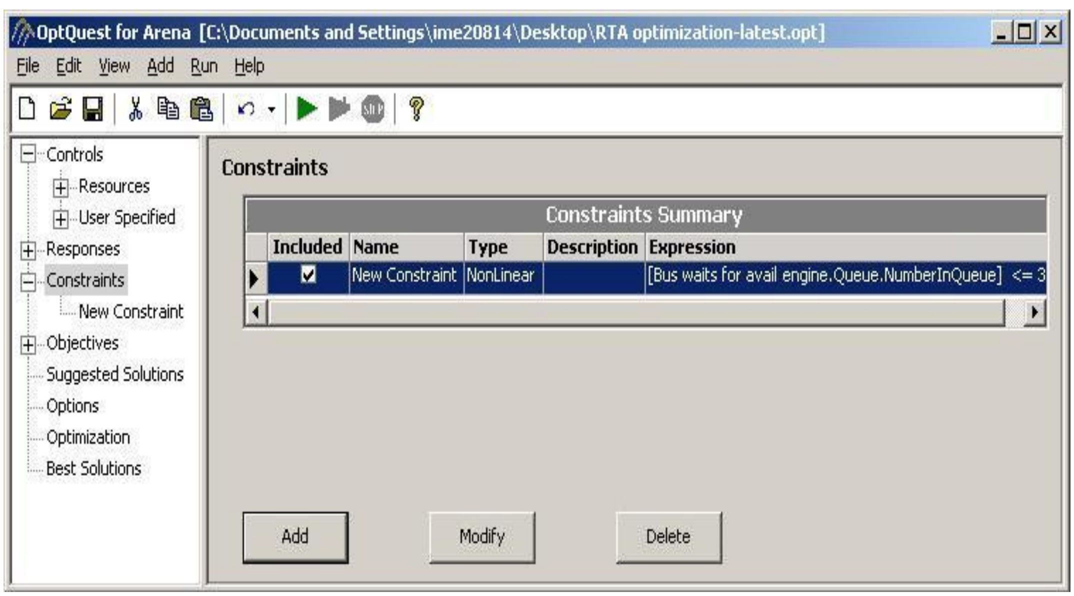

Figure 20. OptQuest's constraints output

The objective of the optimization is to minimize the cost while meeting the demand and sustaining quality. Cost was calculated by using two factors: mechanics wages, and RTA's assigned cost for a rebuilt engine. It is recognized that the cost function is not perfect, as it does not include benefits or overhead costs, and may double-count labor (Figure 21).

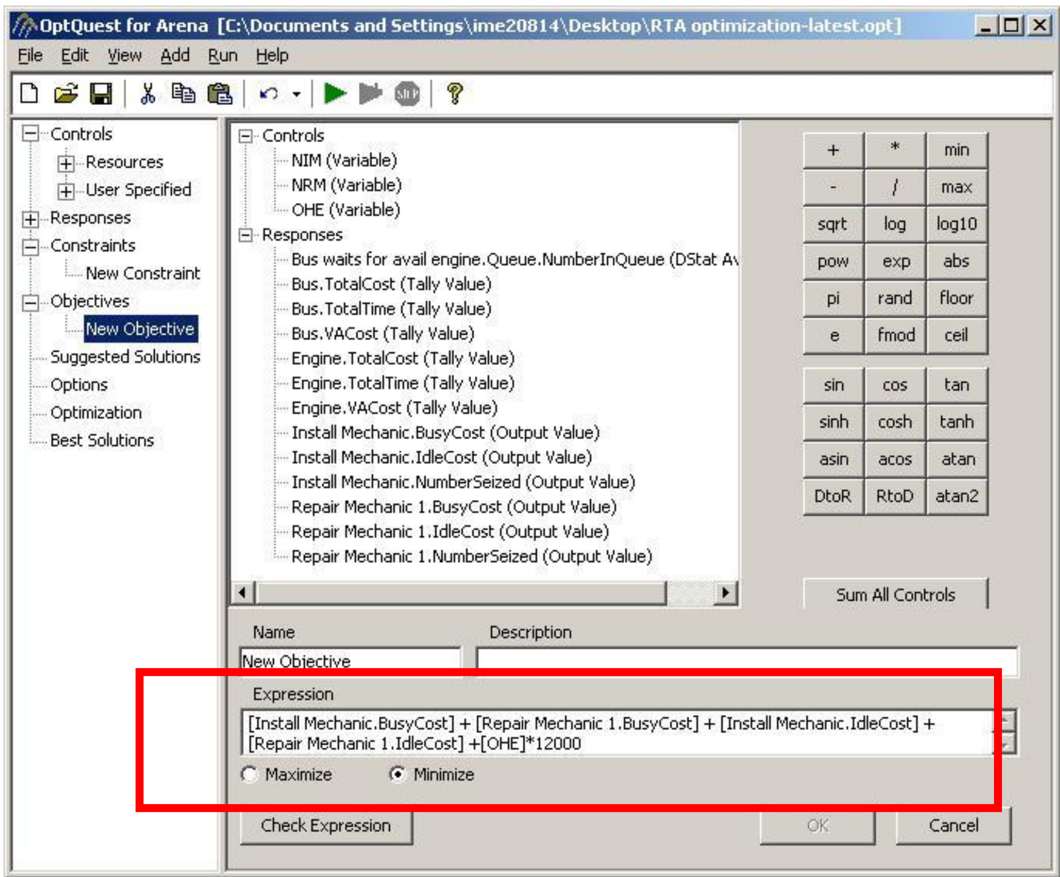

Figure 21. OptQuest's objectives component

The optimization shows that three Engine Rebuild workstations and one Engine Replacement mechanic will minimize RTA's operating cost. Using the numbers in the model, the proposed layout will result in annual savings of $213,000, which is calculated by subtracting the optimized cost given by the expression in Figure 20 from the current operating cost. Labor cost is based on $25/hr wage. The proposed model will sustain one-piece flow and level out the production, avoiding an excess of rebuild (*heijunka*).

# of busses waiting for an engine ≤ 3	
# of install mechanics	1
# of repair mechanics	3
# of on-hand engines	5
Total annual cost: $930,000 (previous state: $1.6M)	

Table II. OptQuest's optimum solution

Table 2 shows the optimum solution for the engine rebuild process. The proposed state consisted of 5 workstations, however, after the simulation it is found that 5-workstation process is not optimal. Thereby, OptQuest reduced the number to 3-workstations. The optimized model has a *takt* time of 26.7 hours, which is comparable to the engine arrival rate of 3.88 days (27.2 hours, using 7.5-hour shifts).

CHAPTER V

DISCUSSION & CONCLUSION

This study yielded both expected and unexpected findings. It was anticipated that Lean production principles would be applicable to a unionized, semi-governmental work environment. It was discussed by previous authors [8,11] that a Lean production system can be implemented, but the impact may not be as dramatic as possible in a non-union environment. In this project at RTA, the implementation results were relatively dramatic, including:

- Increasing in available space by 30%;
- Increasing capacity by 25%;
- Reducing the required staffing from 8 to 5;
- Eliminating of overprocessing and overproduction, and;
- Realizing annual costs savings of $150,000 by staff reduction.

The unexpected finding is the requirement of statistical and scientific skills to maximize the benefits of a Lean implementation. In the literature, Lean is discussed from a business perspective [11]. In many cases, though, scientific tools are required to better implement Lean tools. This study demonstrates that statistical analysis and simulation tools are necessary complements to Lean principles in providing tangible benefits to an organization. This was demonstrated by the simulation of flow in the Engine Rebuild Department, which identified the potential for RTA to increase its annual cost savings from $150,000 to $213,000.

This thesis' research methodology started out as a pure Lean philosophy integration, however, the constraints found in the environment at RTA required an adjustment to maximize the outcome. As demonstrated in Chapter 3 and 4, a hybrid production system, consisting of the necessary Lean and systems engineering tools, is realized.

This thesis' implementation results and process findings show that a pure Lean system is not possible to implement to a unionized/government-subsidized organization. The further study on the selection of production system tools in the literature may be conducted to create different hybrid systems for companies with various work environments.

BIBLIOGRAPHY

[1]. A. Zwas, *Lean Manufacturing Techniques in Bus and Rail Maintenance.* Transportation Research Board Annual Meeting, 2006.

[2]. Association, Japan Management. *Kanban, Just-In-Time at Toyota.* Cambridge, MA : Productivity Press, 1989.

[3]. Greater Cleveland Regional Transit Authority**.** '*Quarterly Management Report First Quarter 2008,"* Cleveland : RTA, 2008.

[4]. Greater Cleveland Regional Transit Authority**.** About RTA: RTA facts. *RideRTA.* [Online], 06 10, 2009. Available: http://www.riderta.com/ar_RTAfacts.asp. [Cited: 06 10, 2010.]

[5]. H. Ford, S. Crowther. *Today and Tomorrow.* New York: Productivity Press, 1988.

[6]. J. Hasenjager, "*Lean government (is not an oxymoron),"* Industrial Engineer, pp.43-47, July 2006.

[7]. J. J.Dahlgaard, "*Lean production, six sigma quality, TQM and company culture,"* The TQM Magazine, pp. 263-281, 2006.

[8]. J. K. Liker. *Becoming Lean: Inside Stories of U.S. Manufacturers.* New York : Productivity Press, 1998.

[9]. J. K. Liker**.** *The Toyota Way.* New York: The McGraw-Hill Companies, 2004.

[10]. J. P. - - ," J. P. Womack 's monthly e-letters, 2009.

[11]. J. P. Womack and D. T. Jones. *Lean Thinking.* New York : Free Press, 2003.

[12]. J. P.Womack, "Yokoten Across the World," Lean Enterprise Institute, 2008.

[13]. J. P. Womack, D. T. Jones, Daniel Roos. *The Machine That Changed The World.* New York: Free Press, 1990.

[14]. Lean Manufacturing at Letterkenny Produces Real World Results, Deborah Elliot. [Online] 2010. http://aec.army.mil/usaec/newsroom/news/news28.html. [Cited: 06 20, 2010].

[15]. M. P. Groover, *Automation, Production Systems, and Computer-Integrated Manufacturing.* Upper Saddle River, NJ : Pearson Education Inc., 2008.

[16]. M. Won, "*The Role of Culture in Implementing Lean Production System*," IFIP International Federation for Information Processing, pp. 413-422, 2007.

[17]. P. Hines, M. Holwe, and N. Rich, *"Learning to evolve, A review of contemporary lean thinking,"* International Journal of Operations & Production Management, pp. 994-1011, 2004.

[18]. S. A. Rooney and J. J. Rooney, "*Lean Glossary*," Quality Progress, pp. 41-47, 2005.

[19]. S. Bhasin and P. Burcher, "*Lean viewed as a philosophy,"* Journal of Manufacturing Technology Management, pp. 56-72, 2006.

[20]. T. Creasy, *"Pyramid: Get bottom-line results by combining LSS and the theory of constraints,"* Quality Progress, pp. 40-45, 2009.

[21]. T. Ohno. *Toyota Production System - Beyond Large-Scale Production.* Cambridge : Productivity Press, 1988.

[22]. T. Y. Choi, "*Bringing Japanese continuous improvement approaches to U.S. manufacturing: The roles of process orientation and communications."* Decision Sciences, pp. xx-xx, 1995.

[23]. Ultramain Systems, Inc. About Ultramain Systems, Inc. *Ultramain Sysems, Inc.* [Online] 2009. http://www.ultramain.com/about. [Cited: 06 18, 2009.]

APPENDICES

APPENDIX A – Raw Data for Engine Inter-Arrival Time

Opened	#	Inter-arrival time
12/13/2005	1	
1/9/2006	2	27
1/9/2006	3	0
1/24/2006	4	15
1/24/2006	5	0
2/2/2006	6	9
2/2/2006	7	0
2/13/2006	8	11
2/14/2006	9	1
2/21/2006	10	7
3/2/2006	11	9
3/13/2006	12	11
3/13/2006	13	0
3/17/2006	14	4
3/23/2006	15	6
3/23/2006	16	0
3/27/2006	17	4
3/27/2006	18	0
3/27/2006	19	0
3/29/2006	20	2
3/31/2006	21	2
4/4/2006	22	4
4/21/2006	23	17
4/21/2006	24	0
4/25/2006	25	4
4/25/2006	26	0
4/26/2006	27	1
4/28/2006	28	2
5/4/2006	29	6
5/4/2006	30	0
5/4/2006	31	0
5/10/2006	32	6
5/19/2006	33	9
5/22/2006	34	3
5/23/2006	35	1
5/25/2006	36	2
5/25/2006	37	0
5/30/2006	38	5
5/31/2006	39	1
5/31/2006	40	0
6/2/2006	41	2
6/2/2006	42	0
6/7/2006	43	5
6/9/2006	44	2
6/9/2006	45	0
6/14/2006	46	5
6/14/2006	47	0
6/21/2006	48	7
6/22/2006	49	1
6/22/2006	50	0
6/23/2006	51	1
6/28/2006	52	5
7/5/2006	53	7
7/6/2006	54	1
7/6/2006	55	0
7/11/2006	56	5
7/17/2006	57	6
7/18/2006	58	1
7/20/2006	59	2
7/20/2006	60	0
7/28/2006	61	8
7/31/2006	62	3
8/2/2006	63	2
8/4/2006	64	2
8/4/2006	65	0
8/11/2006	66	7
8/17/2006	67	6
8/24/2006	68	7
8/30/2006	69	6
8/30/2006	70	0
8/31/2006	71	1
9/6/2006	72	6
9/7/2006	73	1
9/18/2006	74	11
9/20/2006	75	2
9/20/2006	76	0
9/29/2006	77	9
10/5/2006	78	6
10/9/2006	79	4
10/18/2006	80	9
10/21/2006	81	3
10/21/2006	82	0
11/10/2006	83	20
11/10/2006	84	0
11/21/2006	85	11
11/25/2006	86	4
11/25/2006	87	0
11/30/2006	88	5
12/1/2006	89	1
12/7/2006	90	6

12/8/2006	91	1
12/12/2006	92	4
12/15/2006	93	3
12/20/2006	94	5
12/26/2006	95	6
12/27/2006	96	1
1/3/2007	97	7
1/6/2007	98	3
1/6/2007	99	0
1/17/2007	100	11
1/19/2007	101	2
1/23/2007	102	4
1/29/2007	103	6
1/29/2007	104	0
2/5/2007	105	7
2/13/2007	106	8
2/13/2007	107	0
2/14/2007	108	1
2/22/2007	109	8
2/23/2007	110	1
3/2/2007	111	7
3/5/2007	112	3
3/6/2007	113	1
3/9/2007	114	3
3/12/2007	115	3
3/15/2007	116	3
3/16/2007	117	1
3/19/2007	118	3
3/21/2007	119	2
3/21/2007	120	0
3/23/2007	121	2
3/26/2007	122	3
3/30/2007	123	4
3/30/2007	124	0
4/2/2007	125	3
4/6/2007	126	4
4/9/2007	127	3
4/9/2007	128	0
4/13/2007	129	4
4/13/2007	130	0
4/19/2007	131	6
4/21/2007	132	2
4/21/2007	133	0
4/26/2007	134	5
4/27/2007	135	1
5/5/2007	136	8
5/5/2007	137	0
5/7/2007	138	2

5/16/2007	139	9
5/16/2007	140	0
5/22/2007	141	6
5/23/2007	142	1
5/23/2007	143	0
6/1/2007	144	9
6/1/2007	145	0
6/6/2007	146	5
6/8/2007	147	2
6/12/2007	148	4
6/18/2007	149	6
6/19/2007	150	1
6/25/2007	151	6
6/27/2007	152	2
7/6/2007	153	9
7/6/2007	154	0
7/8/2007	155	2
7/11/2007	156	3
7/11/2007	157	0
7/16/2007	158	5
7/17/2007	159	1
7/17/2007	160	0
7/23/2007	161	6
7/24/2007	162	1
7/25/2007	163	1
7/27/2007	164	2
7/27/2007	165	0
7/30/2007	166	3
7/30/2007	167	0
8/3/2007	168	4
8/4/2007	169	1
8/4/2007	170	0
8/6/2007	171	2
8/10/2007	172	4
8/10/2007	173	0
8/10/2007	174	0
8/22/2007	175	12
8/28/2007	176	6
8/31/2007	177	3
9/4/2007	178	4
9/4/2007	179	0
9/6/2007	180	2
9/11/2007	181	5
9/13/2007	182	2
9/14/2007	183	1
9/14/2007	184	0
9/17/2007	185	3
9/20/2007	186	3

9/24/2007	187	4
9/26/2007	188	2
9/27/2007	189	1
9/29/2007	190	2
10/8/2007	191	9
10/9/2007	192	1
10/10/2007	193	1
10/11/2007	194	1
10/23/2007	195	12
11/5/2007	196	13
11/5/2007	197	0
11/6/2007	198	1
11/15/2007	199	9
11/19/2007	200	4
12/6/2007	201	17
12/6/2007	202	0
12/13/2007	203	7
12/13/2007	204	0
12/14/2007	205	1
12/14/2007	206	0
12/26/2007	207	12
12/27/2007	208	1
1/2/2008	209	6
1/10/2008	210	8
1/10/2008	211	0
1/18/2008	212	8
1/18/2008	213	0
1/30/2008	214	12
2/12/2008	215	13
2/15/2008	216	3
2/19/2008	217	4
2/22/2008	218	3
3/3/2008	219	10
3/3/2008	220	0
3/7/2008	221	4
3/7/2008	222	0
3/10/2008	223	3
3/14/2008	224	4
3/14/2008	225	0
3/25/2008	226	11
3/25/2008	227	0
3/25/2008	228	0
3/25/2008	229	0
3/31/2008	230	6
4/4/2008	231	4
4/7/2008	232	3
4/7/2008	233	0
4/14/2008	234	7

4/16/2008	235	2
4/17/2008	236	1
4/22/2008	237	5
4/24/2008	238	2
4/24/2008	239	0
5/7/2008	240	13
5/8/2008	241	1
5/20/2008	242	12
5/20/2008	243	0
5/27/2008	244	7
6/2/2008	245	6
6/4/2008	246	2
6/4/2008	247	0
6/11/2008	248	7
6/12/2008	249	1
6/20/2008	250	8
6/27/2008	251	7
7/2/2008	252	5
7/7/2008	253	5
7/10/2008	254	3
7/16/2008	255	6
7/22/2008	256	6
7/23/2008	257	1
7/24/2008	258	1
8/1/2008	259	8
8/6/2008	260	5
8/6/2008	261	0
8/7/2008	262	1
8/19/2008	263	12
8/20/2008	264	1
8/21/2008	265	1
9/3/2008	266	13
9/5/2008	267	2
9/9/2008	268	4
9/22/2008	269	13
9/22/2008	270	0
9/25/2008	271	3
10/1/2008	272	6
10/3/2008	273	2
10/3/2008	274	0
10/8/2008	275	5
10/16/2008	276	8
10/16/2008	277	0
10/22/2008	278	6
10/22/2008	279	0
10/30/2008	280	8
11/3/2008	281	4
11/12/2008	282	9

11/17/2008	283	5
11/17/2008	284	0
11/24/2008	285	7
11/25/2008	286	1
11/25/2008	287	0
11/28/2008	288	3
12/9/2008	289	11
12/12/2008	290	3
12/12/2008	291	0
12/15/2008	292	3
12/22/2008	293	7
12/31/2008	294	9
1/5/2009	295	5
1/5/2009	296	0
1/7/2009	297	2
1/8/2009	298	1
1/8/2009	299	0
1/14/2009	300	6
1/20/2009	301	6
1/22/2009	302	2
1/30/2009	303	8
2/3/2009	304	4
2/10/2009	305	7
2/25/2009	306	15
3/10/2009	307	13
3/16/2009	308	6
3/16/2009	309	0
3/26/2009	310	10
4/2/2009	311	7
4/15/2009	312	13

APPENDIX B – Simulation Model Block Details

Blocks	Description	Block type	Distribution	Parameters
FBA	Failed bus arrives	Create	Exponential	3 days
ISC	Initial stock created	Create	Constant	9999999
REI	Repaired engine inventory	Hold	N/A	N/A
SEP	Separate	Separate	N/A	N/A
BW	Bus waiting for engine	Hold	N/A	N/A
EA	Engine becomes available	Pick up	N/A	N/A
EI	Engine install	Process	Triangular	8,12,14 min
SEP	Separate	Separate	N/A	N/A
BL	Bus leaves	Dispose	N/A	N/A
EPS	Engine parameter set	Assign	N/A	N/A
ER 1	Engine repair 1	Process	Triangular	12,15,18 hr
ER 2	Engine repair 2	Process	Triangular	12,15,18 hr
ER 3	Engine repair 3	Process	Triangular	12,15,18 hr
ER 4	Engine repair 4	Process	Triangular	12,15,18 hr
ER 5	Engine repair 5	Process	Triangular	12,15,18 hr
S 0	Station 0	Station	N/A	N/A
S 1	Station 1	Station	N/A	N/A
S 2	Station 2	Station	N/A	N/A
S 3	Station 3	Station	N/A	N/A
S 4	Station 4	Station	N/A	N/A
S 5	Station 5	Station	N/A	N/A
L 1	Leave 1	Leave	Exponential	5 min
L 2	Leave 2	Leave	Exponential	5 min
L 3	Leave 3	Leave	Exponential	5 min
L 4	Leave 4	Leave	Exponential	5 min
L 5	Leave 5	Leave	Exponential	5 min