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Evaluation of Lean Systems in Rail Maintenance Operations

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EVALUATION OF LEAN SYSTEMS IN RAIL MAINTENANCE OPERATIONS

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

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EVALUATION OF LEAN SYSTEMS IN RAIL MAINTENANCE OPERATIONS

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ABSTRACT

The recognized strength of lean systems is its broad applicability to every process industry even though they include some complicated and time-intensive processes. However, this conception is based on the tools and philosophy of Lean systems and the nature of the industry. The required craftsmanship and repetitive processes in rail maintenance define the uniqueness of this research

The objective of this thesis was to research the opportunities and applicability for lean systems in rail maintenance. During the research a unique system, consisting of Lean systems and systems engineering tools, is realized and tried to integrate instead of a pure Lean system. This thesis details the potential implementation of Lean systems in the Greater Cleveland Regional Transit Authority's rail maintenance facility, and presents the results of the potential transformation.

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CHAPTER I

THESIS OVERVIEW

1.1 Introduction

Lean manufacturing or lean systems, often simply, "Lean," is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for. Basically, lean is centered on preserving value with less work. Lean manufacturing is a management philosophy derived mostly from the Toyota Production System (TPS) and identified as "Lean" only in the 1990s. It is renowned for its focus on reduction of the original Toyota seven wastes to improve overall customer value, but there are varying perspectives on how this is best achieved. The steady growth of Toyota, from a small company to the world's largest automaker, has focused attention on how it has achieved this. Lean systems is a variation on the theme of efficiency based on optimizing flow; it is a present-day instance of the recurring theme in human history toward increasing efficiency, decreasing waste, and using empirical methods to decide what matters, rather than uncritically accepting pre-existing ideas.

The significance of Lean systems is the applicability area of it, which is unexpectedly wide. When this relatively new method of systems efficiency in introduced to the literature, its substantial benefits attracted most of the companies. Therefore, the researchers have started to investigate if this system is applicable to every repetitive process. Healthcare, service, restaurant, and maintenance industries were the very first pilot areas to evaluate the applicability of Lean Systems integration. Lean systems can be seen as a loosely connected set of potentially competing principles whose goal is cost reduction by the elimination of waste. These principles include: Pull processing, perfect first-time quality, waste minimization, continuous improvement, flexibility, building and maintaining a long term relationship with suppliers, autonomation, load leveling and production flow and Visual control. The disconnected nature of some of these principles perhaps springs from the fact that the Lean Systems has grown pragmatically since 1948 as it responded to the problems it saw within its own production facilities.

1.2 Thesis Objectives

The objective of this thesis was to research the opportunities and applicability for Lean Enterprise in public transportation. During the implementation a unique production system, consisting of Lean and systems engineering tools, is realized and tried to integrate instead of a pure Lean system. This thesis details the implementation of Lean in the Greater Cleveland Regional Transit Authority's rail maintenance facility, and presents the results of the transformation. This thesis will focus on the following areas:

- The principle of Lean Systems
- The principle of maintenance management
- Identify relationship between maintenance and Lean Systems
- Statistical approach to Lean Systems
- Recommendation for future studies

1.3 Thesis Outline

Chapter two provides a broad description on the Greater Cleveland Regional Transit Authority organization and business operation. In chapter two the size of the organization and the field of service is also provided and supported with the facts gained from the company. Chapter three provides a literature review on Lean Systems. The philosophy and tools of Lean Systems are also provided in chapter three. Two case study examples are given in order to bring a broader sense to the understanding of Lean Systems. Chapter four is designated for the description in detail the operations, process flows, management, and specific repair facility processes of the Greater Cleveland Regional Transit Authority Rail Maintenance Facility. In Chapter five the roadmap to data collection and methodology for the statistical analysis aspect of this research is presented. Chapter six is reserved for the actual data collection and tabulation process (time/schedule). Chapter seven presents this research's Lean Systems Analysis process on the collected data. The summary of the results, the researcher's interpretations, meanings and recommendations are discussed in chapter eight. In the final chapter conclusions and possible recommendations for future research in maintenance field is presented.

CHAPTER II

GREATER CLEVELAND & GCRTA

2.1 Greater Cleveland Area

Cleveland obtained its name on July 22, 1796 when surveyors Connecticut Land Company laid out Connecticut's Western Reserve into townships and a capital city they named "Cleaveland" after their leader, General Moses Cleaveland. The Village of Cleaveland was incorporated on December 23, 1814. [3]

Cleveland city has a total area of 82.4 square miles, of which, 77.6 square miles is land and 4.8 square miles is water. The total area is 5.87% water. The shore of Lake Erie is 569 feet above sea level; however, the city lies on a series of irregular bluffs lying roughly parallel to the lake. The land rises quickly from the lakeshore. Public Square, less than a mile inland, sits at an elevation of 650 feet, and Hopkins Airport, only 5 miles inland from the lake, is at an elevation of 791 feet. [4,5]

Table I shows the demographics for Cleveland. As it is seen from the figure the population has remained same – the decrease is negligible. The biggest share of age distribution belongs to the residents who are over 65 and the male – female ratio is very close to one.

Population (2005)		
	Total	
2005 Population	4,013,967	
Population (2010)		
	Total	
2010 Population	3,997,623	
Sex (2005)		
	Total	**%**
Male	1,936,868	48.25%
Female	2,077,099	51.75%
Age Distribution (2005)		
0 - 4	244,582	6.09%
5 – 9	257,350	6.41%
10 - 19	560,101	13.95%
20 - 29	492,196	12.31%
30 - 39	511,595	12.80%
40 - 49	618,359	15.47%
50 - 59	542,970	28.03%
60 - 64	196,123	10.13%
65+	590,691	30.50%

Table I. Demographic Features of Cleveland

2.1.1 Transportation in Greater Cleveland Area

2.1.1.1 Airports

Cleveland Hopkins International Airport is the city's major airport and an international airport. It holds the distinction of having the first airport-to-downtown rapid transit connection in North America, established in 1968. In 1930, the airport was the site of the first airfield lighting system and the first air traffic control tower. Originally known as Cleveland Municipal Airport, it was the first municipally owned airport in the country. In addition to Hopkins, Cleveland is served by Burke Lakefront Airport, on the north shore of downtown between Lake Erie and the Shoreway. Burke is primarily a commuter and business airport. [6]

2.1.1.2 Port

The Port of Cleveland, located at the Cuyahoga River's mouth, is a major bulk freight terminal on Lake Erie, receiving much of the raw materials used by the region's manufacturing industries. [7]

2.1.1.3 Railroads

Amtrak, the national passenger rail system, provides service to Cleveland, via the Capitol Limited and Lake Shore Limited routes, which stop at Cleveland Lakefront Station. Cleveland has also been identified as a hub for the proposed Ohio Hub project, which would bring high-speed rail to Ohio. Cleveland hosts several inter-modal freight railroad terminals. [8]

2.1.1.4 Mass transit

Cleveland has a bus and rail mass transit system operated by the Greater Cleveland Regional Transit Authority (RTA). The rail portion is officially called the RTA Rapid Transit, but local residents refer to it as *The Rapid*. It consists of two light rail lines, known as the Green and Blue Lines, and a heavy rail line, the Red Line. In 2008, RTA completed the Health Line, a bus rapid transit line, for which the Cleveland Clinic and University Hospitals purchased naming rights. It runs along Euclid Avenue from downtown through University Circle, ending at the Louis Stokes Station at Windermere in East Cleveland. In 2007, the American Public Transportation Association named Cleveland's mass transit system the best in North America. [9]

2.1.1.5 Inter-city Bus Lines

National Inter-city bus service is provided at a Greyhound station, located behind the Playhouse Square theater district. Megabus provides service to Cleveland and has a stop outside of Tower City Center in downtown Cleveland. Lakefront Trailways provides regional inter-city bus service to popular destinations from their terminal south of Cleveland in Brook Park, and Medina County Transit provide connecting bus service to the Greater Cleveland Regional Transit Authority. Geauga County Transit and Portage Area Regional Transit Authority (PARTA) also offer connecting bus service in their neighboring areas. [10]

2.2 Greater Cleveland Regional Transit Authority

The Greater Cleveland Regional Transit Authority is the public transit agency for Cleveland, Ohio, United States, and the surrounding suburbs of Cuyahoga County. RTA is the largest transit agency in Ohio, providing over 44 million trips to residents and visitors of the Cleveland area in 2010. RTA owns and operates the RTA Rapid Transit rail system, which consists of one heavy rail line (the Red Line) and two light rail lines (the Blue and Green Lines). The majority of RTA's service consists of buses, including regular routes, express or flyer buses, loop and paratransit buses. In December 2004, RTA adopted a revised master plan, Transit 2025, in which several rail extensions, bus line improvements, and transit oriented improvements are discussed. [11]

RTA has equipped all of its mainline buses with bicycle carriers. Each bus can carry two bicycles. Bicycles are also allowed on rapid transit trains (with a maximum limit of two per car) at all times, although operators have discretion to refuse bicycles if a train is overcrowded.

2.2.1 History of Greater Cleveland Transit Authority

The GCRTA was established on December 30, 1974, [12] and on September 5, 1975 assumed control of the Cleveland Transit System. RTA's major predecessor, the Cleveland Transit System, was the first transit system in the western hemisphere to provide direct rapid transit service from a city's downtown to its major airport. Cleveland Transit System operated the heavy rail line from Windermere to Cleveland Hopkins International Airport and the local bus systems, and Shaker Heights Rapid Transit, which operated the two interurban light rail lines from downtown to Shaker Heights. A month later, the RTA assumed control over the suburban bus systems operated by Maple Heights, North Olmsted, Brecksville, Garfield Heights, and Euclid. [13]

The RTA had to undertake a number of renovations to the rail system, as the Shaker Heights lines (renamed the Blue and Green lines) had not been significantly renovated since their creation in 1920. They were largely rebuilt by 1981, and the downtown station at Tower City Center was heavily rebuilt by 1987. In 1994, a walkway and skyway was added from the Tower City station to Progressive Field and Quicken Loans Arena, and the Blue and Green lines were extended to the Waterfront area by 1996.

In 2007, RTA was named the best public transit system in North America by the American Public Transportation Association, for "demonstrating achievement in efficiency and effectiveness." [14]

Since its formation, RTA has greatly expanded the number of buses it operates, made numerous improvements to stations and support facilities, created the Transit

Police, and expanded its Paratransit services for senior citizens and disabled persons. The highlights of major achievements of RTA in its history are;

- 1979, RTA's fleet included 1,020 buses and 166 rail cars and according to 1980 US census the population of Cleveland was 573,822. RTA today has 492 vehicles on fixed routes; 1,332 shelters; 8,557 bus stops and 84 routes. In total RTA is providing 17.1 million service miles. The current population of Cleveland, OH is 431,630.
- January 1995, RTA opened a new $19.2 million garage on Harvard Avenue in Newburgh Heights, with the largest indoor compressed natural gas fueling station in North America, however the Harvard garage was closed due to budget crisis and majority of the workers were laid off.
- October 19, 2004 A federal Full Funding Grant Agreement was signed, and ground was broken near Playhouse Square for the $200 – million Euclid Corridor Transportation Project.
- October 1, 2007, RTA named Best in North America by APTA (American Public Transportation Association). The award is presented GCRTA for their excellence in public transportation system. The Award was not specifically for RTA's excellence in maintenance services.

However, the biggest budget crisis in RTA history took place in late 2008 and effected the entire organization dramatically. The crisis resulted in RTA to increase the fares and reduction of major services. Currently, the biggest project in RTA history - $200 million Euclid Corridor Transportation – is cutting service between 9:00 am and 4:00 pm, which is a great indication of RTA's situation. [13]

2.2.2 Funding for Greater Cleveland Regional Transit Authority

When RTA was formed, the voters of Cuyahoga County approved a 1% county-wide sales tax, which constitutes about 70% of its operating revenue. This funding source has helped RTA maintain a higher level of service than other transit agencies in comparable cities, and it also helps RTA retain some degree of political autonomy. However, it also makes RTA unusually susceptible to economic downturns.

In recent years, RTA has undertaken great efforts to improve efficiency and eliminate unnecessary costs. These efforts have included mergers with the two remaining autonomous transit agencies in Cuyahoga County, the North Olmsted Municipal Bus Transit and Maple Heights Transit, and the redesigning of its routes in the suburban areas southeast, west, and south of Cuyahoga County. However, the plan that RTA launched in order to overcome the budget challenges consists of six steps:

1. RTA is requesting that the State of Ohio work with NOACA to provide $8 million of grant funding for operations, and $3.456M of grant funding for ADA/Paratransit for 2010 and 2011. Of this amount, $6.2 million is already programmed for 2010, with the balance pending.
2. Reduction of personnel costs through reduction of positions, payroll and fringe benefits:
    - ♦ December 2008: RTA reduced salaried positions by 5% (complete)
    - ♦ September 2009: Layoff of 53 bargaining unit employees (85 total positions) as a result of elimination of Community Circulator service (complete)

- ♦ November 2009: RTA reduced salaried positions by an additional 3% (complete)

3. Reduce aggregate payroll costs of RTA personnel:

- ♦ January 2009: Salaries of RTA's salaried staff were frozen (complete)
- ♦ June 2009: Salaries of RTA's salaried staff were reduced by 3% (complete)
- ♦ Deferral of last pay in 2009 to early 2010 for salaried staff (in process)
- ♦ RTA has proposed to achieve significant labor cost reductions through collective bargaining with unions representing its bargaining unit employees (pending)

4. Achieve cost savings through changes to RTA health insurance program:

- ♦ RTA has proposed to achieve health care cost savings through collective bargaining with unions representing its bargaining unit employees (pending)

5. Achieve cost savings by changing or deferring certain employment benefits:

- ♦ RTA has proposed to cost savings through collective bargaining with unions representing its bargaining unit employees (pending)

6. The RTA staff proposes to maintain current fares ($2.25 base) for 2010 and 2011 (pending). Public Hearings on this proposal took place in early 2010. This will generate an additional $8.4 million in revenue for RTA to fund important services. [17]

	Bus/ Rapid	Park & Ride	Loop	Senior Disabled	Para-transit	Out of County	Trolley
Cash	$2.25	$2.50	$1.50	$1.00	$2.25	$3.50	Free
All day Pass	$5.00			$2.50			
5 Trip Fare card	$11.25	$12.50	$7.50	$5.00			
7 Day Pass	$22.50	$25.00		$10.00			
Monthly Pass	$85.00	$95.00		$38.00			

Table II. The fare prices for GCRTA

Table II expresses the current fare prices for Cleveland residents. Although GCRTA provides so many options for the residents the fare prices remain expensive and not easily affordable. [16]

Table III frames the current GCRTA facts explicitly and provides a common understanding of what GCRTA is capable of. Compared to equal size cities (Cincinnati, Columbus, Detroit, etc.) Cleveland is still the city, which has the biggest mass transportation. [15]

2.3 Organizational Structure of GCRTA

GCRTA 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. GCRTA performs maintenance tasks, which requires highly skilled labor. Promotion to upper grades is based on mechanic examinations held by RTA's training department. [21]

RTA's managerial structure (Figure 1.) is a vertical, top-to-bottom management system. At GCRTA 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. [21]

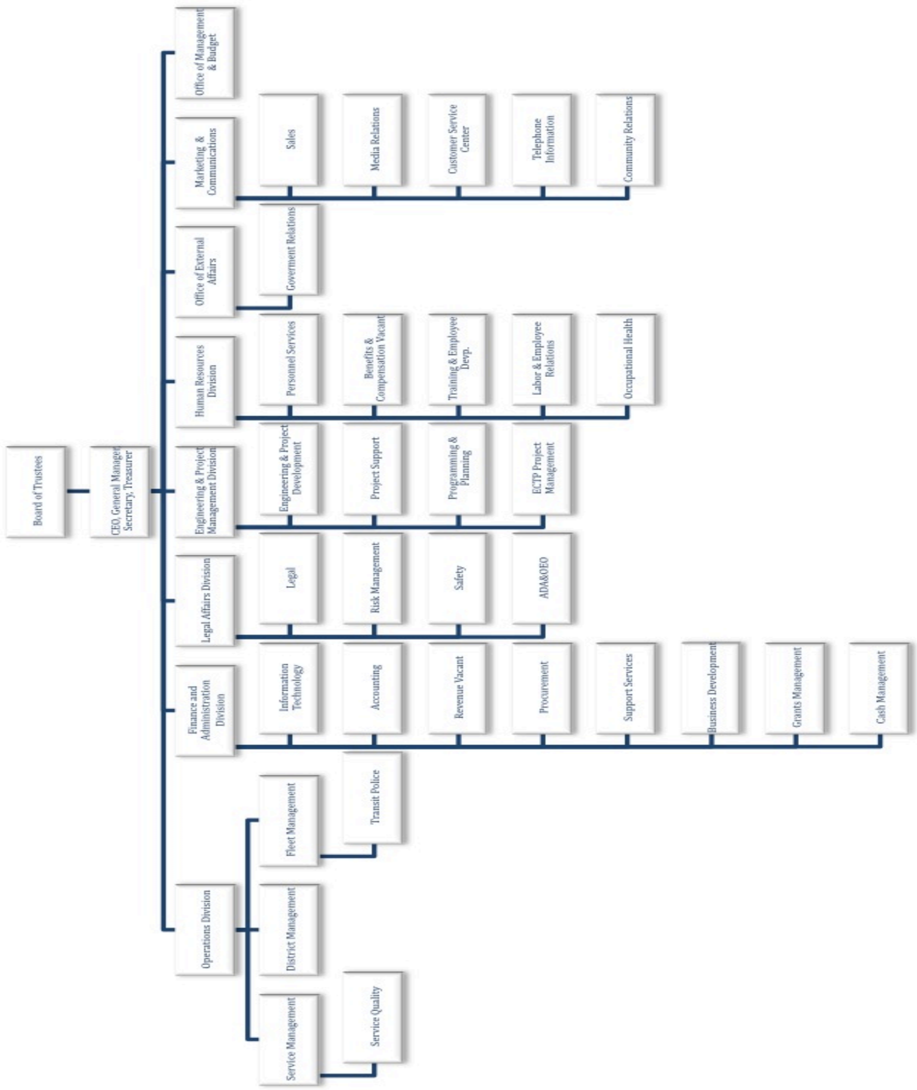


Figure 1. GCRTA Organizational Chart

This concept is called *yokoten* by Toyota Motor Company, meaning horizontal transfer of information and knowledge across an organization. Yokoten is a Japanese word that roughly translates to “best practice sharing”. Yokoten helps to ensure that all plants “level up” to the best performance in the group. [18]

GCRTA FACTS	
Annual Operating Budget	$246.5 million
Blue/Green Line Rapid Transit (Includes Waterfront Line)	3 routes; 48 light-rail cars; 34 stations; 18 miles of one-way track
Bus Rapid Transit (BRT) Service	1 route on Euclid Avenue and Public Square; 9.4 miles of bus-only lanes; 20 Rapid Transit Vehicles (RTVs); 59 stations and 3 platform stops
Bus Service	492 vehicles on fixed routes; 1,332 shelters; 8,557 bus stops; 84 routes; 17.1 million service miles
Commuter Advantage program	505 employers; 11,261 commuters; $6,300 estimated savings per commuter
Downtown Trolleys	2 routes; 11 vehicles
Employees	2,374
Paratransit	80 vehicles; 540,739 passenger trips
Parking Lots	8,800 spaces
Rail Service	2.6 million service miles, estimated
Red Line Rapid Transit	1 route; 60 heavy-rail cars; 18 stations; 19 miles of one-way track
Ridership	49.9 million passenger trips
RTA Web Site, www.rideRTA.com	More than 1.6 million visitors viewed more than 9.5 million pages
RTA-Owned Bridges	85 bridges; 1 tunnel
RTAnswerline, 216-621-9500	More than 922,000 calls were received
Service Area	458 square miles; 59 municipalities; 1.3 million people

Table III. GCRTA Facts

CHAPTER III

INTRODUCTION TO LEAN SYSTEMS

3.1 History of Lean Systems

As organizations have struggled to remain profitable during periods of economic slowdown, many have embraced lean systems as a tool to improve competiveness. Like many improvement programs, lean systems implementations have not succeeded universally in their application and the literature contains examples of both lean systems implementation success and failures. [23]

The roots of lean systems originate with early automotive manufacturing. The master craftsmen that first built individual cars possessed a wide range of skills and abilities, but with low efficiency and at high cost. Henry Ford recognized these limitations and broke the assembly process down into 30 – second tasks, which were performed almost a thousand times a day. In the 1950's, Eiji Toyoda and Taichi Ohno merged the knowledge and skill of master craftsmen with the standardization and efficiency of the moving assembly line and added the concept of teamwork to create the Toyota Production System (TPS). John Krafcik introduced the term "lean production system" in 1988 in his review of the Toyota Production System, and the term "lean manufacturing" was popularized by Womack, in The Machine that Changed the World. [23]

Lean Manufacturing has many definitions associated with it. Some researchers provide definitions specific to manufacturing processes while others employ a more general definition that could be applied to a variety of industries. [2]

3.2 Definition of Lean Systems

James Womack and Daniel Jones define lean manufacturing in their book "lean thinking" as a five step process: defining customer value, defining the value stream, making it "flow," "pulling" from the customer back, and striving for excellence. [28] To be a lean organization requires a way of thinking that focuses on making the product flow through value-adding processes without interruption (one-piece flow), a "pull" system that cascades back from customer demand by replenishing only what the next operation takes away at short intervals, and culture in which everyone is striving continuously to improve. [27]

Taichi Ohno, founder of TPS, said it even more succinctly:

"All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by removing the non-value-added wastes." (Ohno, 1988)

3.3 Important Words: *Value, Waste, and Flow*

Lean thinking starts with the customer and the definition of value. Therefore, as a process is a vehicle to deliver value (a product) to a customer, the principles of lean thinking should be applicable to the process industries and the processes within that industry. [19]

The identification of value propositions for specific customers is the starting point. Without a robust understanding of what the customer values you cannot move forward. Outside of the process industries there are many examples of what we mean by a ‘value proposition’ - as a consumer swimming goggles what we value may be the ability to swim with a clear vision, for others the value may be related to cost or specific design features or even the color of the goggles. Ultimately, the answer to the question “What does the customer want from this process?” (Both the internal customer at the next steps in the production line and the final, external customer) defines value. [19]

Any activity in a process, which does not add value to the customer, is called waste. Sometimes the value is a necessary part of the process and adds value to the company and this cannot be eliminated, e.g., financial controls. There are seven main types of waste as outlined in Figure 2. [19]

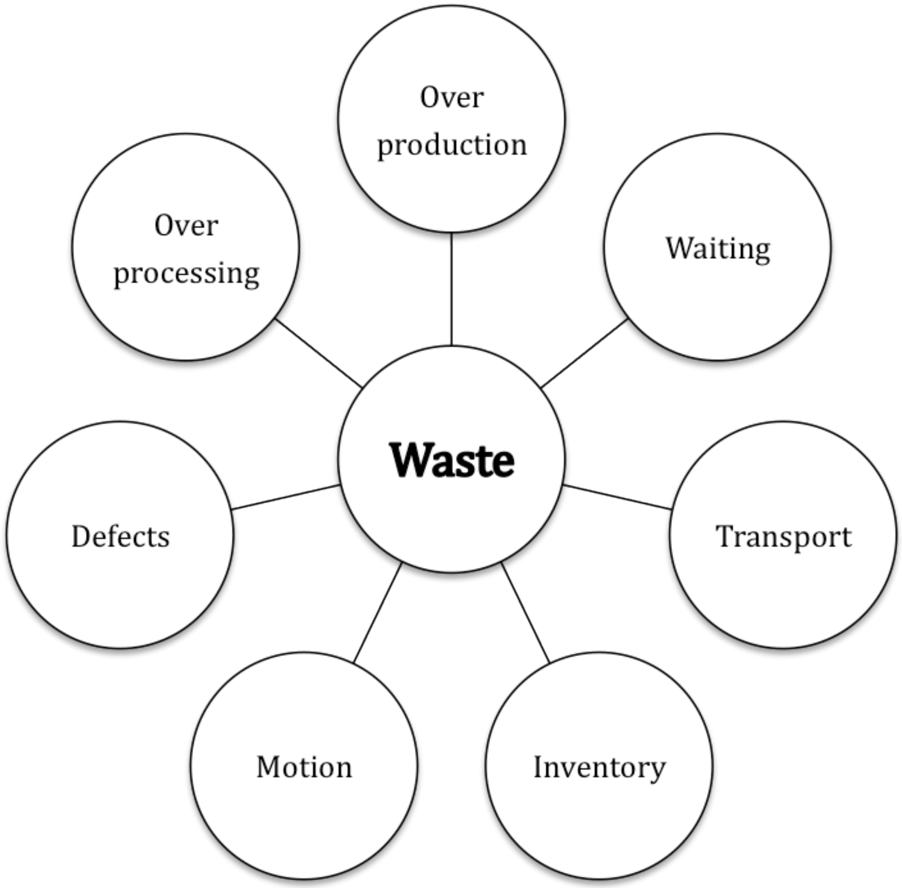


Figure 2. The seven types of waste

1. Overproduction. Producing items for which there are no orders, which generates such wastes as overstaffing and storage and transportation costs because of excess inventory. [2]
2. Waiting (time on hand). Workers merely serving to watch an automated machine or having to stand around waiting for the next processing step, tool, supply, part, etc., or just plain having no work because of stock outs, lot processing delays, equipment downtime, and capacity bottlenecks. [2]

3. Unnecessary transport or conveyance. Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes. [2]
4. Over processing or incorrect processing. Taking unneeded steps to process the parts. Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher-quality products than is necessary. [2]
5. Excess inventory. Excess raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also excessive inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup time. [2]
6. Unnecessary movement. Any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts, tools, etc. Also, walking is waste. [2]
7. Defects. Production of defective parts or correction. Repair or rework, scrap, replacement production, and inspection mean wasteful handling, time, and effort. [2]

Flow is probably the hardest lean concept to understand. It is the concept, which most obviously contradicts with mass production systems; the comparison of one-piece flow versus batch and queue processes. [2]

It is lack of flow in the processes, which accounts for the huge warehouses which house the mass of inventory, which consumes the working capital of the business. [1]

To understand the flow you need to understand the concept of the value-stream – that linkage of events or activities which ultimately delivers value to a customer. A value stream crosses functional and, usually, organizational boundaries. [26]

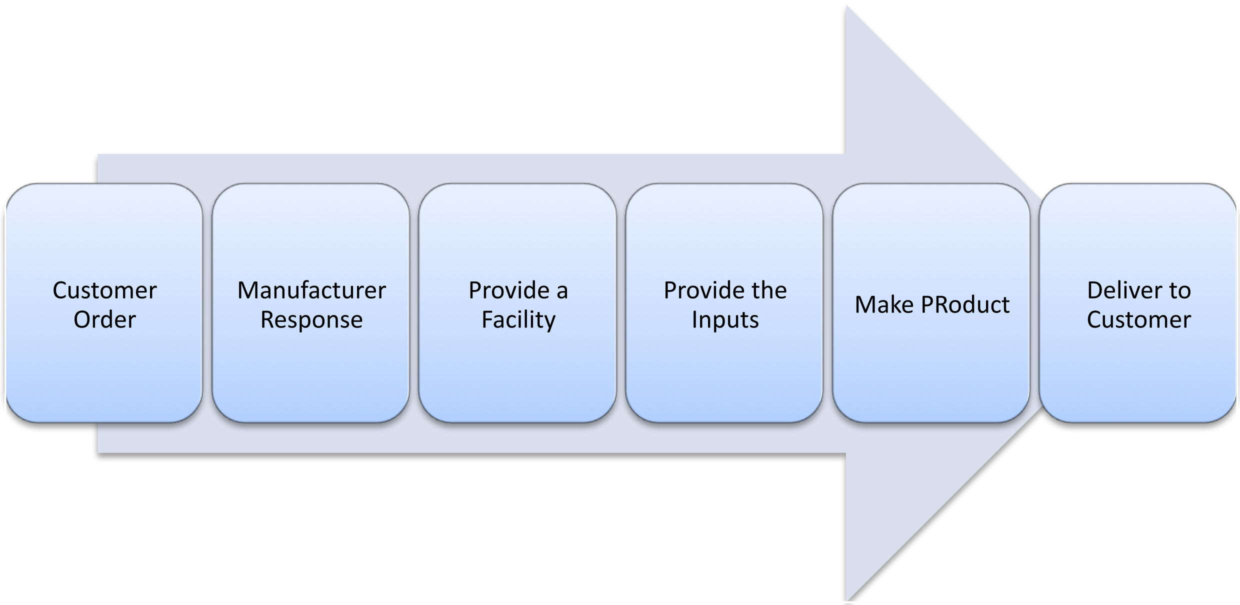


Figure 3. A Simple Value Stream

Figure 3 shows a simple value stream, which would be typical for a toll manufacturer. The value stream does not show all the supporting activities, only the main value adding stages and the key multi-functional teams involved. Flow thinking is easiest to see in conventional, discrete-product manufacturing, which is where flow techniques were pioneered. However, once managers learn to see it, it's possible to introduce flow in any activity and the principles are in every case the same. [19]

3.4 Philosophy and Tools of Lean Systems

Lean system is a unique approach to process oriented activities. It is the basis for much of the "lean production" movement that has dominated the manufacturing trends. The operational excellence is based in part on tools and quality improvement methods, such as just in time, kaizen, one-piece flow, jidoka, and heijunka. But tools and techniques are no secret weapon for transforming a business. Toyota's continued success at implementing these tools stems from a deeper business philosophy based on its understanding of people and human motivation. Its success is ultimately based on its ability to cultivate leadership, teams, and culture, to devise strategy, to build supplier relationships, and to maintain a learning organization. [2]

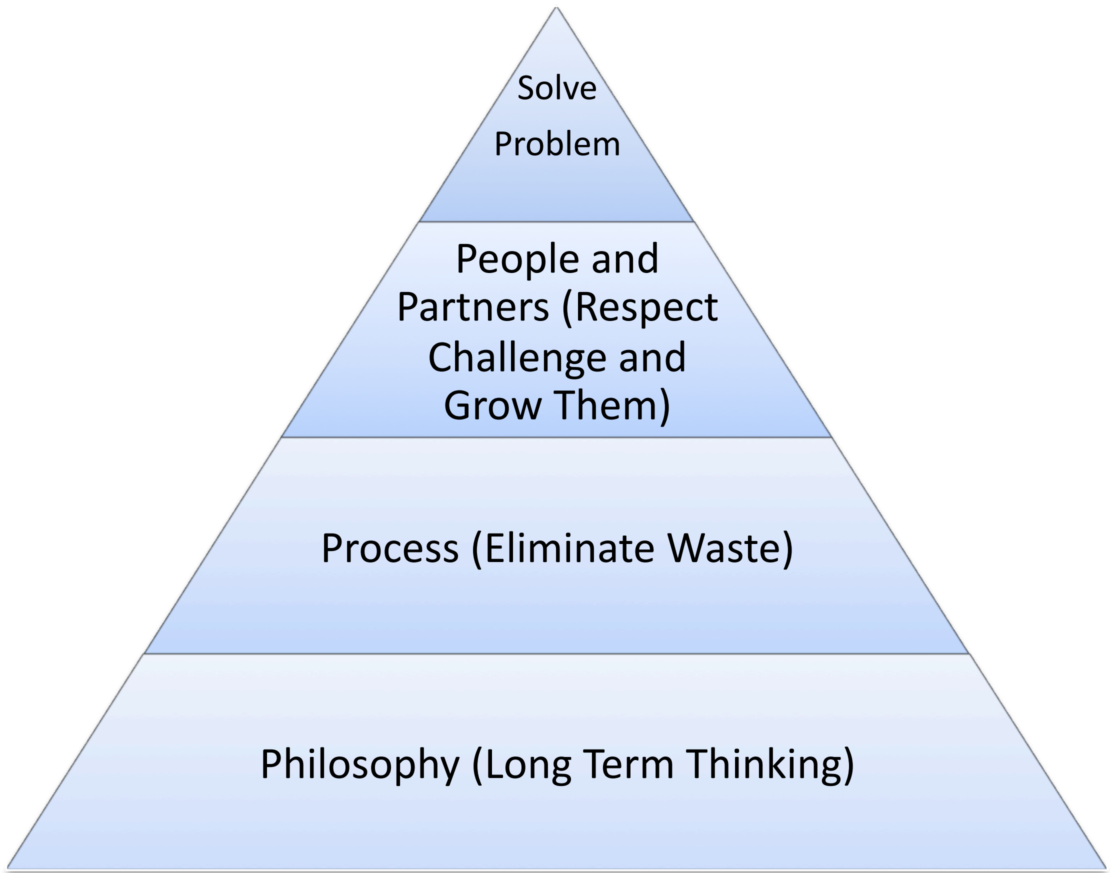


Figure 4. A Model of Lean Systems

Figure 4 illustrates the pyramid structure for Lean Systems, and as it is seen from the figure the most important aspect of Lean Systems is the philosophy (long term thinking). Management decisions should be based on a long-term philosophy, even at the expense of short-term financial goals. Lean thinkers are aiming for ‘perfection’ and in doing so and improvement cycle is never ending. For many in the process industries this culture change is the hardest change of all. [2]

However, for assured sustainability the organizations who are truly lean will invest the time and effort to support a change in culture - the way we do things around here. [2]

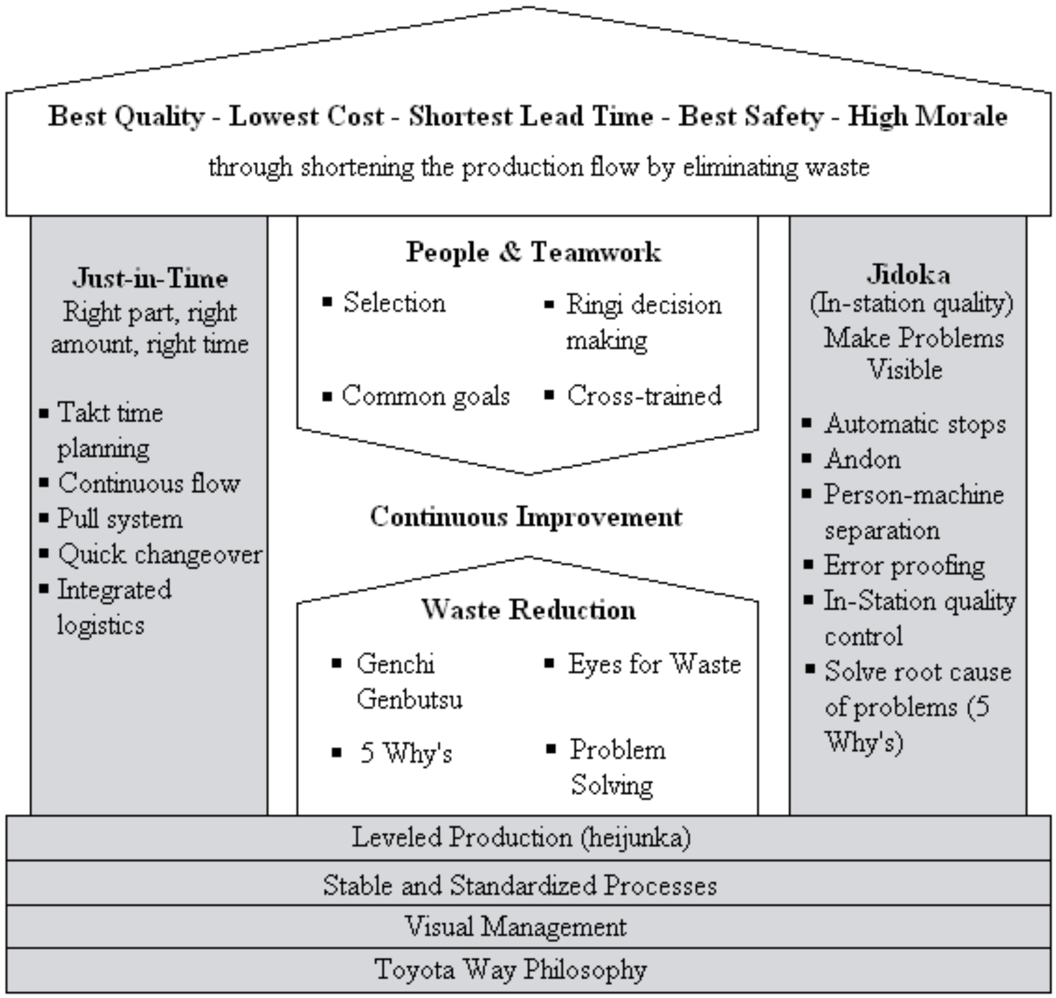


Figure 5. House Diagram for Lean Systems

The TPS house diagram is one of the most recognizable symbols in modern manufacturing because a house is a structural system and is strong only if the roof, pillars, and the foundation of the house are strong. Therefore, Figure 5 is a good depiction of the Toyota Production System, and it also emphasizes that it is not just a set of lean tools like just-in-time, cells, 5S, etc. It is a sophisticated system of production in which all of the parts contribute to a whole. [2]

Each element of the house by itself is critical, but more important is the way the elements reinforce each other. JIT (just in time) means removing, as much as possible, the inventory used to buffer operations against problems that may arise in production. The ideal of one-piece-flow is to make one unit at a time at the rate of customer demand or takt (German word for rhythm). Using small buffers (removing the "safety net") means that problems like quality defects become immediately visible. This reinforces jidoka, which halts the production process. This means workers must resolve problems immediately and urgently to resume production. At the foundation of the house is stability. Ironically, the requirement for working with little inventory and stopping production when there is a problem causes instability and a sense of urgency among workers. [21]

There are many tools and techniques to support each step in the process. Table IV shows a sample of the tools a 'lean thinker' would have in their toolkit. What surprises many skeptics is that the lean principles can be put into action using tools which are very familiar to those who have been involved in performance improvements. [19]

Tool	Description	Typical Use
Force field diagramming	• A tool which allows analysis of the forces supporting or resisting a particular change	• When looking at a typical design • When looking at the implementation planning for a change
IPO diagramming	• A basic flowchart tool mapping inputs, processes and outputs.	• To design a team session at any stage of the implementation of lean
Process flow mapping	• A map showing each process step in the value stream	• A data collection activity • Also used to analyze VA and NVA steps
Time –value mapping	• A map of the time taken for each process step in the value stream	• A data collection activity • Also used to analyze VA and NVA steps
Spaghetti diagramming	• A map of the physical path taken by a product as it passes down the value stream	• A data collection activity
Five whys	• Taichi Ohno had a practice of asking why five times whenever a problem was found, in order to find the root cause	• As a part of the data analysis so that the root cause problem can be solved in the design phase
Five S's	• Seiri – separate required from unnecessary tools and remove the latter • Seiton – arrange tools for case of use • Seiso – clean-up • Seiketsu – maintain the system you have set • Shitsuke – get into the habit of following the first four S's	• Can be used at the start of a lean induction to break down barriers and get a team to own their workspace • Often used during Kaizens as workplace layout and tidiness is often an issue which causes waste

Table IV. A Sample Lean Toolkit

3.5 Five S's

5S is a philosophy for workplace organization that eliminates waste, it organizes and manages the workspace, with the intent to improve efficiency by eliminating waste, improving flow and reducing process unevenness. 5S was originally invented by Toyota, and has been translated into English. [23]

Sorting (Seiri). Reviewing all the tools and materials used in a work area, and keeping only the essential items on hand. Everything else is stored or discarded.

Straighten (Seiton). Arranging tools, equipment, and parts in a manner that promotes flow in work area. Material is kept at the point of use, and the process is set in an order that maximize efficiency. For example, a shadow board shows where tools belong.

Sweeping (Seisō). Keeping the workplace clean and neat. Dirt and clutter can hide equipment problems, and create an unsafe work environment. A clean environment improves morale. Equipment problems are harder to ignore in a clean work area.

Standardizing (Seiketsu). Standardized work creates consistency in the workplace and in the end product. Associates develop and share best work practices in their areas of responsibility.

Sustaining the discipline (Shitsuke). Maintaining and continuing the gains from 5S. Commitment by all associates is necessary to prevent a decline back to the bad old ways of operating. [1,2,26]

3.6 Value Stream Mapping

Value stream mapping is a helpful method that can be used in lean environments to identify opportunities for improvement in lead-time. Although value stream mapping is often associated with manufacturing, it is also used in logistics, supply chain, service related industries, healthcare, and product development. [25]

In a build-to-the-standard form Shigeo Shingo suggests that the value-adding steps be drawn across the centre of the map and the non-value-adding steps be represented in vertical lines at right angles to the value stream. Thus the activities become easily separated into the value stream, which is the focus of one type of attention and the 'waste' steps another type. He calls the value stream the process and the non-value streams the operations. The thinking here is that the non-value-adding steps are often preparatory or tidying up to the value-adding step and are closely associated with the person or machine/workstation that executes that value-adding step. Therefore each vertical line is the 'story' of a person or workstation while the horizontal line represents the 'story' of the product being created. An example for a Value Stream Map provided below on Figure 6. [32]

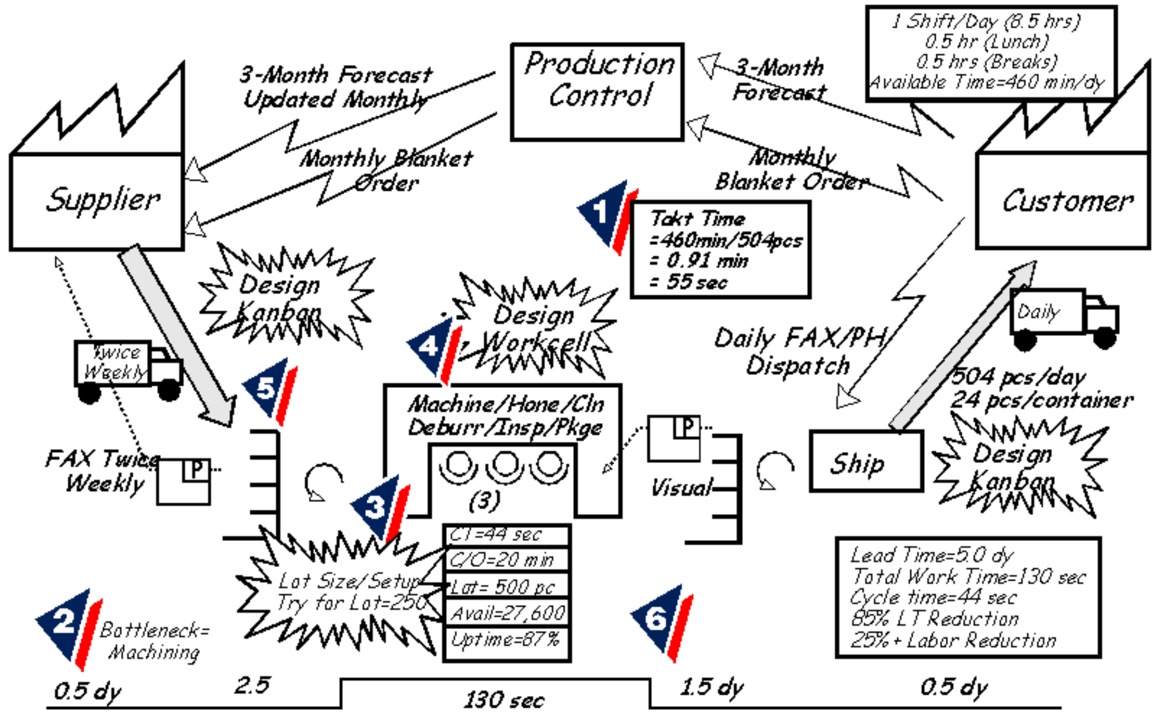


Figure 6. Sample Value Stream Map

3.7 Kanban

Kanban is a Japanese word that means “signboard.” This is a term that has become synonymous with “demand scheduling” or Just-in-Time (JIT) Manufacturing. Its roots can be traced to the early days of Toyota’s Total Production System (TPS) of the late 1940s and early 1950s. Kanban became popular in the U.S. during the global recession of the late 1970s, when it was important for companies to reduce waste and cut costs. [31]

The premise of kanban is to create visual indicators that allow workers involved in production to be the ones who determine how much of a product to produce and when to change over to making a different product. Kanban rules also tell the workers what steps to take and who to go to when they have problems. Workers then produce product based on actual usage, rather than forecasted usage. They only produce new product to replace the amount of product sold or consumed. [31]

Kanban is based on the principles we see working in a supermarket. A supermarket must keep product on the shelves so customers can purchase it. But, they do not want to have too much inventory on the shelves. [31]

Shelves must be restocked just before they are emptied of product. A supermarket must match customer demand with the amount of product on the shelves. [31]

3.8 The Benefits of Being "Lean"

The benefits seen within process industries, can be summarized in four bullet points:

- Decreased lead times for customers;
- Reduced inventories for manufacturers;
- Improved knowledge in management;
- Stronger and healthier processes (as measured by less errors and therefore less rework and less over processing)

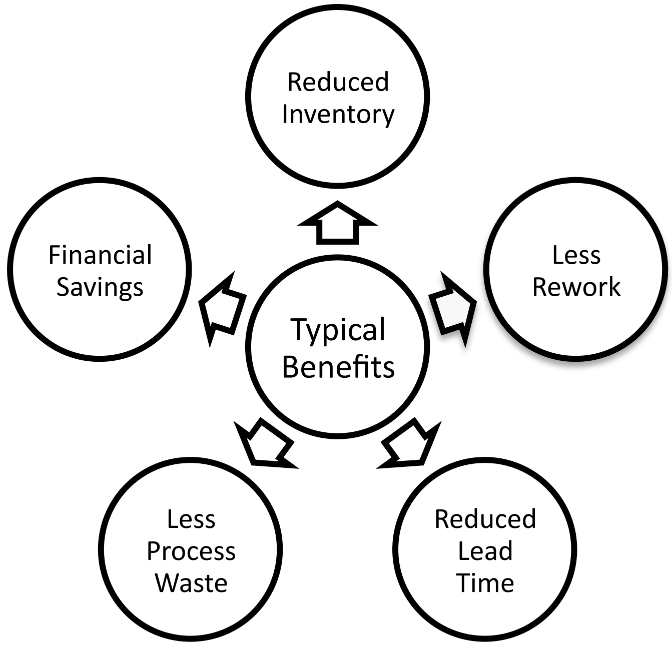


Figure 7. The Benefits of "Lean"

Lean systems have now spread to many different process industries and lean thinking has been applied to all aspects of the supply chain. There are many well-documented examples of the application of 'lean thinking' to business and industry processes such as project management, construction, design, governmental operations and so on. [19]

Lean can be applied to all aspects of the various industries and should be if the maximum benefits within the organization are to be sustainably realized. The two biggest obstructions with the application of lean thinking to business processes are the misconceptions of not getting enough tangible benefits out of the transformation and the business processes are already efficient and there is no room for improvement. [19]

- There are numberless tangible benefits associated with lean business processes. Most importantly, a lean business process will be faster, which leads to a more utilized and efficient organization.

- The perception that a business process is already efficient is all too often an illusion. Many business processes may appear very efficient, however, the implementation of lean thinking forces us to review the whole supply chain in which the business process sits, and this frequently reveals bottlenecks and pockets of inefficiency. [19]

3.9 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. [22]

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. [22]

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. [22]

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. [30]

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. [30]

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. [29]

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. [29]

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. [21]

CHAPTER IV

CENTRAL RAIL MAINTENANCE FACILITY

4.1 Introduction to CRMF

RTA opened its new $23-million Central Rail Maintenance Facility (CRMF) on April 29, 1984 on a 20-acre (81,000 m^2) site adjacent to the East 55th rail station. The new yard for all rapid transit cars was built on the site of the former rail yard of the Nickel Plate Road. The nearby Kingbury Shops originally built for the Shaker Rapid Transit were closed as operations were consolidated in the Central Rail facility.

RTA is currently performing all of the rail maintenance operations in the CRMF. The list of operations being performed is,

- Rail car inspection: All of the rail cars, which are reported as defected, are inspected prior to the maintenance operations.
- Rail car maintenance: The maintenance operations are defined as: electrical, truck, HVAC, body, motor unit. These operations will be discussed in depth later in this chapter. It is necessary to emphasize that the mentioned are the operations, but not the departments. In other words, these operations are what CRMF is capable of in rail car maintenance. Even though the Motor Unit is located outside

- of the Truck shop and considered as a different department, it is still considered as an internal customer to the Truck Shop and the Truck Shop's performance is highly dependent on the Motor Unit. It is also necessary to emphasize that the scope of this research is limited to Motor Unit and Truck Shop, however, the other departments will also be explained in the following section in order to present a better understanding of the facility.
- Rail road maintenance: This part of maintenance is relatively distance oriented compared to the other maintenance operations and performed by CRMF if necessary.
- Mid-life inspection: After 15 years of service each rail car goes through a mid-life inspection, which is a detailed process and out of scope for this research.

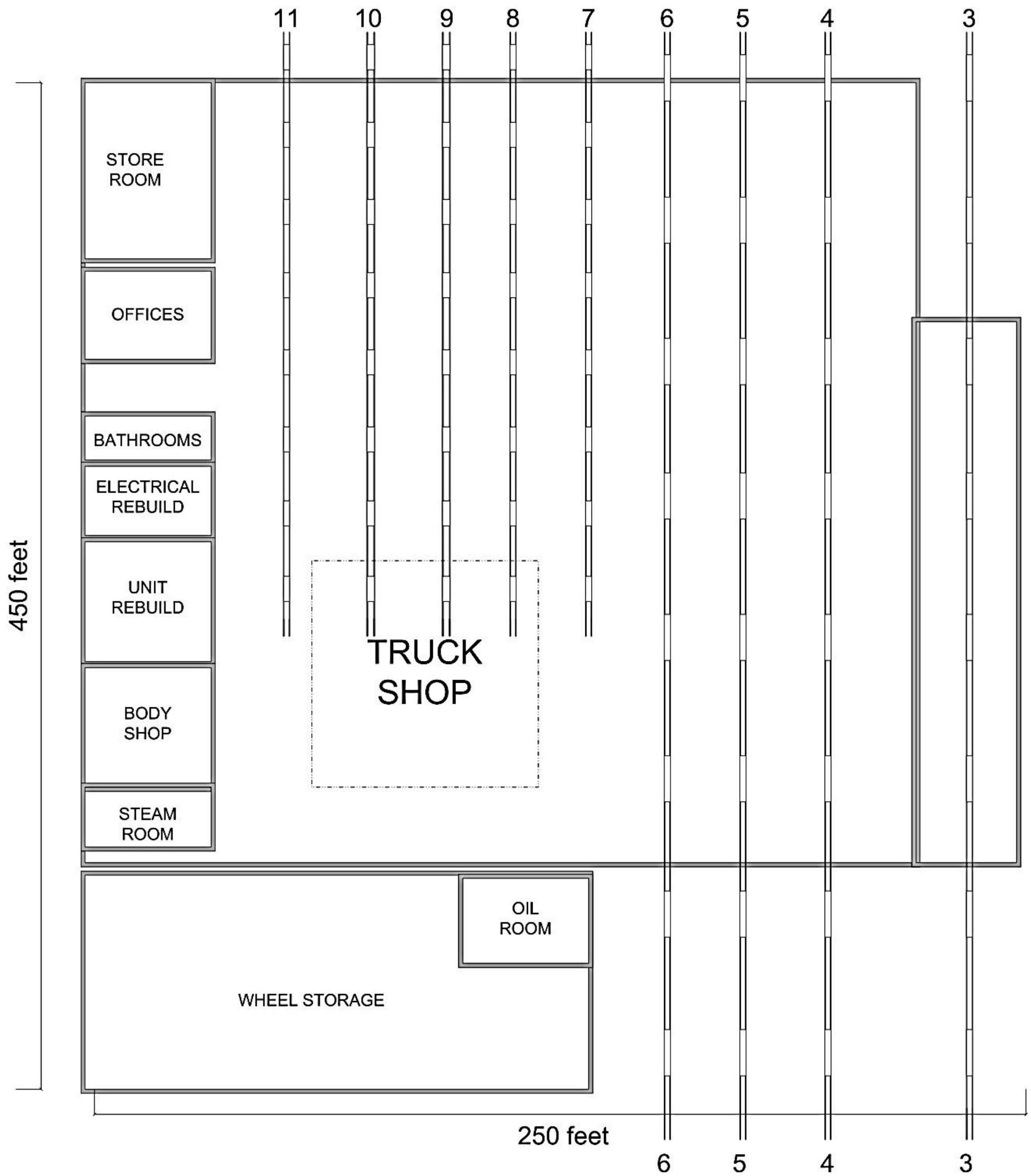


Figure 8. Floor Layout of CRMF

Figure 8 is the floor layout of CRMF and as it is seen from the figure, CRMF has a storing room where the registered inventory is kept. The straight lines are representing the railway, which goes inside of the job shop. As it is seen in the figure, the profound number of rail lanes in the job shop permits extra movement and holds the maintenance capacity in maximum. Offices are reserved for procurement team and supervisors. There is also a printing and office supplies inventory room inside of the office space. Electric unit is the branch where all the electrical repairs/maintenance is took place. Unit rebuild area is used for only motor rebuild. Wood and machine shop are interrelated and considered as one whole unit and all of the machining and body maintenance is performed at this unit. Steam room and Truck Storage (Wheel Storage) belong to truck shop where the main repair activities are performed. Truck shop is considered as the heart of the facility and plays an important role in rail maintenance. Although Truck Storage area belongs to truck shop, it is used by all of the units as an informal inventory area. Unregistered inventory is kept in this storage area. The capacity of each unit will be discussed later in this chapter.

4.2 Central Rail Maintenance Facility Departments

Central Rail Maintenance Facility consists of four major departments; Electrical Department, Body Shop, Unit Rebuild, and Truck Shop.

4.2.1 Electrical Department

Electrical department is one of the four main bodies of Central Rail Maintenance Facility and the responsibilities of this department are;

Electrical defects

Electronic defects

Inspection

Car movement (decision of which car will be repaired first)

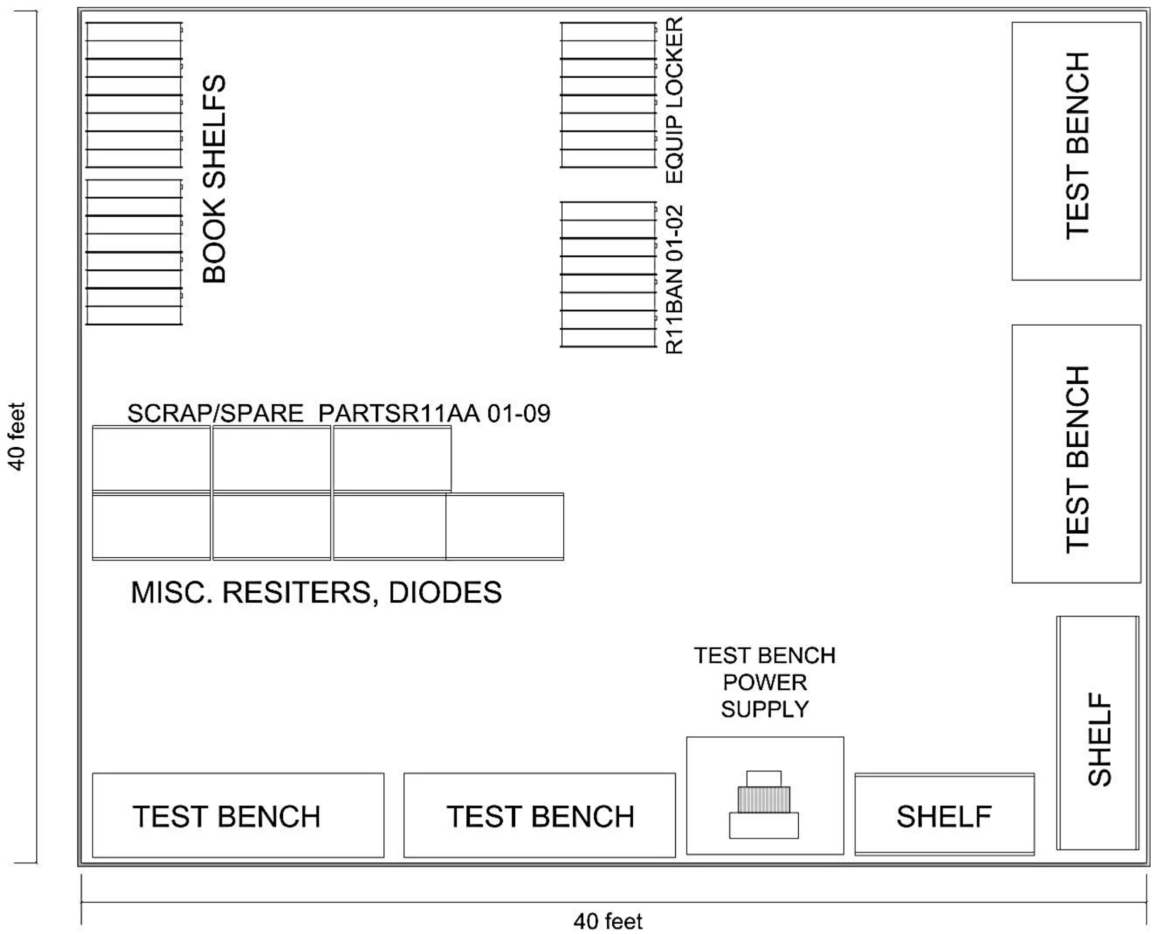


Figure 9. Electrical Department Floor Layout

Figure 9 presents the more detailed floor layout for the electrical department. All technicians work the day shift except one, which works on the night shift. The supervisor's responsibilities go beyond electrical repair. He organizes all the car moves within the shop and he is required to review and assign work request/work orders. The uses of an off system report is updated by the supervisor and used by all to manage shop function.

His crew is generally defect orientated but does retain a substantial amount of rebuilt items. A number of these items are not set up in stock nor captured properly in Ultramain, which is highly detailed inventory software. This is most prevalent on the Electronics side of the operation. The supervisor has eight mechanics of which he is responsible for.

4.2.2 Body Shop

The body department is responsible for general body, paint, and fabrication repair. They are also responsible in contributing to the inspection crew (number of employees assigned to inspection varies from time to time), and for scheduling interior washes. Cars routinely delivered late, not at all, or the wrong car, which is a result of poor communication between departments. The body shop consists of 8 mechanics.

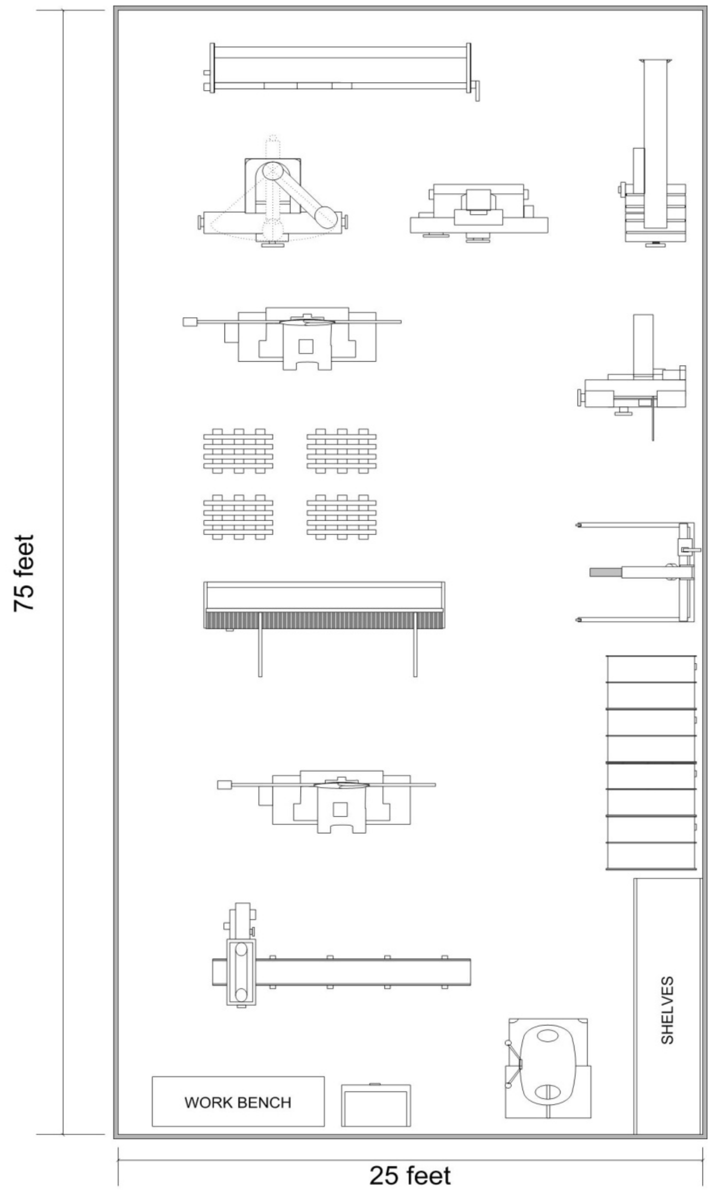


Figure 10. Body Shop Floor Layout

Figure 10 presents the more detailed floor layout for the Body Shop. Performance issues are revolved around part availability. Unfortunately, for some tasks mechanics have to strip other cars to get cars repaired. It has occurred that mechanics even have a Mid-Life train salvaged for parts, which reveals a major problem in the inventory department.

4.2.3 Unit Rebuild

Unit rebuild department is responsible for Inspection, Heat & AC, Air Systems and Motors. Unit rebuild consists of three mechanics and those mechanics are also asked to perform inspection if there is a lack of number of mechanics in the inspection area.

Figure 11 presents the more detailed floor layout for the for the Motor Unit (Unit Rebuild) area and as it is seen from this figure the area provides every type of rebuild process, however, the lack of experience and number of mechanics limit the rebuild capabilities. The demand for motors varies form season to season and winter is the most demanding season in terms of need in motors. Thus, during winter the unit rebuild department is extremely busy and struggles to meet the demand in motors. The coded drawings next to track eleven represents the shelves for unit rebuild mini storage area (e.g. R6AA01R).

There are nine different types of motors that GCRTA has and uses in rail cars, which are 1266 Traction Motor 45-6100, 4FL02050 Traction Motors 45-101000, 5CY1036E1 CBM Breda 45-10160, 5CY1049E3 TBM 45-6250 TCC, T8416 A/C Compressor Motor 52-10001 Breda, GS1801L A/C Compressor Motor 52-6015 TCC, T8417 EBM 52-10021 Breda, and EG205 EBM 52-6150. According to the defect the unit rebuild department decides to send the motor to a vendor or rebuilding it themselves.

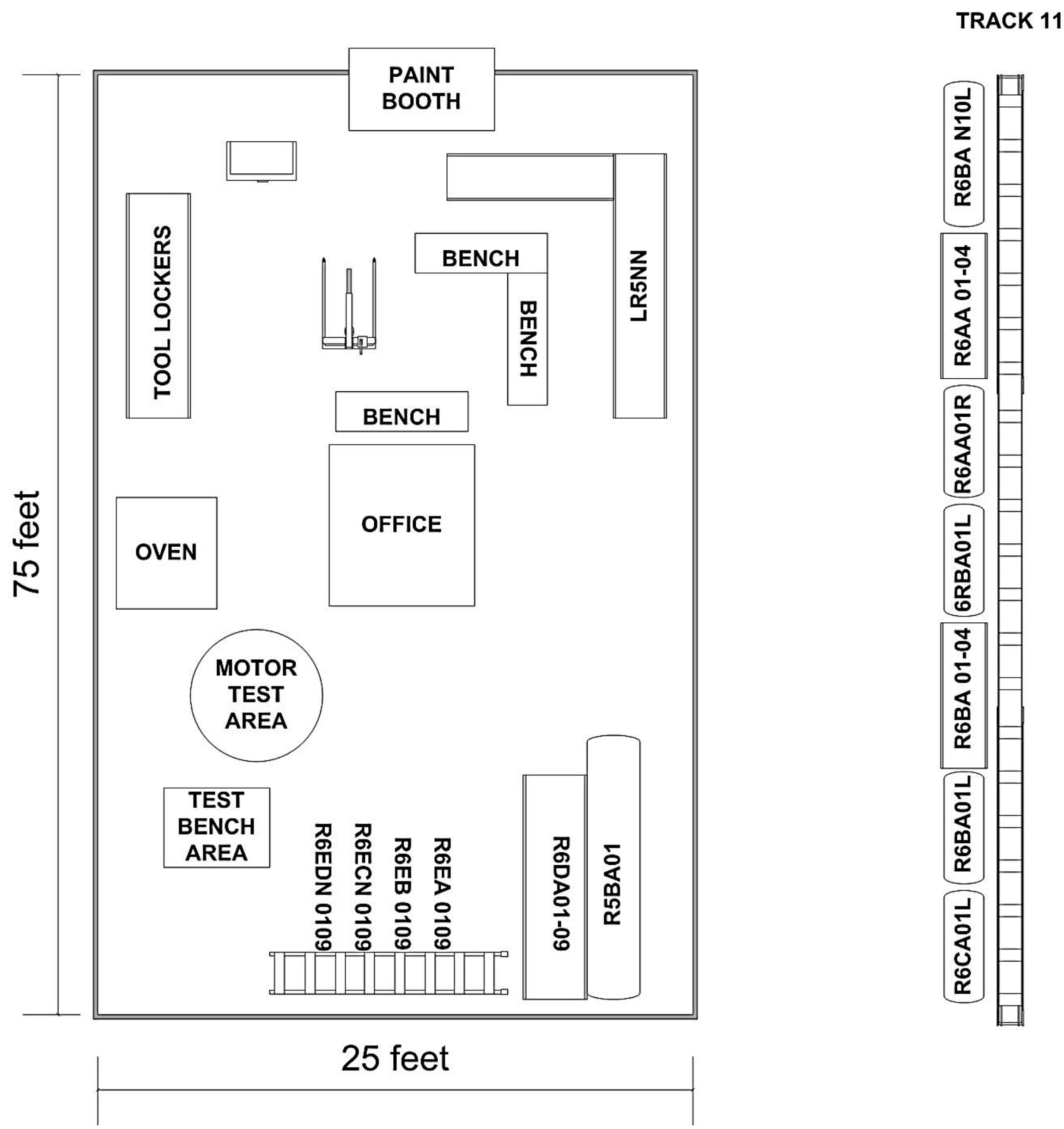


Figure 11. Unit Rebuild Floor Layout

The sand blasting and baking process is considered as a constraint in this process because of the location of the sand blasting machine and the capacity of the oven. There are two sand blasting machines at the CRMF, however the one with better blasting power is located at the end of the facility that requires too much travelling time and distance and even though the capacity of the oven is four, because of the fluctuating motor demand the oven is not running on its best capacity.

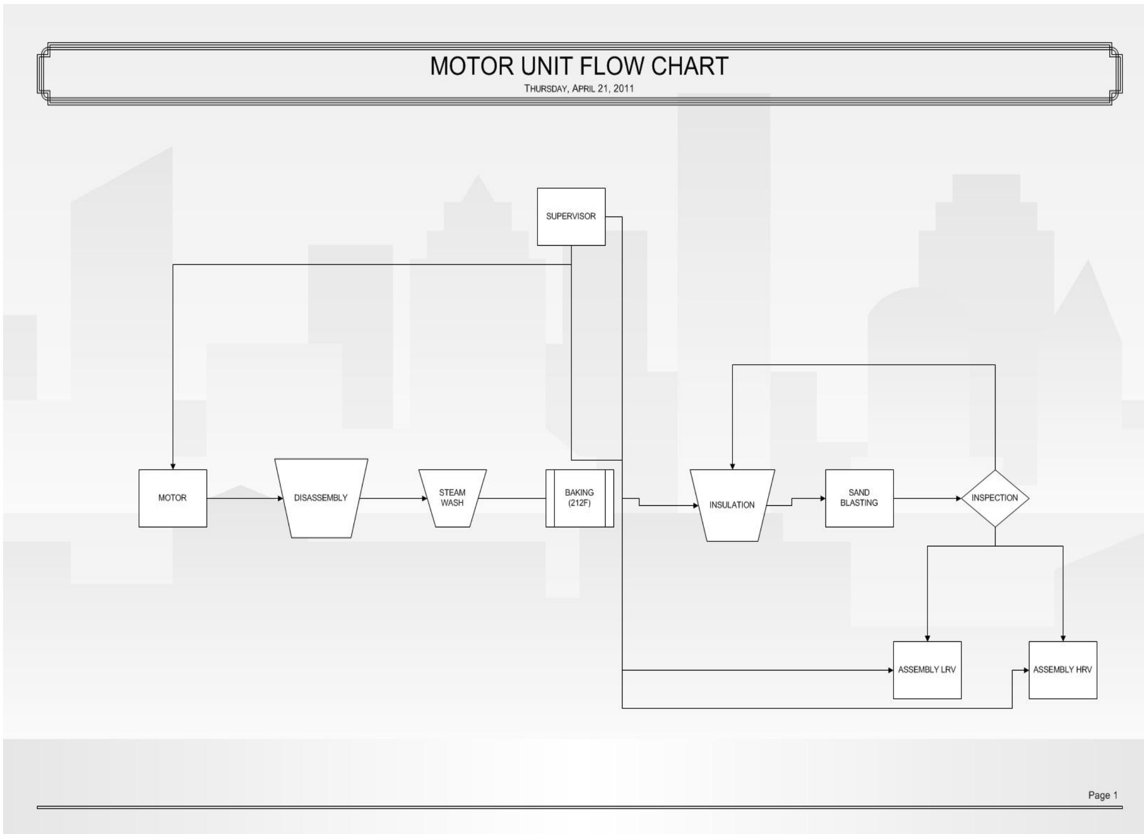


Figure 12. Unit Rebuild Flow Chart

Figure 12 presents the flow chart, which depicts an algorithm for the Unit Rebuild operations. The Unit Rebuild area provides the rebuilt motors to the Truck Shop. Hence, the Unit Rebuild department can be considered as an internal customer to the Truck Shop.

4.2.4 Truck Shop

As it is expressed earlier in this chapter Truck Shop is considered as the heart of the Central Rail Maintenance Facility and the major assembly and maintenance operations are performed at this department. Even though the job shop is defined as an interrelated shop the main focus is held on Truck Shop.

There are two types of rail cars that GCRTA possess: HRV (Heavy Rail Vehicle) and LRV (Light Rail Vehicle). Truck shop is responsible for the maintenance of both types and has two different crews for the maintenance operations. Both crews are specialized in their operations. Since the entire maintenance operations are divided into sections the Truck Shop is the end part of the operation and extremely dependent on the performance of each and every one of the departments. Figure 13 is the flow chart for the HRV maintenance. As it is seen in the figure boring process is a concern, which might yield loss in time. The boring process depends on the craftsmanship and there is only one experienced mechanic who is capable of performing boring process. There might

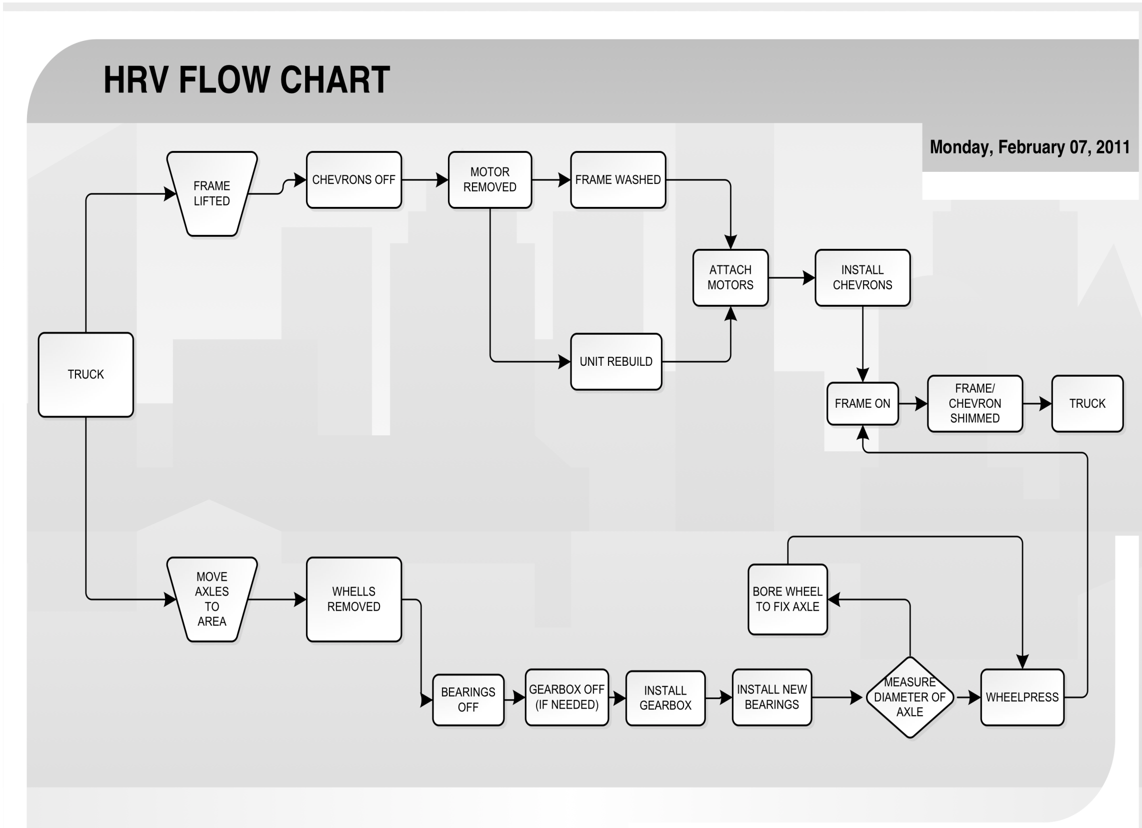


Figure 13. HRV Maintenance Flow Chart

be severe consequences in terms of financial aspects of the facility, if the wheels are bored falsely, hence, there is a great amount of pressure on the shoulders of the mechanic. The wheel pressing process can also be considered as craftsmanship since the result depends on the performance of the responsible mechanic.

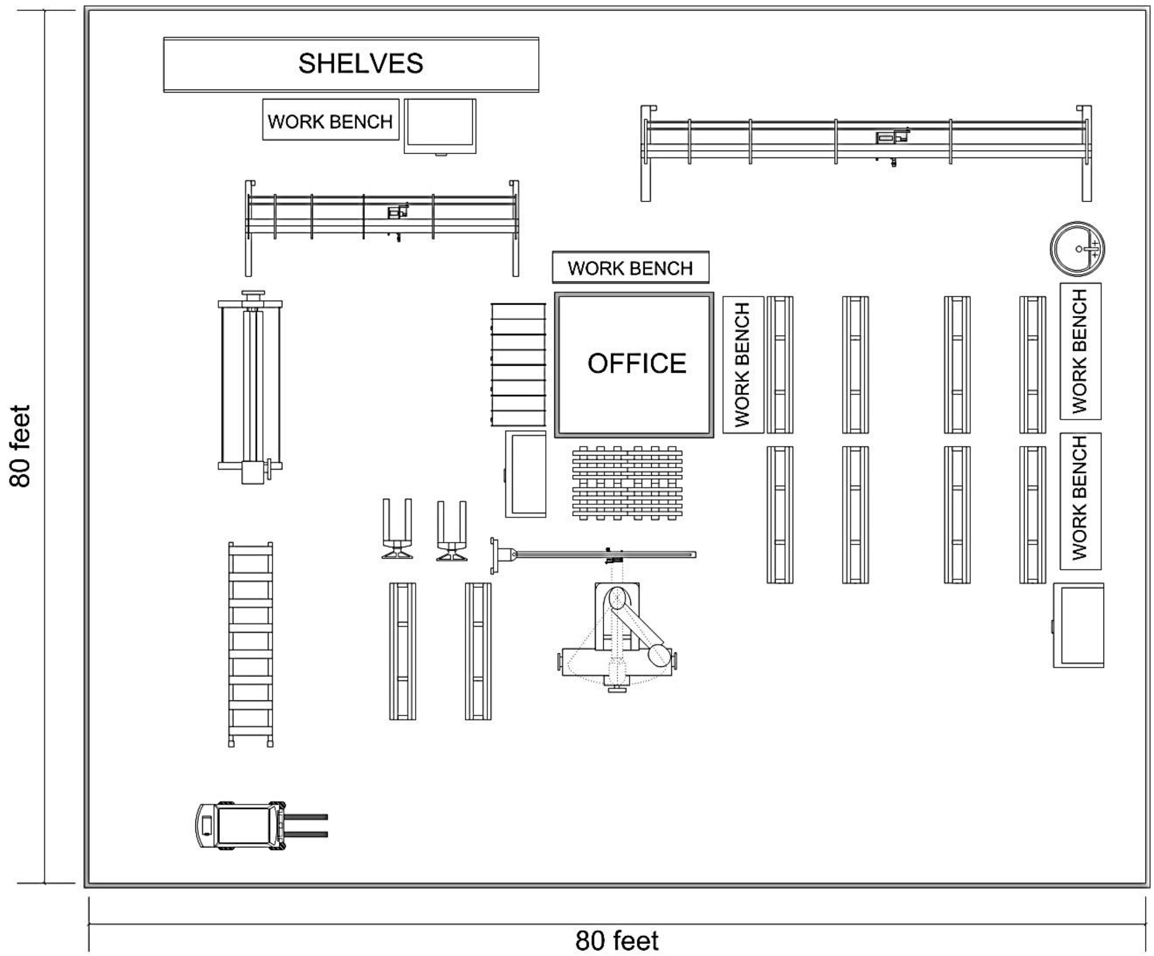


Figure 14. Truck Shop Floor Layout

Figure 14 presents the more detailed floor layout for the Truck Shop. The operations performed in this department are highly technical and the presented floor layout depicts the technicality of the area. The maintenance process begins with the work order, which is made and decided by the Electrical Department supervisor and right after the work order two less experienced mechanics are assigned to move the rail car in the job shop and detach the truck. As it is mentioned earlier, truck is the heart and most detailed component of the rail car. As a result of this fact it also takes the longest repairing time in the entire maintenance operations.

4.2.4.1 Truck Shop Storage Area

The importance and uniqueness of truck shop gave birth to the necessity of a separate inventory area for Truck Shop, and from the very first day of the CRMF, Truck Shop has its own storage area. However, as time went by, the area has begun to be used by other departments and currently the area is a miscellaneous storage place not particularly for Truck Shop.

Because of the procurement and financial constraints Tuck Shop has filled its storage area with wheels worth of $200K. The uniqueness of the rail wheels requires massive amount of order in order to get price discount, and also because of the wheel manufacturing process the wheels must be ordered nine months prior to the usage. These facts are important constraints for the Truck Shop management.

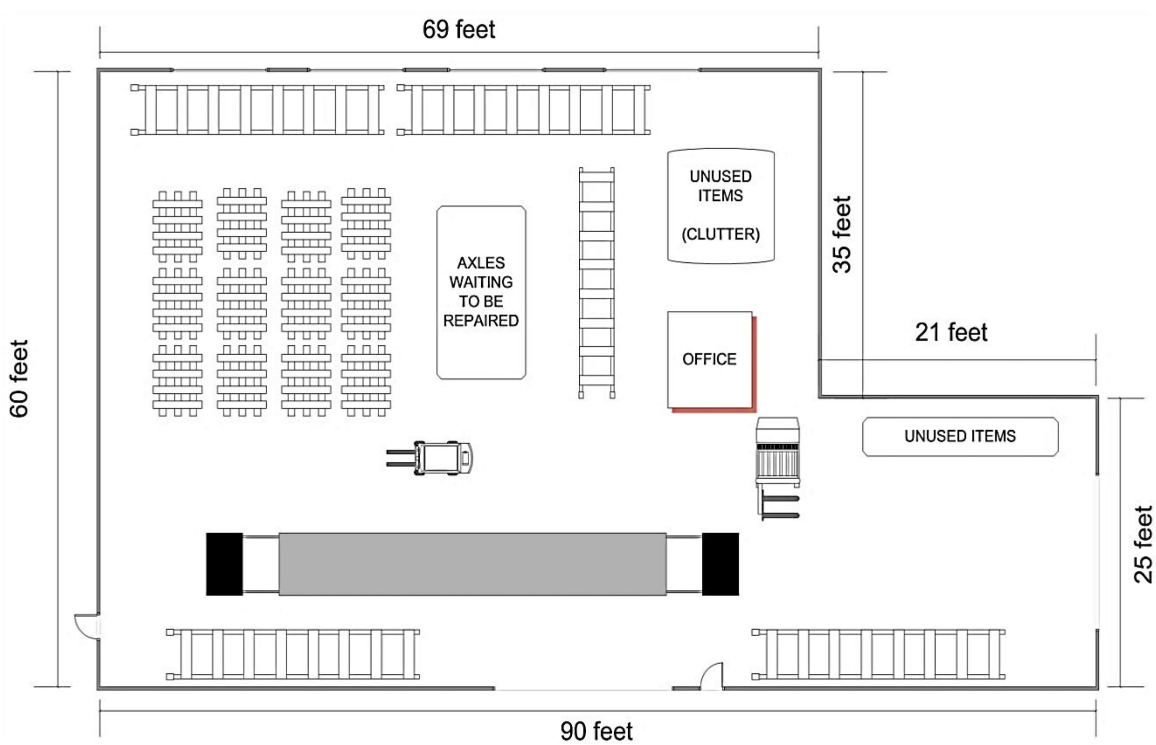


Figure 15. Truck Shop Storage Area Floor Layout

Figure 15 presents the more detailed floor layout for the Truck Shop Storage Area. One of the biggest problems that CRMF is facing with is this storage area where millions of dollars of investment is left to die. It can be clearly seen from the captions presented in Figure 16 the area is unorganized and cluttered.

Reluctance has caused the Truck Shop storage area permanent clutter and unorganized inventory. The inventory kept in Truck Shop storage area is not registered in the Ultramain and as a result of this nobody knows exactly what is kept in the room. According to the observations and the conducted interviews, there are some untouched parts and even brand new motors, which were purchased twenty years ago and left to die.

Figure 16. Captions from TS Storage Area

4.3 CRMF Organizational Structure

CRMF management is a small team compared to the corporate level management team, which enables the facility to manage faster and smoother. Every morning a meeting is held in the conference room where the daily tasks and goals are discussed. The supervisors and responsible individual then communicates with his team and explains the daily task and goals to them. These daily short meetings enhance the communication between the mechanics and the management. However, according to the observations that made in 2009, there is a concern in loss of productive time between the daily meetings and morning breaks.

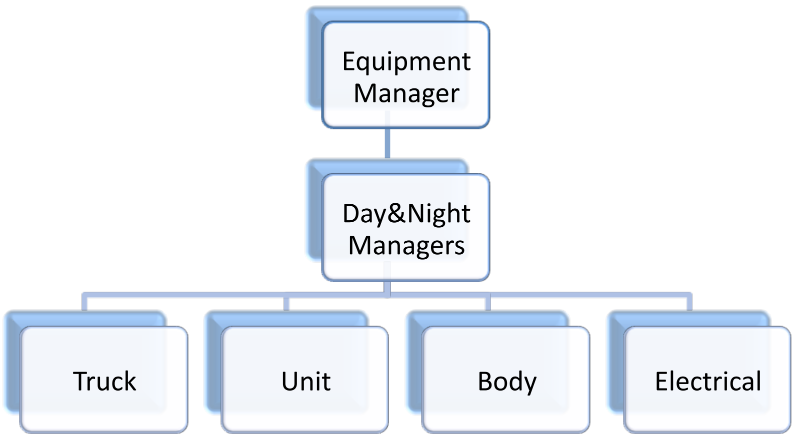


Figure 17. CRMF Organizational Chart

As it is seen in the Organizational Chart presented in figure 17, the CRMF has a very simple hierarchic structure, which is one of their strongest features and with good communicational skills this feature better enables the entire facility to work more efficiently.

RTA uses a workplace suggestion tool called Problem Identification/Corrective Action (PICA) form 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 management implements their ideas. 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. 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. 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 CRMF 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. [21]

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 relation. [21]

4.4 Conceptual Value Stream Map

The blank value stream maps (Figure 18 and Figure 19) presented in this section are a conceptual framework for the following chapter. The data boxes represent the individual processes of the entire operation. Inside of these data boxes, the cycle time, number of workers, and utilized time is presented. The arrows represent the flow between these operations in two different ways – pull system or push system. The circler arrow represents the pull system in the operation. The yellow bursts are used to indicate the diseased parts of the flow and point out where to tackle first. These bursts are also used to diagnose the problems. In the bottom part of the presented blank value stream map there is a time line. This time line shows the value added and non value added times both individually and collectively. The necessary value added type (muda) is addressed later in the following chapter. Value stream mapping tools and symbols are also presented in the Appendix B.

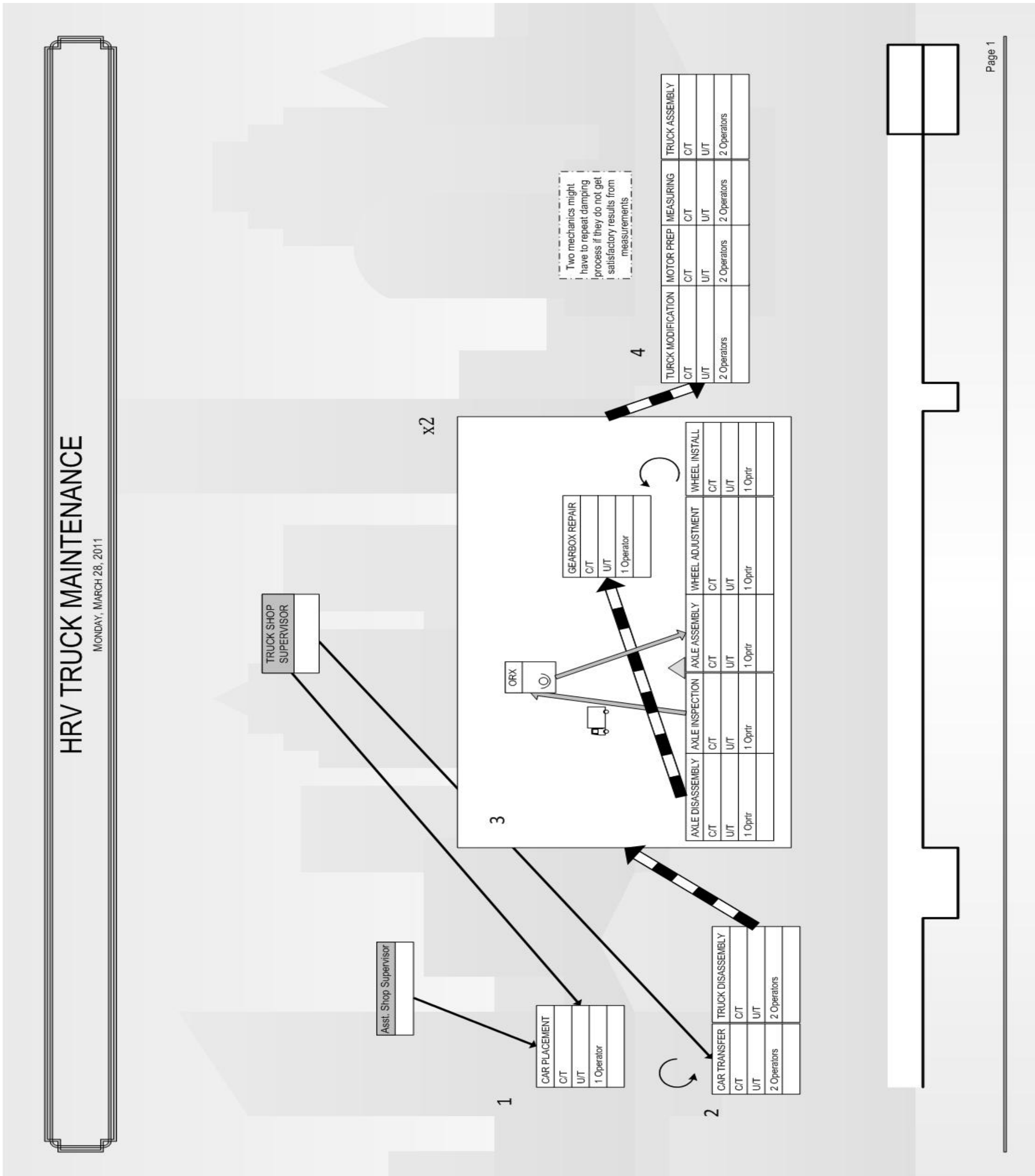


Figure 18. Conceptual VSM for HRV Maintenance

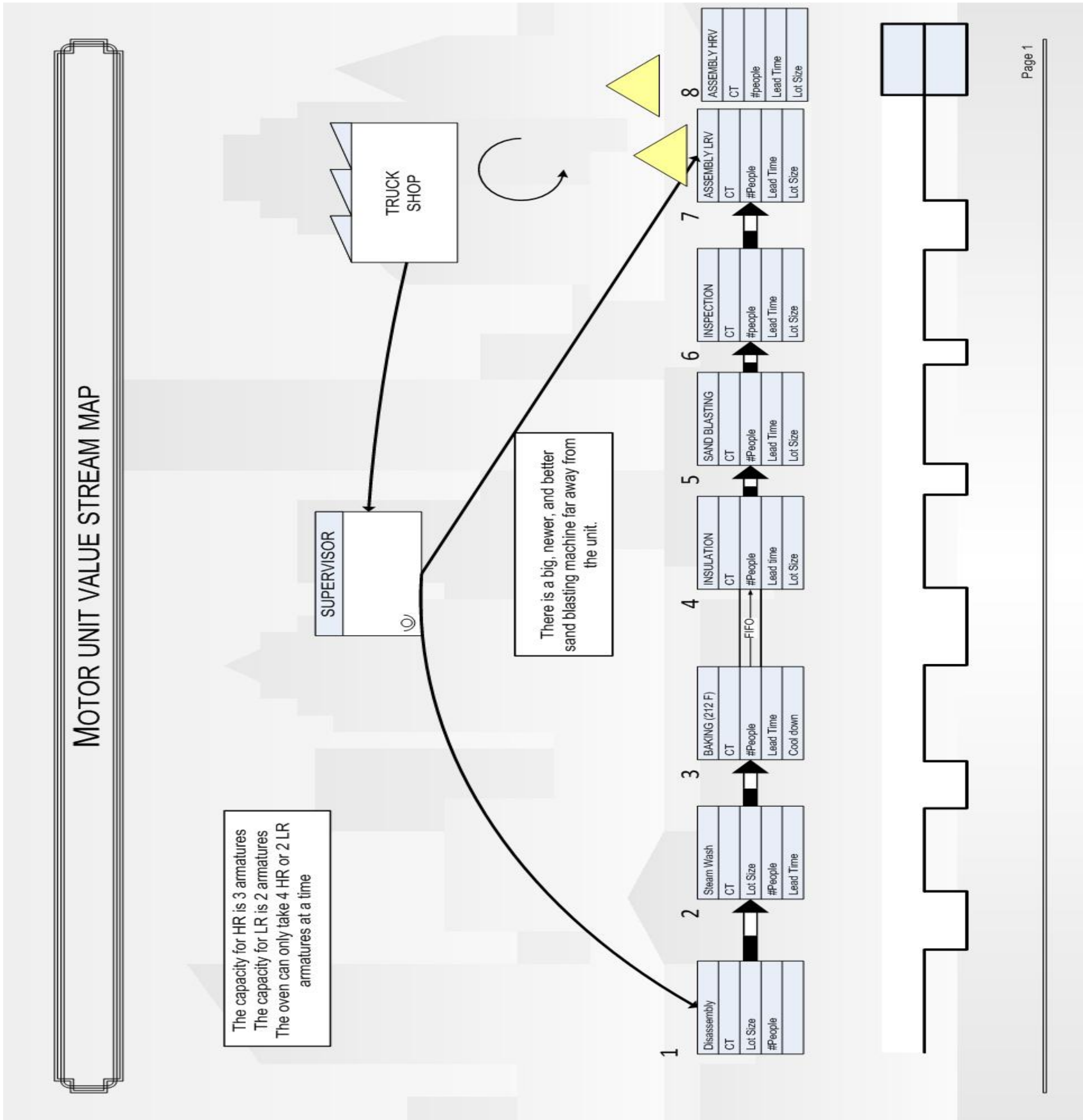


Figure 19. Conceptual VSM for Motor Unit

CHAPTER V

EXPERIMENTAL DESIGN METHODOLOGY

The initial roadmap for this thesis did not have a statistical analysis, but statistical analysis methods contributed to the research tremendously. The purpose of this chapter is, to define the statistical and experimental tools, which are used in this research. 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 the RTA staff does not use it.

The mentioned ERP system is highly complicated and also being used by some very successful companies and organizations such as Boeing and Cleveland Clinic. The system enables staff to store historic inventory data, however, it requires great amount of detail and time to operate the system. RTA already has less number of mechanics and as a result of this, the ERP system is not being used for the statistical analysis purpose.

5.1 Data Collection Methodology

Data collection process is the first and far most important step of statistical analysis and experimental design methodology. It should be done in a professional and consistent manner. The commonly adapted and most conventional method for this purpose is time study.

Time study is a direct and continuous observation of a task, using a timekeeping device (e.g. stopwatch) to record the time taken for accomplish a task. After recording the time, the worker's performance time (level) is recorded, and then the data are used to make the standard time for the task. Personal time, Fatigue, and delays are then added to the standard time that had been made. The data collection methodology for this research is very similar to time study methodology, however as it is mentioned in the second chapter GCRTA has a unique work environment and being a unionized job shop is one of the features of it. The unionized job shop was a constraint to the researcher for the data collection process. Even though substantial amount of visitations are made to the job shop it was not agreed to conduct a time study in the job shop by the union and the management. Hence, the time study was made in a secretive and reliable manner.

5.2 Value Stream Mapping at GCRTA

Value stream mapping is used as a road map for data collection in this research as well as pointing out the diseased areas. The researcher has extremely benefited the effectiveness and easiness of VSM. The researcher has recorded all the times in the Value Stream maps that are presented in this research. Over one hundred and twenty visitations are made to the maintenance facility for the purpose of data collection in a period of eleven months.

5.2.1 Motor Unit Value Stream Mapping

The presented value stream map (Figure 20) is drawn for the purpose of addressing the diseased sections of the motor unit and it should be emphasized that the VSM is representing the before stage of Motor Unit. The biggest constraint that CRMF Motor unit has is the number of mechanics working at that area. The current recession that U.S. is undergoing has affected CRMF significantly in terms of workforce at the facility. Not only motor unit, but also each and every department of CRMF is suffering from the same problem. One supervisor is responsible for the motor unit and he is the one who makes the work orders for weekly goals.

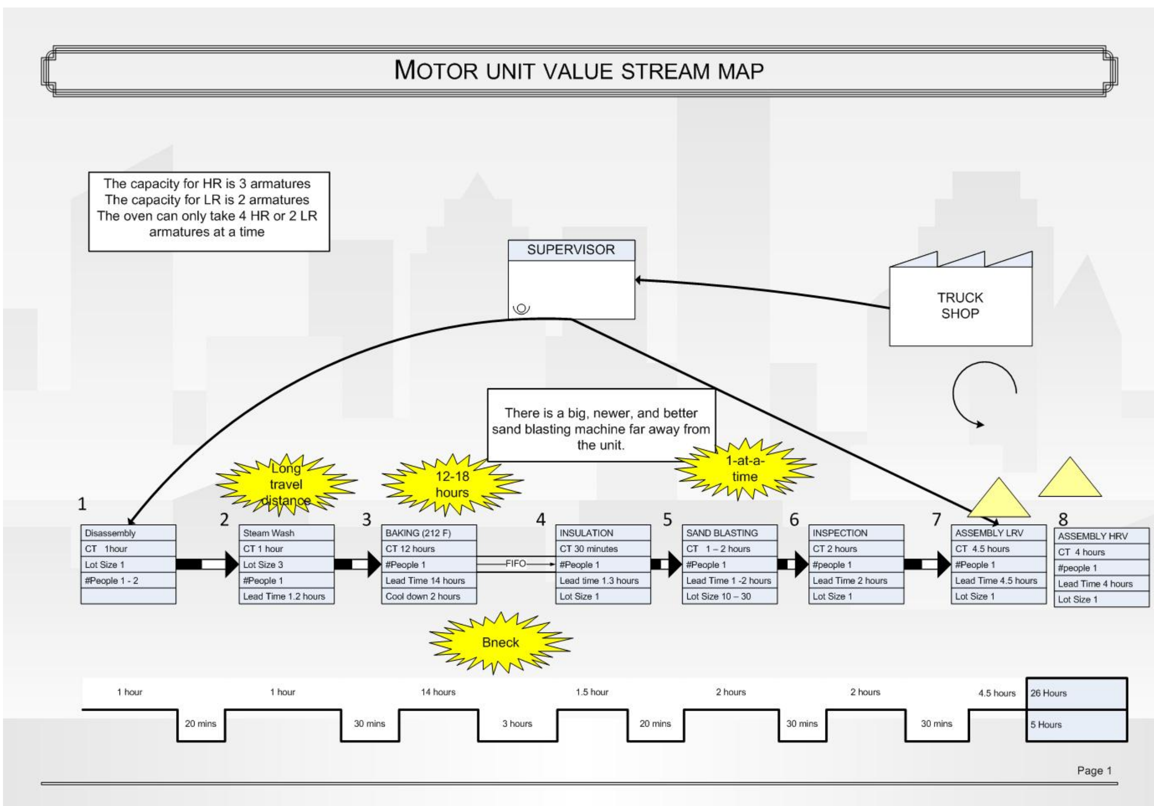


Figure 20. Motor Unit Value Stream Map

As it is explained the current financial crisis that RTA undergoes is also affecting the responsibilities of the supervisors. The supervisor who is responsible for the electrical operations and maintenance now also has to supervise the motor unit, which used to be supervised by the motor unit supervisor.

A closer look to the stations provides the issues with the system. The disassembly is an absolute necessity but the interesting point of this process is that the motor is never disassembled completely. One level-four-grade mechanic is responsible for this process. Since there are nine different types of motors, the standardization is a very difficult task to achieve and the only one mechanic even makes this task unachievable.

The mechanic uses a hydraulic lift and a cart for the transportation from the motor unit to the steam wash room. The second section is steam washing and it is performed by the one and only mechanic who is assigned for the motor rebuild. The most important problem with this section is the travel distance. The cycle time for this process is one hour. Although the steam wash is a relatively fast process, the carriage of the motor results in a substantial amount of time loss.

The third process is baking the motors. The longest time is spent for this process in the entire motor unit department, and this process is considered as the bottleneck. The biggest problem is the unscheduled operations with the oven. The capacity is 3 armatures for heavy rail vehicle motor and 2 for light rail vehicle and it is never 100% utilized. It takes 12 to 18 hours to bake an armature according to the features of it. The oven is operated in the first-in-first-out manner. Also bringing the motor back from the steam wash room and putting it in the oven is extremely labor intensive and consumes big amount of time – 26 minutes. After the baking process all the transportation times are negligible because the remaining procedure is conducted in the motor unit area and the mechanic does not have to travel long distances in order to complete the section process.

The fourth section is the insulation process and it is crucial for the electromagnetic flow. The mechanic is highly experienced in the insulation process and by using his experience and expertise he saves 45 minutes in the insulation process. The insulation waiting time is also considered as necessary non value added time, because after painting the motor the mechanic has to wait for the paint to dry. The same problem occurs in this process similar to baking. The mechanic only completes one motor at a time and he waits the same amount of time for each motor to dry out. After sand blasting and inspection the mechanic assembles the motor and fills out a completion form and carries the good motor to the place where the good motors are kept, which is in front of the unit rebuild area.

5.2.2 Truck Shop Value Stream Mapping

The main focus of this research as the truck shop and the value stream map presented below in Figure 21 is drawn for the truck shop / heavy rail maintenance.

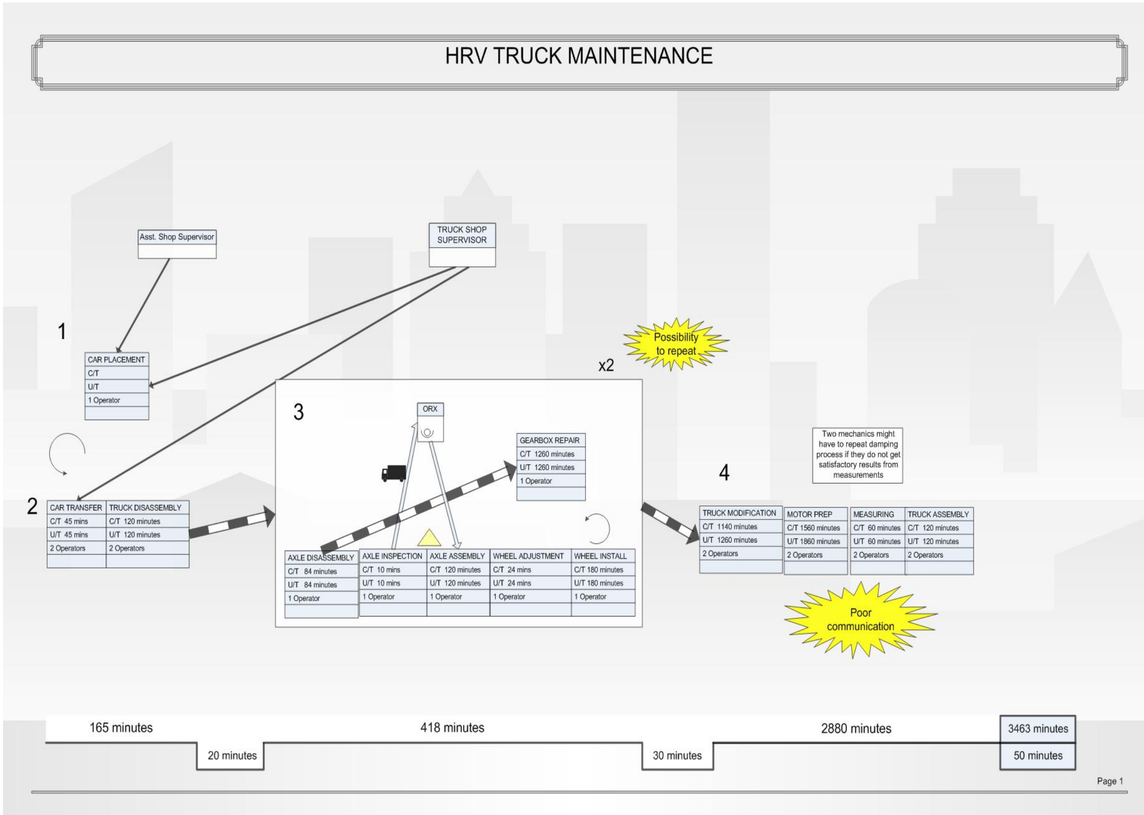


Figure 21. HRV Truck Shop VSM

Two mechanics are assigned to car placement task by the assistant supervisor of the Truck Shop. Truck shop only has an assistant supervisor because he will be promoted to the supervisor position after the probation period. The cycle time for this task is 43 minutes. Although it is a relatively easy task, if any mistake is made with the detachment of the truck from the rail car, the mechanics will loose fifteen to twenty minutes. Car placement process has to be operated by no less than two mechanics because of the safety regulations.

In the next section, the same mechanics disassemble the truck and the cycle time for this section is one hour and fifteen minutes. After this point the frame is taken to the steam wash. Steam-wash room is next to the assembly bench and the transportation time is negligible.

Axle maintenance is an independent process performed by one level-five-grade mechanic. He is one of the most experienced mechanics in the job shop. The worn wheels are taken out and the mechanic inspects axle for the diameter of the new axle. Wheel pressing machine is used for pressing in and out the wheels. This task is also highly labor intensive. The bridge crane is assigned to axle assembly, which saves the mechanic's time and energy. If the inspected axle's size is not satisfactory, mechanic bores the new pair of wheels to match it. After the adjustment, wheels are installed to the axles by using the wheel-pressing machine. For the wheel adjustment operation the total traveling time is twenty minutes. The wheels are not light enough to be carried by the mechanic; thus, he uses a crane to load the wheels on the boring machine. The bad axles are sent to ORX (a vendor of RTA) to be fixed. The total cycle time for axle maintenance is five hours. All the equipment is extremely heavy and the mechanic has to use hoisters and a bridge crane and as a result of this transfer and installation take long time.

The axle consists of three parts; axle, wheels, gearbox. The gearbox maintenance is done by one grade-four-mechanic and he is already ahead of the schedule by a substantial portion.

The third section is truck modification and performed by two grade-four-level mechanics. The purpose of this process is to fix the hardware problems with the frame, attachments, and chevron springs. Since the problem with the truck varies, there is no uniform cycle time for this operation, however, the observations shows that the usual cycle time varies between 19 to 24 hours.

The remaining sections are the easiest parts of the truck maintenance process, which are dampening and reassembly. These two operations are performed by two mechanics and the cycle time is 2 hours and 13 minutes.

5.3 Seasonal Distribution of Motor Unit Work Orders

Due to Cleveland's climate the maintenance necessity varies from season to season. As the motor unit department explained thoroughly in the previous section, it can easily be said that motor is the heart of the truck; hence, the maintenance of motors plays a tremendous role on the entire operation. The pie chart below is a representation of the distribution of the work orders for motors according to seasonal changes.

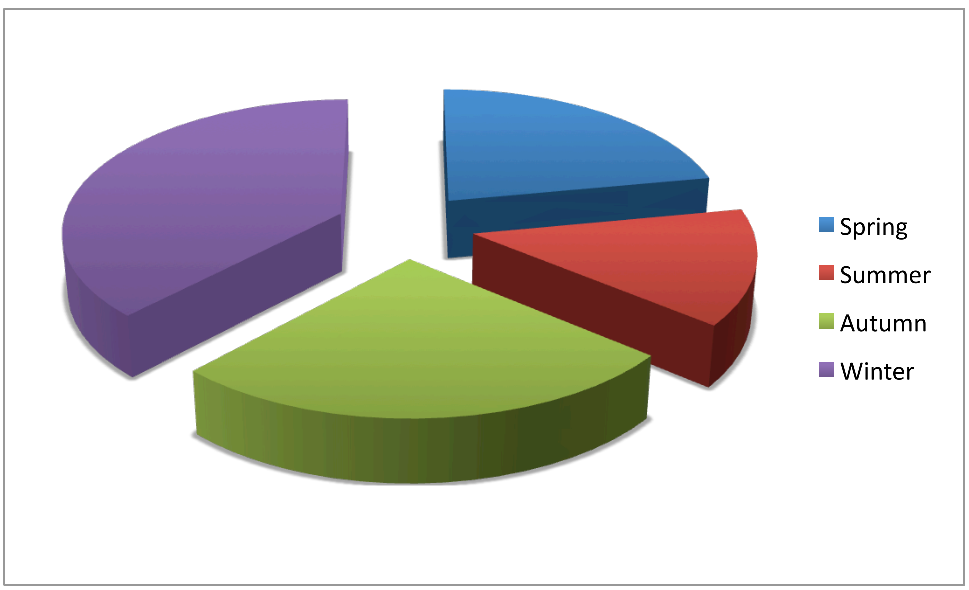


Figure 22. Seasonal Motor Distribution

The severe winter conditions in Cleveland resulted in most breakdowns in the year with a number of 73, the following number of breakdowns are 52, 44, and 28; which corresponds autumn, spring, and summer respectively. CRMF staff is using summer, which is the least busy season, to rebuild buffer inventory for motors. By achieving this task the workload on their shoulders becomes lighter for winter.

5.4 Data Collection Agenda

The researcher has collected the data in the manner, which is explained then. The Gantt Chart presented below was the observation methodology followed. Figure 23 is only one example of several observations and it is repeated for six times and the data is presented in chapter six.

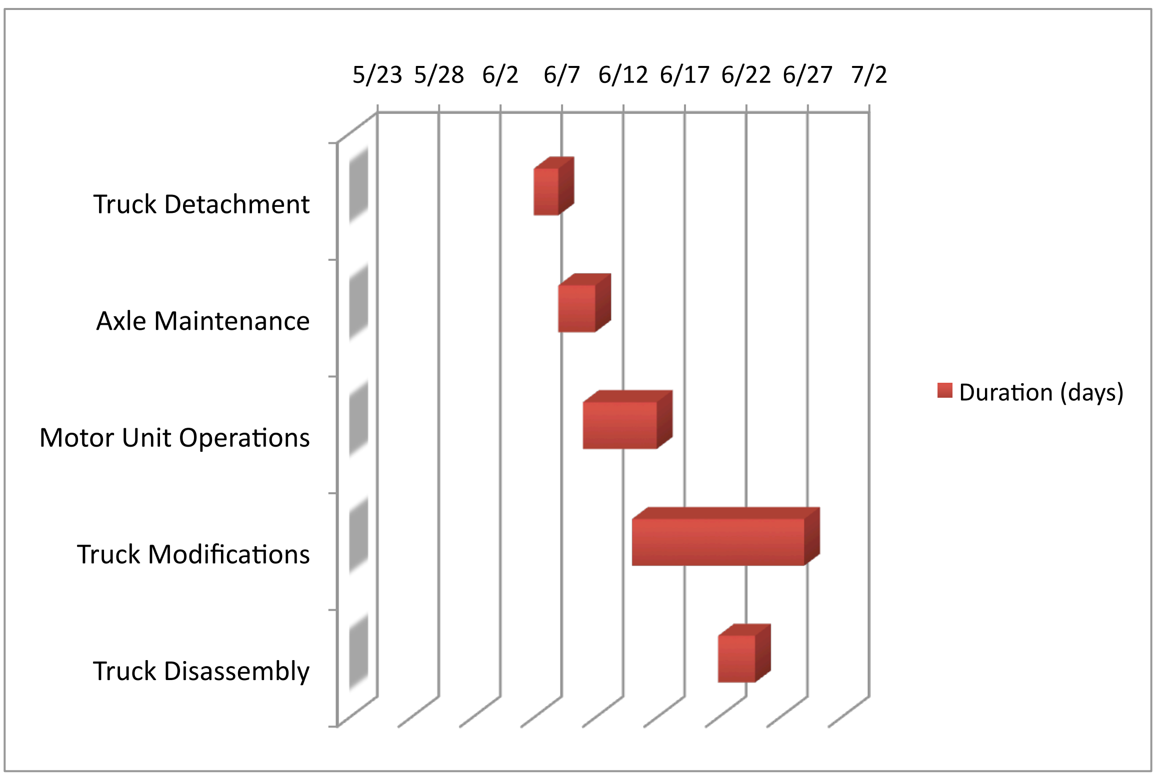


Figure 23. Gantt Chart for the Observations

In the light of the explanations above these observations were repeated for six times by the researcher in order to define the takt time of the truck maintenance, number of work orders, seasonal defect occurrence, and individual section cycle times. With the collected data the necessary experimental design calculations are made and presented in the following chapter.

The tabular form of the first observation's starting dates, ending dates and durations are presented in the table below.

Tasks	Start Date	Duration (days)	End Date
Truck Detachment	6/8/09	2	6/10/09
Axle Maintenance	6/10/09	3	6/19/09
Motor Unit Operations	6/12/09	6	6/26/09
Truck Modifications	6/16/09	14	7/17/09
Truck Disassembly	6/23/09	3	6/29/09

Table V. Gantt chart data

The researcher has made visitations on certain days of the week, which are Monday, Wednesday, and Friday. He also made several visitations on other weekdays but compared to the regular visitations the unusual ones are negligible. The observations have lasted for eleven months in the most regular way. During this time span six repetitions of the presented Gantt Chart has been made and as a result six different sets of data is collected. These six data packs are presented in the following chapter. As it is presented in Table V the five different areas limit the scope of the research. In order to be consistent with the data sets, same amount of data is collected in each observation. Table VI presents the amount of data collections discriminately.

The starting and ending dates presented in the Table V is not representing the entire observation process but just a single repetition of it and in addition to the table V there has been made five more repetitions. The observations made the research data more reliable and the starting and ending dates for the repetitions are presented in Table VI. However, it is important to underscore that the time spent on each observations stood still. In other words, each observation is an exact replica of one another.

	Repetition #1		**# of Data Each Rep**
Task	**Starting Date**	**Ending Date**	
Truck Detachment	6/8/09	6/10/09	4
Axle Maintenance	6/10/09	6/19/09	4
Motor Unit Operations	6/12/09	6/26/09	4
Truck Modifications	6/16/09	7/17/09	4
Truck Disassembly	6/23/09	6/29/09	4
	Repetition #2		
	Starting Date	**Ending Date**	
Truck Detachment	7/20/09	7/24/09	4
Axle Maintenance	7/24/09	7/31/09	4
Motor Unit Operations	7/29/09	8/12/09	4
Truck Modifications	8/7/09	9/2/09	4
Truck Disassembly	8/28/09	9/2/09	4
	Repetition #3		
	Starting Date	**Ending Date**	
Truck Detachment	9/7/09	9/11/09	4
Axle Maintenance	9/11/09	9/21/09	4
Motor Unit Operations	9/18/09	9/30/09	4
Truck Modifications	9/30/09	10/21/09	4
Truck Disassembly	10/14/09	10/21/09	4
	Repetition #4		
	Starting Date	**Ending Date**	
Truck Detachment	10/26/09	10/30/09	4
Axle Maintenance	10/30/09	11/9/09	4
Motor Unit Operations	11/6/09	11/23/09	4
Truck Modifications	11/23/09	12/23/09	4
Truck Disassembly	12/18/09	12/23/09	4

Table VI. Observation Dates and Data Collections

Task	Repetition #5		
	Starting Date	Ending Date	
Truck Detachment	1/4/10	1/8/10	4
Axle Maintenance	1/8/10	1/18/10	4
Motor Unit Operations	1/15/10	1/29/10	4
Truck Modifications	1/29/10	2/26/10	4
Truck Disassembly	2/22/10	2/26/10	4
	Repetition #6		
	Starting Date	Ending Date	
Truck Detachment	3/1/10	3/5/10	4
Axle Maintenance	3/5/10	3/15/10	4
Motor Unit Operations	3/12/10	3/26/10	4
Truck Modifications	3/22/10	4/6/10	4
Truck Disassembly	4/2/10	4/6/10	4

Table VI. Observation Dates and Data Collections - Continuation

CHAPTER VI

EXPERIMENTAL DESIGN AND ANALYSIS

This chapter is organized for the purpose of conveying the experimental data analysis and data sets. The presented value stream maps in the preceding chapters are filled with the proper data, which were collected in the CRMF. As discussed earlier in chapter V, six different set of observations made in different dates and to be consistent with the observations same number of data is collected for each and every operation. The unique operation of rail maintenance is resulted in long observation hours.

6.1 System Control

From the library of statistical tools, control chart technique was selected in order to conspicuously display variations in the system.

A control chart is one of the primary techniques of statistical process control. This chart plots the averages of measurements of a quality characteristic in samples taken from the process versus time. The chart has the centerline and upper and lower control limits. The centerline represents where the process characteristics should fall if there are no unusual sources of variability present.

A control chart is a very useful process monitoring technique; when unusual sources of variability are present, sample averages will plot outside the control limits. This is a signal that some investigation of the process should be made and corrective action taken to remove these unusual sources of variability.

Below are the control charts for observed system components of CRMF truck maintenance process. The control charts have been drawn in two different manners, which are a control chart for sample mean (x bar) and a control chart for sample range (R chart). An X bar chart is used to monitor the average product quality and a range chart is often used to monitor the standard deviation. Ninety-five percent for confidence interval has been used for all the control chart calculations. With each of the control charts, mean and standard deviation are calculated and presented by the help of Minitab software program.

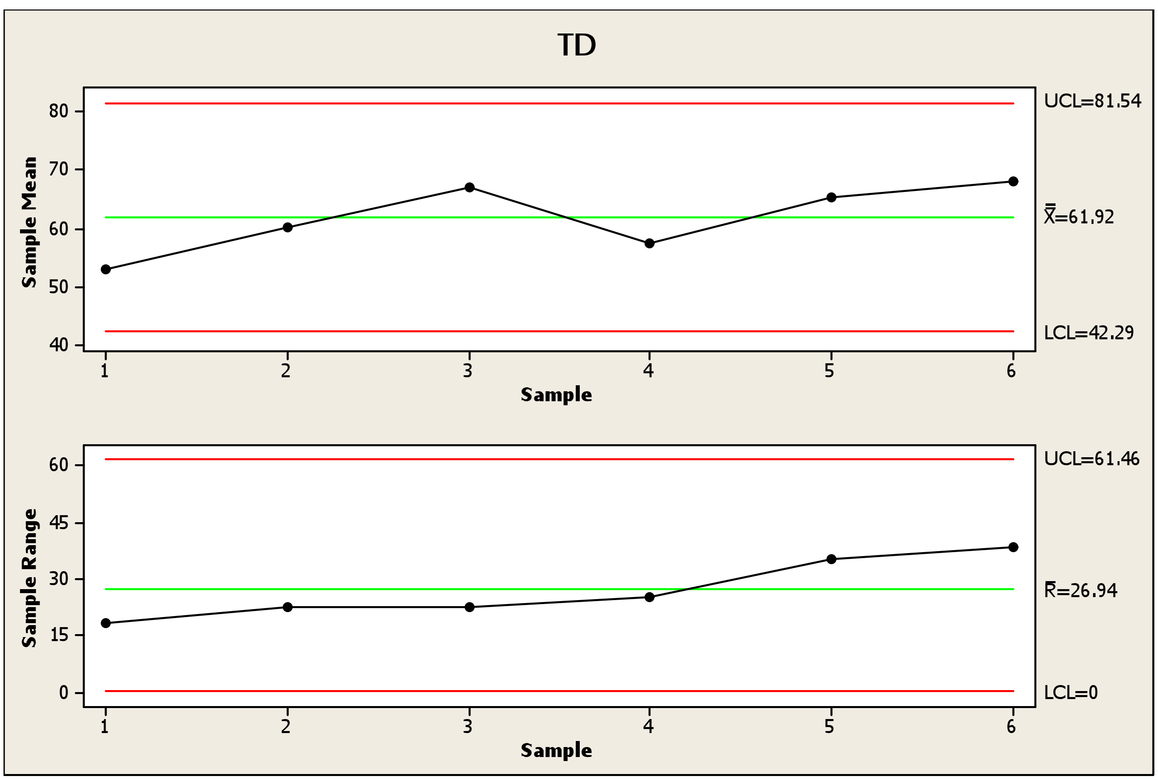


Figure 24. Control Charts for Truck Disassembly

Figure 24 is the control chart for Truck Disassembly process and according to the charts the process is in control. The mean for the process is 61.9167 minutes and the standard deviation is 13.0850 minutes.

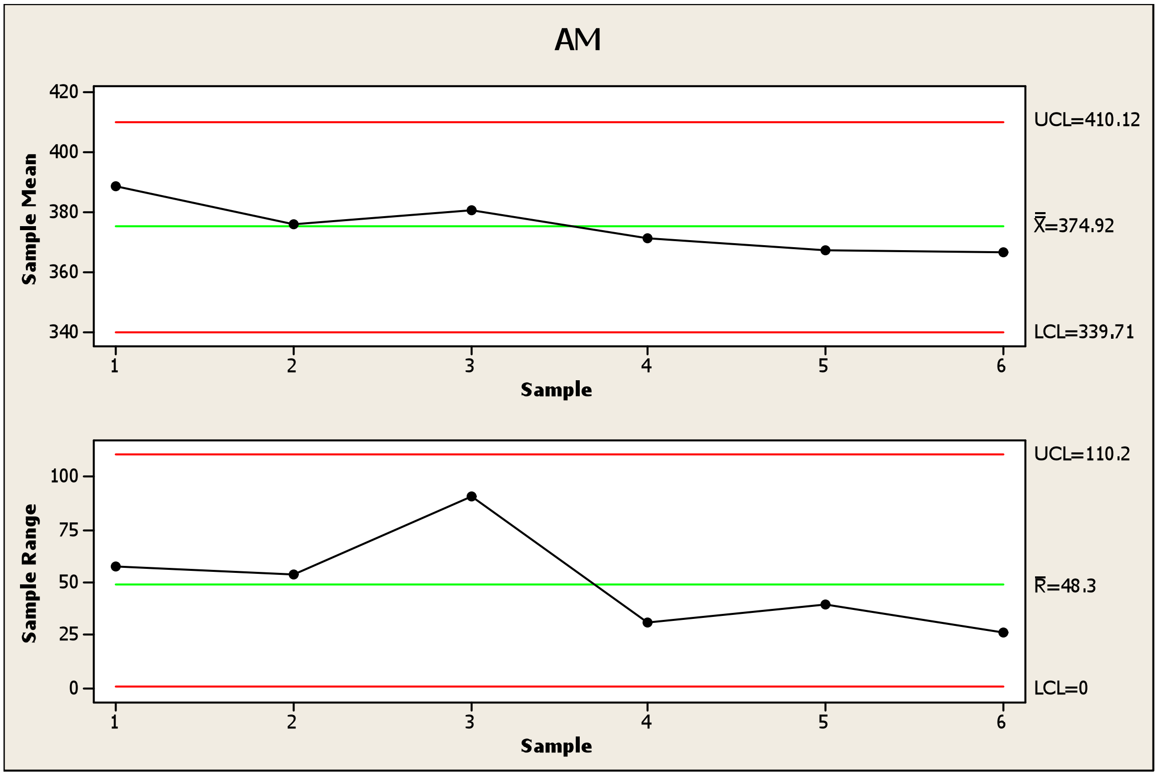


Figure 25. Control Charts for Axle Maintenance

Figure 25 is the control chart for axle maintenance process and according to the chart the process is in control. The mean for the process is 374.917 minutes and the standard deviation is 23.4698 minutes.

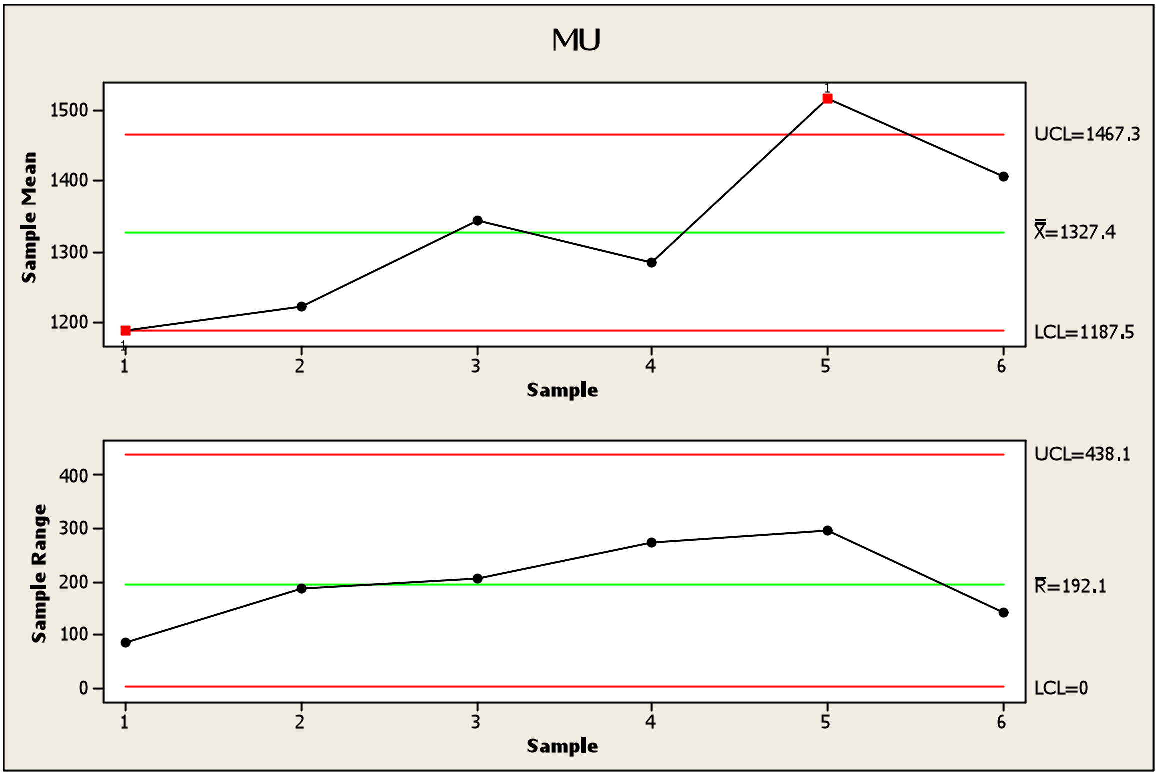


Figure 26. Control Charts for Motor Unit

Figure 26 is the control chart for motor unit operations process and according to the chart the process is not in control. The test failed at points 1 and 5 because these points are located more than three standard deviations away from the centerline. The mean for the process is 1327.42 minutes and the standard deviation is 93.2736 minutes.

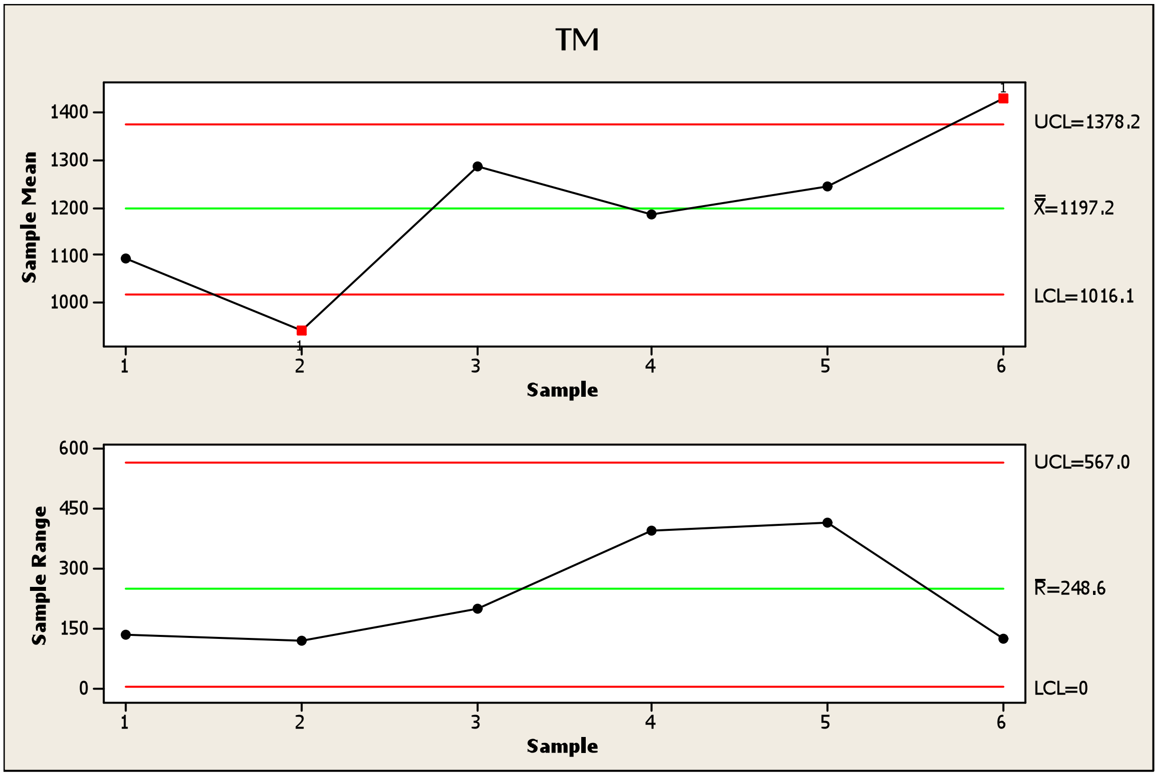


Figure 27. Control Charts for Truck Modifications

Figure 27 is the control chart for truck modifications process and according to the control chart the process is not in control. The test failed at points 1 and 6 because these points are located more than three standard deviations away from the centerline. The mean for the process is 1197.17 minutes and the standard deviation is 120.720 minutes.

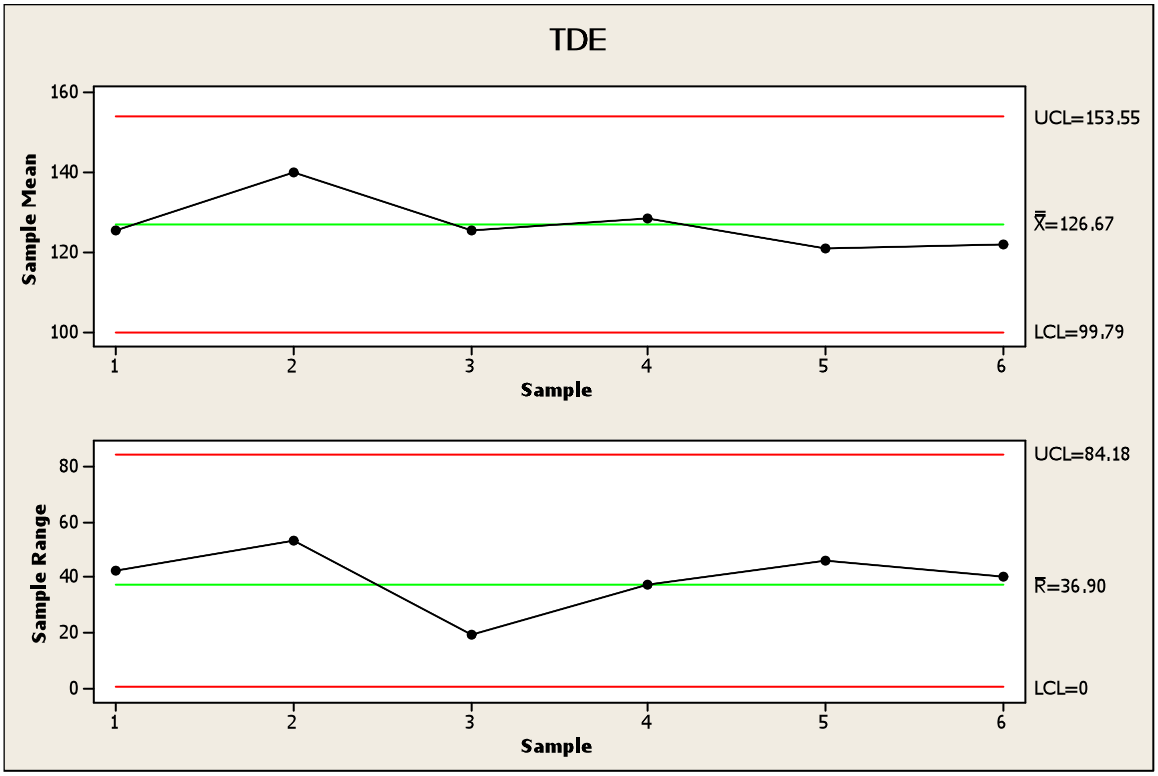


Figure 28. Control Charts for Truck Detachment

Figure 28 is the control chart for truck detachment and according to the control chart the process is in control. The mean for the process is 126.667 minutes and the standard deviation is 17.9208 minutes.

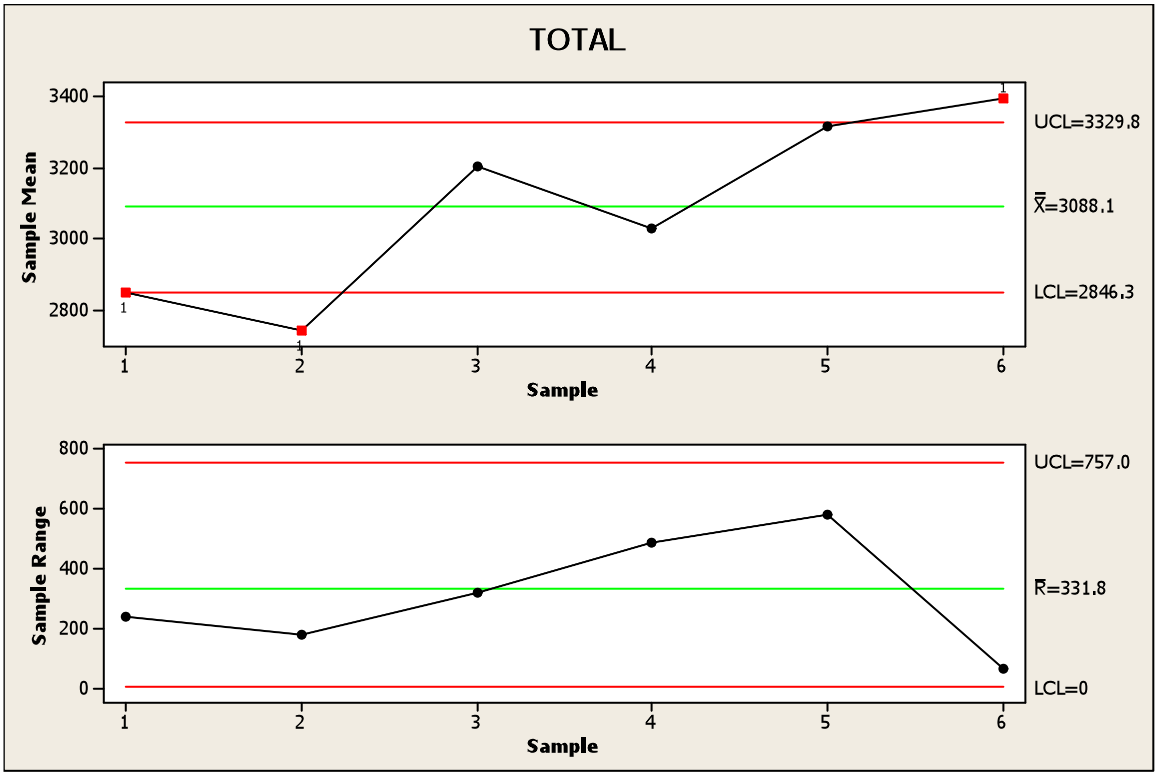


Figure 29. Control Charts for TOTAL Maintenance

Figure 29 is the control chart for the entire truck maintenance process and according to the control chart the process is not under control. The test failed at points 1, 2, and 6 because these points are located more than 3 standard deviations away from the centerline. The mean for the process is 3088.08 minutes and the standard deviation is 161.157 minutes.

To better understand the maintenance time frequency the histogram of entire truck maintenance operations is plotted and presented below (Figure 30).

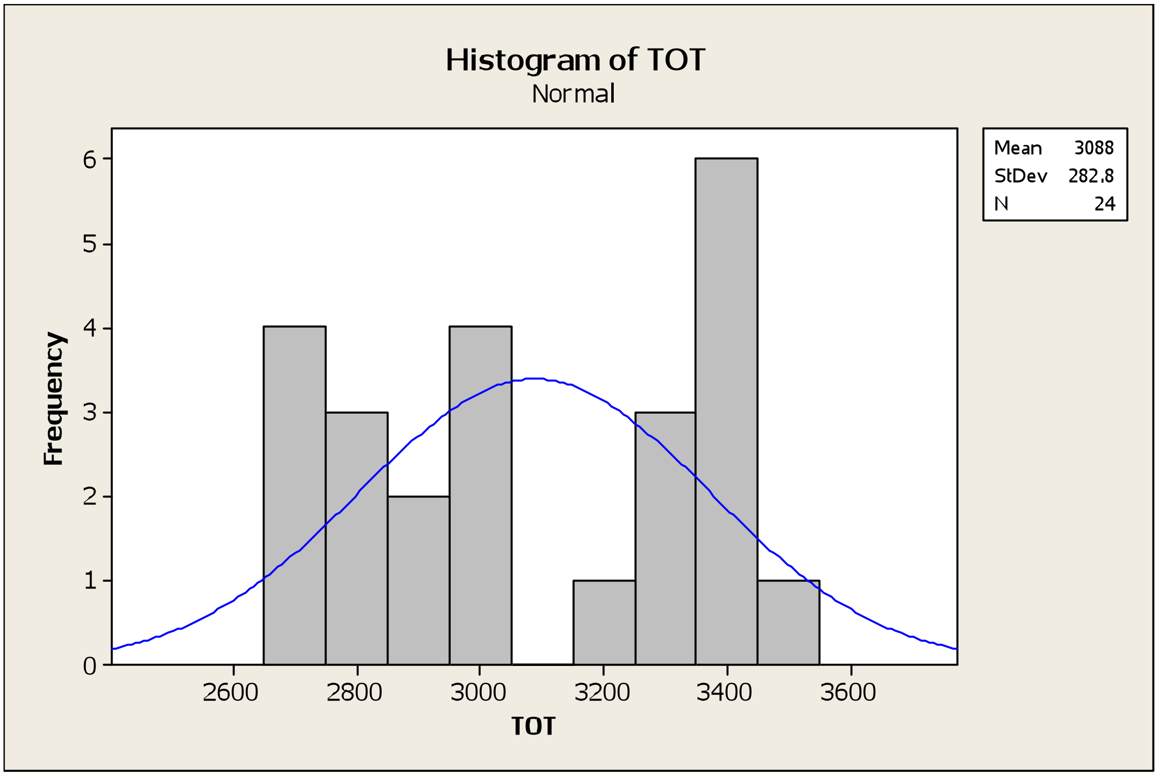


Figure 30. Histogram of TOTAL Maintenance

This histogram indicates that variance of total time is significantly different than a traditional histogram pattern. The normality of data is also examined in Figure 31. Even though the p value for the normality test is low, for the sake of calculations and this analysis it is assumed that the data is normally distributed.

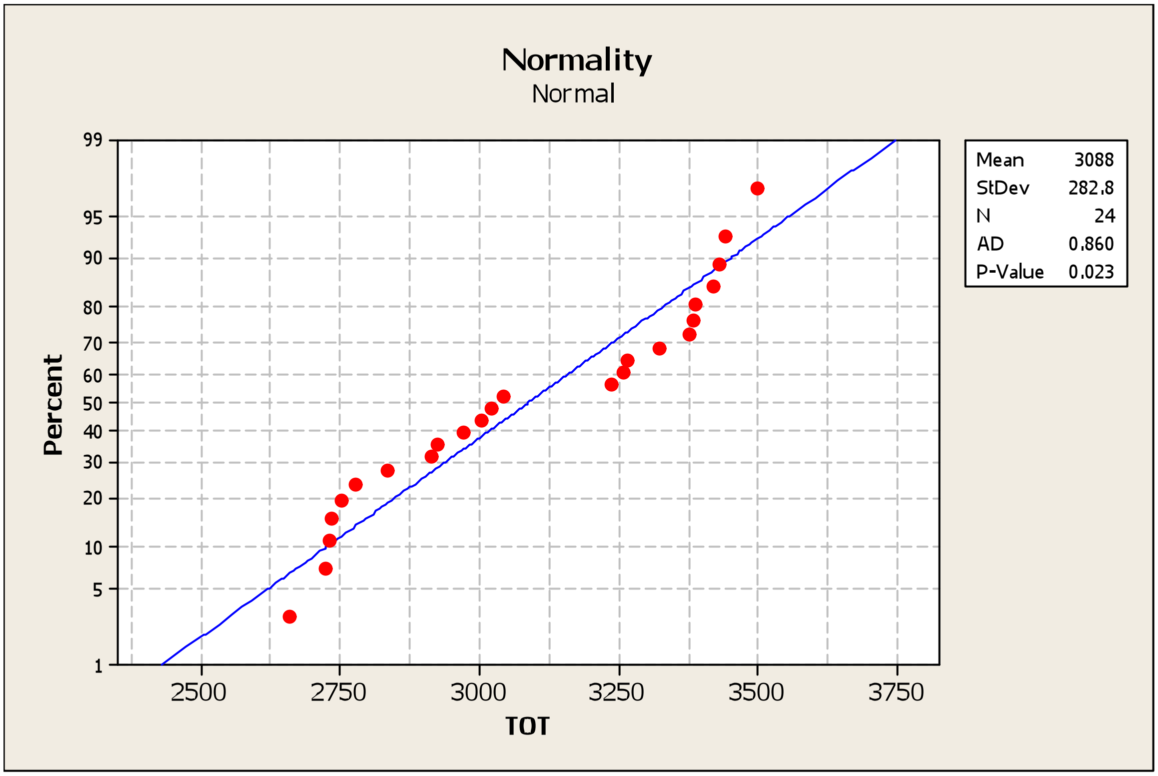


Figure 31. Normality Diagram

6.2 Conclusion of Analysis

It is clearly seen from the control charts and calculations that the truck maintenance process needs immediate improvements/adjustments. The most useful aspect of the control charts is that they point out the process variation, which is addressed by Jack Welsh as evil. The variance is an indicator that the system is not stable. The variability range should be decreased, thus, the system will be in control. The recommendations will be discussed and presented in Chapter 7.

CHAPTER VII

POTENTIAL LEAN IMPLEMENTATION AND RECOMMENDATIONS

In the previous chapters the constraints are briefly explained and it is unnecessary to recapitulate them. The unionized job shop, unique rail maintenance operations as explained in the previous chapters, and work force are three constraints, which resulted in implementation pending. The national recession in year 2010 has also caused to postpone the implementation recommendations due to the funding difficulties. Later on this chapter the potential implementation recommendations and projected future state is presented in the same manner as chapters four and five – value stream mapping.

In Chapter six, the system is explained as not controlled after some series of statistical analysis. This issue can be overcome by series of lean systems implementation.

7.1 5S Implementation

The 5S implementation is the very first step of the lean transformation of GCRTA, because of its quick results and applicability. The considered 5S implementation areas are unit rebuild area and truck shop, which are the main focus of this research.

The projected 5S implementation should start with sorting according to the appropriate order of 5S. The presented picture below represents the cluttered work space in truck shop and it can only be organized by 5S but more especially sorting. It is usual to see red tags in a sorting step of a 5S transformation, however, because of the unique tasks that truck shop has, there should be used three different colors; red, yellow, and green. Red is obviously for the equipment that has not been used for a long period of time. Yellow is for any equipment which has not been used in the last four months and green is for the equipment that is used every week. All of the items should be tagged for the uniqueness of the tasks in order to categorize all of the equipment and get rid of the red-tagged items. The management's commitment is essential in this step, and full trust should be established between implementation team and management. The idea of "I may need it" is nothing but helpful, and will hinder the further steps of 5S implementation. The management should be loyal to the established criteria for the sorting step. If the equipment has not been used for twenty years, it will not be used in the next few weeks.

The second S stands for straightening as explained then. In this process everything has a place and everything is in its place. A shadow board and organized and unlocked drawers should be introduced to the truck shop. By this way the mechanics will not have to look for a wrench or a screw driver for twenty minutes and every tool he needs will be somewhere close to him, where he will find it easily. The straightening step will enable the mechanics to perform the same tasks in a lot faster manner. Apart from the speed, the frustration will also fade away from his/her mind. Searching for a wrench for twenty minutes and then seeing the wrench in some other mechanic's hands is a very frustrating experience. Besides of the time benefits, the mental benefits are also very important for the mechanics and the results will most certainly will reflect to the performance and quality of the service provided.

The third S stands for shine as explained then. This process is neither hard to achieve nor too complicated, however, when you look at the entire 5S transformation all of the steps have the same level of priority because they complete each other. Cleaning the work space might be easy, however, keeping it is very hard to achieve. It is proven that things can easily go back to good old days.

The fourth S stands for standardization. The two most difficult steps are sorting and standardization. Standardizing the tasks is a very difficult objective to achieve because of the uniqueness of the rail maintenance. A standardized job manual should be established with a full consensus. This way, it will be easy to monitor the operations, and most importantly the time variance for the same task will be a very small fraction. The standard job list ought to be established as well for the ease of the job in order to be used by the mechanics. This will also be helpful for an inexperienced mechanic to perform a fine job after a basic training. The most difficult part of this potential step is the commitment of the mechanics. As explained before, the job is not standardized and there is no flow on the job shop. The job highly depends on craftsmanship, the mechanics are reluctant to change, and most of them want to keep things as they are. Another point of view for this step comes from the job type – craftsmanship. Most of the mechanics are highly experienced in their areas and they take a standardized job as an insult. It is also extremely difficult to convince the mechanics that the job can be standardized. They are aware of the uniqueness of the tasks and reluctant to standardize them, however, the categories for their tasks remain same for years and a detailed road map for their maintenance operations can easily be provided to them.

The fifth and last S stands for sustaining. In the lean transformation philosophy there is always room for improvement. The last S ought to be considered under two point of views. One is to sustain the results from the 5S implementation. This first part is not too difficult because everybody in the job shop from the janitors to the manager will be extremely happy with the results and they will take going back to the old style as a nightmare. The second part is to repeat the same steps in a certain period of time. This second point of view is recommended because of the potential unrealized clutter and organization failure. The management will be surprised with the results of the second turn, and the 5S implementation will be a tradition in the facility rather than a one-time implementation. The recommended 5S implementation period is every six months. Since the mechanics and management will be experienced in this process, the next turns will be easier to achieve and the clutter will come to the surface easier than the first turn.

The quick and reliable results of the 5S implementation will bring management and mechanics one step closer to full commitment. It is why 5S implementation is recommended as the very first step. More importantly low cost of its implementation also makes it attractive to the management.

7.2 Kanban Implementation

The projected application area of this specific lean system tool is truck shop. During the wheel pressing process at truck maintenance operation, it is explained that the mechanic spends too much time on going to the truck storage area, loading the wheels on a forklift and carrying them back to the pressing machine. This observation gave birth to the use of a kanban box right next to the boring machine. The kanban box will keep six wheels and will be filled by the garage man, who is responsible for handling and cleaning operations of the facility when there are two wheels left in the box. After this plan, the mechanic will save a substantial amount of time and energy and will not have been distracted by handling. It is also necessary to emphasize that it is not going to be an ordinary kanban application. It is considered to designate an area for the wheels by the boring machine and keep the wheels on a wooden rack. Technology should not play a big role in this implementation because of two reasons, the first of which is already explained – funding difficulties. The second reason is to establish a basic understanding in the job shop and make a smooth transition to a leaner system. Pushing the most advanced methods will cause both confusion and funding cuts. After achieving the transition advanced technology for a kanban implementation can very well be introduced to the system. By that way, mechanics will not be confused and adapt the newer technology easily.

7.3 Communications and Scheduling

Communications between departments is a crucial aspect of any kind of operations especially in rail maintenance because of its uniqueness. As explained in the previous chapters there are several departments, which are highly dependant on each other and the lack of communication will result in severe problems such as not meeting the deadlines and ultimately not providing sufficient public transportation to the city.

This issue is also depicted in chapter 4, by using value stream mapping. The push arrows are demonstrating the operation flow in the truck shop.

One of the most powerful lean techniques is using cross-functional teams, however, it is hardly possible to establish this philosophy in a unionized job shop. The mechanics are not allowed to work in an area, which is not mentioned in their job description. The CRMF is already suffering enough from a lack of work force and this constraint is cornering the management in terms of finding solutions to it. After establishing a smooth flow and full communication between departments some of the mechanics will not be as busy as they are currently. Hence, these mechanics can be assigned to the tasks where they are needed.

In order to establish an explicit awareness and communications it is recommended to use an andon board between departments and a main andon board for the entire facility. The desired andon boards should essentially be visible for the related departments and they should also be designed to be visible for everyone if possible. With the help of the andon boards the mechanics will be able to arrange their pace and sustain a smooth flow. For instance, the truck shop will not have to hurry and wait for the unit rebuild. If the unit rebuild is behind the schedule than the truck shop can very well slow down its pace and some of the mechanics can be assigned to another task.

Mechanics, managers, and union stewards should redefine some points of their agreement. After full consensus, the mechanics should be permitted to take part in cross-functional teams. This way, the biggest constraint – number of mechanics – will be partially solved and this will enable management to implement the majority of this research's recommendations.

On the other hand, scheduling is a bleeding wound in the facility. None of the maintenance operations are scheduled with anticipation. The operations are scheduled as first comes first served basis. The scheduling problems cause to accumulate number of rail cars, which are waiting to be maintained. It is true that there are already great amount of maintenance operations waiting in the line and proper scheduling is an absolute necessity to decrease the number not only in terms of scheduling the rail cars but also scheduling every aspects of the maintenance, such as baking process in the unit rebuild area. As it is explained in Chapter 5 baking is the most time consuming part of the operation sequence and should be planned in the most efficient way.

7.4 Projected Value Stream Maps

It is explained earlier that value stream mapping was taken as a road map for both data collection and finding out the diseased areas. The same system is going to be used to present smoother and leaner maintenance operations. Since because there are some constraints, all the implements of lean systems methodology should be considered and modified prior to the applications indiscriminately, but more especially the value stream mapping.

7.4.1 Projected Value Stream Map for Unit Rebuild Area

The presented value stream map in figure 32 is the more detailed future state for the unit rebuild area. The first and far most important recommendation is to assign at least two more mechanics for the entire motor rebuild operations. It is possible to achieve this by using cross-functional teams as explained then. By the benefit of having a number of skillful mechanics the operations will be performed in a smooth and flowing manner. Standardization will be easier and the burden will be released from the current mechanic. All the other elements of the lean transformation will come later.

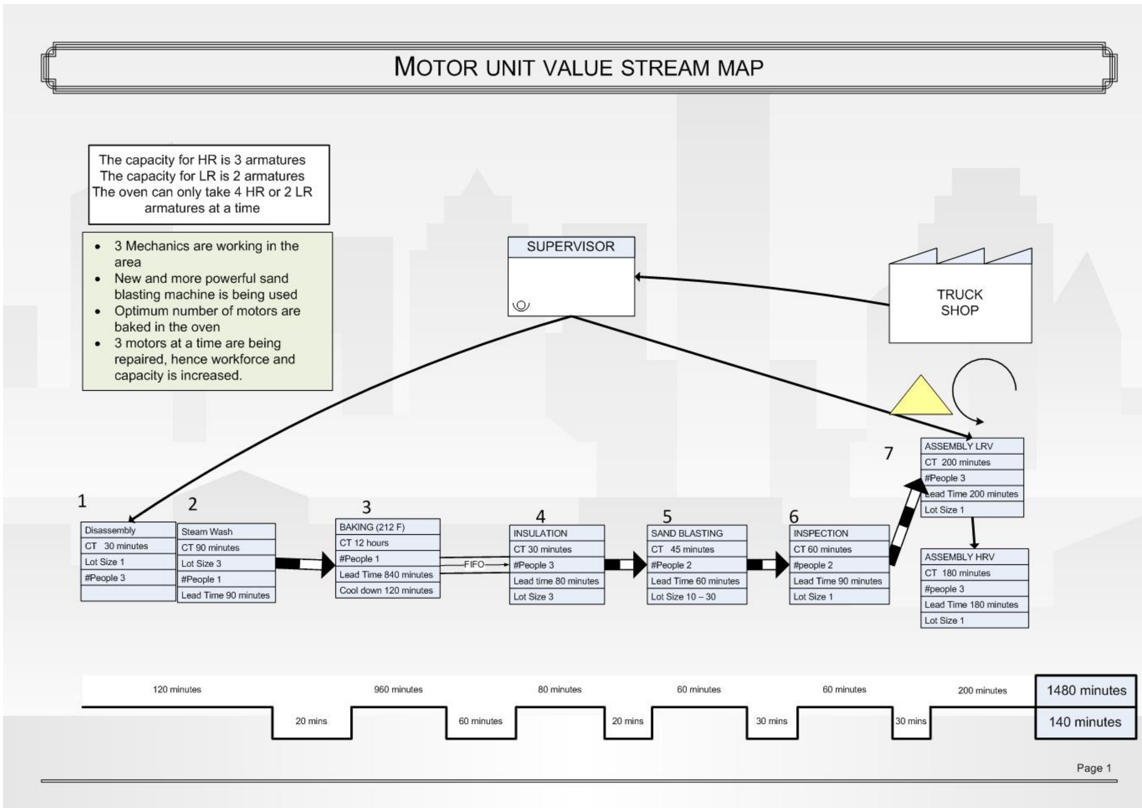


Figure 32. Motor Unit Future State VSM

The current floor layout of the unit rebuild area is a perfect setting for a one-man-operation. In other words, for craftsmanship. However, the focused area is a maintenance facility and in a very unique way. It is a standardized operation. It is nonsense to expect the maintenance operations go as smooth as manufacturing operations, however, with a combined technique of craftsmanship and lean systems, they can work a lot smoother than the current state. The next recommendation for the unit rebuild area is to change the floor layout into an unorthodox assembly line. The processes should be allocated justly between the mechanics. It is necessary to reemphasize that the bleeding wound of truck maintenance is the number of good motors. By establishing a solid unit rebuild pace, the truck shop will be able to use it's entire capacity. The recommended floor layout cannot be a dramatic change because of the weight and setting of some machines such as the oven. Dramatic floor layout change is going to be labor intensive, expensive and is going to take tremendous amount of time. The shop cannot afford to lose anymore time. The more detailed projected floor layout plan for unit rebuild area is presented in figure 33.

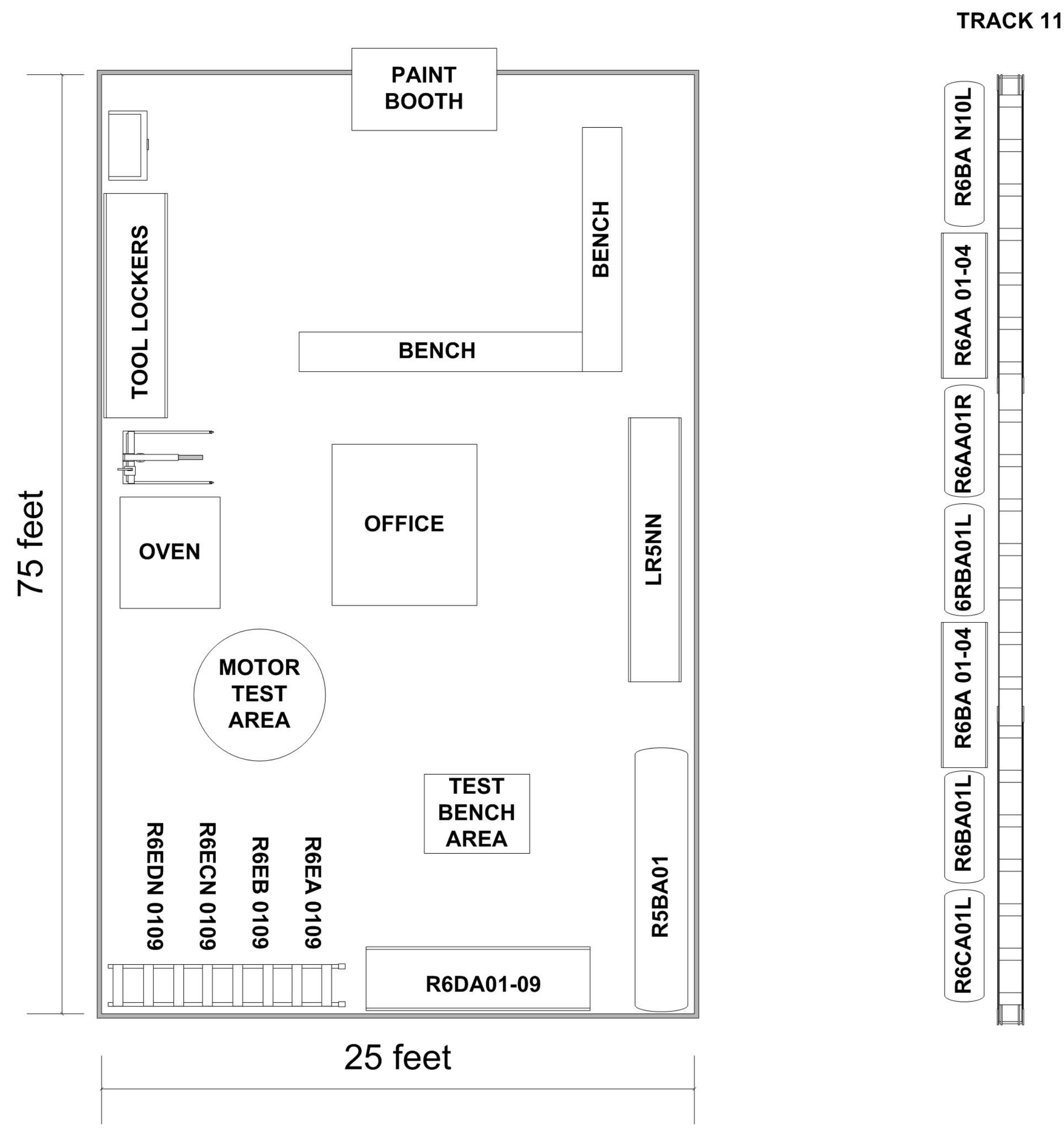


Figure 33. Unit Rebuild Future State Floor Layout

As depicted in figure 33 three mechanics are able to work in harmony with enough working space for each of them.

7.4.2 Projected Value Stream Map for Truck Shop

The presented value stream map in figure 34 is the more detailed future state for the Truck Shop. The recommendations for the Truck Shop should be implemented after the Unit Rebuild implementations because as explained than the Truck Shop is an internal customer for the Unit Rebuild and they wait for the good motors to continue to the truck maintenance.

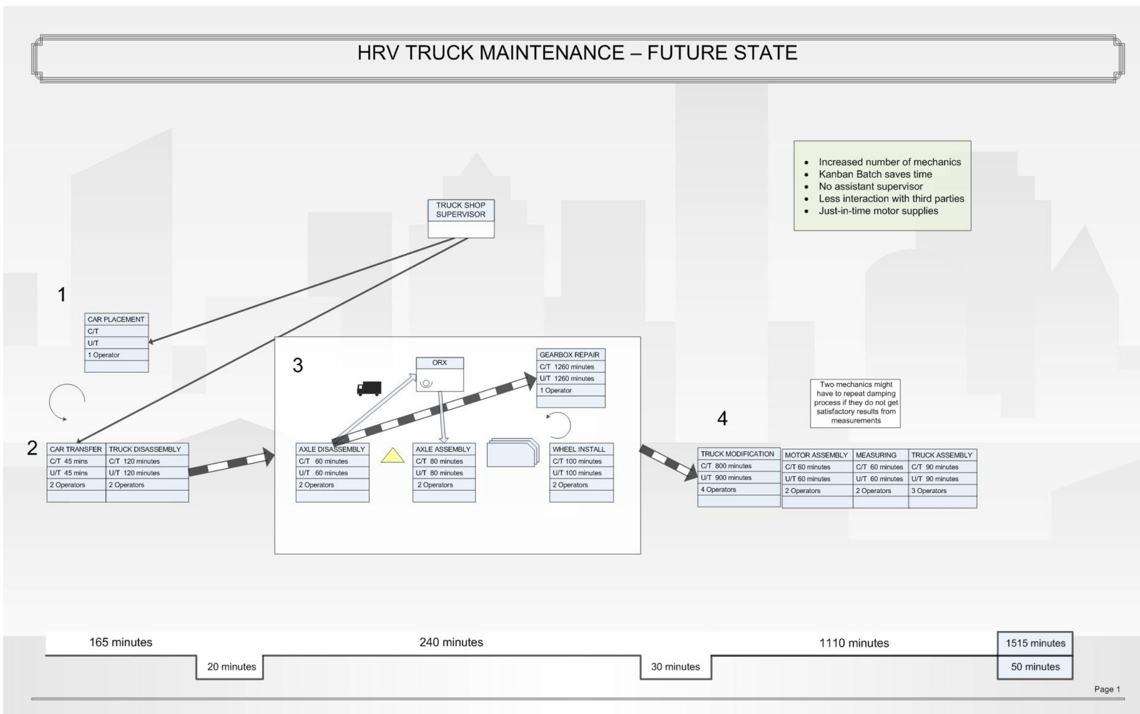


Figure 34. Truck Shop Future State VSM

Once The Unit Rebuild recommendations are implemented the Truck Shop will be able to perform in full capacity and possibly in a faster pace. As a result of this faster pace, they will be in need of more mechanics. For the initial adaptation to the lean philosophy cross-functional teams can be used to answer this situation, however, in long term the CRMF will have to hire new employees in order to keep the maintenance rate (takt time) up. The next recommendation is to create a training area at the Truck Storage area in order to train not only the inexperienced mechanics but also all the mechanics for the benefit of using cross-functional teams. The mechanics should be trained by using the "dummy" truck and will gain experience of general maintenance operations; thereby they will be better enabled to contribute to the truck maintenance operations. The layout change is nearly impossible because of the machines used in Truck Shop. It will be very expensive to change the layout and all the operations have to be ceased for a long period of time if the layout is changed.

CHAPTER VIII

CONCLUSION & FUTURE WORK

8.1 Conclusion

In the light of the presented analyses and discussions the researcher has come to the end of pure lean systems integration is not applicable to the Rail Maintenance operations. It is not debatable that lean tools are very effective and the results attract every manager no matter what the operation is. However, with a unionized job shop and a type of maintenance, which is highly dependant to craftsmanship, it is impossible to apply pure lean tools.

A modified – hybrid – lean philosophy should be introduced to CRMF. The desired transformation will most certainly make the facility leaner as long as the mentioned tools are tailored to fit for CRMF.

Conclusively, it is necessary to combine craftsmanship and lean systems and give birth to a hybrid system for rail maintenance operations. Moreover, with the number of mechanics CRMF has it is very hard to sustain the improvements and even perform a single task in an efficient way. It is recommended to CRMF to hire more mechanics or transfer some experienced mechanics from other GCRTA maintenance facilities in order to fulfill the improvement tasks and sustain the new maintenance system.

8.2 Future Work

This research also opens numberless doors to the future research in the same topic. The presented future work is still waiting to be done.

- Organizing the inventory and supply chain management at CRMF and by doing so contributing to the hybrid lean system.
- Evaluating the possible hybrid lean implementations in terms of economical applicability.
- Establishing a leaner job shop at CRMF by implementing possible hybrid lean tools.
- Evaluating management and cultural aspects of the organization and how they would effect the lean transformation

BIBLIOGRAPHY

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

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

3. Case Western Reserve University & Western Reserve Historical Society "The encyclopedia of Cleveland History" [Online] Available: http://ech.cwru.edu/. [Cited: 09 01 2011]

4. United States Census Bureau "Fact Sheet Cleveland city, Ohio" [Online] Available: http://factfinder.census.gov/servlet/SAFFFacts?_event=&geo_id=16000US3916000&_geoContext=01000US%7C04000US39%7C16000US3916000&_street=&_county=cleveland&_cityTown=cleveland&_state=04000US39&_zip=&_lang=en&_sse=on&ActiveGeoDiv=&_useEV=&pctxt=fph&pgsl=160. [Cited: 11 04, 2011]

5. "Cleveland – Hopkins International Airport." [Online] Available: http://www.airnav.com/airport/KCLE [Cited: 11 04, 2011]

6. The Plain Dealer, Jesse. Tinsley "*Burke to host air service again; Startup offers no-hassle hop to Detroit.*" 07 18, 2006.

7. "Port of Cleveland" [Online] Available: http://www.portofcleveland.com/ [Cited: 11 04,2011]

8. The Plain Dealer, Karen Farkas *"Passenger rail service between Cleveland and Sandusky to be studied".* [Online] 02 02, 2010. Available: http://blog.cleveland.com/metro/2010/02/passenger_rail_service_between_1.html [Cited: 11 04, 2011]

9. Greater Cleveland Regional Transit Authority *"Greater Cleveland: Best Location for Public Transportation in the Nation"* (Press release). [Online] October 1, 2007. Available: http://www.riderta.com/newsroom/releases/?listingid=1096. [Cited: 11 04, 2011]

10. Greater Cleveland Regional Transit Authority *"Out-of-County Connections".* [Online] Available: http://www.riderta.com/ro_outofcounty.asp. [Cited: 11 04, 2011]

11. Greater Cleveland Regional Transit Authority "Planning & Development - Transit 2025 Plan". [Online] Available: http://www.riderta.com/transit2025/. [Cited: 11 04, 2011]

12. The Encyclopedia of Cleveland History. Case Western Reserve University. Greater Cleveland Regional Transit Authority". 1997-06-16. Retrieved 2009-11-26.

13. Greater Cleveland Regional Transit Authority *"About RTA: History of Public Transit in Greater Cleveland".* [Online] Available: http://www.riderta.com/ar_RTAhistory.asp. [Cited: 11 04, 2011]

14. Greater Cleveland Regional Transit Authority**.** "*About RTA: RTA facts. RideRTA.*" [Online], 06 10, 2009. Available: http://www.riderta.com/ar_RTAfacts.asp. [Cited: 10 18, 2010.]

15. Greater Cleveland Regional Transit Authority. "*Fares*". [Online]. Available: http://www.riderta.com/fares [Cited: 11 04, 2011]

16. Greater Cleveland Regional Transit Authority. "*Budget Challenges*". [Online]. Available: http://www.riderta.com/budgetchallenges/ [Cited: 11 04, 2011.]

17. J. P.Womack, "Yokoten Across the World," Lean Enterprise Institute, 2008.

18. T. Melton. "*THE BENEFITS OF LEAN MANUFACTURING What Lean Thinking has to Offer the Process Industries*" 2005 Institution of Chemical Engineers pp. 663 – 673

19. J. M. Worley and T. L. Doolen. "*The role of communication and management support in a lean manufacturing implementation*" Management decision Vol. 44 No.2 2006 pp.228-245

20. Levent Baykut. "*Opportunities for Lean Enterprise in Public Regional Transportation*" Master's Thesis. Fenn College of Engineering, Cleveland State University pp. 7-8, August 2010

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

22. James P. Womack, Daniel T. Jones, and Daniel Roos. *The Machine That Changed the World : The Story of Lean Production.* Harper Perennial Publishers, 1991

23. Roy Andersson, Henrik Eriksson and Hakan Torstensson. *"Similarities and differences between TQM, Six Sigma and Lean"* The TQM Magazie Vol 18 No.3, 2006 pp.282-296

24. Fawaz A. Abdulmalek, Jayant Rajgopal. "*Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study"* Int. J. Production Economics 107 (2007) pp. 223-236

25. Roberto Panizzolo."*Applying the lessons learned from 27 lean manufacturers. The relevance of relationships management"* Int. J. Production Economics 55 (1998) pp.223-240

26. Maike Scherrer – Rathje, Todd A. Boyle, Patricia Deflorin. "*Lean, take two! Reflections from second attempt at lean implementation"* Business Horizons (2009) 52, pp 79-88

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

28. Lean Manufacturing at Letterkenny Produces Real World Results, Deborah Elliot. [Online] 2010. http://aec.army.mil/usaec/newsroom/news/news28.html. [Cited: 11 04, 2011].

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

30. KANBAN Demand Scheduling for Lean Manufacturing, Graphic Products, Inc.

31. Shongo, Shigeo, *A Revolution in Manufacturing: The SMED System*, Productivity Press, 1985

APPENDIX A

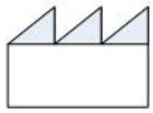
(Statistics for the Analyses)

	Operation	1 (min)	2 (min)	3 (min)	4(min)
Repetition #1	TD	58	46	45	63
	AM	417	372	360	405
	MU	1213	1134	1182	1219
	TM	1163	1032	1044	1130
	TD	120	150	122	108
	TOTAL	**2971**	**2734**	**2753**	**2925**
Repetition #2	TD	70	55	68	48
	AM	345	373	387	398
	MU	1245	1294	1109	1243
	TM	930	864	983	981
	TD	133	144	114	167
	TOTAL	**2723**	**2730**	**2661**	**2837**
Repetition #3	TD	59	71	80	58
	AM	340	380	430	373
	MU	1392	1458	1272	1254
	TM	1394	1231	1332	1198
	TD	138	119	123	120
	TOTAL	**3323**	**3259**	**3237**	**3003**
Repetition #4	TD	47	53	72	58
	AM	372	387	368	357
	MU	1428	1156	1257	1293
	TM	1273	1340	1191	944
	TD	144	107	134	127
	TOTAL	**3264**	**3043**	**3022**	**2779**
Repetition #5	TD	54	77	83	48
	AM	383	377	344	364
	MU	1444	1577	1674	1380
	TM	1404	1377	1204	989
	TD	134	89	125	135
	TOTAL	**3419**	**3497**	**3430**	**2916**
Repetition #6	TD	51	89	58	75
	AM	363	373	378	352
	MU	1343	1483	1396	1412
	TM	1512	1392	1423	1401
	TD	117	104	122	144
	TOTAL	**3386**	**3441**	**3377**	**3384**

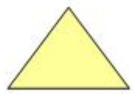
APPENDIX B

(Value Stream Map Icons)

Process

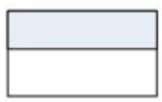


Customer



Inventory

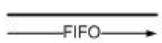
Push Arrow



Process Control

Data Table

Timeline segment



First in First Out

Physical Pull

Kaizen Burst

Shipment Arrow