

**UNIVERSIDADE DE SÃO PAULO  
ESCOLA DE ENGENHARIA DE SÃO CARLOS  
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**BUILDING A LEAN MANUFACTURING SYSTEM TO  
IMPROVE THROUGHPUT AND QUALITY AT  
OTTENWELLER COMPANY INC**

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**Building a Lean Manufacturing System to Improve Throughput and Quality at  
Ottenweller Company Inc**

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## ABSTRACT

PIOVEZAN, G. (2015). Building a Lean Manufacturing System to Improve Throughput and Quality at Ottenweller Company Inc. Trabalho de Conclusão de Curso, Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.

Lean Manufacturing has been one of the most pursued methods of elimination of waste and maximization of utilized resources by manufacturing and service businesses seeking to enhance productivity and quality, from a perspective of customer value. One of the initial steps for the implementation of Lean is the analysis of the current state, followed by a proposal encompassing future scenarios. This senior project report describes the challenges faced at this stage in the metal business at issue, Ottenweller Company Inc. A literature review of concepts, tools and techniques of lean production will be presented, as well as the application and adjustment of the lean system to the company scenario to bring up solid results to that business. As most prominent result, it was captured significant cycle-time reduction, impacting dramatically on cost savings and sprint capacity for both parts analyzed in this report and the entire resource group.

## RESUMO<sup>1</sup>

PIOVEZAN, G. (2015). Estruturando um Sistema de Manufatura Enxuta para Melhorar Produtividade e Qualidade na Ottenweller Company Inc. Trabalho de Conclusão de Curso, Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.

A Manufatura Enxuta tem sido um dos métodos mais buscados para eliminação de desperdícios e maximização dos recursos utilizados por indústrias de fabricação e por empresas de serviços que visam aumentar produtividade e qualidade, a partir de uma perspectiva de valor agregado para o cliente. Um dos primeiros passos para a implementação de modelos enxutos é a análise do estado atual, seguida da proposição de cenários futuros. Este relatório de conclusão de curso descreve os desafios enfrentados nesta fase em uma indústria mecânica em análise, a Ottenweller Company Inc. Uma revisão da literatura sobre os conceitos, ferramentas e técnicas de produção enxuta foi desenvolvida, além de uma aplicação e ajuste do sistema de manufatura enxuta ao cenário da empresa de modo a trazer benefícios sólidos para esta organização. Como resultado mais notável, uma redução do tempo de ciclo significativa foi alcançada, impactando drasticamente nas reduções de custo e gerando um aumento de capacidade para produção de ambos os produtos analisados neste relatório, assim como para todo o grupo de recursos da empresa.

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<sup>1</sup> Este trabalho de conclusão de curso está normatizado de acordo com o Manual de Publicação da American Psychological Association (APA) disponibilizado pela Universidade de São Paulo em [http://www.teses.usp.br/index.php?option=com\\_content&view=article&id=52&Itemid=67](http://www.teses.usp.br/index.php?option=com_content&view=article&id=52&Itemid=67)

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## 1. Introduction

### 1.1. Contextualization of Research

In an increasingly global market, Lean Manufacturing stands out as one of the major initiatives that businesses in the United States have been seeking to embrace in order to remain competitive (Abdulmalek & Rajgopal, 2007). Despite extensive knowledge of operations management, many organizations are struggling to become lean (Rahman, Sharif & Esa, 2013). With the aim of betterment in this area, Ottenweller Company Inc., with whom this senior project is concerned, contacted the Center for Creative Collaboration (C3) at Indiana Institute of Technology to request the formation of a team to structure an applicable lean system customized to operate in its specific conditions. The results presented in this senior project describe Ottenweller Company's experience with the intent of supporting other organizations in the similar situation.

Over the last decades, the application and utilization of lean thinking in production systems has made a substantial impact in distinct sectors of the industrial environment. In order to remain competitive globally, companies seek not only to meet unprecedented changes through offering products and services above expectations, but also to maintain excellent performance in their manufacturing operations.

The topic of this research is related to the improvements and benefits provided by the implementation of Lean Production techniques in a metal industry. Due to the fact that this philosophy strongly supports the deployment of processes with the maximum of value-added activities and without wastes, its application has generated impressive gains in lead time, productivity, and cost reduction. Furthermore, lean methodology provides more accurate control of inventory, faster response times, and better adaptation to demand variations, reaching the market on time and ensuring excellence in customer service (Abdulmalek & Rajgopal, 2007; Womack & Jones, 2004).

Particularly for the process sector, such as the steel industry, the authors Abdulmalek & Rajgopal (2007) performed an assessment of lean tools that can be feasibly applied to the reality of this segment. The analysis between lean tools and their applicability concluded that tools such as value stream mapping, 5S, and visual systems are considered universally applicable; setup reduction, just-in-time, production leveling, and total productive maintenance are partially applicable; and cellular manufacturing is probably inapplicable.

Although value stream mapping, VSM, is widely accepted, the authors also recognized that this tool is not enough to quantify the gains within the early planning and assessment stages during the creation of future scenarios (Abdulmalek & Rajgopal, 2007). In addition, the research of the authors Lasa, Castro & Laburu (2009) proposed an enhancement and refinement of the VSM theory when the goal of the company is not to reach a pure Lean Manufacturing system, but an intermediate improvement level.

This report investigates the first stage of Lean Manufacturing application in a metal industry that has characteristics with no pure lean systems. The barriers and practices are compared with the challenges pointed out by literature, in order to bring insights and new statements, with special focus on VSM.

## 1.2. Formulation of the Problem and Justification

This case study was carried out at Ottenweller Company Inc., a fabricator of steel and aluminum parts in Fort Wayne, Indiana, United States. Seeking improvements in its performance, the company has decided to implement conceptions of the production philosophy focused on Lean Manufacturing for two of its most significant products.

In the past year, 2014, the company's sales volume declined dramatically when it lost its largest production contract in virtue of inadequate delivery and poor quality performance. This means the existing manufacturing system needs a new approach and must be revamped and improved in a short period of time, so that the business will be able to deliver satisfactory performance. More specifically, Ottenweller must have six months of sustained delivery performance of 95% in order to quote new projects for this customer. Furthermore, the company is currently at risk of losing further sales, due to the fact that additional parts may be removed from its current portfolio if improvements do not occur. Ottenweller management is committed to improving its performance to retrieve substantial sales and quote new ones.

The advantages of implementing a Lean Manufacturing system can be broken down into four classifications: safety, quality, productivity, and cost. In other words, the company will be able to reduce the number of accidents related to the production of this customer's products and have a safer workplace for its employees; the number of external rejections will be diminished; the production efficiency will be enhanced; and finally, the costs associated with the disposal of products and expedited shipping will be effectively reduced as a result of the new approach that is being proposed.

The first step consists of creating a value stream map with all necessary information to define the current state of the two most significant parts—classified as OCI4081B and OCI8539A —delivered to the company’s largest customer. The project plan also includes the proposal of future states, in order to indicate new approaches to reach the goals announced, making comparisons between them, giving future recommendations for improvement, and targeting areas of waste.

### 1.3. General and Specific Objectives of Research

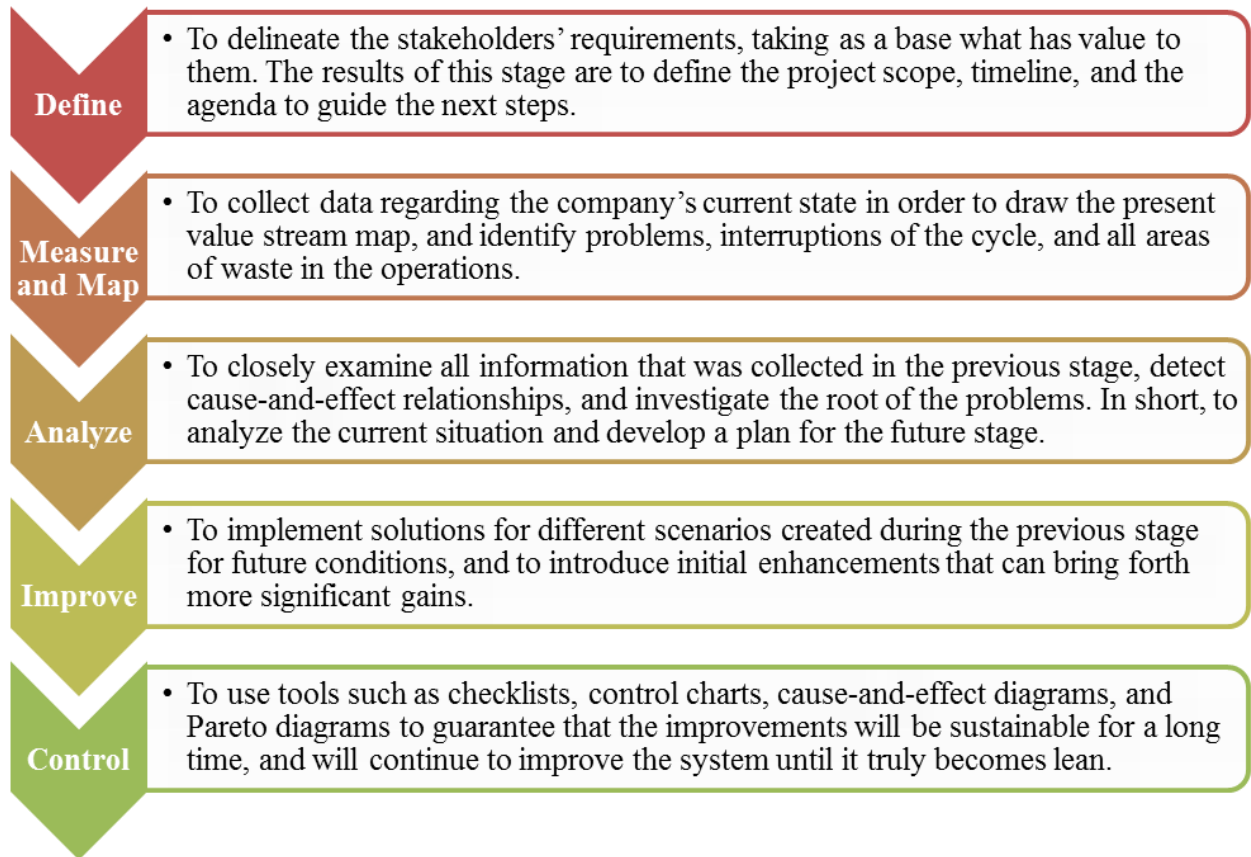
The primary goal in undertaking this senior project is to describe a case of application of the Lean Manufacturing system implemented at Ottenweller. The intent of the initiative is to improve throughput and quality of the products delivered to its top-customer. Ideally, a better relationship with this customer will allow Ottenweller to maintain sales of the current family of parts and work on developing new ones.

More specifically, in this case study, the goals were defined as:

- Address standard work to improve safety performance of new team members:
  - Reduce the number of accidents for this product line from 6 to 0.
- Address fixtures and/or process control documentation to improve quality:
  - Reduce external rejections (ppm) for these products in 81.67%.
- Map the value stream and objectively define the current state.
- Identify areas of waste for these parts:
  - Improve on-time-delivery from 88% to at least 95%;
  - Improve the production efficiency for this customer’s parts from 73% to 87%.
- Discuss the application of the results in order to identify challenges, problems and propose future improvements to the continued application of lean in the company.

## 2. DMAIC: Methodology of Implementation

The methodology DMAIC, inspired by the PDCA cycle, *Plan-Do-Check-Act*, consists of five phases: define, measure, analyze, improve, and control. This tool is often applied to drive Lean Six Sigma projects of continuous improvement based on lean thinking, in order to have a continuous approach to improvements (Rentes, 2000). Each phase is broken down into its own activities, according to Figure 1.



*Figure 1: DMAIC applied in Lean Six Sigma projects*

### 3. Method

#### 3.1. Phases of Research and Timeline

This research will be guided by these general stages proposed in Figure 2.



*Figure 2: Lean Implementation Phases*

Breaking down the phases to more specific activities, the following timeline indicates the estimated date of completion for each proposed goal, according to the Gantt Chart in Figure 3.

Start Week		Feb 2, 2015													
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Notes
Starting	fev	fev	fev	fev	mar	mar	mar	mar	mar	abr	abr	abr	abr	mai	
Define	Formalization of team														Arrangements
	Project Plan														Scope, family of products, timeline, etc.
	Literature review														
Measure and Map	Collect Data														P R O J E C T  E N D
	Value stream mapping														
	Raise problems														
	Identify non-value added and wastes														
Analyze	Analyze of problems and opportunity of improvement														
	Improvement proposals														
	Evaluate and select future stage														
Improve	Manage implementation														
	Prioritize initiatives														
	Application of proposal														Follow kaizens of application
	Analyze of results														
Presentation															Requirement for Senior Project Students
Report															Requirement for Senior Project Students

Figure 3: Gantt Chart

Although the control phase is out of the scope of this report (Figure 3), it will be the final step to guarantee the sustainability of improvements reached at Ottenweller (Figure 1).

#### 4. Literature Review

##### 4.1. Historic Evolution of Lean Thinking

The origin of lean thinking is found on the shop-floors of Toyota Motor Corporation (Shimokawa, 1987; Ohno, 1988; Shingo, 1988; Monden, 1993; Bowen & Spear, 1999; Fujimoto, 1999; Liker, 2004) as a result of the scarcity of resources and intense domestic competition in the market for automobiles. After World War II, Japanese manufacturers faced vast shortages of material, and from that scenario, the Lean Manufacturing concept was originated (Womack, Jones, & Roos, 1990). Toyota Motor Corporation pioneered the lean

approach that consisted of a set of tools and practices that managers used to address the elimination of waste and excess generated during the product flows in the shop-floors, as an alternative model to the mass production system (Hines, Holweg, & Rich, 2004).

According to Hines et al. (2004), the first principles of Lean Manufacturing were applied under the leadership of Taiichi Ohno during the 1950s, but only in 1970 the practices were revealed to other companies for the first time. It took another decade for the first literature in English to be made available, and it was not until the 1990s that it was given the name “lean” (Shingo, 1989; Schonberger, 1982; Hall, 1983; Monden, 1993; Sandras, 1989).

Lean practices and tools helped to make the small company, Toyota Motor, the world’s largest automaker. “Sparked by the superior performance achieved by lean producers over the performance of traditional mass production system designs, western manufacturers emulated the shop-floor techniques, the structural parts of lean, but often found it difficult to introduce the organizational culture and mindset” (Hines et al., 2004). Even nowadays companies find themselves struggling to become completely lean (Abdulmaleka & Rajgopal, 2007).

As reported by Hines et al. (2004), “so many early lean efforts showed localized impact only, and fell short of their intended impact on the overall system’s performance.” Until 1990, the major challenges of this new system were how to incorporate and implement the philosophy in other business views rather than automotive ones, and how to handle the changeability in demand. By that time, inside the plants, the lean implementation was exclusively tool-focused, mistreating the human aspects of the high-performance work system core to the Lean Manufacturing approach (Hines et al., 2004).

The production emphasis prior to the 1990s can be summarized as a concern with quality. Only after 1990, did the principles involving the management of the value stream, identification of value according to the customer’s perspective, the concept of flow material with pull mechanisms, and the pursuance of perfection through reducing the wastes to zero in the production system become highlighted.

Hines et al. (2004) synthesized a brief history of the evolution of lean thinking, in terms of its literature themes, foci, key business processes, and predominant industry sectors. His frame is shown below in Figure 4.

	1980-1990: Awareness	1990-mid 1990: Quality	Mid 1990-2000: Quality, cost and delivery	2000- now: Value system
Literature theme	<ul style="list-style-type: none"> <li>Dissemination of shop-floor practices</li> </ul>	<ul style="list-style-type: none"> <li>Best practice movement, benchmarking leading to emulation</li> </ul>	<ul style="list-style-type: none"> <li>Value stream thinking, lean enterprise, collaboration in the supply chain</li> </ul>	<ul style="list-style-type: none"> <li>Capability at system level</li> </ul>
Focus	<ul style="list-style-type: none"> <li>JIT techniques, cost</li> </ul>	<ul style="list-style-type: none"> <li>Cost, training and promotion, TQM, process reengineering</li> </ul>	<ul style="list-style-type: none"> <li>Cost, process-based to support flow</li> </ul>	<ul style="list-style-type: none"> <li>Value and cost, tactical to strategic, integrated to supply chain</li> </ul>
Key business process	<ul style="list-style-type: none"> <li>Manufacturing, shop-floor only</li> </ul>	<ul style="list-style-type: none"> <li>Manufacturing and materials management</li> </ul>	<ul style="list-style-type: none"> <li>Order fulfilment</li> </ul>	<ul style="list-style-type: none"> <li>Integrated processes, such order fulfilment and new product development</li> </ul>
Industry sector	<ul style="list-style-type: none"> <li>Automotive - vehicle assembly</li> </ul>	<ul style="list-style-type: none"> <li>Automotive-vehicle and component assembly</li> </ul>	<ul style="list-style-type: none"> <li>Manufacturing in general - often focused on repetitive manufacturing</li> </ul>	<ul style="list-style-type: none"> <li>High and low volume manufacturing, extension into service sectors</li> </ul>

Figure 3: The Evolution of Lean Thinking. Source: Hines et al. (2004).

In recent years, lean techniques have been integrated into a variety of businesses, such as government agencies, financial organizations, hospitals and health centers, insurance companies, construction companies, IT operations, and others.

#### 4.2. Toyota Production System

The history of Lean Thinking started in Japan after the Second World War. These principles were developed and implemented by Taiichi Ohno and Shigeo Shingo at Toyota, which became the world standard reference in manufacturing (Ohno, 1988).

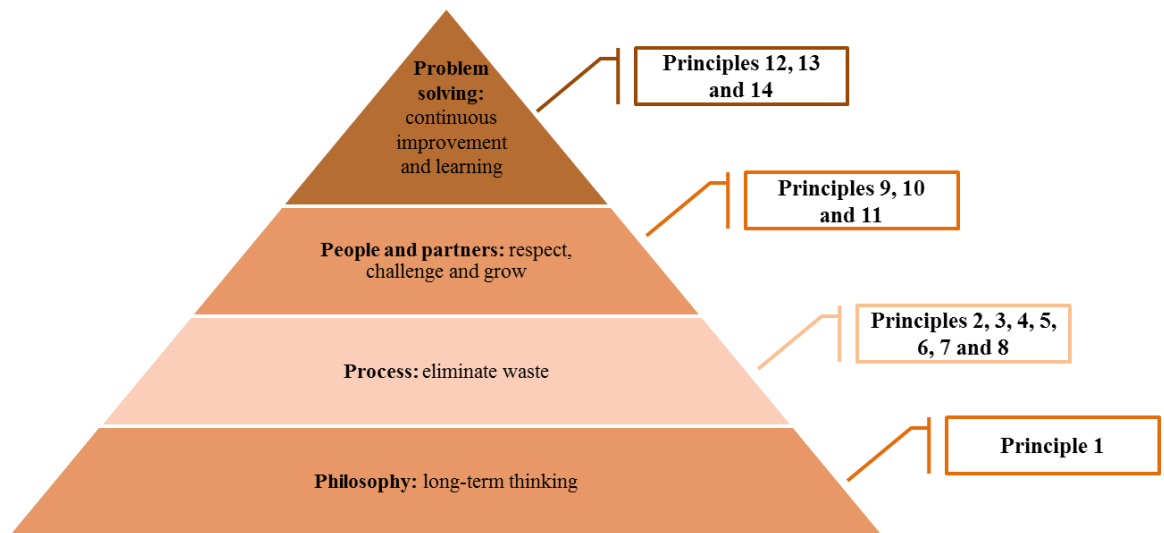
The advancement of Toyota in mass production systems consisted of new guidelines such as: the identification that the machines could be projected to produce only the demanded quantity, without excess; the tools could identify failures and stop the process as soon the first mistake was detected, ensuring total quality; the fast exchange of tools could shorten the time

spent in that which does not add value to the customer; the following process could inform the previous one about the necessity of material, obtaining in this way low cost, high variety, high quality, and fast response time to meet the customer's desires and needs (Lean Enterprise Institute).

#### 4.2.1. The Fourteen Principles of the Toyota Production System

Liker (2004) showed that the success of Toyota is grounded in fourteen principles, which go beyond just the application of tools and techniques, and require committed management, training, compensation and adequate incentives to ensure the maintenance and upgrading of the lean culture.

The principles are divided into four categories: philosophy (long-term thinking), process (enhance processes through the elimination of waste), people and partners (appreciation and development of employees), and problem solving (continuous improvement from the source and organizational learning) (Liker, 2004). Figure 5 shows the relationship between the categories and the fourteen principles:



*Figure 4: The Principles of Lean. Source: Liker (2004)*

- Principle 1: base management decisions on long-term philosophy, even at the expense of short-term financial goals. Generate value to the customers, to the economy, and to the society.
- Principle 2: create continuous process flow to bring problems to the surface, to achieve added value, and eliminate idleness, as well as to make the flow visible to the whole

organization to allow for wholesale understanding of the level of value expected by the customer.

- Principle 3: when continuous flow cannot be achieved, use “pull” systems to avoid overproduction, through the implementation of the just-in-time principle to minimize stocks and to meet daily changes without affecting internal processes.
- Principle 4: level out the workload (*Heijunka*), eliminating the work overload of people, equipment, and instabilities of the production.
- Principle 5: build a culture of stopping to fix problems, to get quality right the first time through methods to ensure it.
- Principle 6: standardized tasks are the foundation for continuous improvement and employee empowerment.
- Principle 7: use visual control so no problems are hidden. Simple indicators help people to realize instantly if there is any problem. When problems surface, they should be analyzed according to their root causes.
- Principle 8: use only reliable, thoroughly tested technology that serves, giving preference to machines and equipment that are easily operated, handled, and transported.
- Principle 9: grow leaders who thoroughly understand the work, love the philosophy, and teach it to others (*Sensei*).
- Principle 10: develop exceptional people and teams who follow the philosophy of the company to obtain great results.
- Principle 11: respect the network of partners and suppliers by challenging them and helping them improve, always looking at them as the extension of the company itself.
- Principle 12: go and see for yourself to thoroughly understand the situation (*Genchi Genbutsu*), not relying on others’ perceptions.
- Principle 13: make decisions slowly by consensus, considering all opinions, and implementing rapidly (*Nemawashi*). The planning should be slow and meticulous, and the execution needs to be fast and effective.
- Principle 14: become a learning organization through relentless reflection (*Hansei*) and continuous improvement (*Kaizen*). Always keep organizational knowledge protected so that mistakes made in the past will be not repeated again.

Likewise Toyota, the challenge for any company that aims to improve its performance through the lean philosophy is in the implementation of these principles in all its operations. In recent years this issue has been intensively investigated and many deployments have been

made, resulting in a theory about the implementation of lean production systems, presented in the following section.

### 4.3. Lean Production System

#### 4.3.1. The Seven Wastes

As stated by Rahman et al. (2013), Lean Manufacturing is a strategy used by industries to meet high throughput or service demands storing very little inventory, and deprived of wastes, wastes being considered “anything other than the minimum amount of equipment, materials, parts, and working time, which absolutely are vital to production.”

The Japanese word for wastes is *muda* and this word refers to seven different types of wastes in Lean Manufacturing: overproduction, transportation, unnecessary motion, waiting, inadequate processing, inventory, and defects Schwain (2004).

According to Ohno (1988), the wastes in the production systems can be broken down into seven categories:

1. Overproduction: to producer faster, sooner, or in greater quantities than customer demand, resulting in leftover of stock;
2. Waiting: employees, parts, information, or material that waits for a work cycle to be completed, causing interruptions in the productive flow.
3. Transportation: excess of movement of people, information, material or parts between process, generating more costs and efforts than necessary.
4. Over-processing: utilization of inadequate tools or procedures beyond the standard required by the customer, instead of utilization of simpler and more efficient approaches.
5. Inventory: level of material, work in progress, or finished goods beyond what is necessary, producing high storage costs.
6. Motion: unnecessary movement of operators, machines, or parts within a process due to workstations with inadequate layout, resulting in ergonomic issues as well.
7. Rework: the production of defected items, creating a high rate of refuse and rework, so that repetition or correction is necessary.

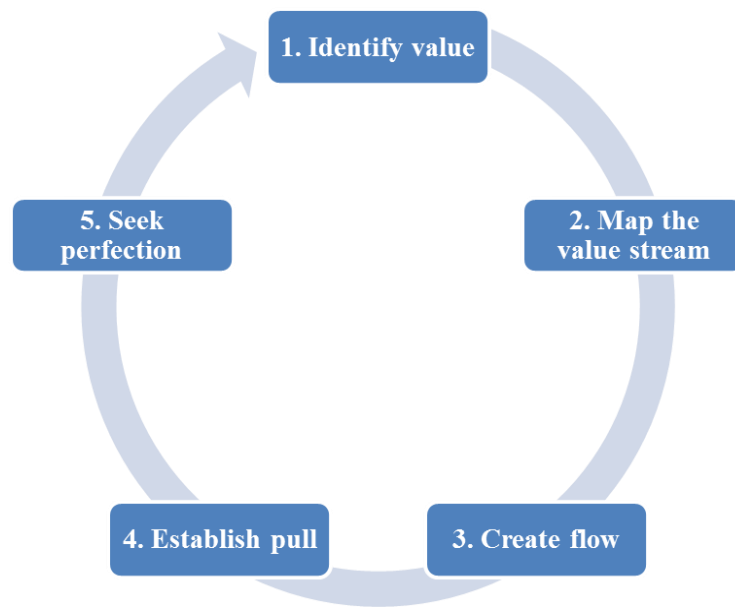
There is an eighth waste that was defined by Womack & Jones (2004), which is the waste of underutilized people. In other words, this waste represents the human talent that is not well-used. It may also be a bigger number of people involved in a job than is necessary, or employees that are not using their creative brainpower.

#### 4.3.2. The Five Principles of Lean Production

According to Womack & Jones (2004), Lean Thinking is based on a five-principle thought process for guiding the implementation of lean techniques:

1. Specify in detail the value meaning of a product from the standpoint of the end customer, in terms of price, quality, flexibility, and velocity of delivery by product family;
2. Identify the value chain for each family of products, including data of each transforming operation necessary, as well as the flow of information related to each family of products, eliminating whenever possible those steps that do not add value to the chain;
3. Design a value stream based on the value chain obtained, without interruptions, in a tight sequence so that the material can flow smoothly toward the customer.
4. Configure the production system in a way that the activation happens from the customer's order, whether he or she be internal or external, so that the flow and the programming always pull value from the next upstream activity, and are not pushed;
5. Seek improvements in the value stream through a continuous process of reduction of wastes; and begin the process again until reaching a state of perfection in which waste no longer exists.

The cycle of lean production according to the Lean Enterprise Institute is showed in Figure 6.



*Figure 5: Cycle of Lean Production. Source: Liker (2004)*

These basic principles can be clustered in three elements: continuous flow, takt-time and pulled programming. The continuous flow is achieved by the production of one-single-piece-flow, which is driven by the reduction of changeover time and by the streamlined organization of people, equipment, and materials.

The takt time evaluates the rate at which the final customer is demanding the product and it is obtained by the division of the total time available for work by the final customer's quantity demanded. The goal is to create a rhythm of production consistent with the takt time, any greater would generate overproduction and any less would not meet the demand.

Finally, the concept of pulled programming implies that production should begin when an order is placed by the process customer—in the last instance, the final customer. This concept is opposite of push programming, which generates its production orders based on demand forecast (Araujo, 2010).

Building on these concepts, the authors Rother & Shook (2003) came up with some key questions that help to plan future scenarios:

1. What is the takt time, based on the available working time of your downstream processes that are closest to the customer?
2. Will you build to a finished goods supermarket from which the customer pulls, or directly to shipping?
3. Where can you use continuous flow processing?

4. Where will you need to use supermarket pull systems?
5. At what single point in the production chain (the pacemaker process) will you schedule production?
6. How will you level the production mix at the pacemaker process?
7. What increment of work will you consistently release and take away at the pacemaker process?
8. What process improvements will be necessary for the value stream to flow as your future-state design specifies?

#### 4.3.3. Identifying and Mapping the Value in Lean Implementations

Figure 7 is a summary of the most common Lean Manufacturing tools and their concepts according to Monden (1993), Feld (2000), Abdulmaleka & Rajgopal (2007), and Abdullah (2003). Although both are widely known and used, this report will focus on those that are applicable to the company profile, in which Ottenweller fits.

Lean Manufacturing Tools	Description
Cellular manufacturing	An organization of all equipment, workstations, and qualified operators arranged for a particular product or similar products, in order to maintain a smooth flow of materials and components through the process.
Just-in-time (JIT)	It is a system that has the orders from the customers as the driving force that transmits backward from the final process all the way to raw material, though a “pull system.” This concept is based on the idea of producing the right part in the right place at the right time.
Kanban system	Kanban is an information system used to control the number of parts that should be produced in each process in order to coordinate the JIP production.
Standardization of work	A needed principle to finish the job, no matter who is working and in which shift the product is being processed, reaching the same level of quality.
Total preventive maintenance (TPM)	A tool oriented to prevent one of the biggest issues of the shop floor: the machine breakdown. It suggests preventive maintenance regularly scheduled for all equipment to detect possible anomalies or malfunctions.
Setup time reduction	Endless effort to reduce the setup time on a machine, the idea consists of moving as many activities as possible from internal setup, which includes activities that can be out only while the machine is stopped, to external setups, which can be done while the machine is running.
Total quality management (TQM)	A system of continuous improvement participative management that is guided by the needs of customers. The key components of this system are: employee involvement and training, problem-solving teams, statistical methods, long-term goals, and recognition of the inefficiencies as a result of the system.
5S	It is a tool for continuous improvement based on the five Japanese words: Seiri (Sort), Seiton (Straighten), Seiso (Sweep and Clean), Seiketsu (Systemize), and Shitsuke (Standardize). In summary, the 5S concept is focused on creating an effective workplace and in standardizing work procedures.

*Figure 6: Lean Manufacturing Tools*

#### 4.3.3.1. Value Stream Mapping (VSM)

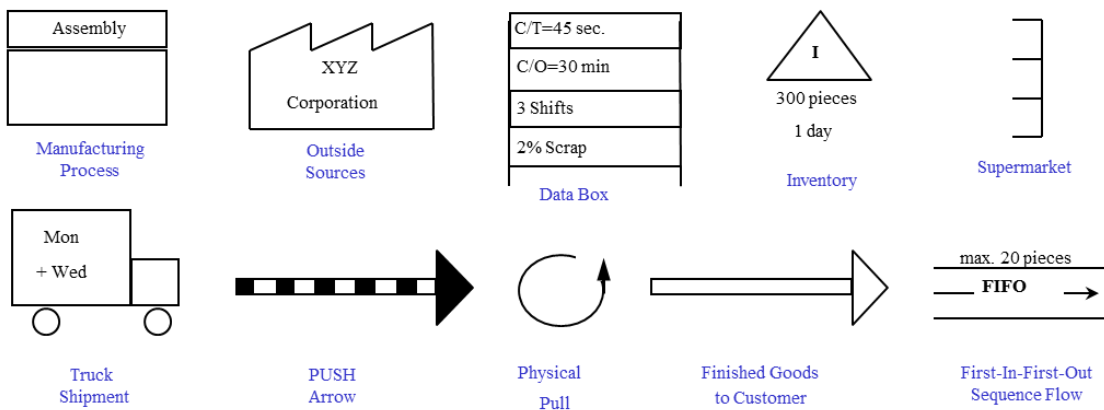
A value stream is the set of value-added and non-value-added activities that are necessary to bring a product through all the flows of materials and information within the overall supply chain from the raw material to the customer (Rother & Shook 2003).

Initially, industries must evaluate and assess the current state of operations in their facilities. The final goal of value stream mapping will be to recognize all sources of waste in the value stream and take steps to eliminate them.

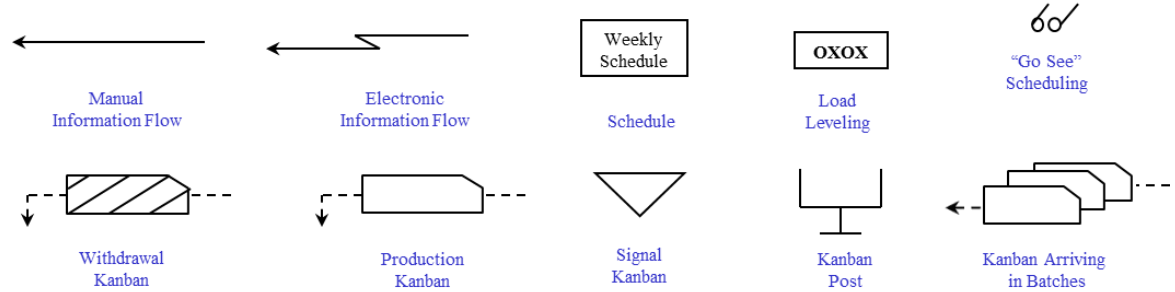
Value stream viewpoint approaches all the material and information flows throughout the organization's entire supply chain in a big picture and not individual processes (Abdulmaleka & Rajgopal, 2007).

The book "Learning to See" by Rother & Shook (2003) references the set of standardized constructs to build a specific flow chart, the value stream map. Figure 8 shows the representation of the main symbols of the diagram.

**Material Flow Icons**



**Information Flow Icons**



**General Icons**

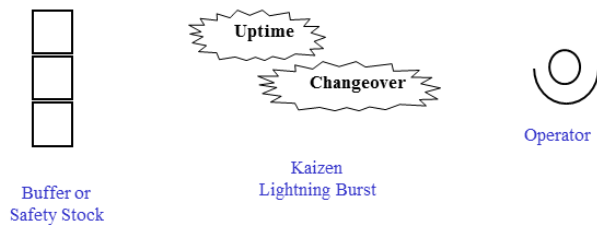


Figure 7: Material and Information Flow Icons. Source: Rother & Shook (2003)

The first step in creating a value stream flow chart is to target a product family for lean implementation and improvement. The next step is to walk along the process and draw a current state map, always by hand in pencil, capturing a snapshot of the things being done at the company. VSM measures inventory, process time, waiting time, lead time, and so on.

After creating the value stream map representing the current state, the next step is to create the future state map, which should represent a scenario of the enhancements in the system after removing wastes. The improvement plan should start with the bottleneck area, which has the maximum cycle time, as indicated on the current map. The process of creating a future state will be completed when lean tools are implemented and there is proof that the changes will make the system more efficient (Abdulmaleka & Rajgopal, 2007).

#### 4.3.3.2. DBR Method

In situations in which organizations desire to reach an intermediate level of improvement applying lean concepts, but they find themselves far from the implementation of pure lean system, the authors Lasa et al. (2009) suggested the use of DBR (Drum, Buffer and Rope) method.

DBR constitutes an intermediate level of leanness to redesign manufacturing systems that are not ready to attain a completely Lean system. This method claims that “the main programming is launched on the bottleneck (Drum) and later, based on its needs, the schedule adapted to the remaining processes (Rope) is transferred, always taking into account that these resources should be programmed to arrive, in the absence of incidents, to parts to the bottleneck with enough time (Buffer)” (Lasa, Castro & Laburu, 2009).

## 5. Ottenweller Company Inc. Case Study

### 5.1. Company and Process Background

The focus of this report is on two product families, OCI4081B and OCI8539A, which are delivered to Ottenweller’s largest customer and are at the top of the company’s sales. Both products run on shared resources and the operations utilized include: engineering part nesting, laser cutting, plasma cutting, tack welding, robotic welding, finish welding, CNC machining, washing, paint, quality inspection, pack and ship to the customer.

The ERP (Enterprise Resource Planning) used by Ottenweller to manage the means of production is able to track everything that has been loaded into the system from customer’s

inputs and the parts status. There are some deficiencies in the ERP system that confer inaccuracy between what the tool exhibits and what it is seen in the shop floor. This is expected to be overcome by lean management.

Average customer demand for OCI4081B and OCI8539A in all colors, which includes cream, orange, flat black, yellow, blue, red, gray, and white, is estimated to be 144 and 102 per month, respectively. Even though the cream parts are responsible for about 78% of the sales, all colors are considered in the scope of this project, since the only difference between a OCI8539A -cream and a OCI8539A orange, for example, is the process of painting in the VSM.

The first operations in which the raw materials, the steel sheets, are submitted to originate the components necessary to assemble the parts, OCI4081B and OCI8539A, are: engineering part nesting, laser cutting, or plasma cutting. Based on the instructions that were received at the beginning of this project, the data for these first operations are not covered in the scope of these VSMS. Ottenweller is aware of the opportunity for improvement and elimination of wastes present in these operations and will be addressing each in a future project.

Once the components are ready to be assembled, OCI8539A parts run in four welding operations, one of which is robotic, and then they go to machining, washing, painting, final inspection, packing, and shipping in that order. On the other hand, OCI4081B has two robotic and two manual welding operations, and it is machined in a distinct CNC machine. All other processes are shared by both products with differences in how OCI4081B and OCI8539A parts are processed in them.

A majority of Ottenweller's manufacturing processes are scheduled to operate in eight hours shifts, three shifts per day, five days a week, with an average of twenty-one days a month. The planning department receives orders from this customer every twelve working days. However, the forecast extends for one year. The production capacity agreed on by Ottenweller and its customer is the solicitation of a maximum of 50 parts per week. Plus, every Monday, the customer sends its electronic request for the colors that are desired for the products ordered; on Tuesdays the POs (Purchase Orders) are accepted internally. Through a computerized MRP system (Material Requirements Planning), the production control department prints out daily schedules for each one of the processes involved pertaining to the parts shipped. These schedules also get on the shop floor through the ERP system installed on computers. Regarding product delivery, the customer sends two trucks to Ottenweller twice a day for shipments; each truck has a capacity of 23 pallets. In other words, each truck can

arrange 23 pallets of OCI8539A and/or OCI4081B in each truck for a total shipping quantity of 46 pallets per day.

## 5.2. VSM, Current State Map

Following the methodology proposed to collect data by Rother & Shook (2003), the approach for the material flow starts at the shipping area, and works backwards through all processes ending with the first one involved in this scope, the tack weld 1. Figure 9 and 10 show the current state maps, where the small boxes in the map represent the process and the boxes below them contain data such as cycle times (C/T), changeover times (C/O), number of shifts, quality data, percentage of resource available to the specific process, maximum number of parts that can be processed in a day at the specific resource, maximum that could be produced in a hypothetical situation when 100% of resource is designated to the part, and machining uptimes. The first sequence of processes was drawn according to the data available in the ERP system. However, when walking the shop floor and talking to the operators and managers at each workstation, the sequence of processes showed itself to not be consistent with reality. Therefore, the final version of the VSM sequence of process indicates exactly which workstation the parts are at instead of where the system indicates they are supposed to be. Quality indicators and machining uptimes are based on the average of historical data. The uptime for Machining Center A is 99% and for Machining Center B is 95%.

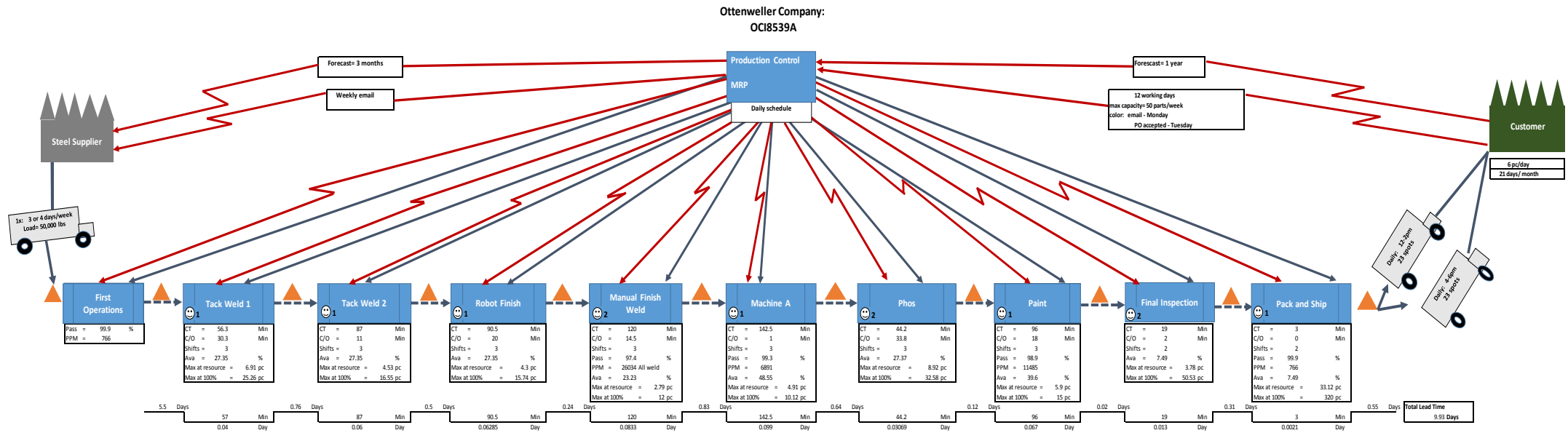


Figure 8: Current state map for OCI8539A

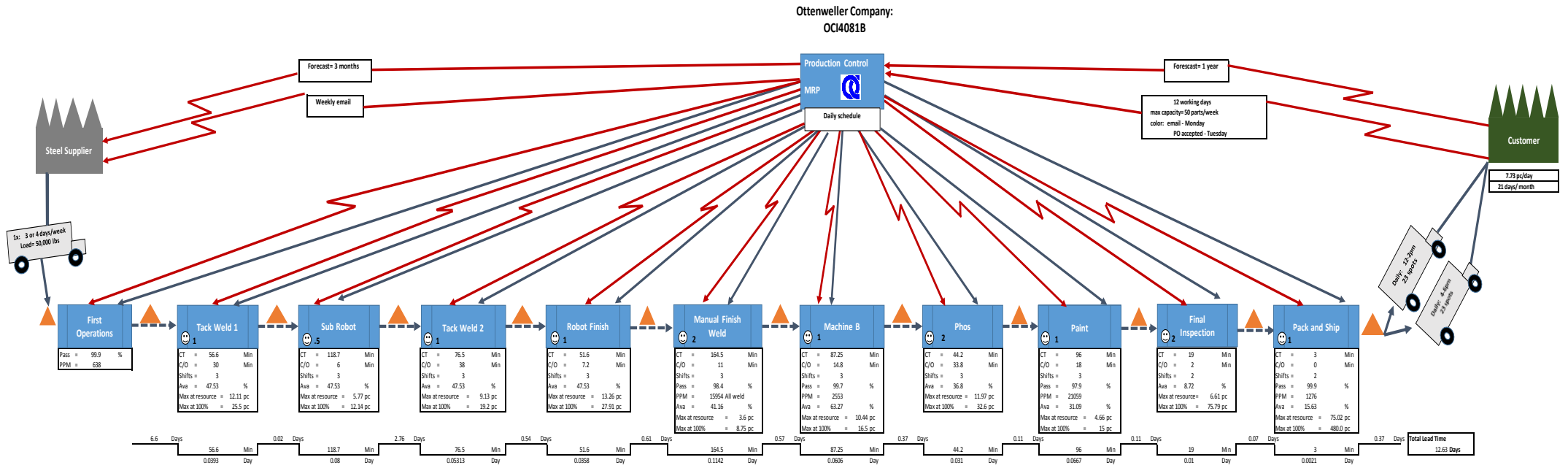


Figure 9: Current state map for OCI4081B

The symbols used to draw these maps, Figure 9 and 10, are from the pattern established by the authors Rother & Shook (2003) as showed in Section 5.3.3.1.

In the beginning of this project, it was decided that the current state map would contain only cream colored parts for the two part numbers because cream represents about 78% of all colors requested. However, during the measuring stage, it was observed that the inventory snapshots collected within processes did not represent only cream parts, since all parts remained the same until the paint operation, at which point the application of paint takes place differentiating the parts one from another by color. The discrepancy was also evident in the considerable increase in inventory between processes not followed by an increase of demand for cream parts during the same period, meaning that the demand for other colors was not taken into account. In light of this and in view of the fact that different colors represent a significant percentage, the team decided to expand the scope for all colors in order to have more precise measurements.

Appendix A and B bring together all data collected during time studies as well as the quantities of inventory present within the entire mapped process evident through snapshots. During the measurement phase, the inventories were counted around 11am, every Monday and Wednesday. That particular time was chosen for two reasons. First, the operators were at lunch from 11 to 11:30am on the first shift, meaning the parts were static, thus facilitating the count of the pieces at the current position in the flow. Second, during this interval, the shipping operation has not yet been done, since the first daily truck arrives at Ottenweller around noon. Through gathering snapshot data, seven cycles of inventory were collected for each one of the parts, and then the means were inserted into the current state maps as viewed in Figures 9 and 10.

Since the first operations, where all of components are cut, are not being considered in this scope, a decision needed to be made about what items should be considered in the inventory snapshots. For the OCI8539A product, which is assembled by thirteen components, the two with the highest cost are: upright plates and the pair of side plates. This division in Figure 9 was made for Tack Weld 1 and Tack Weld 2 processes because after them the part becomes known by OCI8539A, as viewed at the Figure 9. In this analysis, for each set, two side plates and one upright plate are necessary. Following this condition, the side plates were considered in pairs, and the final value to their inventories is the maximum inventory, because it means one product can be completed if all parts necessary are available to go to the next process.

For OCI4081B, which is assembled by nine components, the three with the highest cost are: back plate, pair of side plates, and web plate. That division in Figure 10 was necessary because these are the three initial processes through which the components go before it becomes known as OCI4081B: Tack Weld 1, Robot 1, Tack Weld 2. The inventory time could be obtained through the division of these top level pieces by daily demand in days.

In relation to the time studies, not only meetings with operators and managers were implemented, but also a camera was used in order to analyze cycle times, changeover times, and to determine improvements for processes, procedures and techniques. The cycle times (C/T) were measured as the total time between the movements of one finished good to the movement of the next one, in each operation. The cycle time for each process uses the average cycle-time of all multiple measures made. From this standpoint, the process-lead time of the entire stream could be obtained by the total time of the sum of the cycles for the product, not including inventory time.

By implementing times studies and collecting inventory snapshot data, the production lead-time for each product was calculated by combing its process-lead time and total inventory time. The summary is in Figure 11.

<b>OCI8539A</b>			
<b>Summary Table</b>		<b>Product</b>	
Process Lead-Time (Min)	658.53	Avg Day Dmd	6
Process Lead-Time (Days)	1.37	Hours per Day	8
Total Inventory (Pieces)	57.14		
Total Inventory (Days)	9.52		
Production Lead-Time (Days)	10.90		
<b>OCI4081B</b>			
<b>Summary Table</b>		<b>Product</b>	
Process Lead-Time (Min)	717.29	Avg Day Dmd	7.73
Process Lead-Time (Days)	1.49	Hours per Day	8
Total Inventory (Pieces)	100.54		
Total Inventory (Days)	13.01		
Production Lead-Time (Days)	14.50		

Figure 10: Summary table for VSMs

While working with time studies for cycle times, it was revealed that parts were being reworked at welding operations (Appendixes A and B). Data about quality performance, more specifically rate of defects, was collected and included in the maps (Figure 9 and 10). In reference to last year's records, March-2014 to March-2015, "pass" and "ppm" correspond to the percent of parts with zero defects produced, and the parts per million produced with defect, respectively. Unfortunately, according to current operational procedures, quality inspectors record only the category in which the defects were found, the date of occurrence, and the operator in charge. There is no precise information about where, in the manufacturing processes, the defects were generated. In the maps, there are quality rates only for the processes where it was possible to identify the occurrence of the defect.

Furthermore, despite the fact that these two parts correspond to Ottenweller's parts with the highest production rate, they share resources with other products. The percent of resource available for each part in each process of the stream was measured based on the company's forecast for the year. Considering the statistics of production for Ottenweller's portfolio of products, this data is going to be essential during the planning of Kanbans for the future state. Additionally, the field "maximum at resource" was designed to report how many parts will be able to be produced per day, in the three shifts, based on the resources availability, on the entire demand, for the processing of each one of the parts, OCI4081B and OCI8539A. In a hypothetical situation where only products to this specific customer are manufactured with priority of delivery over other products, and where there are no breaks and downtimes, the capacity of the company was measured as "maximum at 100%". Even though this last parameter is not realistic, it is a basis for understanding the new lean system aptitude in reaching on-time-delivery and increase of production efficiency goals without making strategic investment decisions to boost the existing capacity.

The inventory is represented by orange triangles ahead of the processes, and the blue arrows symbolize where material is transferred. The timeline at the bottom of the maps has the processes lead-times, which is basically the processing time for each process, and the inventory time, which is calculated by dividing the inventory quantity into the daily customer demand for each product.

### 5.3. Analyze the Current Situation

The analysis of the current situation was made by taking the company's goals as guidelines to reach an understanding of the reality observed at Ottenweller and to assure that improvements can be proposed to achieve the company's aims for safety, quality, productivity, and reduction of cost.

With regards to safety, an excessive flow of forklifts and employees transiting through the facilities was identified, mainly due to operations not being grouped close enough to each other to minimize transportation and movement over the stream. There is a lack of designated traffic lanes indicating where forklifts can drive without incurring safety risks, as well as the occurrence of hard braking and horns due to the fact that employees and/or material share the same access ways as the forklifts. Also, the use of distinct cranes crossing products has historically represented danger to the operators.

Concerning quality issues, a common practice throughout the company is the self-inspection, in which the checkup is carried out by the operators who are doing the actual work; they perform the inspection on the work they themselves have done. Based on historical data, the highest occurrence of self-inspection took place right after the processes that had the highest incidences of defects. Only the final inspection, at the end of the flow, is carried out by a quality specialist, when the processing of the parts has been completed and before packing.

Moreover, with respect to quality, it was detected that there is no standard to carry out the manual processes of welding. Welding points are applied on Tack Weld 1 to connect components to the side plates. Some of the parts are welded with multiple points while others are welded with only single ones. The lack of standardization can result in non-value added costs for the parts that are receiving more welding than necessary and it can represent future quality problems in the stream.

When the enhancement of productivity is desired, one of the most significant aspects that should be targeted is production bottlenecks. The bottleneck for OCI4081B, where it has its longest cycle time, is its manual finish weld. As OCI4081B goes through the welding process, its physical structure becomes very restrictive resulting in some locations on the product that robots are not able to reach to weld. This means that operators must position themselves within the product to be able to touch these physical limitations to manually perform the welding operation.

On the contrary, the bottleneck for OCI8539A is not the manual finish weld as it is for OCI4081B; it is the machining process at Machining Center A. The reason for this change is due to the difference in the shape of each part when both side plates have been welded in place. The OCI8539A side plates structure allow the welding through the components within the structure more easily, enabling the previous process, the manual finish weld, to be more agile when compare its cycle time to the OCI4081B.

Another lean strategy to improve productivity is to promote setup reduction, eliminating non-value added time. Currently, many of the setup operations at Ottenweller promote idle time as machines sit inoperative, waiting to start processing parts.

In terms of the current layout and production set up, all assembly processes for OCI8539A are located in building Loc2, even though there is still some physical distance between consecutive processes. Only when the demand for this product exceeds the available capacity in Loc2, is the excess of OCI8539A taken to the other building, Loc3, to be machined. On the other hand, every single OCI4081B makes displacement to Loc3 after its manual finish weld at Loc2 to start its machining process, where the machining center B is located. After this process, all parts return to the previous building to continue the flow. Both machining centers, A and B, are addressed as “monuments”, which means that they require a heavy investment to make changes in their actual positions because of their complexity of deployment. The spaghetti diagram is showed in the Figures 12 and 13. The orange spots represent inventories of the parts in the study. The color blue represents OCI8539A’s flow, and purple, OCI4081B’s.

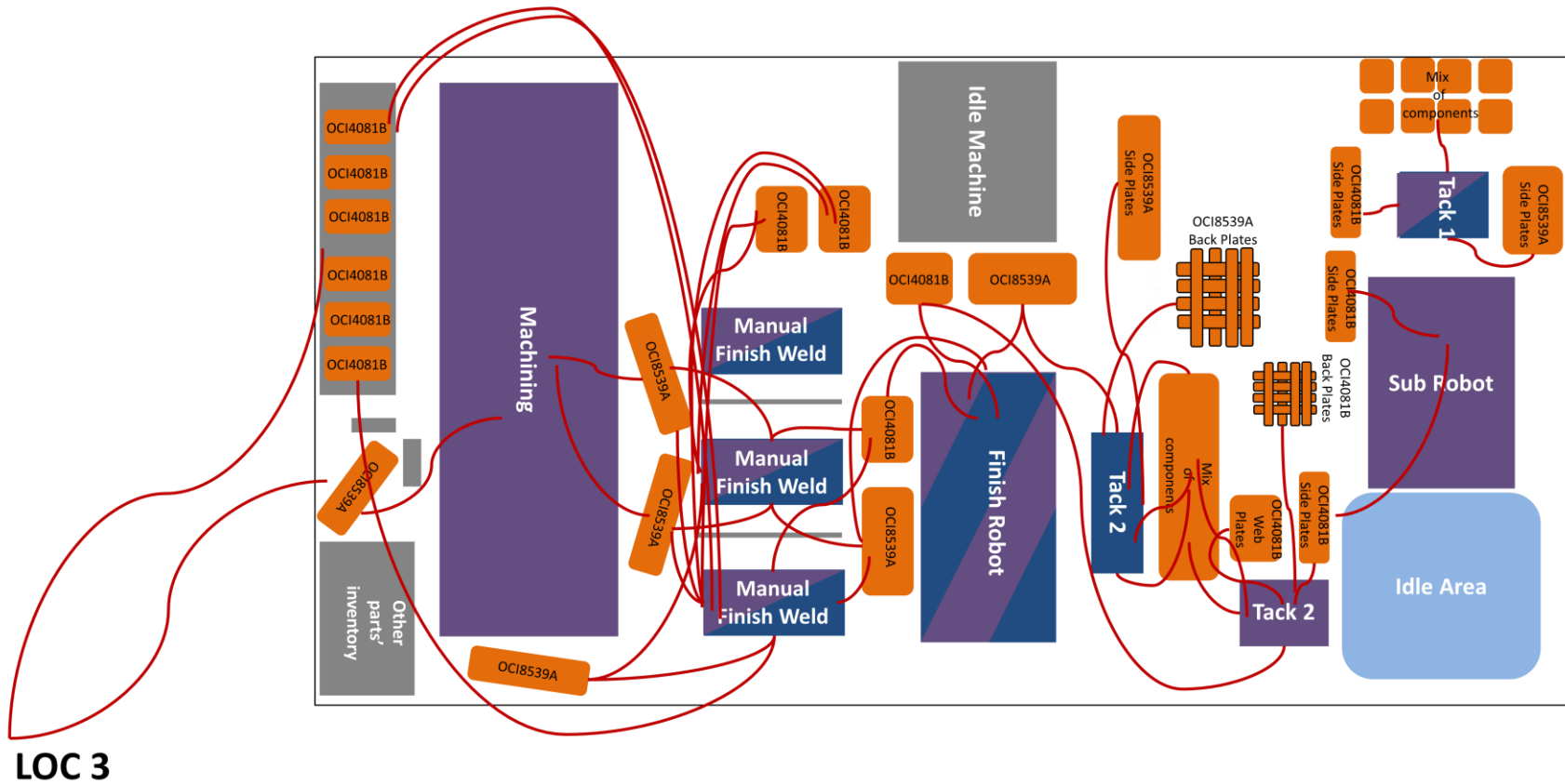
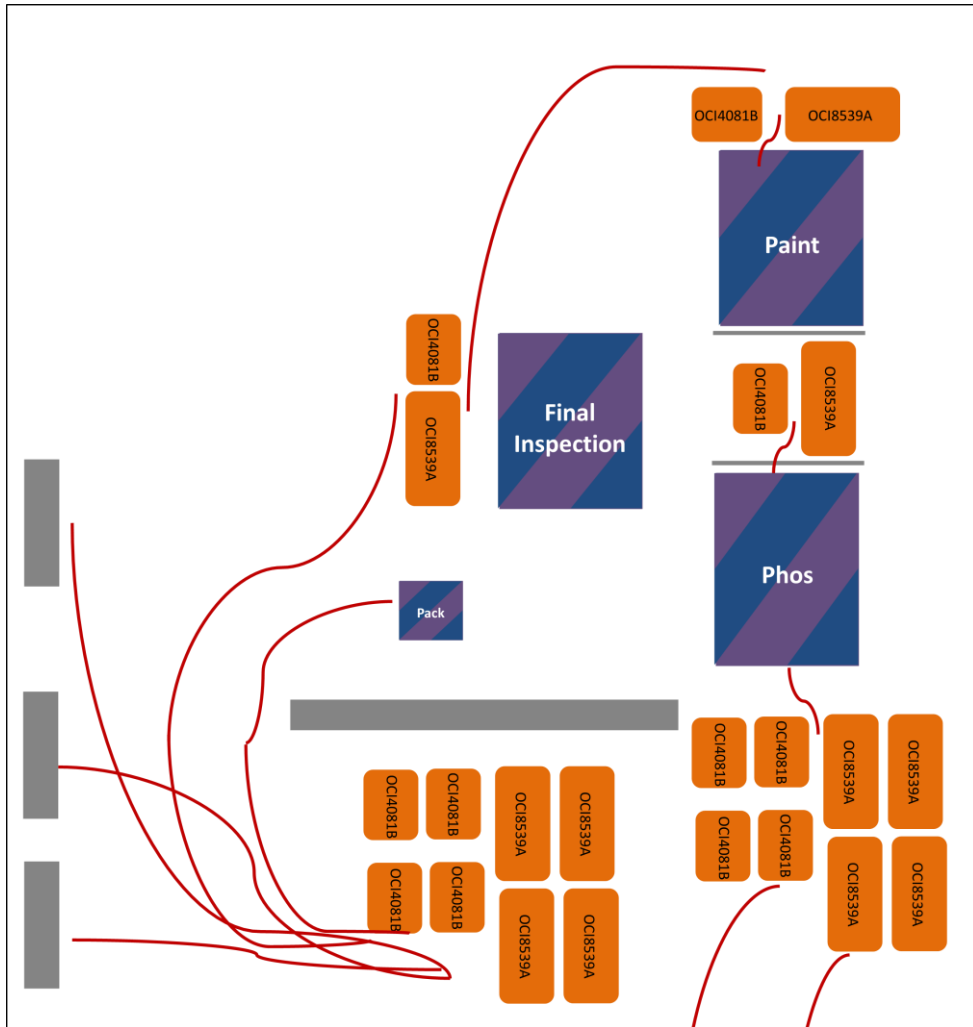


Figure 11: Spaghetti Diagram from Tack 1 to Machining



**LOC 3**

Figure 12: Spaghetti Diagram from Phos to Shipping

Fortunately, OCI8539A is able to run in both machining centers A and B; however, the OCI4081B only can go to machining center B. Through time studies, it was verified that processing time for OCI8539A in machining center B is more efficient; it runs in 1h15min compared to 1h45min in machining center A. Since OCI4081B only fits in machining center B, this machine is basically designated to its production alone. The result is that each OCI8539A is processed in machining center A then, where it normally requires an additional 30 minutes of processing time. The programming of both CNC machines is done by the company's specialists, and the recent improvement at Machining Center B that generated its shorter cycle time when compared to the Machining Center A for OCI8539A, was carried out by internal specialists.

In view of the fact that the demand for OCI4081B is usually higher than OCI8539A, the possibility of making a fixture to run OCI4081B in machining center A as considered as this could also save non-value added cost by avoiding transportation from building Loc2 to Loc3. Coming from the perspective that OCI8539A has a shorter processing time in machining center B, there also might be a potential advantage in developing programs to switch both parts. However, it was found out that the height of OCI4081B is not compatible with Machining Center A; it only fits in B. Changing this resource in order to be able to machine OCI4081B would require heavy investments, which proved to be an unworkable alternative.

Moreover, since Machining Center B has only one fixture to hold OCI4081B, valuable time is wasted when the operator stops the machine to load it. The fixture is able to move horizontally, cleaning access for the next part to start its manufacturing process. However, if the next part to be processed in the machine is also the OCI4081B, the previous part needs to be unloaded with aid of a chain, which takes up a large part of the changeover time. Adding another fixture similar to the horizontal one could generate a significant reduction in non-value added cost related to the waiting time of the machine.

Another interesting occurrence was identified during the OCI4081B changeover time. The parts are received by forklift from the other building and are delivered to the front of the machining center B. Each time, the machine operator must flip the part upside down to be positioned on the fixture. For this operation of flipping, a tool change is required and that process can take about eight minutes. Even though this process is implemented by the operator when the machine is running, in the future, if that non-value added operation could be eliminated, it would free the operator for other activities.

One key element of Lean Manufacturing system in reducing costs is to hold only the necessary level of material to supply the customer demand. This represents a large opportunity at Ottenweller. A frequent accumulation of inventory waiting to be processed is seen, especially before bottlenecks. Beyond the misused investment, it also represents psychology issues for the operators who are often in a situation of exhaustion and delay in their processes. Many times, the orders created from the MRP system do not match with the reality of the quantities of products already sitting on the shop floor. Furthermore, the lack of raw materials and components that are held up in up line processes continue to be an ongoing concern of the operators. Additionally, the company has stipulated a minimum quantity to have on-hand to attend commercial strategies before each process. These issues will need to be addressed in order to implement lean effectively.

Nowadays, Ottenweller works with a programming of minimum lots to guide the production of first components necessary to feed tacking processes. The idea is to maximize the steel sheet cutting operations with the nesting processes (laser, plasma, and flame cut). In the scope of this report, from the first process, tack weld 1, to the very last process, shipping, the parts are transfer one-piece-flow.

Making use of tools for continuous improvement, the event known as a Kaizen Blitz, “a sudden overpowering effort to take process, system, product, or service apart and put it back together in a better way,” was scheduled in the machining and welding areas. Teams of operators and managers were invited to come up with suggestions for improvements during the brainstorming. Using posts-its, sharpie markers and pens, tape, butcher paper, floor tape, foam, shadow boards, and laminates, the employees expressed their ideas during the brainstorming session. The ideas were organized by category, and the team started discussing what ideas could be implemented on a scale of effort (X) and impact (Y) as shown in Figure 14.

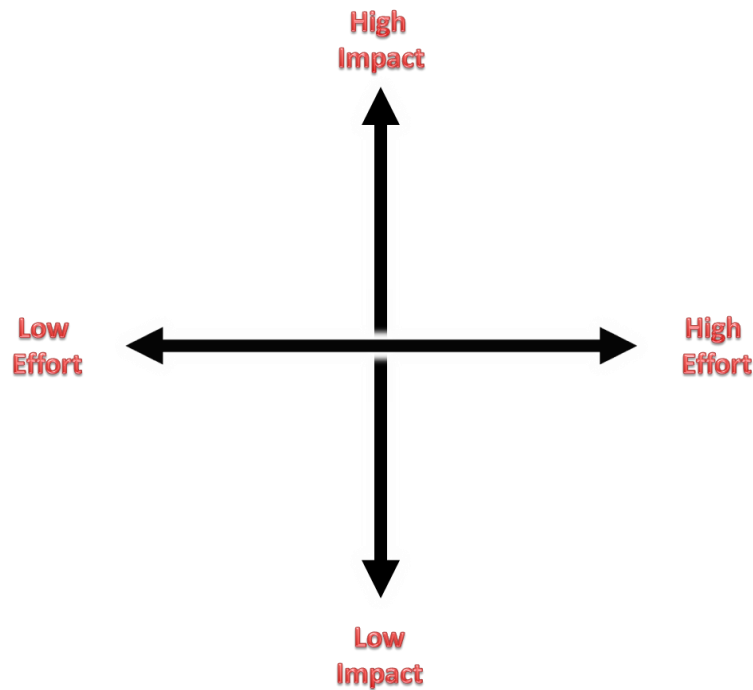


Figure 13: Effort versus Impact Matrix.

Upon reaching this stage, the leader invited the group to generate actions for future implementation. The document called “Action Tracker” containing due dates and owners for each one of them was produced to make sure the ideas would be tracked for accountability. Figure 15 is a summary of the Kaizen outputs.

Key Function	Action Description	Related Goal
Welding	Promote 5S improvement at Weld Area	Safety/Productivity/Cost
Welding	Show Quality Pareto Chart and Tracker at Weld Area	Quality
Welding	Provide protect cords on the OCI8539A at Tack Area	Safety
Welding	New Finish Weld positioner for OCI8539A and OCI4081B	Productivity/Quality
Welding	Designate an operator to load parts in the Robot	Productivity/Cost
Machining	Promote 5S improvement in both Machining centers	Safety/Productivity/Cost
Machining	Update tooling and program for OCI8539A	Productivity/Quality
Production	Provide a dedicated bin to transport OCI4081B upside down	Safety/Productivity/Cost
Production	Provide a Robot Crib for tools in Loc3	Productivity/Cost
Lean	Designate squares for Kanbans and allocate inventory	Safety/Productivity/Cost
Lean	Duplicate bins for component parts at Tack Area	Productivity/Cost
Robotics	Add Robot operation for OCI8539A to reduce constraint on Manual Finish Weld	Productivity
Robotics	Create a Robot program for running parts in both sides of Robotic Weld	Productivity
Engineering	Duplicate pick-off fixtures	Productivity/Quality

Figure 14: Action tracker for Kaizen Blitz

Following discussions with the specialists about applicability, the lean team came up with additional ideas for improvement. Some of these ideas will be implemented over a longer time horizon. The details of the actions implemented in this project are described in the next section.

#### 5.4. Implement The Future Situation

From a whole plant perspective, including all three facilities, the improvements in safety performance can be done through an effective strategy of creating spaghetti diagrams. It permits the team to observe the entire stream in which parts are transported and employees move, providing future improvements to add value. Because components are not always placed close to the operations, a higher level of circulation of operators and forklifts through the facilities and between buildings leads to an increased probability of accidents occurring.

Specifically within OCI8539A and OCI4081B lines, to improve efficiency a layout change and 5S program will be considered to bring proximity of the tools and material to the workshops, as well as to promote a cleaner stream. The benefits involve gains in safety, productivity and reductions in costs.

A 5S program will be implemented following the steps below:

- Organize 5S teams for Tack Weld, Manual Finish Weld and Machining Center areas: operators and managers will be charged with assigning responsibilities and setting completion deadlines for their respective areas.
- Sort: each area will have its boundaries set, and then the teams will sort, tag and remove unneeded items to a reserved area of 5S.
- Set in order: the 5S containment area will be an opportunity for other workstations making efficient uses of materials that are not needed in the previous operations submitted to 5S improvement. The needed items will be placed in nearby locations helping to eliminate unnecessary motion. Removing all non-value added materials will enable operators and managers to standardize workstations through the use of shadow borders and gathering useful materials in smart places.
- Shine: teams will find opportunities to improve cleanliness; the most common tools will be painted with orange color and their respective shadows highlighted with black over the white borders.

- Standardize: a list of all needed materials will be created to check if all items are present on the tool boards. In order to solve the lack of items that results in employees walking to other stations to borrow them, new tools and materials will be obtained to create standard 5S tool boards. The goal is to enable operators to check the condition of the workstation at a glance.
- Sustain: knowing that management support is crucial to the sustainment of an organized workplace, it is proposed that the company designates dedicated 5S facilitators to develop ongoing audit procedures, as well as display all 5S communications and feedback locally in each area.

Regarding the quality issue, a reduction of external rejections for OCI8539A and OCI4081B products at 81.67% shows itself a challenge, yet achievable, goal. Manual Finish Welding is a crucial process in the value-stream map due to its historically high number of defective parts being released to the next operations. In an effort to minimize, if not all together eliminate these defective parts from entering the manufacturing process, both parts will undergo an additional step in which a specialist will inspect the part for quality of welds. This will take place at a third table which is currently idle during all shifts. Welders will leave the completed-welding part for the inspector then, and go to the other free table to start processing a new part. The key to reducing defects lies in effective communication to synchronize the time between parts being completed and the inspector coming to validate them before the part flows to the next operation. Because removing parts of the table represents a considerable portion of the cycle time, it will not be a value added operation if parts need to be switched before the inspection processes occur.

Since it is not currently possible to pull out data for each quality issue welding process individually in order to generate a punctual measures for quality improvements, the following solutions will target that issue:

- Create standardization of work: work instructions will ensure that processes are not adding non-value activities through excessive welding, for example. Standardization will also improve quality since patterns will be reviewed by specialists and operators will be required to follow the instructions exactly, thus avoiding differences between products run by different employees.
- Review inspection forms and check out lists with specialists to be sure they include all necessary information, and provide an ideal frequency for these inspections to occur.

- Create pick off fixtures: working as pokayokes, meaning mistake-proofing systems, these fixtures will be used to tack smaller parts onto bigger ones. The strategies to make an effective use of these fixtures will be:
  - Produce easy fixtures that welders can lift and handle without chance of mistake or doubt;
  - Make sure fixtures will hold parts in place to avoid movements while undergoing the welding process;
  - Drill out inside corners making fixtures sharp when using the inside corner for uniting their components.

It is also expected to see quality rate improvements and gains of productivity in the Machining Center A when it receives the same programming update that was made in Machining Center B in the past.

Since details of defect occurrences are not currently recorded in the system, it is not possible to identify corrective actions to prevent irregularities. Looking towards improving quality, it will be proposed that more accurate descriptions of the defect occurrences be reported in writing at Ottenweller. Investigating and reporting detailed causes of defects enable the creation of mechanisms to prevent recurrences. The systematic improvement of this will be conducted in the following phases: data collection, assessment, corrective actions, and follow-up.

The templates used to record electronic occurrence will detail:

- Type of defect and description given by quality specialists in order to enable understanding of the event;
- At which operation each occurrence took place;
- Conditions before, during, and after the defect occurrence;
- Environmental factors that can be related to the occurrence and relevant to the diagnostic, such as management, training, procedure, personnel, equipment, material, or design;
- Personnel involvement and actions taken;
- Pictures of the defect attached;

After the data collection, the diagnostic phase will happen:

- Identification of the problem;
- Determination of the significance and severity (low, medium, high, very high, and urgent) of the problem;

- Identification of causal factors surrounding the problem;
- Analysis of the reasons why the causes exist, and determining the root causes.

Effective corrective actions should be feasible and appropriate, prevent recurrence, and meet quality goals. After tracking the actions to make sure they are effective in resolving quality problems, follow-ups will be essential to ensure the actions have been adequately implemented avoiding repetition.

As it is examined the efficiency of the production, bottlenecks of both parts, OCI8539A and OCI4081B, will be targeted. The primary solution is to develop the programming to load OCI8539A in Robot 1 that today only OCI4081B is able to run. In this robot, it would be possible to transfer some of the operations that are made in Manual Finish Weld, generating gains of productivity and quality. Even though this process itself is not the bottleneck for OCI8539A, it can open more capacity to run OCI4081B in its own bottleneck, since the OCI8539A can be completed in less time there. Another issue raised about bottlenecks from the brainstorming was the unequal distribution of work between operators, mainly where the bottleneck is. The solution found is to transfer the activity of loading the Robot Finish from the operator responsible for Manual Finish Weld to the welder of Tack 2. This will switch a shared resource of OCI4081B's bottleneck to a shorter cycle-time operation, Tack 2.

As a result of layout changes and 5S improvement, a reduction of setup time promoting better productivity will be observed. In addition, there are still opportunities for changeover improvements through implementation of quick-change devices, conversion of internal setups to external, and elimination of wastes.

The fact that the Machining Centers require heavy investment to be displaced suggests that cell layout for the entire stream is not usually applicable in steel fabrication industries such as Ottenweller, as noted by Abdulmalek & Rajgopal (2007). However, small modifications in the other workstations can be made to improve productivity and eliminate non-value added activities. Aiming to establish a stream as close as possible to a continuous flow, the sub robot will be shifted 90 degrees to the right corner where the area is currently idle.

The Figure 16 and 17 show the new layout plan.

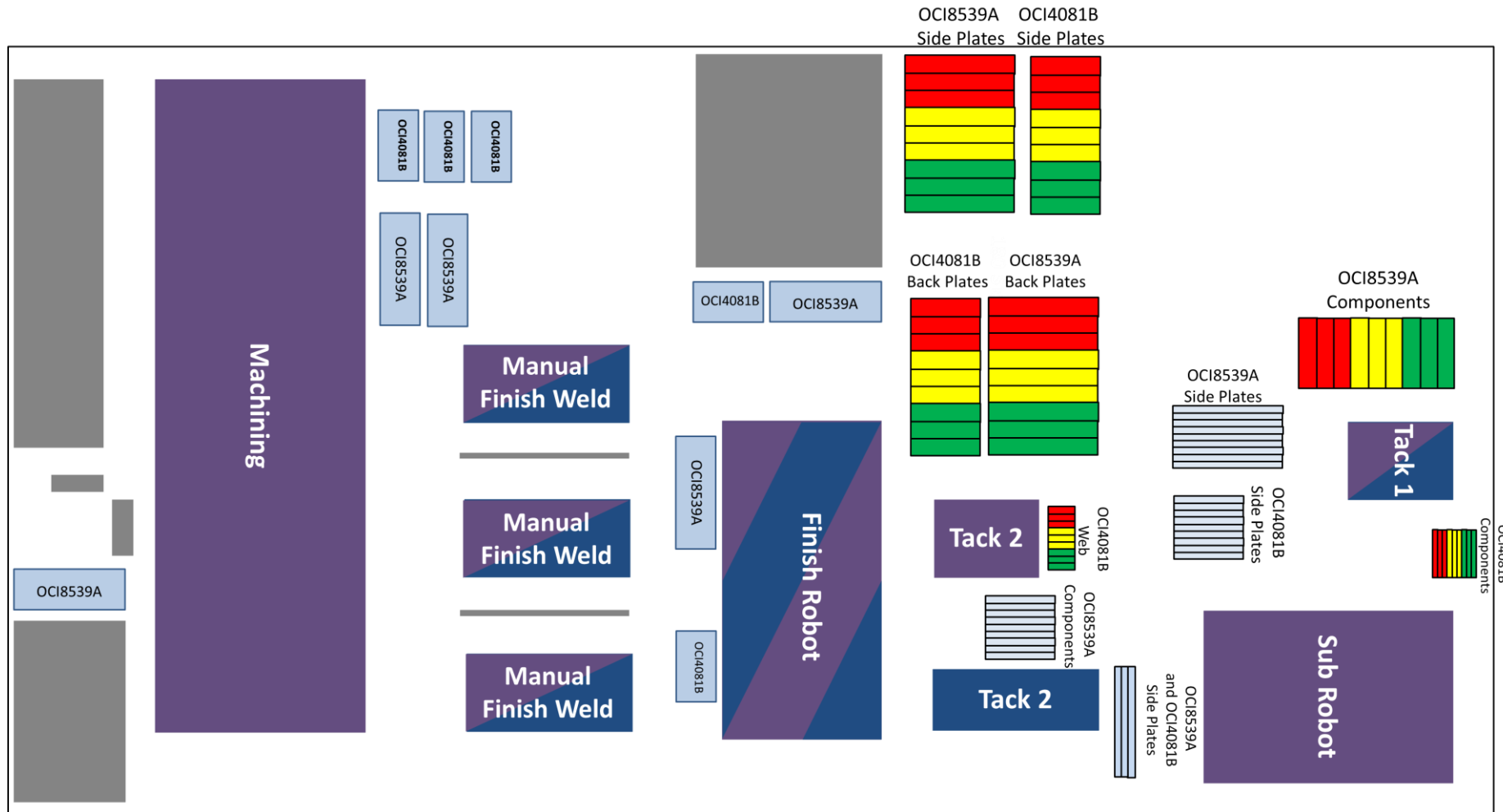


Figure 15: New layout plan from Tack 1 to Machining

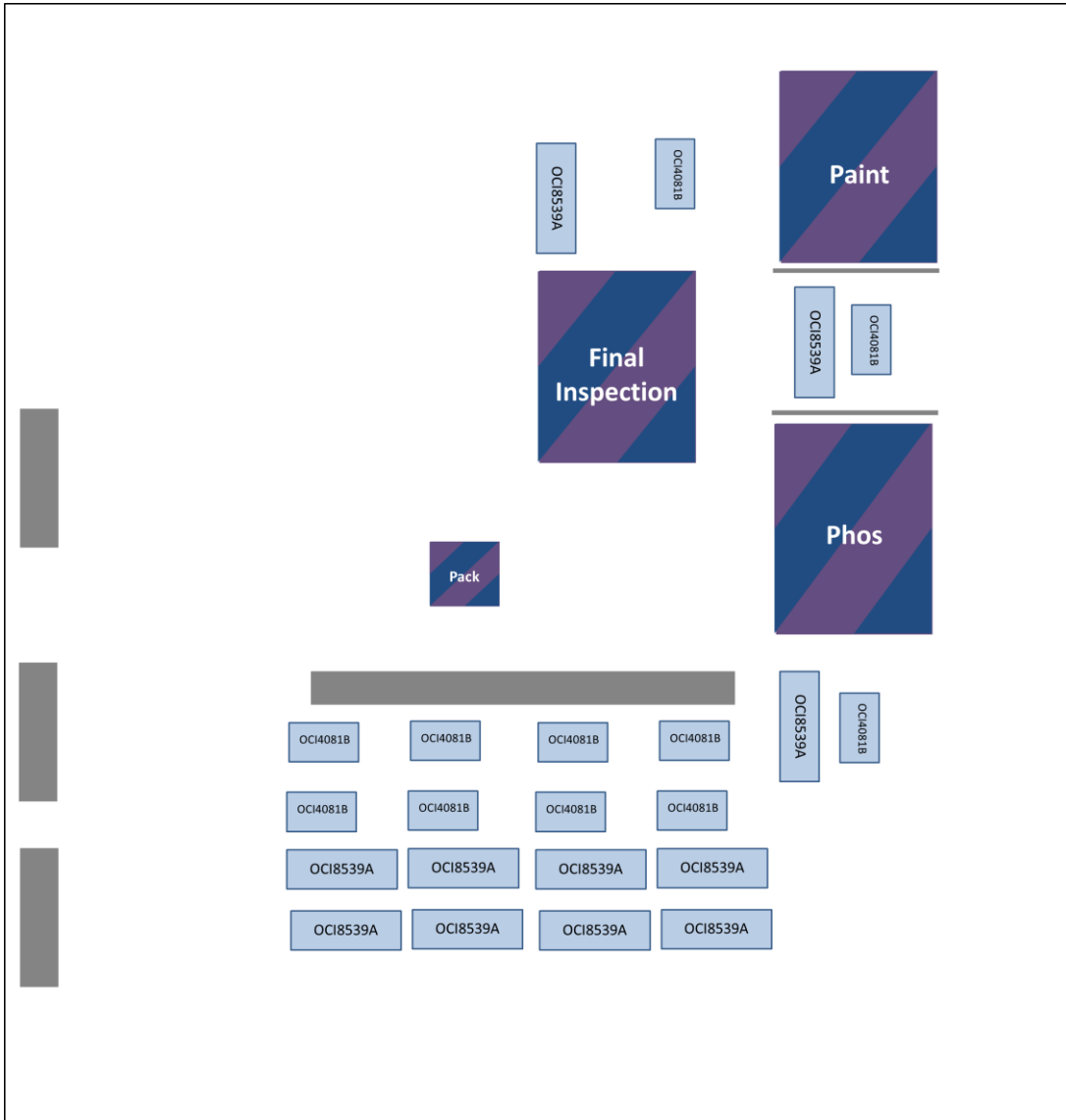


Figure 16: New layout plan from Phos to Shipping

As a solution to eliminate excess inventory, Kanbans will be implemented to orient the production in the first operations, with appropriate dimensioning of buffers and supermarkets, by designating only two bins of components before Tack 1. The decision of controlling inventory by two bins is made based on the capacity of the first operations in supplying Tack Weld 1. Creating standard colors and signage for each bin will provide control of components that should be delivered, not allowing mistakes such as the sending of an odd number of elements that make up pairs in the assembly operation. Likewise, to depict material status and work flow, colored lines will be painted on the floor corresponding to the same colors of the bins.

The process plan is exemplified by Figure 18.

<b>Operation</b>	<b>Operator charged</b>	<b>Activity</b>
10	Tack Operator	Consumes component at sub tack JLG Weld
20	Tack Operator	Returns empty bin to containment area
30	Tack Operator	Pulls in next bin from staging area square
40	Forklift Operator	Unstacks one bin of side plates and fills staging area square
50	Forklift Operator	Returns empty bin to first operation
60	Laser/Plasma Operator	Produces material
70	Forklift Operator	Delivers material to Side Plate Stack

*Figure 17: Process plan to the stock management*

To further enhance the flow of components, production planning will be applied only to bottlenecks instead of all operations, and from bottlenecks to downstream, observing continuous flow. The way Weld Tack I for OCI8539A and OCI4081B is going to receive handling components will follow the FIFO methodology, first-in-first-out. This will streamline the flow of forklifts, save on the efforts of operators, and the movement of cranes.

## 6. Results

In evaluating 5S effectiveness at Ottenweller, the housekeeping methodology provided a starting point for ergonomics and safety enhancements and minimization of wastes at the workstations to reach more efficient operations.

The mantra of the 5S program, “a place for everything, and everything in its right place,” resulted in adequate spaces for placement of needed tools and materials, avoiding accidents, reducing time previously lost to searching and walking. The non-value-added items were taken out of work area, optimizing the work environment. Useless materials in the target boundaries were removed to the 5S containing area, from where they could become value-added items for other operations. In addition, shadows were drawn in the existing tools borders to standardize tools to facilitate the visual management and control.

Concerning stock management, lanes were labeled in the inventory areas thus avoiding trip hazards by opening up walkways for operators. Enlarged images and signage fulfilled the dual mission of serving as a guide for inspection processes, maintenance of 5S, and orientation for forklifts operator regarding where to place inventories. Component bins received color matching with their respective lanes, and standards were recorded in the ERP system in an effort to sustain the enhancements reached.

Regarding quality improvements, visual work instructions were created for all processes and were posted in each area promoting a clear understanding of quality assurance characteristics and enhancing prevention and detection of non-conformances. Furthermore, blackboards were designated for Pareto Charts in welding workstations with the purpose of recording defect occurrences such as: missing welds, incomplete welds, welds in wrong location, lack of fusion, scratches in materials, excessive grinding, porosity, and pinholes.

Addressing the inspection processes carried out at Ottenweller, fixtures were implemented as poke yokes for the welding operations. These mistake-proofing systems provided assurance that parts were not positioned in the wrong angulation, promoting welding errors. These poke yokes also reduced OCI8539A’s cycle time in Weld Tack2 by twelve minutes. Beyond the fact that inspections on the third table would be more efficient whether made by a quality specialist than by the welders; this enables operators focus on their functions aiding in relieving the bottleneck for OCI4081B and in OCI8539A’s second longest cycle time. As Weld Tack2 is completed, lights send a visual signal to inspectors indicating it is time to start the inspection process.

Regarding productivity, it was cogitated to develop a fixture to run OCI8539A also in the existing Sub Robot. Although the idea is viable for the company and its development team, it is not going to be applied due to the fact that it would only save four minutes, which is not worth it. Even though the robot operation could represent vantages in quality, and the equipment is currently unusable, in depreciation, it will be reconsidered in the future.

The layout modification brought many benefits to the company. It opened up an area to install a potential new line in the future, and also favored placing inventories near the operations, headed by Kanbans in some strategic points. Moreover, the freed area already owns a crane available to operate in a future demand. As a result, the stream became more linear with fewer crossings. This improvement impacted safety positively since the new layout eliminated the need for the second crane thus reducing the crossing between the two which had been one of the company's biggest safety issues because of the compromised security of the operators. The layout rearrangement enabled to place the Sub Robot within the area of operation of a unique crane, the one represented by the green color, as it can be seen in Figure 19. The new Spaghetti diagram for OCI8539A and OCI4081B is represented by the Figure 20. The layout modifications improved productivity and costs, created a cleaner circulation of materials and people, and reduced the inventory lagging in the production flow.

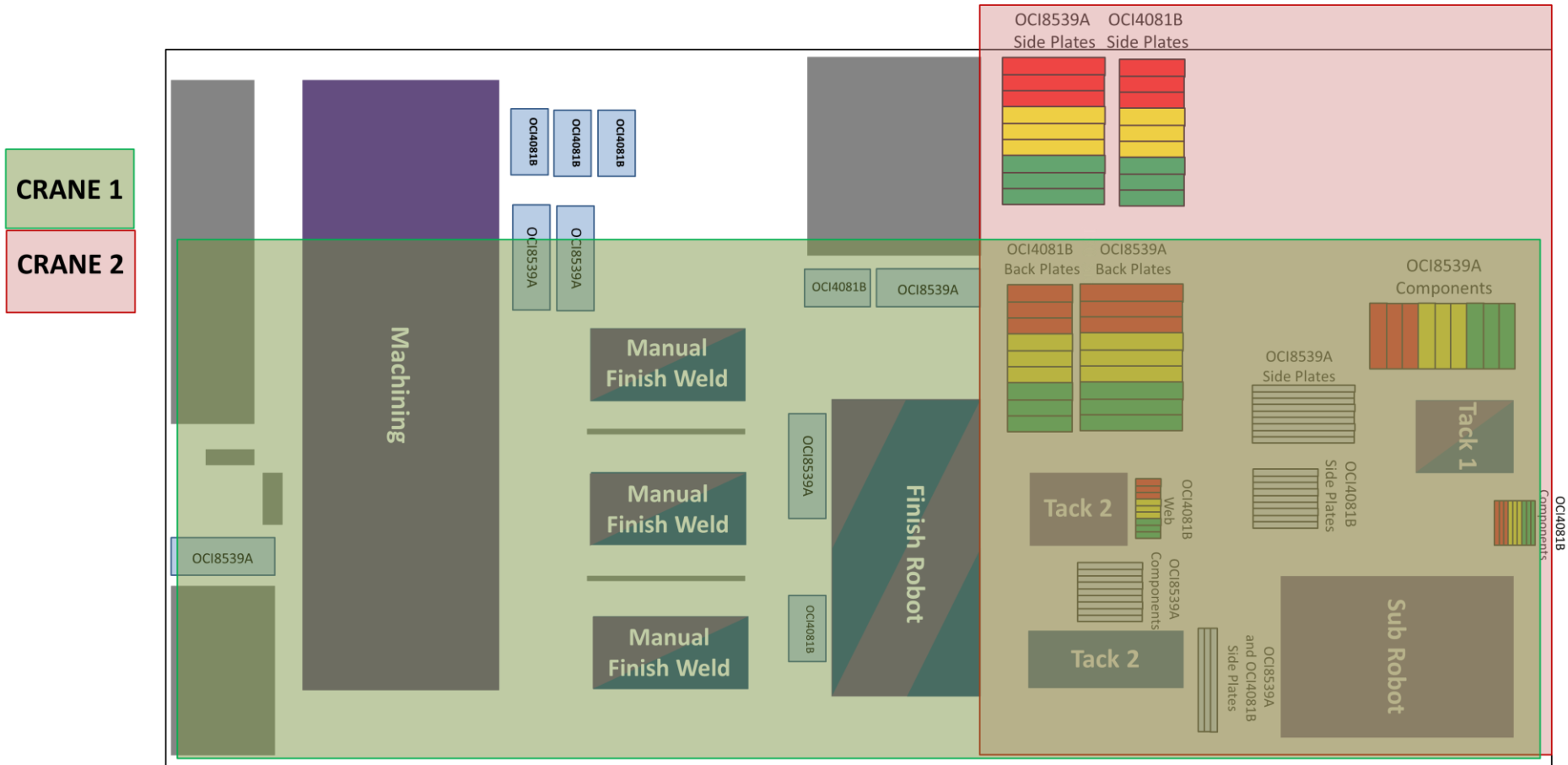


Figure 18: The new use of crane

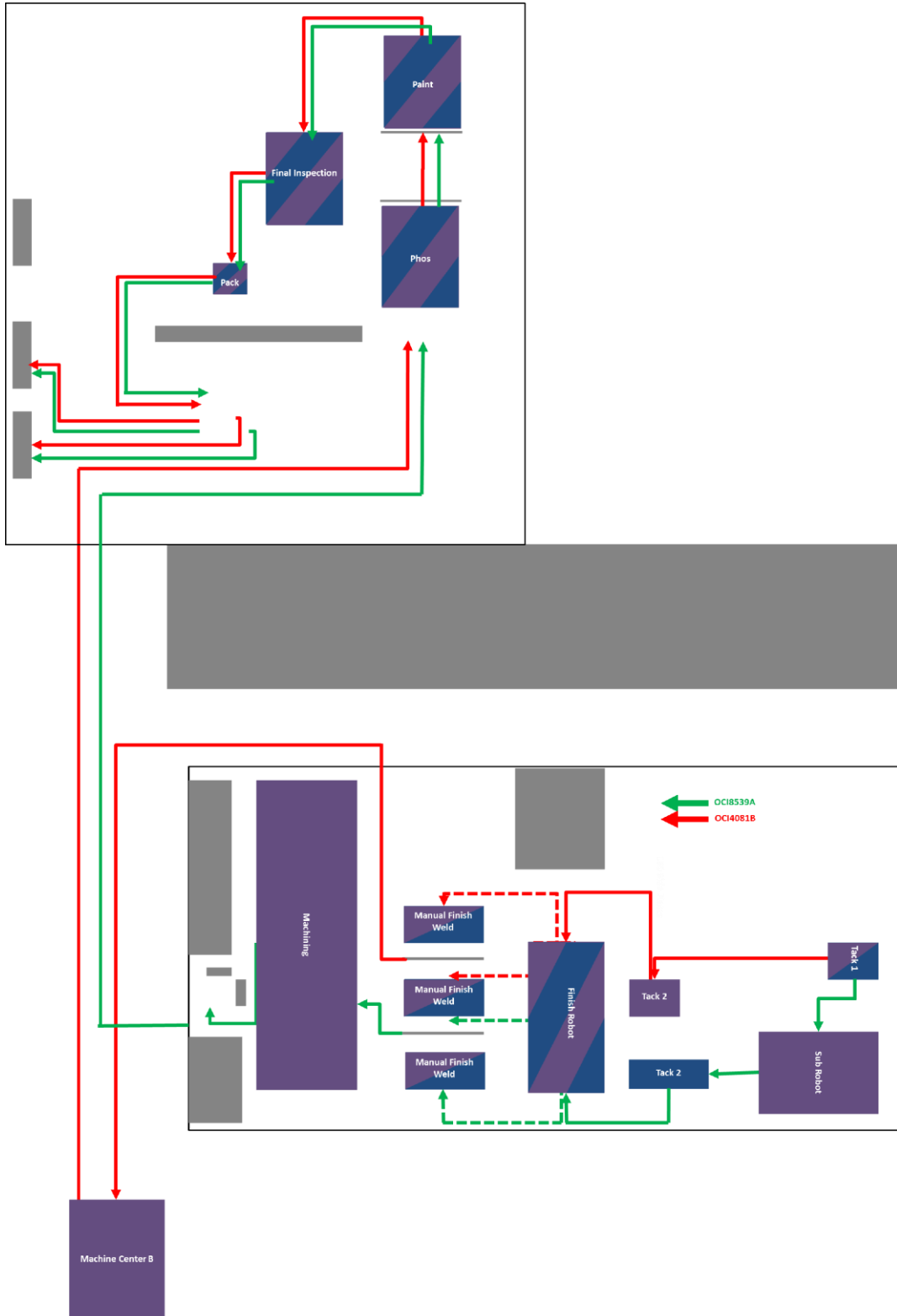


Figure 19: New Spaghetti Diagram

The idea of designing a fixture to run OCI4081B also in Machining Center A was not pursued because the spacing of this machine is not compatible to the height of those parts. For this future state, OCI4081B will continue be transported to Loc3 to be machined. When the demand for OCI8539A exceeds the production capacity at Loc2, it will be transported to Loc3; this will only occur in special cases.

A new fixture to hold OCI4081B in machine (B) is going to be designed in order to eliminate an internal setup, by making it external. According to the current situation, the machine used to sit idle, waiting for the operator to unload the part from the fixture to load the next one.

One of the biggest impacts in the improvements achieved in this project resulted from the acquisition of two new fixtures to replace the tables used in Manual Finish Weld. The fixtures allowed operators to position OCI8539A and OCI4081B using a remote control; thus it became possible to rotate both parts, up to 360 degrees, adjusting them to the correct position for the manual welding. Beyond the safety benefits of eliminating handle risks, the gains in productivity were leveraged. The fixtures also reduced cycle time by thirty minutes, and relieved the operation bottleneck for OCI4081B; this improvement had a tremendous impact.

The second biggest impact came from the kaizen event that updated the Machining Center A programming, resulting in a reduction of thirty minutes in the cycle time of its operation.

The excess inventory within the flow used to drive the company in the opposite direction with regards to every goal aimed at: safety, quality, productivity and cost. Concerning the safety issue, operators needed to apply non-value added efforts to get the right components in the right place at the right time. Regarding quality, defects produced during first operations used to gain scale due to the fact that their production in batches generated defects in batches as well, since they were identified only when the batches arrived at Weld Tack 1, requiring re-work and wastes. About productivity, producing quantities greater than the demand meant an inefficient use of time and money. This could be found in the imbalance of inventory generated due to a lack of key components that made parts wait in line without opportunity to be processed. Finally, the greatest problem: wastes of money, in other words, excess inventory representing inadequate investment.

Contrary to the lean principle of reducing the excess of inventory, a commercial strategy inherent to Ottenweller is to keep “a minimum in hand” amount in strategic operations. In fact, these quantities represent 8.5 days of inventory for OCI4081B and 7.5 for

OCI8539A, which is considered a bold strategy. Looking to combine this strategy with the efficiency aim of a lean system implementation, it was decided to keep this minimum amount just to work as a buffer in case of machine breakdown.

As a result of a proposal for a more efficient stock management, visual controls were drawn up to minimize interpretation problems using standard colors and signage, thus correlating bins to their specific components before Tack Weld 1 for both products. Signage in highly visible places guide forklifts to where the components should be delivered, as well as to serve as Kanbans regularizing the inventory necessary for assembly to meet demand without delays or overproduction. The system of two bins for each component occasioned an enhancement of productivity, as a result of one of the following scenarios: the second bin is filled up while the first one is being consumed, or the second bin is being consumed because the first one became empty and was taken to be refilled. Designating an area for each component with signage for storage and point-of-use consumption improved productivity.

Furthermore, with the acquisition of a production system controlled by Kanbans, a more balanced work distribution was generated between shifts because the operators were guided by demand evidenced by quantity of components, instead of randomly choosing from the accumulation of production orders on hand. According to the commands provided by Kanbans, the lines painted on the floor plus the respective signage defined components and provided directives for forklifts drivers, enhanced productivity and sustained the benefits generated by the layout changes and 5S implementations.

In terms of the information system, the activity of daily print out electronic routers to the processes was eliminated. Instead of receiving papers, employees are now required to check only the ERP system, which saves time and resource for the company.

Aiming to sustain the improvements, a communication board with metrics based on safety, quality, on-time-delivery, and performance meeting attendance has been posted on where it is visible and updated daily. Weekly audits have also been planned to guarantee the maintenance of improvements reached. Good communication and employee' participation are also crucial to sustaining 5S.

## 7. Conclusion and Recommendations

The path towards Lean Manufacturing in the workplace was successful at Ottenweller in avoiding accidents, reducing wastes, optimizing productivity, and delivering high-quality products on time.

As the overall mission of this senior project, all objectives aimed by Ottenweller could be reached to a certain degree. There were improvements highlighted in a safer workplace for employees, higher level of quality, reduction of wastes, increased productivity and performance, reduction of cost, and gains of physical space.

As a result of the Lean Manufacturing system implementation, employees were encouraged and motivated to improve their working conditions, helping them to constantly find opportunities to reduce waste, unplanned downtime, and in-process inventory.

Wastes were hidden as excess tools and equipment hanging around workstations. Time spent searching for tools and materials as well as the time wasted walking or bending could be reduced. With this in mind, excess tools and equipment were removed from the production flow and strategic components were placed closer to the waistline, enhancing the ergonomic conditions in which operators were submitted. In addition to the safety issues, the improvements due to 5S also decreased the circulation of forklifts looking for lacking materials around the facility.

Also through 5S program and layout changes, significant reduction in the square footage of space required for operations were reached. The future recommendations for 5S are:

- Develop daily or weekly checklists to maintain cleanliness of the areas;
- Promote 5S in the whole company;
- Implement robot crib along the company in order to promote a more accurate control missed tools.

Aiming to achieve an increased level of quality, it is suggested to implement appropriate measurement devices, lighting and inspection training. Each time operators are going to be charged for new operations, give adequate training according to the quality requirements, and post paperwork in the shop floor to ensure consistency between all operators and shifts. Now that the company has structured its collection of defect data, it is proposed to promote root cause analysis seeking to find more opportunities for improvement and reduction of wastes, updating posted work procedures as necessary.

Since setups represent a considerable portion of the lead-time, it would serve Ottenweller well in the future to promote more external setups. The first step successfully reduce setup time is to document activities and separate them into internal or external. Once separated, analyze internal setups with the goal of converting them to external setups wherever possible. The next step is to diagnose the need of each event, and then to streamline these remaining internal setups by simplifying, reducing, or eliminating them.

Although initial layout changes were made enhancing productivity, further optimization can be obtained by scrutinizing the entire flow, from the first operation, and then redrawing spaghetti diagrams to analyze the movement of parts through all phases in all three buildings, to find more areas for improvement.

Another consideration for productivity is to balance work between processes and shifts. Currently, work is not distributed in standard form between the three shifts as a majority of products are processed during the first shift. Also, the adoption of labor gymnastics at Ottenweller could generate gains in the employees' health, impacting overall productivity and efficiency.

Even though the activity of flipping OCI4081B parts upside down so they arrive at Machining Center B is classified as an external setup, it is still possible to reduce non-value time in this activity. The recommendation to that point is to develop a mechanism of delivering OCI4081B parts to the customer process already in the position that they go on the fixture.

It is known that many of the first components used afterwards in assemblies are cut in multiple units because of the plasma and laser cut configurations. However, there is a gap between quantities delivered to the first tack and the real demand. For example, since two side plates and one upright plate are needed for each OCI8539A assembled, a recommendation would be to improve the proportionality in which components are sent to be cut. A better plan of corresponding amounts will enhance productivity and reduce cost. One of the biggest advantages Ottenweller has is the flexibility of ordering sheets from any dimension from its supply, so the company can maximize its productivity.

The suggestion for future stock management is to deploy three bins designated for inventories coming from first operations. Based on the Kanban concept of green, yellow, and red colors, each bin would be assigned to one of the colors. This way, when all bins are sitting in lines before Weld Tack I, there is no need of sending orders to produce backwards. However, when the green bin is empty and the forklifts take it to transporting to the other building, where the supplier processes are, there is a way to getting to know exactly when the need of production takes place through the yellow one. Once the yellow bin arrives at the supplier, it is an alert that the reposition must start because the red bin is being consumed.

There is a limitation in how the principle of the two bins is adopted. It does not clarify if the demand for filling the second box at the supplier is urgent or can wait. In other words, it is not possible to track precisely how empty the bin with the components is getting just

through the second bin being sent to the first operation. This could result in a lack of raw materials stopping the flow.

To conclude, the implementation of lean concepts has produced great advantages for Ottenweller, despite the limitations discussed. The results met the goals and exceeded the expectations. It was proven that lean techniques are efficient in improving safety, quality, performance, and in reducing costs. The hope of this senior project is that other Lean Manufacturing initiatives are motivated and longed for at Ottenweller, as well as for other organizations.

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APPENDIX A

OCI8539A									
Note1. FIRST OPS - Currently Out of Scope for VSM. Inventory recorded is in terms of top level part number so if there is 2 side plates per part 1 will be recorded in the operation									
Note2. Icon # is destined to confidential information									
		Std Dev	Mean	Cost	Total	Maximum Inventory LT	#	Date	Time
<b>Queued Inventory</b>	OCI8539A upright		15.75	17,214	#		33	23-Feb-15	11:00 AM
	OCI8539A sideplate		7.23	33,286	#			24-Feb-15	11:00 AM
<b>Tack Weld 1</b>	<b>VSM Op #1</b>	Std Dev	Mean					5-Mar-15	5-Mar-15
			8.33	56.33				24-Feb-15	11:00 AM
			3.08	30.33				24-Feb-15	11:00 AM
<b>Materials</b>	OCI8539A Upright		0.00	0.00				26-Feb-15	11:00 AM
	OCI8539A Sideplate (2 per)							2-Mar-15	1:30 PM
								4-Mar-15	11:15 AM
								9-Mar-15	11:00 AM
	2 Operation Multiplier								
<b>Finish Goods Inventory</b>	OCI8539A upright		0	0	#		0	23-Feb-15	11:00 AM
	OCI8539A sideplate		0	0	#			24-Feb-15	11:00 AM
								24-Feb-15	11:00 AM
								26-Feb-15	11:00 AM
								2-Mar-15	1:30 PM
								4-Mar-15	11:15 AM
								9-Mar-15	11:00 AM
<b>Queued Inventory</b>	OCI8539A upright		2.06	4,5714	#		4.6	23-Feb-15	11:00 AM
	OCI8539A sideplate		0.82	1,9286	#			24-Feb-15	11:00 AM
<b>Tack Weld 2</b>	<b>VSM Op #2</b>	Std Dev	Mean					23-Feb-14	
			0.00	87.00				87	
			0.00	11.00				11	
<b>Materials</b>	OCI8539A Upright	GR	0.00	0.00				2	
	OCI8539A Sideplate (2 per)	80 1/2"						1	
		80 1/2"						1	
<b>Finish Goods Inventory</b>	OCI8539A		0.45	0.29	#			23-Feb-15	11:00 AM
								24-Feb-15	11:00 AM
								24-Feb-15	11:00 AM
								26-Feb-15	11:00 AM
								2-Mar-15	1:30 PM
								4-Mar-15	11:15 AM
								9-Mar-15	11:00 AM
<b>Queued Inventory</b>	OCI8539A		1.67	2,7143	#			23-Feb-15	11:00 AM
<b>Robot Finish</b>	<b>VSM Op #3</b>	Std Dev	Mean					23-Feb-15	23-Feb-15
			17.50	90.50				108	73
			16.00	20.00				36	4
<b>Materials</b>		GR	0.00	0.00				2	2
								1	1
<b>Finish Goods Inventory</b>	OCI8539A		0	0	#			23-Feb-15	11:00 AM
								24-Feb-15	11:00 AM
								24-Feb-15	11:00 AM
								26-Feb-15	11:00 AM
								2-Mar-15	1:30 PM
								4-Mar-15	11:15 AM
								9-Mar-15	11:00 AM



Queued Inventory			Std Dev	Mean	Cost	Total	#																								
OCI8539A			2.50	1.57	#	#	6 0 5 0 0 0 0																								
Pack & Ship			Std Dev	Mean			Date																								
VSM Op #9			0.00	3.00	Cycle Time (Minutes)		12-Feb-15																								
Materials			0.00	0.00	Change Over (Minutes)		3																								
GR "			0.00	0.00	Shift #		0																								
			0.00	0.00	Value Added Time		1																								
					# of Operators		1																								
					Resource Uptime																										
					Defect Rate																										
					Lunch Time Indicator																										
					Other Data Note		* OCI40818 Pack & Ship counted for OCI8539A																								
Finish Goods Inventory			Std Dev	Mean	Cost	Total	#																								
OCI8539A			3.61	3.29	#	#	<table border="1"> <thead> <tr> <th>Date</th> <th>Time</th> <th>#</th> </tr> </thead> <tbody> <tr> <td>23-Feb-15</td> <td>11:00AM</td> <td>0</td> </tr> <tr> <td>24-Feb-15</td> <td>11:00 AM</td> <td>0</td> </tr> <tr> <td>24-Feb-15</td> <td>11:00 AM</td> <td>1</td> </tr> <tr> <td>26-Feb-15</td> <td>11:00 AM</td> <td>11</td> </tr> <tr> <td>2-Mar-15</td> <td>1:30 PM</td> <td>4</td> </tr> <tr> <td>4-Mar-15</td> <td>11:15 AM</td> <td>5</td> </tr> <tr> <td>9-Mar-15</td> <td>11:00 AM</td> <td>2</td> </tr> </tbody> </table>	Date	Time	#	23-Feb-15	11:00AM	0	24-Feb-15	11:00 AM	0	24-Feb-15	11:00 AM	1	26-Feb-15	11:00 AM	11	2-Mar-15	1:30 PM	4	4-Mar-15	11:15 AM	5	9-Mar-15	11:00 AM	2
Date	Time	#																													
23-Feb-15	11:00AM	0																													
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24-Feb-15	11:00 AM	1																													
26-Feb-15	11:00 AM	11																													
2-Mar-15	1:30 PM	4																													
4-Mar-15	11:15 AM	5																													
9-Mar-15	11:00 AM	2																													





Queued Inventory				Std Dev	Mean	Cost	Total								
OCI4081B				0.83	0.86	#	#								
<b>Paint</b>	<b>VSM Op</b>	<b>#8</b>	Materials	GR	-	Std Dev		Cycle Time (Minutes) Change Over (Minutes) Shift # Value Added Time # of Operators Resource Uptime Defect Rate Lunch Time Indicator Other Data Note	20-Feb-15						
						Mean			1	1	0	0	2	2	0
						0.00	96.00								
						0.00	18.00								
								Date		Time					
								#		#					
Finish Goods Inventory				Std Dev	Mean	Cost	Total								
OCI4081B				0	0	#	#								
Queued Inventory				Std Dev	Mean	Cost	Total								
OCI4081B				0.64	0.86	#	#								
<b>Final Inspection</b>	<b>VSM Op</b>	<b>#9</b>	Materials	GR	-	Std Dev		Cycle Time (Minutes) Change Over (Minutes) Shift # Value Added Time # of Operators Resource Uptime Defect Rate Lunch Time Indicator Other Data Note	10-Feb-15						
						Mean			0	0	2	1	1	1	1
						0.00	19.00								
						0.00	2.00								
								Date		Time					
								#		#					
Finish Goods Inventory				Std Dev	Mean	Cost	Total								
OCI4081B				0.00	0.00	#	#								
Queued Inventory				Std Dev	Mean	Cost	Total								
OCI4081B				1.05	0.57	#	#								
<b>Pack and Ship</b>	<b>VSM Op</b>	<b>#10</b>	Materials	GR	-	Std Dev		Cycle Time (Minutes) Change Over (Minutes) Shift # Value Added Time # of Operators Resource Uptime Defect Rate Lunch Time Indicator Other Data Note	12-Feb-15						
						Mean			0	3	1	0	0	0	0
						0.00	3.00								
						0.00	0.00								
								Date		Time					
								#		#					
Finish Goods Inventory				Std Dev	Mean	Cost	Total								
OCI4081B				2.83	3.00	#	#								