Improving the Stainless Steel System at Process Technology International Using 5S, Process Improvement, and Inventory Control

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Executive Summary

Process Technology International (PTI) is a small manufacturing company producing industrial equipment used in the processing of steel. The purpose of this project is to reduce costs and improve inefficiencies within the stainless steel system.

After meeting with industry sponsors and determining their most pertinent issues, we decided to search for inefficiencies in three places: inventory controls, manual processes, and physical workspace arrangement. To measure how the current inefficiencies were affecting costs, the team performed EOQ analysis on the inventory controls and time study evaluations on the processes. By collecting demand data, holding cost, ordering cost and price break cost data from the steel providers, EOQ analysis was able to be performed. The team then began taking time studies of the relevant processes, identifying and timing movements that were considered 'non-value-added' meaning they added no value to the process.

With the non-value-added steps identified, a cost was assigned to each based on the time that it took, and the labor cost of the worker performing the process. The team performed pareto analysis to identify the costliest steps and performed a descriptive and qualitative analysis to determine which non-value-added movements could be eliminated by either process improvement, workspace improvement, or a combination of the two.

The team identified four alternatives with the potential to reduce costs and inefficiencies:

Solution 1. EOQ Implementation
Implement an economic order quantity and reorder points for stainless steel inventory controls. These give the purchasing department specific inventory levels at which they will order specific quantities that optimize stainless steel ordering, holding, and unit costs.

Solution 2. Standard Operating Procedure Implementation
Create and implement standard operating procedures (SOPs) for the welding processes. Each SOP will specifically instruct the operator to layout necessary tools such that later excess movement is avoided.

Solution 3. Workspace Improvement
Build and utilize a new stainless steel storage rack, two dedicated carts, and specialized tool storage at the two welding stations. Use the new organized rack, tool holders, and carts to cut

down on wasted time spent searching for materials, searching for tools, and manually transporting items across warehouse.

Solution 4. 5S Total Quality System Implementation

Completely overhaul facility with a 5S quality system that implements all of the other suggestions and additionally adds demarcation and color-coded labeling to the various storage areas throughout facility. 5S system eliminates non-value-added movements from processes and improves efficiency throughout entire system.

Using cost-benefit analysis, the team found that each solution provided potential cost savings.

TOPSIS analysis was performed using five variables: cost of implementation, annual cost savings, time to implement, employee acceptance, and ease of implementation. The TOPSIS analysis revealed that the workspace improvement suggestions (solution 3) provided the closest-to-ideal solution to the stainless steel system inefficiencies.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

INTECO PTI Process Technology International, LLC has supplied chemical energy systems for the steel industry in particular for Electric Arc Furnaces (EAF), including oxy-fuel burners, material injection systems, control and automation systems, preheating and drying combustion systems, since 1993. The company employs a team of qualified engineers, metallurgists, technical support personnel and fabricators thoroughly experienced in the steel industry to satisfy the customer's demands. The spare parts and repair team has the ability to receive components, refurbished to original specifications and make them ready for immediate use to fit any maintenance or down time schedule. The company also offers a complete inventory with all the quality products needed to satisfy steel mills as well as components that starts from raw material parts to finished goods.

1.2 Problem Overview

PTI has experienced higher than expected costs on raw materials over the past several years. They have been forced to make inventory adjustments to account for loss of raw material at each of their annual inventory counts. A further analysis shows that they are ordering every two weeks which is likely sub-optimal given the cost of ordering vs the cost of holding. This design group has used a branched ‘5 Why?’ iterative analysis technique to assess the root cause of the problem.

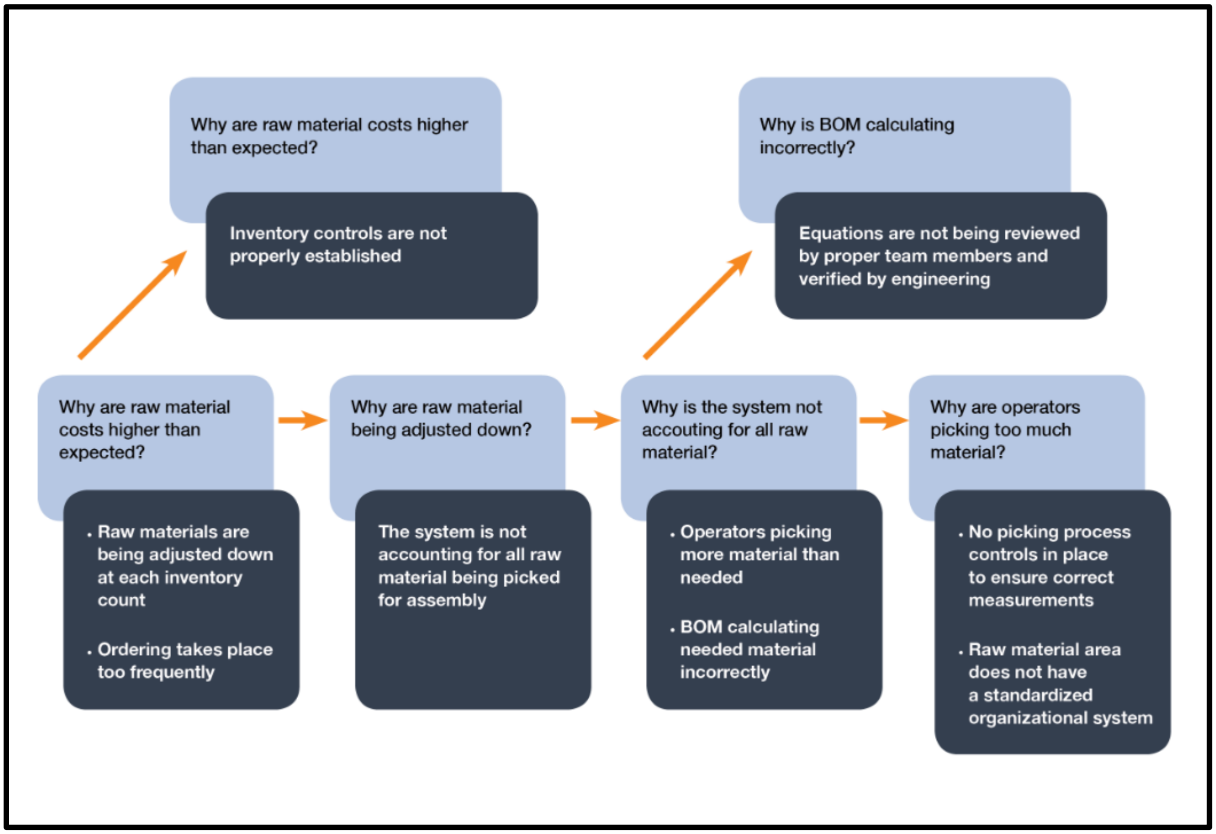

Figure 1. '5 Why' Root Cause Analysis

As illustrated in Figure 1, the identified root causes of the unexpectedly high raw material costs are a combination of (1) improper establishment of inventory controls, (2) A lack of picking process controls and SOPs that would ensure correct measurement and reading of BOM, and (3) The stainless steel areas do not have a standardized organizational system in place.

The estimated cost of these losses is substantial. We hope to reduce waste of raw material, improve inventory controls, improve process controls for picking and assembly, and implement a total quality system that creates a standardized and organized workspace for operators on the machine shop floor.

1.3 System Overview and Major Developments

The system is the combined physical space and processes used to transform raw material into finished product. The physical space consists of the stockroom and raw material storage areas, and the primary processes are receiving/ordering, picking, and BOM quantity calculations. The design will use 5S techniques on the physical space, and EOQ, 5 Why, and Quality Control Limits, on the processes, to improve the overall functionality of the system.

1.3.1 System Diagram

The basic structure of the proposed solutions and flow of the project is illustrated in figure 2, below.

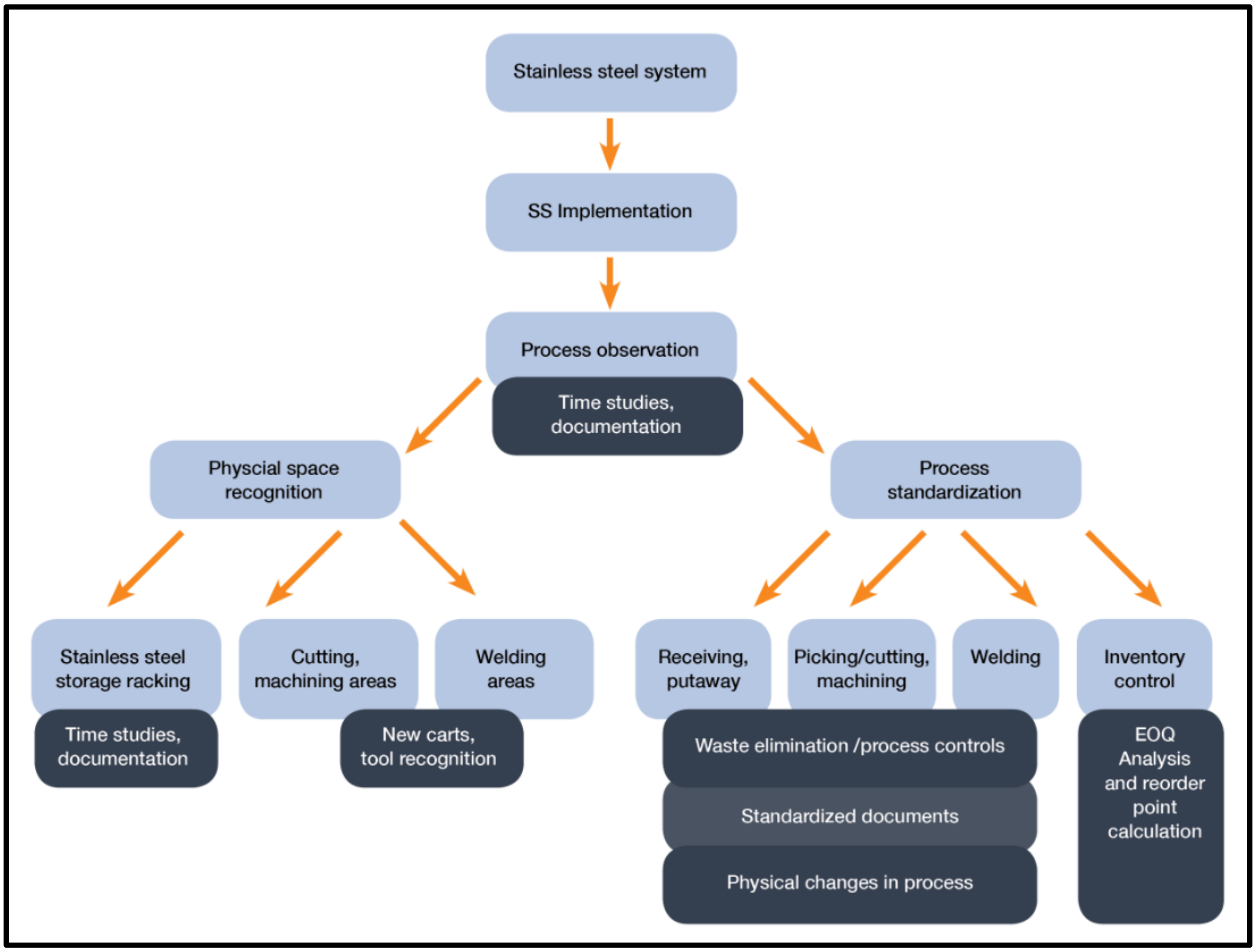

Figure 2. System Block Diagram

1.3.2 Minimum Success Criteria

A successful implementation of this design is to be defined as meeting the following minimum success criteria:

- Implementation of ordering process that result in reduction of annual raw material costs by 10%
- Implementation of cutting process that results in reduction of annual raw material loss by 50%
- Establishment of Process control limits that give statistical control to all raw material handling processes
- Establishment of SOPs for the following processes that result in annual savings of $15,000:
    - Receiving/Putaway
    - Picking/Cutting/Machining
    - Welding 1
    - Welding 2
- Complete reorganization of raw material storage and work areas that meet the following criteria:
    - Necessary tools are within reach of operator
    - Necessary raw materials are available and sorted from most commonly used, to least commonly used
    - Areas for storage and work are clearly demarcated using obvious tape and/or signage
    - Carts are installed on both sides of middle aisle for transporting material resulting in savings of $4,000 annually in wasted transport time
    - Stainless Steel racking installed with color-coded labeling that sorts various sizes

2. Literature Review

A review of the literature gives precedence for the system design we propose. Our team analyzed several recent and relevant studies pertaining to process control, workspace organizational systems such as 5S, and EOQ inventory analysis.

2.1 Process Control Limits and Standardized Work in Shop Floor Applications

Several articles outlining methods of process improvement within a manufacturing setting were reviewed. Theroux *et al.* (2014) describe a system for applying control charts to simple short production runs in an aerospace manufacturing plant. The team found several processes that were out of statistical control and suggest the use of process control limits as a means to track variance from the mean in a given process. This presents the possibility to implement a similar style of quality controls within the PTI facility. Hayes (1998) gives several examples of best practices in machine shops. This includes organizational improvements, such as organizing tools and keeping areas clean and clearly marked. This gives an early structure that indicates the best practices that can be implemented through a 5S type implementation. Hill (1956) describes how to better use control limits with quantitative variables to give results. Mor *et al.* (2019) provides methodology for calculating the expected productivity gains through implementation of standard work methods, specifically within the manufacturing sector. Pötters *et al.* (2018) indicate the superiority of Poka Yoke as a method for process improvement and presents methods of implementation within a manufacturing facility. Martin and Bell (2011) describe a system for implementing standardized work procedures within a manufacturing environment.

2.2 5S Implementations and Measures of Success

Understanding the concepts of 5S implementations and the methods by which to measure success of a workspace improvement system was a priority for our research team. Many studies were reviewed to get a broader understanding of the settings in which 5S can be successful, and how to measure that success once sustainability is achieved.

Patel *et al.* (2017) describe a 5S implementation used to reduce material searching time. Specific elements of improper storage space utilization, low productivity, unnecessary materials within the workplace, and unequal participation of workers were identified as indications of improvements possible through 5S. Randhawa and Ahuja (2017 and 2018) performed two studies evaluating the economic impact and effectiveness of a 5S implementation. These articles give a method to set metrics for evaluating the 5S implementation once complete, and provide us with validation for the economic evaluation methods we have in place. Sangode and Deekshabhoomi (2018) outline another methodology for evaluating the efficacy of a 5S implementation, providing a way to calculate cost baseline and measure post implementation success using efficiency measures. Zuliana *et al.* (2019) give an example of a successful 5S implementation in a machining facility, outlining specifics of workspace arrangement for machining stations. Michalska and Szewieczek (2007) focus on describing the 5S methodology and the way it was implemented through a manufacturing company; They introduce us to the 5S methodology, and why it is such a popular tool used among professionals who are pursuing continuous improvement. The article outlines the use of a questionnaire to identify needs within a shop floor that can be addressed by a 5S system. Kawalec *et al.* (2018) give a structured method for establishing failure modes within the context of a 5S implementation. This can be used to identify the quantity of mistakes made and the rarity of each mistake and how they contribute to non-value-added processes.

2.3 EOQ Inventory Analysis

Understanding the impact of EOQ inventory analysis and the methods of implementation that could be used within a procurement department was a priority for the research team since a large portion of the analysis involved inventory control. Several articles were reviewed.

Zinn and Charnes (2005) give a comparison of two methods for determining optimal ordering strategies. We have chosen to go with an EOQ model. This is further explained by Pang *et al.* (2018) who give a generalized example of how to model the impact of an EOQ model within a company.

Agarwal (2014) outlines how EOQ analysis can benefit any industrial company. The article demonstrates how inventory is a major component of all industries. He explains how it is essential to manage inventories efficiently to avoid the costs of changing production rates, overtime, sub-contracting, unnecessary cost of sales and back order penalties during periods of peak and dynamic demand. Economic Order Quantity (EOQ) models have been effectively employed in marketing, automotive, pharmaceutical, and retail sectors of the economy for many years. The model gives the optimal solution in closed form which helps to know about the behavior of the inventory system. The closed-form solution is also easy to compute. The objective is to find the economic order quantities for both the retailer and the warehouse which minimize the total cost. All this can be applied to the orders in our facility of the raw materials which do not currently have any economically analyzed ordering methods in place.

3. Methodology

3.1 Defining the Problem

As illustrated in chapter 1, the problem at PTI is a three-faceted issue. The problems focused on for this project are listed below:

- **Problem 1.** Improper Establishment of Inventory Controls
- **Problem 2.** Lack of controls and standardized procedure for stainless steel processes
- **Problem 3.** Non-standard and disorganized stainless steel storage area

The goal is to address each problem individually with solutions derived from the 5S methodology. The first 3 S's (sort, set in order, shine) can be applied to eliminate waste in both process and physical space. The final 2 S's (standardize and sustain) allow for the implementation of process and inventory controls. This can be accomplished through standardized work documents and EOQ inventory analysis.

3.1.1 System Identification

The system is the combination of all processes, physical spaces, and resources that are involved in the handling and storage of stainless steel within the PTI facility. To begin the process of defining the problem in its entirety, the team gathered information on all aspects of the stainless steel system.

3.1.1.1 Process Identification

The first step was to identify all processes that are involved in the stainless steel system, since this system is the focus of the design. The processes we identified were:

1. **Inventory Control/Ordering** – The process of replenishment and the management of inventory levels based on demand

2. **Receiving/Putaway** – The process of checking the received orders from the supplier and putting them in the proper location

3. **Picking*** – The process of reviewing the work order, finding the proper size steel beams needed, and attaching and transporting the needed beams to the cutting station from storage

4. **Cutting*** – The process of loading the water-band saw with steel beams, establishing length needed, and starting and finishing a cut (includes scrapping of leftover steel)

5. **Machining*** – Process of moving cut pieces from saw to machine, using power-driven machine to remove material from workpiece to shape it to its intended design with high degrees of precision

6. **Primary Weld** – Process of retrieving finished pieces from machining, welding the main structure of the burner to the copper nozzle using two weld paths

7. **Secondary weld** – Process of retrieving pieces from initial welding station, welding extraneous burner parts to the main structure, closing the burner, and transporting to shipping

***Note:** For the purposes of this project, the Picking, Cutting, and Machining Processes will be combined into a single process for ease of data evaluation. The tasks are all performed by the same employee in sequential order.

3.1.1.2 Physical Space Identification

The next step was to identify all physical spaces involved in the handling and storage of stainless steel. The relevant spaces identified were:

1. **Stainless Steel Storage Racking –** Racking used to store stainless steel rods prior to cutting

2. **Cutting Station –** Table and bandsaw where full stainless steel rods are brought to be cut

3. **Machining Station –** Station where cut pieces are fabricated into conical rods to be used in burner assembly

4. **Welding Station 1 -** Station where primary welds are made to form main interior section of burner using fabricated stainless steel rods.

5. **Welding Station 2 -** Station where secondary welds are made to exterior section of burner using steel elbow joints

An image highlighting the relevant areas is shown in figure 3 below.

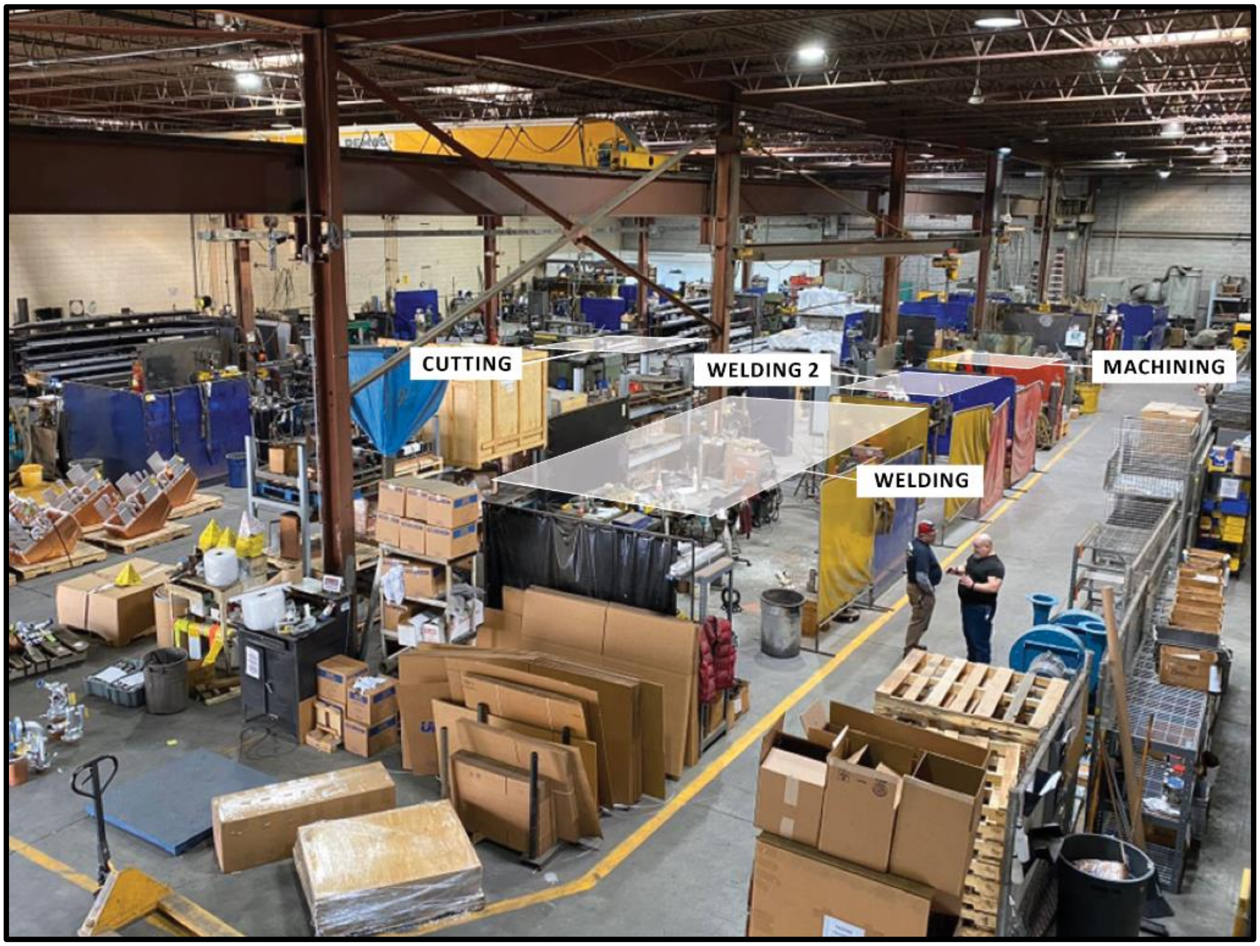

Figure 3. Machine shop layout with highlighted stainless steel stations

3.1.1.3 Resource Identification

The final portion of the system is the resources that are used to process stainless steel within the facility. The resources relevant to our project are the following:

1. **Holding Costs** – Property tax and estimated opportunity costs associated with stored inventory

2. **Ordering Costs** – Estimated labor costs associated with placing a single order for stainless steel

3. **Floor Labor Costs** – Hourly labor costs of non-welding operations within the shop floor (machining, cutting, picking, etc.)

4. **Welding Costs** – Hourly costs associated with welding operations including both labor and materials

3.2 Data Collection and Analysis

We decided to focus on collecting and analyzing data related to inventory control, process improvement, and workspace efficiency since these are the potential primary root causes that were identified in the problem definition.

3.2.1 Data Collection and Analysis for Inventory Control

In order to improve inventory control, this team suggests performing an inventory analysis and developing an Economic Order Quantity (EOQ) model for raw material ordering. This analysis requires collecting specific sets of data, most notably the historical sales data and the BOM for each finished assembly, along with cost data for raw materials, holding costs and ordering costs.

3.2.1.1 Data Collection for EOQ Inventory Analysis

Data was collected that reflected the demand of each stainless steel part over the past 3 years. Table 1 contains the raw demand data, seen below. Total demand for all stainless steel was valued at $139,289.84.

Table 1. Demand Data for Stainless Steel 2017-2019

	2017		2018		2019		Total Sum	Total Sum of
Part #	Sum of Demand	Sum of Cost	Sum of Demand	Sum of Cost	Sum of Demand	Sum of Cost		
P180012	218.64	$4,577.81	221.61	$1,205.27	213.81	$0.00	654.06	$5,783.08
P180029	71.85	$999.00	251.81	$3,052.54	168.9	$1,668.60	492.56	$5,720.14
P180015	162.45	$2,739.61	164.03	$3,327.72	157.61	$5,530.90	484.09	$11,598.23
P180014	111.42	$1,814.85	164.83	$4,952.00	148.5	$3,348.00	424.75	$10,114.85
P120045	92.87	$2,830.40	138.15	$7,007.61	139.85	$6,984.20	370.87	$16,822.21
P120039	109.53	$1,826.00	100.26	$3,596.39	83.67	$6,921.20	293.46	$12,343.59
P180010	89.01	$818.39	98.18	$435.00	72.62	$0.00	259.81	$1,253.39
P180013	99.6	$2,985.61	88.2	$3,154.40	59	$8,352.09	246.8	$14,492.10
P180028	55.47	$2,630.00	86.36	$1,615.95	75.92	$3,901.60	217.75	$8,147.55
P120044	53.78	$2,816.35	61.04	$2,260.52	69.8	$1,345.20	184.62	$6,422.07
P120006	48.03	$669.72	51.45	$1,114.72	50.6	$2,702.92	150.08	$4,487.36
P180004	75.4	$540.87	10.35	$0.00	23.45	$0.00	109.2	$540.87
P180008	24.76	$457.60	33.01	$0.00	51	$0.00	108.77	$457.60
P180017	41.6	$4,527.10	7.8	$0.00	34.57	$0.00	83.97	$4,527.10
P180035		$0.00		$0.00	64.2	$2,089.80	64.2	$2,089.80
P180016	32.16	$2,066.31	9.44	$0.00	19.77	$1,866.80	61.37	$3,933.11
P180021	18.1	$1,976.46	34.05	$1,101.00	3.4	$0.00	55.55	$3,077.46
P120005	13.5	$351.00	20	$295.00	16.2	$0.00	49.7	$646.00
P180011	0	$639.09	36.1	$0.00	9	$0.00	45.1	$639.09
P120043	11.57	$731.50	14.31	$0.00	12.34	$1,212.80	38.22	$1,944.30
P180032	9.9	$954.10	10	$0.00	4.65	$2,806.00	24.55	$3,760.10
P120014	22.5	$6,851.00	0	$0.00	0	$0.00	22.5	$6,851.00
P370433	0	$0.00	0	$0.00	20	$96.00	20	$96.00
P180044	0	$0.00	18	$3,124.24	0	$0.00	18	$3,124.24
P180036	0	$0.00	0	$0.00	6.4	$1,319.60	6.4	$1,319.60
P120037	0	$2,725.21	6	$0.00	0	$0.00	6	$2,725.21
P180018	1.54	$0.00	0	$0.00	2.33	$2,346.81	3.87	$2,346.81
P180006	2.76	$0.00	0	$332.58	0	$0.00	2.76	$332.58
P180053	0	$0.00	0	$134.40	0	$0.00	0	$134.40
P180051	0	$840.00	0	$2,720.00	0	$0.00	0	$3,560.00
Grand Total	**1366.44**	**$47,367.98**	**1624.98**	**$39,429.34**	**1507.59**	**$52,492.52**	**4499.01**	**$139,289.84**

Additionally, data was collected to establish the ordering cost and holding cost for stainless steel. Holding costs were estimated to be 4% of item cost annually, which includes property tax and the opportunity cost of the inventory capital expenditure. Opportunity cost is the expected economic return on capital of an alternative investment. The cost of ordering and setup was estimated to be $70, based on time estimates given by the procurement team for time spent on each order and the value of that labor. Table 2, below, summarizes this information.

Table 2. Holding Cost and Ordering Cost for EOQ Analysis

Holding Cost	4%
Ordering Cost	$70.00

3.2.1.2 Applying Pareto Analysis for Part Selection

The demand data was then sorted from highest demand to lowest and Pareto analysis was performed to determine the items that most influenced demand. Part #s, P180012, P180029, P180015, P180014, P120045, P120039, P180010, P180013, and P180028 were found to account for nearly 80% of the total stainless steel demand, so it was decided that these parts would be focused on for EOQ analysis. Figure 4, below, illustrates the results of the pareto analysis.

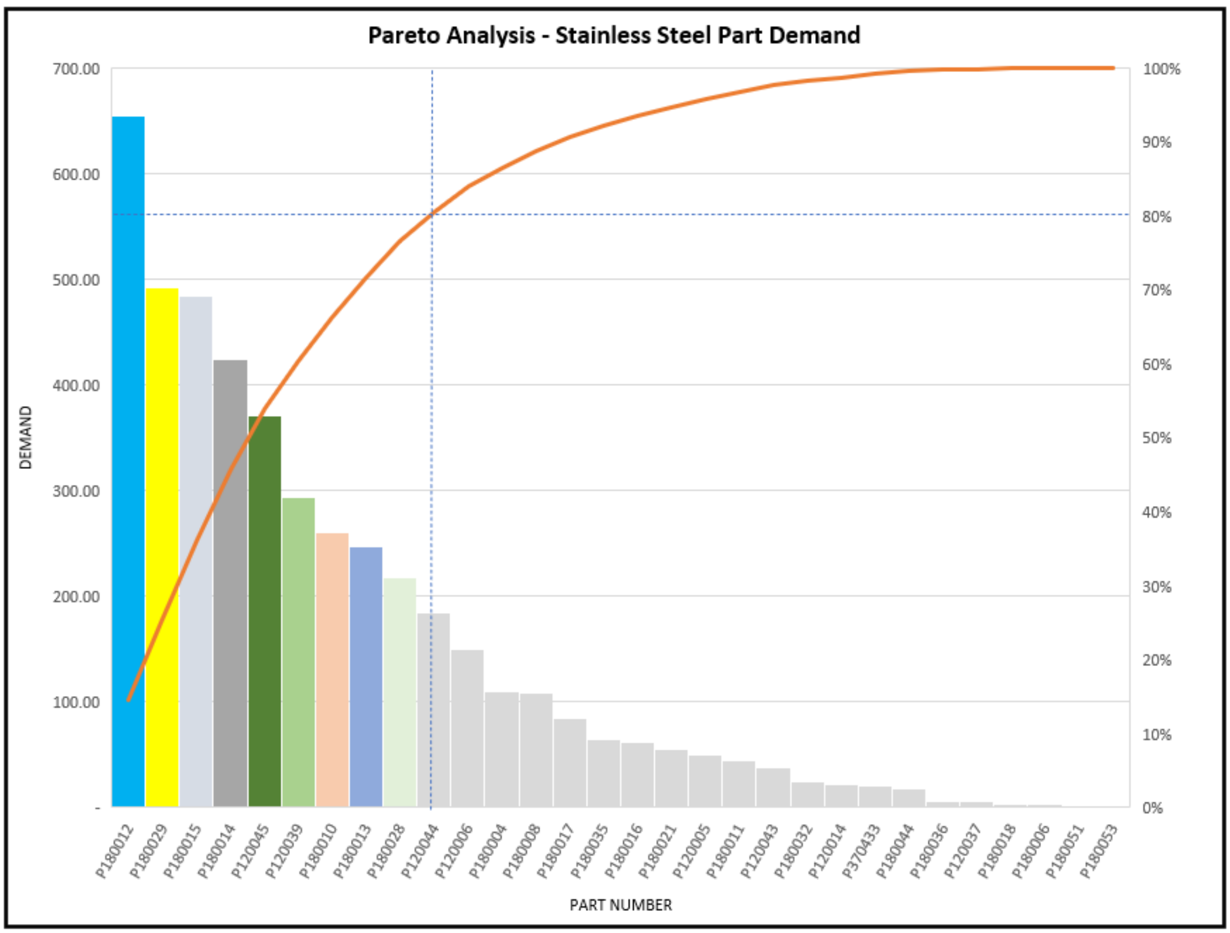

Figure 4. Pareto Chart of Stainless steel Parts by Demand

3.2.1.3 EOQ Analysis

Prices were obtained from suppliers for each of the analyzed parts. The full costing estimate can be seen in Appendix D. Prices were given in a quantity break discount structure with orders less than 100 feet being more expensive than orders between 100 feet and 160 feet which were more expensive than orders greater than 160 feet.

Using the following EOQ equation, optimal order quantities were established for each part

$$Q^* = \sqrt{\frac{2dK}{h}}$$

Where Q* is optimal order quantity, d is demand, K is ordering cost, h is holding cost. Because the pricing structure was broken into 3 categories $Q < 100$, $100 < Q < 160$, and $160 < Q$, analysis was performed at each price level to determine the optimal quantity.

3.2.1.4 Reorder Point Calculation

The next step was to calculate the reorder point for each to give an optimal stock level at which to reorder the parts to avoid stocking out. The following equation was used to determine reorder point.

$$R = S + (D * L)$$

Where R is reorder point, S is safety stock, D is demand and L is lead time.

Safety stock was calculated using this formula.

$$(D_{Max} * L_{Max}) - (D_{Avg} * L_{Avg})$$

Where D_{Max} *and* L_{Max} are the maximum expected demand and lead time respectively where D_{Avg} *and* L_{Avg} are the calculated average demand and lead time. Maximum demand was estimated using a review of historical data to determine the most used in a single day over the previous 3 years. Lead time maximum was estimated based on historical lead time variance.

3.2.2 Data Collection and Analysis of Process and Workspace Inefficiency

In order to establish a cost baseline for the process and physical workspace inefficiencies noted in the problem definition, the team had to devise a measurement strategy. In order to measure the costs, it was necessary to identify the non-value-added movements that occurred during regular cycles of each process. A non-value-added movement is any movement that is unnecessary while performing a process caused by an inefficiency in the process or workspace arrangement. Examples of this are retrieving necessary tools that are stored too far from the processing area, double work where a process step is performed at two different times unnecessarily, and failing to perform steps that would improve the processing time of future cycles.

To accomplish the task of measuring these inefficiencies, it was decided that process observation and time studies would be the best way to capture the data. Once the team had the time data, the data was analyzed to identify process changes and workspace changes that would eliminate the non-value-added movements observed.

3.2.2.1 Time Study Overview

Time studies (work measurement) were performed for each of the materials handling processes involved in the production of the burners. Time studies allow the group to establish a cost baseline and to identify non-value-added process steps, and create a proper standardized operating procedure for each process. For each time study, a single cycle was observed and timed and non-value adding process steps were identified. An example of the data collection template for each time study is seen in figure 5 below.

[Process Name]				
Step	**Action(s) Performed**	**Time Taken (min)**	**Non Value Added Time Spent (min)**	**Comment on NVA**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
	Total			

Figure 5. Time Data Collection Template Example

3.2.2.2 Time Study Data Collection

The results from each time study are below.

The first set of data collected was for the combination of processes machining, picking, and cutting, which occur in sequence. The total process time observed was 67.25 minutes, and the total non-value-added time observed was 3.25 minutes. The non-value-added movements were time spent searching for the correct pipe, chain length for the crane, and the movement between the storage, crane, and cutting areas. Other observed movements that did not add value were finding correct locations to put pipe away, manually carrying pipes across shop floor, and bending down repeatedly to reach the parts being machined and to put them away. The completed data collection sheet is below in table 3.

Table 3. Machining-Picking-Cutting Process Time Study Data

Picking - Cutting - Machining Time Study				
Step	**Action(s) Performed**	**Time Taken (min)**	**Non Value Added Time Spent (min)**	**Comment on NVA**
1	**Review Work Order and Determine Parts**	0.75	0	
2	**Pick Pipe from Racking** Operate Crane Toward Rack Locate Pipe for cutting Locate chain and add to crane Load pipe and operate crane to saw	7.75	1.25	Time spent finding correct pipe, finding correct length chain, moving between areas
3	**Cut Pipe** Set up pipe in saw Set up machine for cut Run Saw	17	0	
4	**Prep cut pieces and transfer to machining** Rinse debris from parts and place part on floor Rinse debris from machine Operate crane to return piece to racking Transfer pieces to machine station	4.5	1.5	Finding correct location to put pipe away, dirty area takes longer to clean, manually carrying pipes across shop floor
5	**Machine piece**	29.5	0	
6	**Finish parts and transfer** Make 45 degree cuts in lip of parts Place finished parts in box designated for finished parts	7.75	0.5	Finidng location to put parts, bending over, over-movement
	Total	**67.25**	**3.25**	

The second set of data collected was for the primary welding process. The total process time observed was 66.53 minutes, and the total non-value-added time observed was 15.2 minutes. The non-value-added movements observed were numerous and included the following:

- Manually writing out parts and amounts needed
- Using a small hand cart resulted in 4 trips between machining and welding
- Movement back and forth within the welding station grabbing tools
- Interruptions to work by coworkers
- Putting on and taking off gear when it wasn't necessary

The complete data collection sheet is in table 4 below.

Table 4. Welding Process 1 Time Study Data

Welding Process 1 Time Study				
Step	Action(s) Performed	Time Taken (min)	Non Value Added Time Spent (min)	Comment on NVA
1	**Review Work Order and Determine Parts Needed for Weld**	31	5	Parts were reviewed manually and written out by hand, could be done by computer
2	**Collect Parts**	6	3.8	Multiple trips were made using a small hand truck. Time that could have been avoided if one trip was made using a cart
3	**Prep Nozzle** Layout nozzle on stand and wet Heat Nozzle Using Torch, Transfer to Assembly Table	6.23	0.75	Overmovement between table and heating stands and shelf to grab necessary supplies, supplies could be readied
4	**Prep 3 Inch Root Path Weld** Arrange Pipe in Nozzle and attach weld tip Arrange Needed tools and get Corrrect Welding Rod, put on gear	2.25	0.75	Moving back and forth to grab tools and prep supplies that could have been easily accessible
5	**3 Inch Root Path Weld**	17.45	1.6	Moving back and forth to grab welding rods etc… Each interruption, mask had to be adjusted
6	**Prep 3 Inch Cover Path Weld** Insert into Clamp, load inner rod Get proper welding rod, put on gear	2.5	0.7	Collecting tools from out of reach places, sitting then standing repeatedly
7	**3 Inch Cover Path Weld**	3.6	0.8	Stopped weld to get up and retrieve brush from other table
8	**Prep 5 Inch Root Path Weld** Load 5 inch pipe on base unload burner from clamp Hammer edges to even out Set up for weld with new tip, rod , and gear	3	0.5	Moving back and forth unnecessarily
9	**5 Inch Root Path Weld**	18.4		
10	**Prep 5 Inch Cover Path Weld** Clean root path, brush excess material away Transfer to clamp, insert stabilizing rod Get tools, change tip and rod, put on gear	2.7	0.8	Putting on and taking off gear at wrong time, moving back and forth too often, transferring tools
11	**5 inch Cover path weld**	4.4	0.5	Grabbed tools and brush from other table mid-weld
	Total	**97.53**	**15.2**	

The final set of data collected was for the secondary welding process. The total process time observed was 120.2 minutes, with 6.2 minutes of non-value-added time. Non-value-added movements observed included overheating floors which caused a rest period between floors, movement to retrieve tools from far away, excess back-and-forth movement, and manual transport of completed part to shipping. This information is summarized in table 5, below.

Table 5. Welding Process 2 Time Study Data

Secondary Weld Process Time Study				
Step	**Action(s) Performed**	**Time Taken (min)**	**Non Value Added Time Spent (min)**	**Comment on NVA**
1	Serial Number and Weld	7.2	0	Numbers were placed near the welding area. They were organized in order, so there was not time wasted looking for the items
2	Welding Floors	19.5	2.1	Extra heat caused some rest between each floor.
3	Welding Oxygen Elbow Joint and Letter	15.2	0	Numbers were placed near the welding area. They were organized in order, so there was not time wasted looking for the items
4	Welding Gas Elbow Joing and Letter	14	0	Numbers were placed near the welding area.
5	Welding and Machining Little Flange	29.5	1.4	Tool to machine the part was located far from where the welder was. Reposition this tool would increase productivity
6	Welding Kemper Union and Rings on Injection Pi	5.2	0.5	Moving back and forth to pick all the injection pipes (3 per burner)
7	Welding Timarco	10	0	Timarco had no issues or wasted time welding
8	Finishing and Painting	19.6	2.2	Grabbing complete part to the shipping area. A good cart that can hold multiple burners would help to reduce this time.
	Total	120.2	6.2	

3.2.2.3 Analysis of Time Study Data

With the data collected, it was necessary to evaluate the data to later identify potential solutions. The evaluation process consisted of reviewing the observed non-value-added time, and calculating the cost of each.

First, the resource costs for these processes were provided by the sponsors at PTI, with welding labor costs totaling $60/hr., and floor labor costs totaling $40/hr. We then determined the number of cycles that occur each workday for each of the three time studies. Based on historical data, we know the average number of burners produced/day is 6. Since all processes are related and sequential, the number of cycles for every process is approximately 6/day. A summary of this resource and process cycle data is in Table 6, below.

Table 6. Labor Cost and Cycle Data for Each Observed Process

Process Name	Hourly Cost	Cycles/Day
Primary Welding	$ 60.00	6
Secondary Welding	$ 60.00	6
Machining-Cutting-Picking	$ 40.00	6

Using this information, we can look at the total cost of the observed non-value-added time for each process. The first step is to calculate the non-value-added time for each process in hours, since the data was collected in minutes but the cost data is in hours. To do this we simply divide the observed time by 60 to get the time in hours/cycle. For primary welding this is .253 hours/cycle, for secondary welding this is .103 hours/cycle, and for machining-cutting-picking this is .054 hours/cycle. Next, we need to multiply this time by the number of cycles daily and the hourly cost to get the daily cost associated with the non-value-added time.

For primary welding, the cost is found to be $91.20/day, for secondary welding the cost is found to be $37.20/day, and for machining-cutting-picking, the cost is found to be $13.00/day. The daily cost and hourly time data are summarized in Table 7 below.

Table 7. Non-Value-Added Time Cost Analysis

Process Name	Observed NVA Time (min/cycle)	Observed NVA Time (hrs/cycle)	Daily Cost of NVA Time
Primary Welding	15.2	0.253	$ 91.20
Secondary Welding	6.2	0.103	$ 37.20
Machining-Cutting-Picking	3.25	0.054	$ 13.00

The next step was to analyze the individual process steps to see which steps were the primary drivers of daily cost. To do this, we identified each process step by the process name followed by step number to generate a unique ID for each process step. They were then arranged into a single table of data. From there, we calculated the cost associated with each process step using the labor cost and cycle data listed in table 6. We then arranged them in order by percentage of total cost from greatest to least. This data table can be seen in Table 8 below.

Table 8. Combined Data Sheet for Process Step Level Analysis of Non-Value-Added Time

Step Unique ID	Action(s) Performed	Time Taken (min)	Non Value Added Time Spent (min)	Hourly Cost	NVA Time (hours/cycle)	Daily Cost of NVA Time	% of Total	Cumulative % of Total
PrimaryWeld1	Review Work Order and Determine Parts	31	5	$ 60.00	0.083	$ 30.00	21.2%	21.2%
PrimaryWeld2	Collect Parts	6	3.8	$ 60.00	0.063	$ 22.80	16.1%	37.3%
SecondWeld8	Finishing and Painting	19.6	2.2	$ 60.00	0.037	$ 13.20	9.3%	46.7%
SecondWeld2	Welding Floors	19.5	2.1	$ 60.00	0.035	$ 12.60	8.9%	55.6%
PrimaryWeld5	3 Inch Root Path Weld	17.45	1.6	$ 60.00	0.027	$ 9.60	6.8%	62.4%
SecondWeld5	Welding and Machining Little Flange	29.5	1.4	$ 60.00	0.023	$ 8.40	5.9%	68.3%
MCP4	Prep cut pieces and transfer to machining	4.5	1.5	$ 40.00	0.025	$ 6.00	4.2%	72.6%
MCP2	Pick Pipe from Racking	7.75	1.25	$ 40.00	0.021	$ 5.00	3.5%	76.1%
PrimaryWeld7	3 Inch Cover Path Weld	3.6	0.8	$ 60.00	0.013	$ 4.80	3.4%	79.5%
PrimaryWeld10	Prep 5 Inch Cover Path Weld	2.7	0.8	$ 60.00	0.013	$ 4.80	3.4%	82.9%
PrimaryWeld3	Prep Nozzle	6.23	0.75	$ 60.00	0.013	$ 4.50	3.2%	86.1%
PrimaryWeld4	Prep 3 Inch Root Path Weld	2.25	0.75	$ 60.00	0.013	$ 4.50	3.2%	89.3%
PrimaryWeld6	Prep 3 Inch Cover Path Weld	2.5	0.7	$ 60.00	0.012	$ 4.20	3.0%	92.2%
SecondWeld6	Welding Kemper Union and Rings on Injection Pi	5.2	0.5	$ 60.00	0.008	$ 3.00	2.1%	94.3%
PrimaryWeld8	Prep 5 Inch Root Path Weld	3	0.5	$ 60.00	0.008	$ 3.00	2.1%	96.5%
PrimaryWeld11	5 inch Cover path weld	4.4	0.5	$ 60.00	0.008	$ 3.00	2.1%	98.6%
MCP6	Finish parts and transfer	7.75	0.5	$ 40.00	0.008	$ 2.00	1.4%	100.0%
SecondWeld1	Serial Number and Weld	7.2	0	$ 60.00	0.000	$ -	0.0%	100.0%
SecondWeld3	Welding Oxygen Elbow Joint and Letter	15.2	0	$ 60.00	0.000	$ -	0.0%	100.0%
SecondWeld4	Welding Gas Elbow Joing and Letter	14	0	$ 60.00	0.000	$ -	0.0%	100.0%
SecondWeld7	Welding Timarco	10	0		0.000	$ -	0.0%	100.0%
MCP1	Review Work Order and Determine Parts	0.75	0	$ 40.00	0.000	$ -	0.0%	100.0%
MCP3	Cut Pipe	17	0	$ 40.00	0.000	$ -	0.0%	100.0%
MCP5	Machine piece	29.5	0	$ 40.00	0.000	$ -	0.0%	100.0%
PrimaryWeld9	5 Inch Root Path Weld	18.4		$ 60.00	0.000	$ -	0.0%	100.0%
	Total	284.980	24.650		0.411	$ 141.40	100.0%	

Using this data table, a Pareto chart was generated to identify the process steps that most needed to be focused on for our project. The pareto chart is below in figure 6.

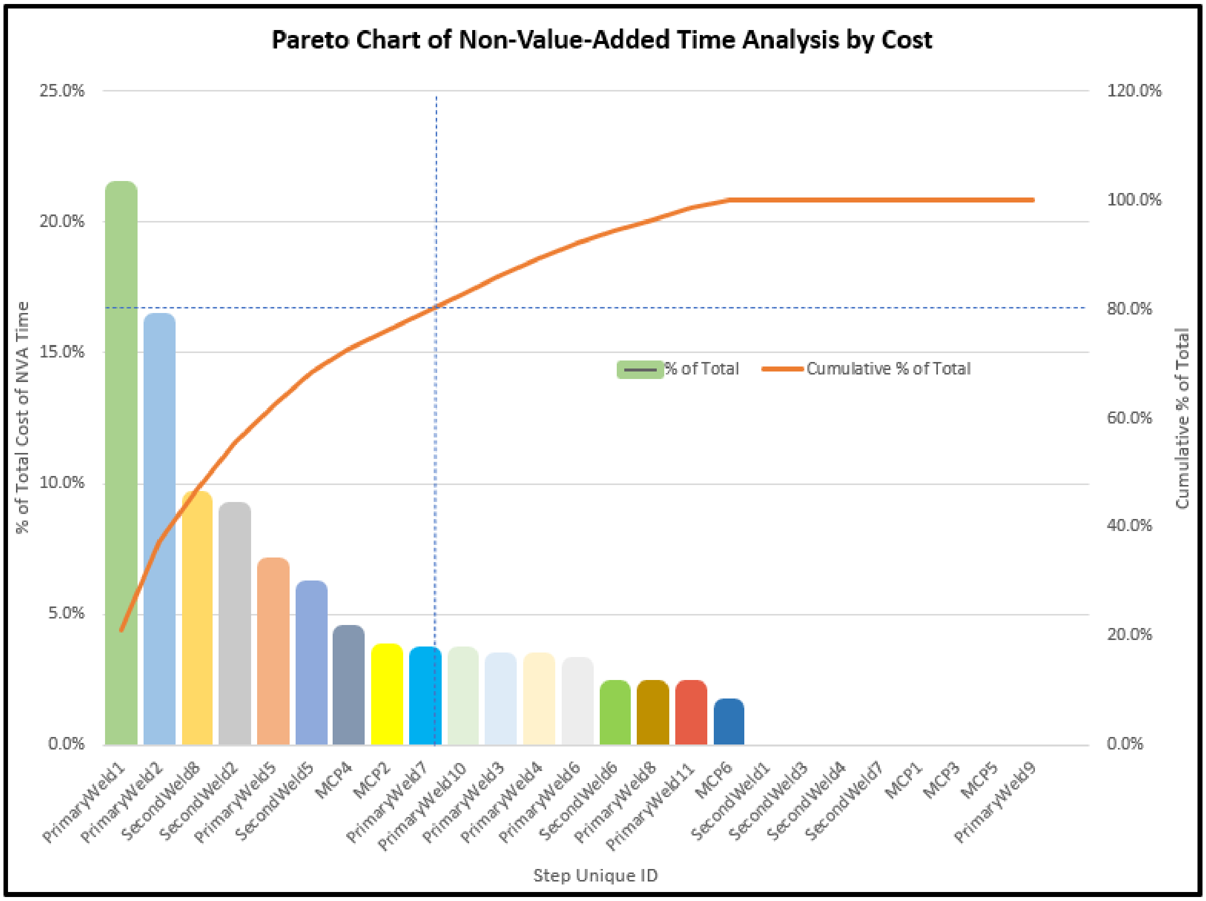

Figure 6. Pareto Analysis of Non-value-added Cost by Process Step

As seen in the chart, the process steps to be focused on are the following (listed in order of costliness):

- Primary Welding Step 1
- Primary Welding Step 2
- Secondary Welding Step 8
- Secondary Welding Step 2
- Primary Welding Step 5
- Secondary Welding Step 5
- Machining-Cutting-Picking Step 4
- Machining-Cutting-Step 2
- Primary Welding Step 7

Once these steps were established, the team analyzed these steps to determine what was occurring that was causing the large amounts of non-value-added time.

3.2.2.4 Descriptive Analysis of Non-Value-Added Time Process Steps

For the descriptive analysis, the team went through each of the major non-value-added time cost contributing steps and gave a detailed explanation of the step and the cause of the wasted time.

- **Primary Welding Step 1:** This is the step where the work order is reviewed and the parts are selected to be cut and machined. This is a preliminary step at the beginning of the day and all of the daily cycles are done at once. The unnecessary time in this step is being caused by a lack of data on the work order, causing the operator to have to manually write out all of the parts needed and the amounts they need for the weld. The manual writing takes nearly 30 minutes each day.

- **Primary Welding Step 2**: Step where the machined parts are collected at the machining station and brought to the welding station. The unnecessary work here is due to making several trips back and forth between the two stations using a small hand cart that is not designed to transport the rod-shaped items being carted back and forth.

- **Secondary Welding Step 8**: Step where the operator moves the items between welding station #2 and the shipping station once item is finished. The unnecessary movement here is in the method of transporting the items. Once again, a small hand cart is used, and the cumbersome items have to be moved one at a time.

- **Secondary Welding Step 2:** This is the step where the floors are welded on the burner assembly. Due to excess heat buildup, the process had to be halted after each floor was completed which caused the observed non-value-added time.

- **Primary Welding Step 5:** This is the 3-inch root path weld. In this step, the welder creates the weld around the 'root path' which is the inner weld between two objects. The unnecessary time spent here was due to excess movement by the operator. The welding rods needed for the completion of the step were not easily reached, and the operator was forced to adjust the welding gear each time they needed to get a new piece which happened several times during a single cycle.

- **Secondary Welding Step 5:** This is the welding and machining of the little flange for the burner. The excess time in this step was due to having to retrieve the appropriate tool for machining. This tool was located far away from where the welder was working.

- **Machining-Cutting-Picking Step 4:** This is the final step at the cutting machine where the newly cut pieces are washed and transferred to the machining station. The non-value-added time in this step was due to a dirty workspace causing delay in cleaning, manually transporting the pieces from the saw to the machining station, and a delay while locating the correct location to return the unused raw material to on the storage rack.

- **Machining-Cutting-Picking Step 2:** This is the step where the operator locates the needed pieces on the storage rack and readies the crane to transfer the pieces to the saw. The wasted time in this step was due to the disorganized storage rack in the area making it difficult to locate the necessary items.

- **Primary Welding Step 7:** This is the 3-inch cover path weld. In this step the welder creates the cover path weld over the root path weld. The unnecessary time in this step was due to the weld taking place at a clamp several meters from the site of the root path weld. This distance had to be walked several times due to tools that are necessary for both welds only being available at one site. This movement mid-weld between stations and the gear adjustments needed with each movement caused the non-value-added time.

3.2.2.5 Qualitative Analysis of Non-Value-Added Process Steps

The team then faced the task of assigning a qualitative indicator to determine how the non-value-added movements could be eliminated from the processes.

It was determined that every non-value-added movement could be eliminated with either (1) creation of new standard operating procedure (SOP), (2) workspace rearrangement, (3) either, or (4) both. Based on the work required to eliminate the issue we created a checklist to see which of our steps belonged in which group. The results are shown in table 9 below.

Table 9. Checklist to Determine Elimination Method for Non-Value-Added Time

Step Unique ID	(1) Can be eliminated using only SOP?	(2) Can be eliminated using only workspace rearrangement?	(3) Can be eliminated using either SOP or workspace rearrangement?	(4) Can only be eliminated using both SOP in combination with a workspace rearrangement?
PrimaryWeld1	✓			
PrimaryWeld2		✓		
SecondWeld8		✓		
SecondWeld2				✓
PrimaryWeld5	✓	✓	✓	
SecondWeld5	✓	✓	✓	
MCP4		✓		
MCP2		✓		
PrimaryWeld7	✓	✓	✓	

This gave the team four distinct classifications of process steps:

Classification 1: non-value-added time that can be eliminated using SOPs. (Primary Welding Step 1)

Classification 2: non-value-added time that can be eliminated using workspace rearrangement. (Primary Welding Step 2, Secondary Welding Step 8, Machining-Cutting-Picking Step 4, and Machining-Cutting-Picking Step 2)

Classification 3: non-value-added time that could be eliminated with either an SOP or a workspace rearrangement. (Primary Welding Step 5, Secondary Welding Step 5, and Primary Welding Step 7)

Classification 4: non-value-added time that could ONLY be eliminated with a combination of SOP and workspace arrangement. (Secondary Welding Step 2)

4. Results and Problem Solution Suggestions

With the data collected and analyzed it was necessary to begin discovering solutions to the problems identified and analyzed. For this step we went through our analysis, first the inventory control analysis, which focused on performing EOQ analysis, followed by the process and workspace inefficiency analysis. From this we determined actionable steps that could be taken to effectively capture the potential savings found, thru process implementation, process improvement, or workspace rearrangement.

4.1 Solution 1 – EOQ Analysis Implementation

The first solution outlined is a solution focused solely on inventory control. The results and costs of this solution are below.

4.1.1 EOQ Analysis Results

For the EOQ analysis, the next step was to calculate the order quantities and reorder points that would be required if the EOQ system were to be used. The only actionable step here, should the system prove to be more effective than the current ordering process is to establish reorder points and implement them during the ordering process, ordering the identified EOQ with each order.

4.1.1 Optimal Order Quantity

Using the method outlined in section 3.2 above, the optimal order quantities for the parts determined to be the most critical are outlined in table 10 below. The highlighted cell in the 3 Q* columns indicates the optimal price break quantity to order at.

Table 10. EOQ Analysis Results - Optimal Order Quantity by SKU

Part Number	Unit Cost per ft ($)	Demand ft	Total Demand in 3	Holding Cost/ft	Average Demand (ft/yr)	Average Unit Cost ($)	Cost per Order	Q* (n<100')	Q* (100'<n<160')	Q* (n>160')
P120039	$ 87.80	83.67	293.46	$2.54	97.82	$63.48	$ 70.00	**75.54**	77.50	78.26
P180010	$ 8.06	72.62	259.81	$0.32	86.60	$8.06	$ 70.00	133.53	**139.84**	151.25
P180012	$ 10.57	213.81	654.06	$0.42	218.02	$10.57	$ 70.00	195.62	212.24	**218.93**
P180014	$ 27.90	148.5	424.75	$0.78	141.58	$19.61	$ 70.00	130.72	**138.06**	141.36
P180015	$ 33.52	157.61	484.09	$0.95	161.36	$23.82	$ 70.00	127.03	**130.82**	134.43
P180028	$ 48.77	75.92	217.75	$1.41	72.58	$35.23	$ 70.00	**72.00**	73.52	75.77
P180029	$ 16.69	168.9	492.56	$0.56	164.19	$13.97	$ 70.00	175.07	191.26	**199.01**
P120045	$ 49.89	139.85	370.87	$1.73	123.62	$43.37	$ 70.00	**98.06**	**101.50**	102.98
P180013	$ 20.33	59	246.8	$0.66	82.27	$16.39	$ 70.00	105.23	**109.53**	112.50

These results give the optimal order quantities for each part which will be kept in stock.

4.1.2 Reorder Points

The resulting reorder points can be seen in Table 11 below. Figure 7, below the table, gives a summary of the EOQ and reorder point for each part.

Table 11. Reorder Points by Part

Part Number	Max Daily Usage	Max Lead time	Quantity Used Daily (QUD)	Average Lead Time(ALT)	Safety Stock Quantity (SSQ)	Reorder Point
P120039	2.93	10.00	0.27	7.00	27.47	29.35
P180010	2.60	10.00	0.24	7.00	24.32	25.98
P180012	6.54	10.00	0.60	7.00	61.22	65.41
P180014	4.25	10.00	0.39	7.00	39.76	42.48
P180015	4.84	10.00	0.44	7.00	45.31	48.41
P180028	2.18	10.00	0.20	7.00	20.38	21.78
P180029	4.93	10.00	0.45	7.00	46.11	49.26
P120045	1.50	10.00	0.14	7.00	14.05	15.01
P180013	3.71	10.00	0.34	7.00	34.72	37.09

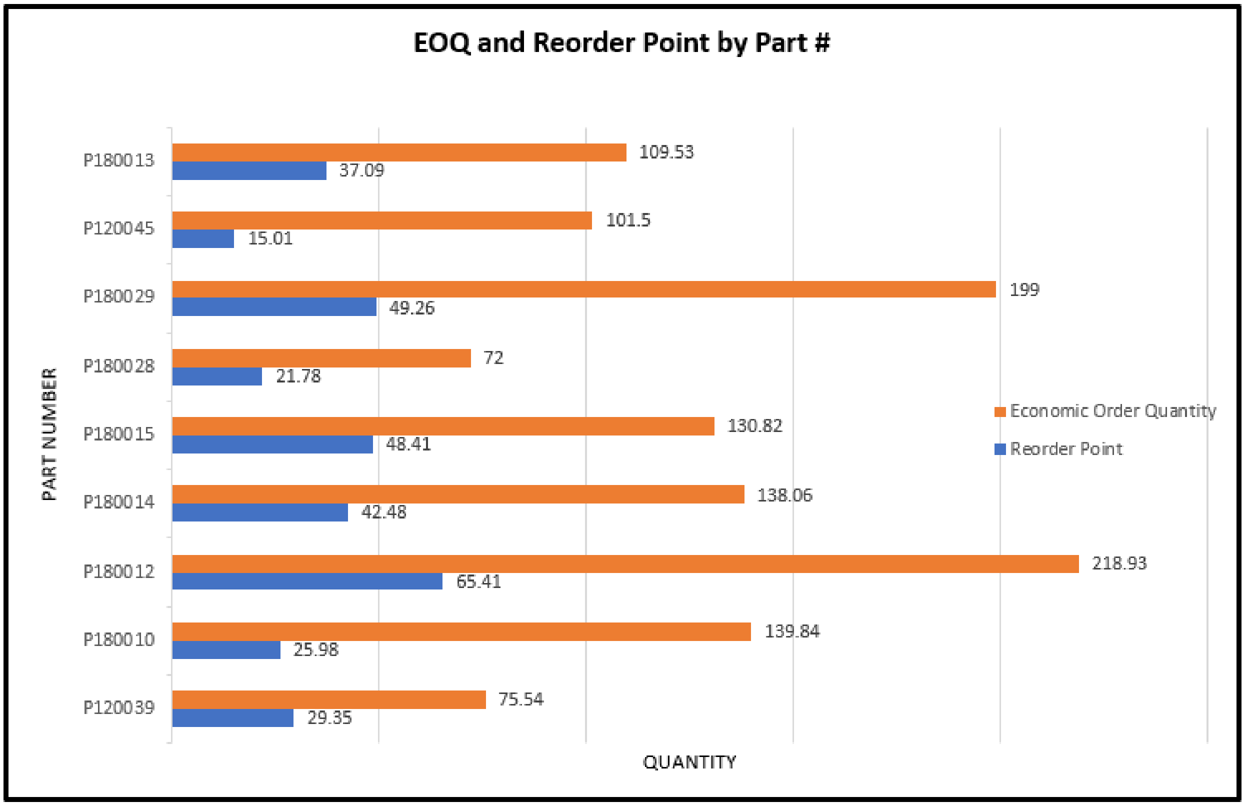

Figure 7. EOQ and Reorder Point Summary Table

4.1.3 Economic Analysis - Solution 1

Using the EOQ alongside the historical costs we are able to estimate the savings that can be realized using the EOQ model. Total cost is determined by the following equation:

$$DU + \frac{DK}{Q} + \frac{QH}{2}$$

Where D = Demand, U = Unit Cost, K = Ordering Cost, H = Holding Cost, and Q = Quantity Ordered.

Using this we can calculate the total cost before and after EOQ implementation to get the total cost difference between the two methods.

Table 12 below illustrates the cost savings for each part given the better pricing received from the suppliers. These results indicate that an average annual savings of $4,245.04 and a 10-year savings of $46,336.05, since the cost of steel tends to rise over time, can be realized using an EOQ ordering policy.

Table 12. Cost savings using EOQ model for Ordering

Part Number	Unit Cost After EOQ	Unit Cost Before EOQ	Ordering Cost before EOQ	Ordering Cost after EOQ	Holding Cost before EOQ	Holding Cost After EOQ	Total Cost Before	Total Cost After	Δ (Savings)
P120039	$4,532.35	$4,532.35	$171.19	$90.65	$50.78	$57.68	$4,754.32	$4,680.68	$73.64
P180010	$2,167.54	$2,377.30	$151.56	$43.35	$6.45	$35.81	$2,535.31	$2,246.70	$288.60
P180012	$3,485.41	$4,365.52	$381.54	$69.71	$8.45	$50.21	$4,755.51	$3,605.33	$1,150.18
P180014	$3,589.44	$4,003.61	$247.77	$71.79	$15.69	$51.11	$4,267.07	$3,712.34	$554.73
P180015	$4,317.11	$4,578.76	$282.39	$86.34	$19.06	$56.43	$4,880.20	$4,459.89	$420.31
P180028	$3,528.18	$3,528.18	$127.02	$70.57	$28.18	$50.59	$3,683.38	$3,649.33	$34.05
P180029	$2,887.60	$3,731.39	$287.33	$57.75	$11.18	$44.37	$4,029.89	$2,989.72	$1,040.17
P120045	$4,262.94	$4,567.43	$216.34	$86.54	$34.70	$73.28	$4,818.47	$4,422.75	$395.72
P180013	$2,628.76	$2,847.83	$143.97	$52.58	$13.11	$35.91	$3,004.90	$2,717.25	$287.65
								Total Annual Savings	$4,245.04
								Estimated 10 Year Savings	$46,336.05

Cost to implement the EOQ system would include approximately 12 hours of labor for creating the SOPs and training for the ordering staff. The labor value of these hours is approximately $70. This is a total of $840 for training and process creation. This is based on the same hourly rate used to calculate the ordering costs in section 3.2.1.1. The below table 13 shows the cost breakdown of the EOQ solution.

Table 13. EOQ Implementation Cost-Benefit Analysis Summary

Solution	Cost to Implement	Estimated Annual Cost Savings	Net Cost Savings Year 1
EOQ Implementation	$ 840.00	$ 4,245.04	$ 3,405.04

4.2 Solution 2 – Standard Operating Procedures (SOPs)

The second potential solution the team explored was the creation of standard operating procedure to eliminate some of the non-value-added process observed during the time studies outlined in section 3.2.2. The first step was to go through the qualitative analysis from section 3.2.2.5 and determine which of the non-value-added actions observed would be eliminated through SOPs.

4.2.1 Non-Value-Added Time Eliminated Via SOP Creation

The process steps identified in the qualitative analysis section as containing non-value-added movement that can be eliminated via creation of new standard operating procedure are the steps belonging to Classification 1, and Classification 3.

These include the Primary Welding Step 1, Primary Welding Step 5, Secondary Welding Step 5, and Primary Welding Step 7.

These steps all contain non-value-added movement that benefits from process change. Primary Welding Step 1 could be fixed simply by changing the process to have the required materials print on the initial work order. The manual process of writing each line out by hand is extremely time consuming and could be completely eliminated by this simple step.

Primary Welding Step 5, Secondary Welding Step 5, and Primary Welding Step 7 could all be fixed by adding process steps to ensure all necessary tools are arranged at each space PRIOR to equipping the welding gear. The non-value-added movement observed in these steps was all related to small tools or necessary equipment that was left at a different workspace at the beginning of the step, despite being necessary for the current step.

4.2.2 Suggestions of Specific Process Steps and Necessary SOPs

Based on the above results, we can conclude that the only SOPs that are necessary to be created to realize benefit, are for the primary and secondary welding processes. Below are minor suggestions that will eliminate the observed inefficiencies.

Primary welding process: Step 1 must ensure that the printed work order contains the line item data for the needed materials. This prevents manual arithmetic and writing of lines by the operator.

Both Processes: There must be a step which requires all necessary tools be laid out prior to putting on welding gear. In the current process the worker just grabs tools as needed from wherever it was last used. Creation of a checklist to make sure they have all needed tools would be simple and effective. This will eliminate the work stoppages observed where the welder was forced to remove gloves and mask, walk to another station and grab tools, then re-equip the gear.

4.2.3 Economic Analysis - Solution 2

To conduct economic analysis for the second solution, we can combine the results from the section 3.2.2.5 qualitative analysis with the data from the time study analysis in 3.2.2.3. This will allow us to perform a cost-benefit analysis of implementing new standard operating procedure.

The total daily cost of non-value-added time for the 4 steps identified is $30.00 for Primary Welding Step 1, $9.60 for Primary Welding Step 5, $8.40 for Secondary Welding Step 5, and $4.80 for Primary Welding Step 7. This totals to $52.80/day. The average work-year contains 261 workdays excluding holidays and weekends. This comes out to an annual cost of $13,780. This information is summarized in Table 14 below.

Table 14. Summary of Cost Savings for SOP Implementation

Step Unique ID	Action(s) Performed	NVA Time (hours/cycle)	Daily Cost of NVA Time	Annual Cost of NVA Time
PrimaryWeld1	Review Work Order and Determine	0.083	$ 30.00	$ 7,830.00
PrimaryWeld5	3 Inch Root Path Weld	0.027	$ 9.60	$ 2,505.60
SecondWeld5	Welding and Machining Little Flange	0.023	$ 8.40	$ 2,192.40
PrimaryWeld7	3 Inch Cover Path Weld	0.013	$ 4.80	$ 1,252.80
		Total	**$ 52.80**	**$ 13,780.80**

The estimated cost of the SOP creation involves the training of the staff and implementation of the processes. There are two welders who would need to be trained, along with engineering staff who would need to be trained as well. The total process for creation of SOPs and training is expected to take 16 hours. Welding hours cost approximately $60/hour. For two welders, the total cost of creation and implementation comes out to be $1,920. The total net cost analysis for the implementation of solution two can be seen in table 15 below.

Table 15. SOP Implementation Cost-Benefit Analysis Summary

Solution	Cost to Implement	Estimated Annual Cost Savings	Net Cost Savings Year 1
SOP Implementation	$ 1,920.00	$ 13,780.00	$ 11,860.00

4.3 Solution 3 – Workspace Improvements

The third solution the team suggests is to make workspace improvements to eliminate some of the non-value-added process observed during the time studies outlined in section 3.2.2. The first step was to go through the qualitative analysis from section 3.2.2.5 and determine which of the non-value-added actions observed would be eliminated through workspace improvements

4.3.1 Non-Value-Added Time Eliminated Via Workspace Improvements

The process steps identified in the qualitative analysis section as containing non-value-added movement that can be eliminated via workspace improvements are the steps belonging to Classification 2 or Classification 3.

These include the Primary Welding Step 2, Secondary Welding Step 8, Primary Welding Step 5, Secondary Welding Step 5, Machining-Cutting-Picking Step 4, Machining-Cutting-Picking Step 2, and Primary Welding Step 7

These steps all contain non-value-added movement that benefits from workspace improvements. Primary Welding Step 2, Secondary Welding Step 8, and Machining-Cutting-Picking Step 4 can all be attributed to manual efforts to move product from one station to another using inadequate equipment. These could be eliminated using dedicated carts that are equipped to store the quantity of material being transported in one trip.

Machining-Cutting-Picking Step 2 could be eliminated by building a new storage rack for the stainless steel area.

Primary Welding Step 5, Secondary Welding Step 5, and Primary Welding Step 7 could be eliminated by building specialized, easy-access storage in the given areas that houses the necessary tools for all processes performed at the area noted.

4.3.2 Suggestions for Elimination of Non-Value-Added Time Using Workspace Improvements

4.3.2.1 Dedicated Carts for Transporting Material Between Stations

The primary suggestion for improving the workspace is to introduce two carts dedicated to the transportation of raw material between stations within the warehouse. This will eliminate the non-value-added time observed in Primary Welding Step 2, Secondary Welding Step 8, and Machining-Cutting-Picking Step 4, where the operator was observed making multiple slow trips between stations to transport material.

The cart could double as functional storage for completed, machined parts waiting to be transported to welding. The current storage is seen below in figure 8.

Figure 8. Machining Station Storage of Completed Parts

The sponsors have confirmed that they are able to build a cart in house, with the only outside purchase required being the casters (wheels) for the cart. To determine the options we performed a comparison, spec analysis, and cost analysis of various wheel types to purchase for the cart to be created. The cart is determined to require a load capacity of at least 1500 lbs, since this is the maximum weight being transported at any one time between multiple stations. Figure 9 below gives a summarized view of the information needed for caster selection.

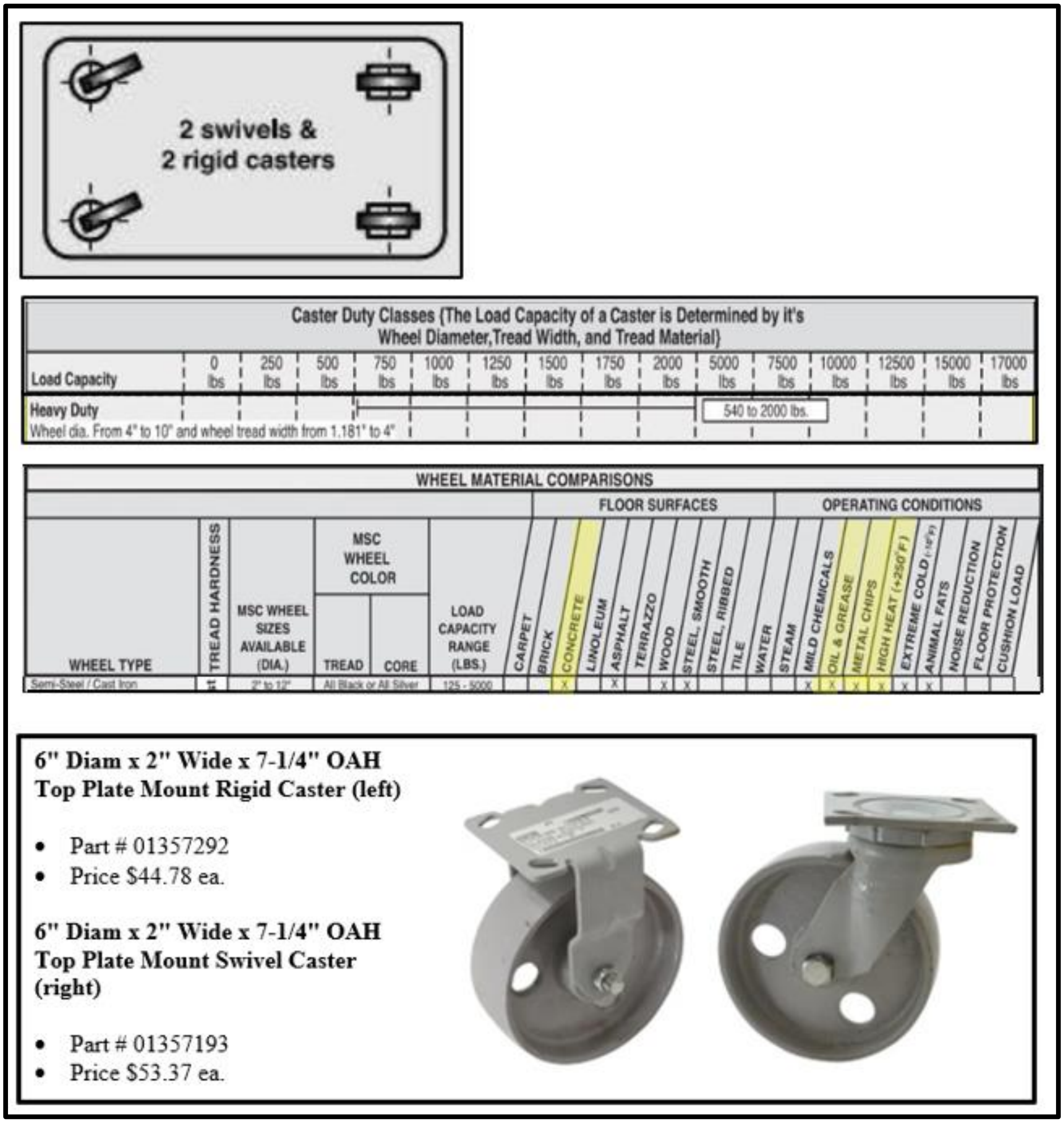

Figure 9. Caster Selection Chart

As indicated, the wheels were selected to fit the ‘2 swivels & 2 rigid’ assembly type. This is a cart that allows steering at the front wheels but maintains rigid wheels on the back. The casters were selected from the heavy-duty section to bear a weight between 540 and 2000lbs. This represents a wheel diameter between 4” to 10” with wheel tread width between 1.81” and 4”. Surfaces and operating conditions narrowed down the choice to the semi-steel /cast iron caster, in order to operate on concrete, with conditions of oil & grease, metal chips, and high heat regularly experienced within the facility.

A concept of the cart design is seen in figure 10 below.

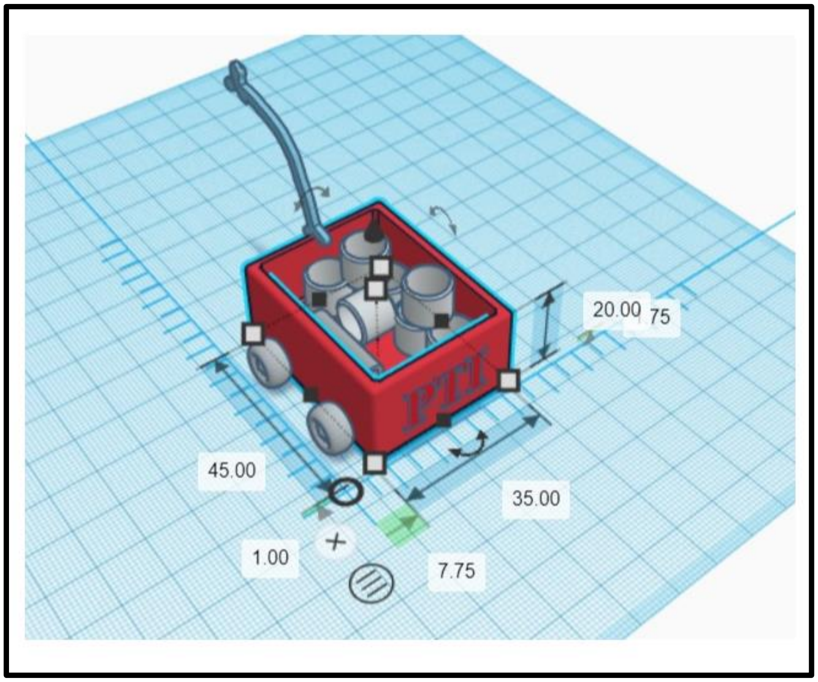

Figure 10. Concept Cart Design for Stainless Steel Transport

The cost of the wheels of the cart comes out to $392.60 for two carts. The expected labor costs are 10 hours of work at $40.00/hr, or $400. The expected stainless steel cost for building the frame of the carts is $540, or 20 feet at $27/ft. This comes out to a total of $1,332.60. This information is summarized in table 16 below.

Table 16. Cart Cost Summary Table

Resource	Cost Per Unit	Units	Total Cost
Swivel Casters	$ 53.37	4	$ 213.48
Rigid Casters	$ 44.78	4	$ 179.12
Steel	$ 27.00	20	$ 540.00
Labor	$ 40.00	10	$ 400.00
		Total Cost	**$ 1,332.60**

4.3.2.2 Stainless Steel Rack Changeover

The addition of a new stainless steel rack that is specialized for holding bulk stainless steel rods allows us to eliminate the non-value-added time from Machining-Cutting-Picking Step 2.

In the current system, space is underutilized as beams are being stacked inefficiently on ground pallets, and only on one side of the cantilevered racking. The space is also very cluttered and disorganized with several different SKUs occupying the same levered space. There is no labeling on the individual pieces, nor the sections of racking where they are being stored so the operator is required to locate the correct piece by searching through the pile and measuring pieces that they believe are the one they need. An image of the current stainless steel rack can be seen in figure 11 below.

Figure 11. Stainless Steel Storage Rack

The rack will be built in the facility by the staff on hand, and customized to the standards of the facility. The cost of the steel for the rack is expected to be $1,080 or 40 feet at $27/ft. The cost of labor is expected to be $800, or 20 hours at $40/hr. This is summarized in table 17 below.

Table 17. Stainless Steel Storage Rack Cost Summary

Resource	Cost Per Unit	Units	Total Cost
Steel	$ 27.00	40	$ 1,080.00
Labor	$ 40.00	20	$ 800.00
		Total Cost	**$ 1,880.00**

A design of the suggested improved rack is shown in figure 12 below.

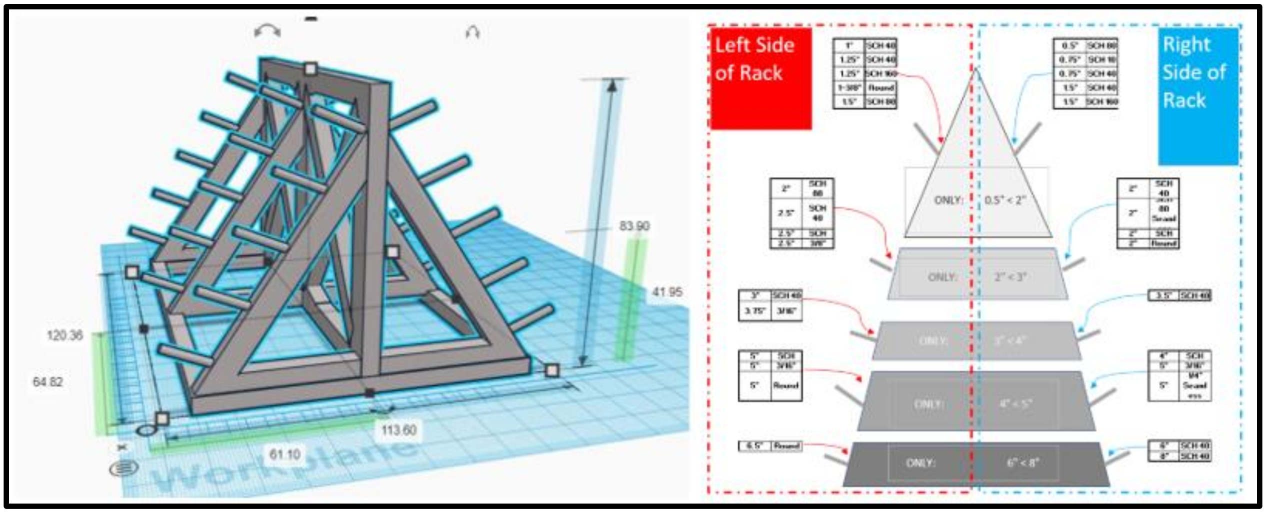

Figure 12. Improved Stainless Steel Storage Rack Concept Design

The rack will have color coordinated slotting that helps the operator quickly identify the needed pieces when picking for cutting.

4.3.2.3 Specialized Storage Organizers for Welding Stations

The final workspace improvement suggestion is to add specialized storage organizers for the two welding stations. The storage organizers would be slotted with open easy-access for specific tools. Each tool needed for the welding processes would be given a specific slot. If there is a tool that is required in multiple areas it should be purchased for each station that requires it. This will eliminate non-value-added time observed in Primary Welding Step 5, Secondary Welding Step 5, and Primary Welding Step 7.

The expected cost for an organizer that would suit the needs is approximately $208/station or $416 total based on the walled organizer seen on amazon, pictured in figure 13 below. 4 hours of labor at $40/hr are expected as well for set up, labeling and organization. This comes to a total of $576.

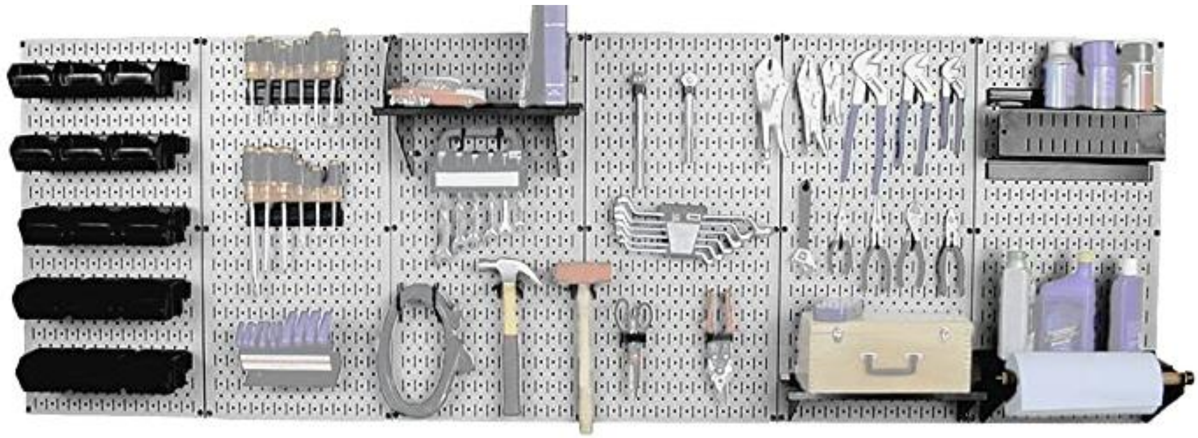

Figure 13.Steel Wall Organizer for Tools

Total cost for the specialized tool storage implementation is summarized in table 18 below.

Table 18. Specialized Tool Organizer for Welding Stations

Resource	Cost Per Unit	Units	Total Cost
Steel Wall Organizer	$ 208.00	2	$ 416.00
Labor	$ 40.00	4	$ 160.00
		Total Cost	**$ 576.00**

4.3.3 Economic Analysis of Solution 3 - Workspace Improvements

To conduct economic analysis for the second solution, we can combine the results from the section 3.2.2.5 qualitative analysis with the data from the time study analysis in 3.2.2.3. This will allow us to perform a cost-benefit analysis of implementing workspace improvements

The total daily cost of non-value-added time for the 7 steps identified is $22.80 for Primary Welding Step 2, $13.20 for Secondary Welding Step 8, $9.60 for Primary Welding Step 5, $8.40 for Secondary Welding Step 5, $6.00 for Machining-Cutting-Picking Step 4, $5.00 for Machining-Cutting-Picking Step 2 and $4.80 for Primary Welding Step 7. This totals to $69.80/day. The average work-year contains 261 workdays excluding holidays and weekends.

This comes out to an annual cost of $18,217.80. This information is summarized in Table 19 below.

Table 19. Cost Savings Summary for Workspace Improvements

Step Unique ID	Action(s) Performed	NVA Time (hours/cycle)	Daily Cost of NVA Time	Annual Cost of NVA Time
PrimaryWeld2	Collect Parts	0.063	$ 22.80	$ 5,950.80
SecondWeld8	Finishing and Painting	0.037	$ 13.20	$ 3,445.20
PrimaryWeld5	3 Inch Root Path Weld	0.027	$ 9.60	$ 2,505.60
SecondWeld5	Welding and Machining Little Flange	0.023	$ 8.40	$ 2,192.40
MCP4	Prep cut pieces and transfer to machi	0.025	$ 6.00	$ 1,566.00
MCP2	Pick Pipe from Racking	0.021	$ 5.00	$ 1,305.00
PrimaryWeld7	3 Inch Cover Path Weld	0.013	$ 4.80	$ 1,252.80
		Total	$ 69.80	$ 18,217.80

As discussed in 4.3.2, the costs of the implementation of the workspace improvements we suggest are $1,332 for carts, $1,880 for the shelf and $576 for the specialized tool storage. This comes to a total of $3,788 to implement all suggestions. The net cost-benefit analysis is outlined below in table 20.

Table 20. Cost-Benefit Analysis for Workspace Improvements

Solution	Cost to Implement	Estimated Annual Cost Savings	Net Cost Savings Year 1
Workspace Improvements	$ 3,788.00	$ 18,217.80	$ 14,429.80

4.4 Solution 4 – 5S Implementation

The final solution we are evaluating is a combination of the previous solutions into a single total quality system known as 5S. The 5S system is derived from the abbreviation sort, set in order, shine, standardize, and sustain. A total 5S implementation would incorporate workspace improvements, standard operating procedures as well as inventory controls.

Additional improvements not currently analyzed or accounted for include: the floors will be arranged with clearly demarcated walkways. The scrap area will be reworked to have clearly labeled slotted storage for each size of pipe. There will be a clearly labeled area designated for '5S' supplies such as cleaning supplies, labeling, color coded stickers, and other necessary items to maintain the '5S' system within the shop.

Using 5S, each area will be **sort**ed, removing waste and unnecessary items from the area. **Set in order** will be accomplished by rearranging each area so that tools are arranged in an optimal pattern to avoid over-movement. Additionally, new equipment will be built or purchased, specialized for the needs of each station and process. **Shine** will be a deep cleaning, removing the layer of metal dust covering the floor and establishing routine cleanings and checks of the machines and equipment. This will also require cleaning the entire facility, establishing clear walkways, demarcated zones for work and storage, and clear signage to establish organization. All of these actions will be supported by the **standardize**d processes and new processes will be created that emphasize the importance of the 5S system. **Sustain**ing could be achieved by hiring a quality manager to regularly check that procedures are being followed properly and to reinforce a culture of continuous improvement. Ideally, a system like this would affect every process, and the changes suggested above could be expanded to include other systems within the machine shop such as the other raw materials.

The 5S option offers several improvements over the other solutions. Most prominently, a color coded system has been devised to better organize the stainless steel racking. The color coded system can be seen below in figure 14. The system is devised with a specific color designed for each pipe 'schedule' (thickness of material wall).

Stainless Steel Raw Material Rack by Schedule

Thickness	SCH 10	SCH 40	SCH 80	SCH 160	3/16"	3/8"	1/4"	ROUND
Diameters	0.75"	0.75"	0.5"	1.25"	3.75"	2.5"	5" Seamless	1-3/8"
		1"	1.5"	1.5"	5"		5" Wall SS - Tube	2"
		1.25"	2" Seamless	2"				5"
		1.5"	2" Welded					6.5"
		2"	2.5"					
		2.5"						
		3"						
		3.5"						
		4"						
		5"						
		6"						
		8"						

Figure 14. Stainless Steel Color Coding System by Schedule and Diameter

This system would be applied to the rack as seen below, in figure 15.

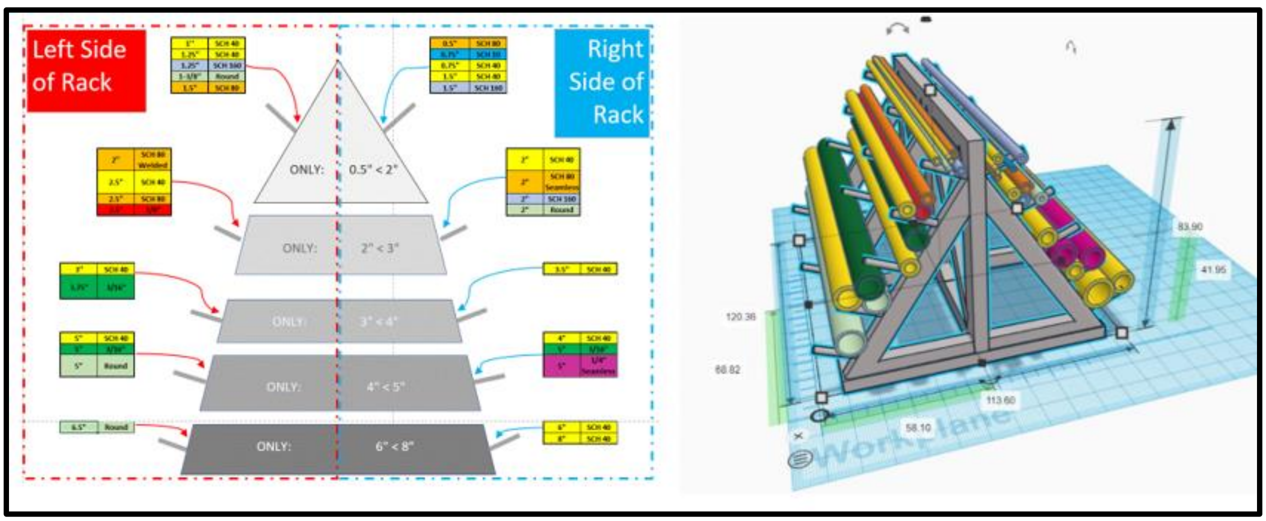

Figure 15. Rack Diagram With Color Coding Layout

4.4.1 Economic Analysis – Solution 4

The cost of a 5S implementation can be analyzed by reviewing the costs of the other 3 solutions as well as doing an analysis of expected additional costs that are likely to be incurred to fully transition the facility to a 5S total quality system. A breakdown of additional costs has been analyzed by the team assessing needs. Training and cleaning are expected to take an additional 60 hours at an average of $120/hr for all floor workers. This totals to $7200. Additional materials include walkway labeling ($75), and other facility labeling ($30) to mark out each area, walkway, and storage area with color coded labeling that identifies specific purposes. There is also additional cost for specialized tool storage in the machining and cutting areas ($416). The final additional added cost is in the creation of new standardized process for the processes not previously discussed. This includes receiving/putaway, and machining-cutting-picking. Each SOP is expected to take 8 hours to create at $40/hr. This totals to $640. The total additional cost comes out to $8361. The additional costs are summarized in table 21 below.

Table 21. Additional Cost Breakdown of 5S Implementation

Resource	Cost Per Unit	Units	Total Cost
Walkway Labeling	$ 25.00	3	$ 75.00
Color Coded Labeling	$ 10.00	3	$ 30.00
Specialized Tool Storage	$ 208.00	2	$ 416.00
Training Labor	$ 120.00	60	$ 7,200.00
SOP Creation Labor	$ 40.00	16	$ 640.00
		Total Cost	**$ 8,361.00**

The cost benefits of 5S include all of the combined benefits of the previously discussed solution with several additional benefits. The primary benefit is the capturing of all of the non-value-added time observed during the time studies and analyzed in section 3.2.2.3. This totals cost savings of $141.40/day. With 261 days in a work year this totals $36,905.40 in annual savings.

The total costs associated with implementation are $8,361 for the additional costs associated, $3,788 for workspace improvements, $1,920 for SOP implementation, and $840 for EOQ implementation. This totals to $14,909 for implementation. The total cost savings associated with implementation are $36,905.40 for non-value-added time capture and $4,245.04 for EOQ savings. This is a total of $41,150.44 in cost savings for a 5S implementation.

The net cost-benefit analysis is displayed in table 22 below.

Table 22. 5S Implementation cost-benefit analysis

Solution	Cost to Implement	Estimated Annual Cost Savings	Net Cost Savings Year 1
5S Implementation	$ 14,909.00	$ 41,150.44	$ 26,241.44

4.5 Summary of Results

The following is a summary of the results described in the preceding four sections of Chapter 4.

The team identified four potential solutions for the problems we discussed in Chapter 3.

Section 4.1 discussed an implementation of economic order quantity. The team found that this would cost approximately $840 to implement, but would provide savings of $4,245.04, for a net savings in year 1 of $3,405.04.

Section 4.2 discussed an implementation of new standard operating procedures for the welding processes. The team found that this would cost approximately $1,920.00 to implement, but would provide savings of $13,780.00, for a net savings in year 1 of $11,860.00.

Section 4.3 discussed an implementation of a workspace arrangement featuring a new stainless steel storage rack, two new dedicated carts, and new specialized storage for the welding areas. The team found that this would cost approximately $3,788.00 to implement, but would provide savings of $18,217.80, for a net savings in year 1 of $14,429.80.

Section 4.4 discussed a full implementation of a 5S total quality system. The team found that this would cost approximately $14,909.00 to implement, but would provide savings of $41,150.44, for a net savings in year 1 of $26,241.44.

The results of all four cost-benefit analyses are summarized in table 23, below.

Table 23. Summary of Cost-Benefit Analyses Results

Solution	Cost to Implement	Estimated Annual Cost Savings	Net Cost Savings Year 1
EOQ Implementation	$ 840.00	$ 4,245.04	$ 3,405.04
SOP Implementation	$ 1,920.00	$ 13,780.00	$ 11,860.00
Workspace Improvements	$ 3,788.00	$ 18,217.80	$ 14,429.80
5S Implementation	$ 14,909.00	$ 41,150.44	$ 26,241.44

5. Conclusions and Final Recommendation

With analysis complete and a full breakdown of the economic analysis for each solution suggestion, the team faced the task of determining the ideal solution for the company. The team decided to perform TOPSIS analysis to choose the best alternative given the fours solutions presented in chapter 4.

5.1 TOPSIS Analysis

TOPSIS Analysis is a method by which the best alternative of multiple solutions to a problem can be identified using a normalized comparison. The benefit of TOPSIS is the ability to normalize variables, and compare qualitative variables using simple numerical conversions. This provides a powerful comparative analysis tool when choosing between several similar but varied choices.

5.1.1 Choosing the Comparative Variables

The first step was to choose the variables which the team planned to use to analyze the data. Because this was a cost savings analysis, and the primary focus was to decrease costs, the two primary quantitative variables were chosen to be annual cost savings and cost to implement. Annual cost savings is the estimated annual cost savings impact of the given solution resulting from a successful implementation, calculated at the year 1 savings value. Cost to implement is the estimated one-time cost to successfully implement each solution.

The team then chose three qualitative variables that were useful in determining the likelihood of acceptance by the industry sponsors. The first variable chosen was ‘time to implement’ with a 5 value range from Very Short to Very Long. The second variable chosen was ‘employee acceptance’ with a 5 value range from Very Low to Very High. The third variable chosen was ‘ease of implementation’ with a 5 value range from Very Easy to Very Hard. These three variables allowed the team to make a recommendation that took non-numerical factors into account.

Time to implement is important because of the opportunity cost associated with a long implementation, and the potential for cost overrun. In a long implementation, projects can often get sidetracked by employee turnover or unforeseen events, this makes a long implementation less desirable than a short implementation time. Time to implement was estimated using the number of steps involved, the labor hours required, and most importantly the number of training hours required to accomplish the task.

Employee acceptance is important because employee pushback can derail a project implementation. If employees do not clearly see how the return on investment will benefit them directly; they are likely to resist change. This variable was estimated by the questionnaire responses given regarding each of the proposed solutions. The more open to the suggestions, the more likely employees are to accept their implementation.

Ease of implementation is important because complexity and moving parts can cause unexpected costs to arise. If there are areas where analysis was not as thorough as necessary, surprise cost can derail the implementation. Ease was estimated based on the number of changes, and number of people involved in each of the suggestions.

5.1.2 Assigning Value to the Comparative Variables for each Solution

With the variables determined, the team assigned values using the economic analysis from chapter 4, and the estimation methods listed in section 5.1.1.

The 'EOQ Implementation' suggestion had an estimated cost savings of $4,245 an implementation cost of $840, an estimated short time to implement, an estimated high employee acceptance rate, and estimated easy implementation.

The 'SOP implementation' suggestion had an estimated cost savings of $13,780, an estimated cost to implement of $1,920, an estimated medium time to implement, an estimated medium employee acceptance, and an estimated medium ease of implementation.

The 'Workspace rearrangement' suggestion had an estimated cost savings of $18,217.80, an estimated cost to implement of $3,788, an estimated medium time to implement, an estimated very high employee acceptance rate, and an estimated medium ease of implementation.

The '5S System' suggestion had an estimated cost savings of $41,150.44, an estimated $14,909 cost to implement, an estimated very long time to implement, an estimated low employee acceptance rate, and an estimated very hard implementation.

Table 23, below, summarizes this data.

Table 24. Initial Variable Values for TOPSIS Analysis

Solution	Annual Cost Savings	Cost to Implement	Time to Implement	Employee Acceptance	Ease of Implementation
EOQ Implementation Only	$4,245.00	$840.00	Short	High	Easy
Standard Operating Procedure Implementation	$13,780.00	$1,920.00	Medium	Medium	Medium
Workspace Rearrangement (Rack, Cart, Specialized Storage at Each Workspace)	$18,217.80	$3,788.00	Medium	Very High	Medium
5S Total Implementation (Full rearrangement, SOPs and Inventory Controls)	$41,150.44	$14,909.00	Very Long	Low	Very Hard

Next, the team devised quantitative assignments for each of the qualitative variables. Responses of 'very short', 'very low', and 'very easy' were given values of 1, 'short', 'low','easy' were given values of 3, 'medium' was given a value of 5, 'long', 'high', and 'hard' were given values of 7, and ‘very long’, ‘very high’, and ‘very hard’ were given values of 9. This is shown in table 24 below.

Table 25. Quantitative Substitution for Qualitative Variables

Time Response	Acceptance Response	Ease Response	Quantitative Value
Very Short	Very Low	Very Easy	1
Short	Low	Easy	3
Medium	Medium	Medium	5
Long	High	Hard	7
Very Long	Very High	Very Hard	9

With quantitative substitutions in place the values became 3, 7, 9 for EOQ implementation for time to implement, employee acceptance and ease of implementation respectively. The values became 5, 5, 5 for SOP implementation, 5, 9, 5 for Workspace rearrangement, and 9, 3, 9 for 5S implementation. The numerical values are summarized in table 25, below.

Table 26. TOPSIS Analysis, qualitative variables with numerical replacements

Solution	Annual Cost Savings	Cost to Implement	Time to Implement	Employee Acceptance	Ease of Implementation
EOQ Implementation Only	$840.00	$4,245.04	3	7	3
Standard Operating Procedure Implementation	$13,780.00	$1,920.00	5	5	5
Workspace Rearrangement (Rack, Cart, Specialized Storage at Each Workspace)	$18,217.80	$3,788.00	5	9	5
5S Total Implementation (Full rearrangement, SOPs and Inventory Controls)	$41,150.44	$14,909.00	9	3	9

5.1.3 Normalizing Values

The next step was to normalize the values of each variable so as to have moderately equivalent ranges of values in each column. To normalize a value within a set of values, standard method is to square the value and divide that by the sum of squares for the set, then take the square root of the response. This equation is as follows for a value x_i in a set with n values.

$$\sqrt{\frac{x_i^2}{x_1^2 + x_2^2 + \cdots + x_n^2}}$$

Applying this to table 25 above, the following data set is obtained.

Table 27. TOPSIS Analysis - Normalized values for each variable

Solution	Annual Cost Savings	Cost to Implement	Time to Implement	Employee Acceptance	Ease of Implementation
EOQ Implementation Only	0.0178	0.2641	0.2535	0.5466	0.2535
Standard Operating Procedure Implementation	0.2927	0.1195	0.4226	0.3904	0.4226
Workspace Rearrangement (Rack, Cart, Specialized Storage at Each Workspace)	0.3870	0.2357	0.4226	0.7028	0.4226
5S Total Implementation (Full rearrangement, SOPs and Inventory Controls)	0.8742	0.9276	0.7606	0.2343	0.7606

As summarized in table 26, above, the normalized values of each solution range from 0 to 1, with values relatively close to 0 being low, and values close to 1 being high.

5.1.4 Selecting Positive and Negative Ideal Solutions

The next step was to choose weights for the variables according to the sponsor's top priorities. The weight determines how much each variable weighs in the final decision. A high weight indicates the variable is important in making the final decision, a low weight means a variable is less important in making the final decision.

We knew there was limited room in the budget for implementation so cost to implement received the highest weight (.3). We also knew that employee acceptance would be less important if the sponsor saw value in our project since they controlled the processes and could convince the floor workers of the value and push the implementation through. For this reason we gave employee acceptance the lowest weight (.1). The remainder of the variables received average weighting (.2) since they were relatively equal in importance.

To achieve the weighted values, each column is multiplied by its assigned weight. Normalized annual cost savings values were multiplied by .2, normalized implementation cost values were multiplied by .3, normalized time to implement values were multiplied by .2, normalized employee acceptance values were multiplied by .1, and normalized ease of implementation values were multiplied by .2.

With the weights applied each variable was assigned a descriptor of either maximize or minimize according to its ideal value. Savings are desirable to be maximized, so it was assigned maximize. Cost is desirable when minimized, so it was assigned minimize. Time to implement, employee acceptance and ease of implementation were assigned minimize, maximize, maximize respectively.

With an understanding of the ideal outcomes, a positive ideal solution could be identified, where the most desirable values in each column are chosen. A negative ideal solution was also identified, as the set of least desirable value in each column.

The final resulting positive ideal solution is .170, .040, .051, .070, .152 for annual cost savings, cost to implement, time to implement, employee acceptance, and ease of implementation respectively.

The final resulting negative ideal solution is .004, .280, .152, .023, .051 for annual cost savings, cost to implement, time to implement, employee acceptance, and ease of implementation respectively.

This information is summarized in table 27 below, with the positive ideal highlighted in yellow and the negative ideal highlighted in red.

Table 28. Summary of Positive and Negative Ideal Paths

	Annual Cost Savings	Cost to Implement	Time to Implement	Employee Acceptance	Ease of Implementation
Min or Max	*Maximize*	*Minimize*	*Minimize*	*Maximize*	*Maximize*
Weighted Values	*0.2*	*0.3*	*0.2*	*0.1*	*0.2*
EOQ Implementation Only	0.0036	0.0792	0.0507	0.0547	0.0507
Standard Operating Procedure Implementation	0.0585	0.0358	0.0845	0.0390	0.0845
Workspace Rearrangement (Rack, Cart, Specialized Storage at Each Workspace)	0.0774	0.0707	0.0845	0.0703	0.0845
5S Total Implementation (Full rearrangement, SOPs and Inventory Controls)	0.1748	0.2783	0.1521	0.0234	0.1521

5.1.4 Calculating the Closest-to-Ideal Solution

The first step in calculating the ideal solution is calculating each solution's 'separation' from the positive and ideal solution. This is done by calculating the variance of each solution value from each ideal value. This is represented by the equation:

$$\sum_{i=1}^{n} \sqrt{(x_i - P_i)^2}$$

Where, n is the number of variables, x is the value of the variable for the given equation and P is the positive ideal value for the variable. Similarly, the negative ideal is represented by the equation:

$$\sum_{i=1}^{n} \sqrt{(x_i - N_i)^2}$$

Where N is the negative ideal value for the variable. Using this equation, the calculated positive separation for EOQ Implementation is .204, for SOP Implementation is .142, for Workspace improvement is .128, and for 5S implementation is .267. The calculated negative separation for EOQ implementation is .226, for SOP implementation is .260, for Workspace improvement is .128, and for 5S implementation is .199. This information is summarized in table 28 below.

Table 29. Separation from Ideals for Each Solution

Solution	Separation from Positive Ideal	Separation from Negative Ideal
EOQ Implementation Only	0.204	0.226
Standard Operating Procedure Implementation	0.142	0.26
Workspace Rearrangement (Rack, Cart, Specialized Storage at Each Workspace)	0.128	0.128
5S Total Implementation (Full rearrangement, SOPs and Inventory Controls)	0.267	0.199

Using the separation from ideal, the closeness to ideal solution can be calculated by taking the ratio of the separation from ideal to the sum of separation for each solution. This is represented by the equation:

$$\frac{S_N}{(S_N + S_P)}$$

Where S_N is separation from negative ideal and S_P is separation from positive ideal. The results for each solution are .5247 for EOQ Implementation, .6268 for SOP Implementation, .6496 for workspace improvement, and .4271 for 5S Implementation.

Based on this, the workspace improvement option is the best solution offered. Table 29 below shows the results of the closeness calculation.

Table 30. Closness to Ideal Solution Calculation Results

Solution	Closeness to Ideal Solution	Rank
EOQ Implementation Only	0.5247	3
Standard Operating Procedure Implementation	0.6268	2
Workspace Rearrangement (Rack, Cart, Specialized Storage at Each Workspace)	0.6496	1
5S Total Implementation (Full rearrangement, SOPs and Inventory Controls)	0.4271	4

5.2 Recommendation and Conclusion

Based on the results of the TOPSIS analysis, the closest-to-ideal solution presented is the workspace improvement suggestions outlined in section 4.3, solution 3.

The following is a summary of the team's recommendations based on the analysis performed:

- Build new racking for stainless steel storage using the designs provided
- Build two dedicated carts to be used to transport material between the various stations
- Purchase and install customized tool storage for the two welding stations

The implementation of these recommendations is expected to cost $3,788 and expected to return an annual savings of $18,217.8 resulting in a net savings of $14,429.80 in the first year. This return will be realized through labor savings.

6. Project Management Overview

6.1 Budget

The budget for the suggested changes needed for this project are shown below.

Table 31. Budget for Suggested Solution

Resource	Units	Cost/Unit	Total Cost
Steel for Cart	20	$ 27.00	$ 540.00
Casters for Cart	8	$ 49.08	$ 392.60
Labor for Cart	10	$ 40.00	$ 400.00
Steel for Racking	40	$ 27.00	$ 1,080.00
Labor for Racking	20	$ 40.00	$ 800.00
Tool Organizers	2	$ 208.00	$ 416.00
Labor for Organizer Install	4	$ 40.00	$ 160.00
		Total	**$ 3,788.60**

6.2 Team Assignment and Overall Schedule

Below is the Gantt Chart for this project showing how the group progressed through the various tasks in the project.

Improving Inventory Controls of Raw Materials	Project Duration	Project Start Date	Project End Date
Process Technology International	108	1/15/2020	5/2/2020
Group 4			

Task ID	Task Description	Days	Start Date	End Date	Progress
	Preliminary Design Review (PDR)				
1	Literature review	3	1/23/2020	2/7/2020	100%
2	Project focus narrowing	2	1/25/2020	2/8/2020	100%
3	Facility meeting and proposed technical solution	2	2/9/2020	2/10/2020	100%
4	Data investigation	3	2/10/2020	2/14/2020	100%
5	Review solutions to the problem	1	2/14/2020	2/19/2020	100%
	In Progress Review (IPR)				
1	Meeting to approach solutions	2	2/19/2020	2/25/2020	100%
2	Meeting at facility to review pro	3	2/26/2020	3/2/2020	100%
3	Time study collection	5	3/3/2020	3/8/2020	100%
4	EOQ Analysis	5	3/9/2020	3/14/2020	100%
5	Meeting to review progress and	3	3/15/2020	3/18/2020	100%
	Critical Design Review (CDR)				
1	Meeting for overall improvemer	2	3/17/2020	3/19/2020	100%
2	Finalize designs & SOP	6	3/20/2020	3/26/2020	100%
3	Savings and budget analysis	7	3/27/2020	4/3/2020	0%
4	Result analysis	4	4/4/2020	4/8/2020	0%
	Final Design Review				
1	Video	2	4/9/2020	4/11/2020	0%
2	Poster	1	4/12/2020	4/22/2020	0%
3	Final review	4	4/23/2020	4/27/2020	0%
4	Final presentation	4	4/28/2020	5/2/2020	0%

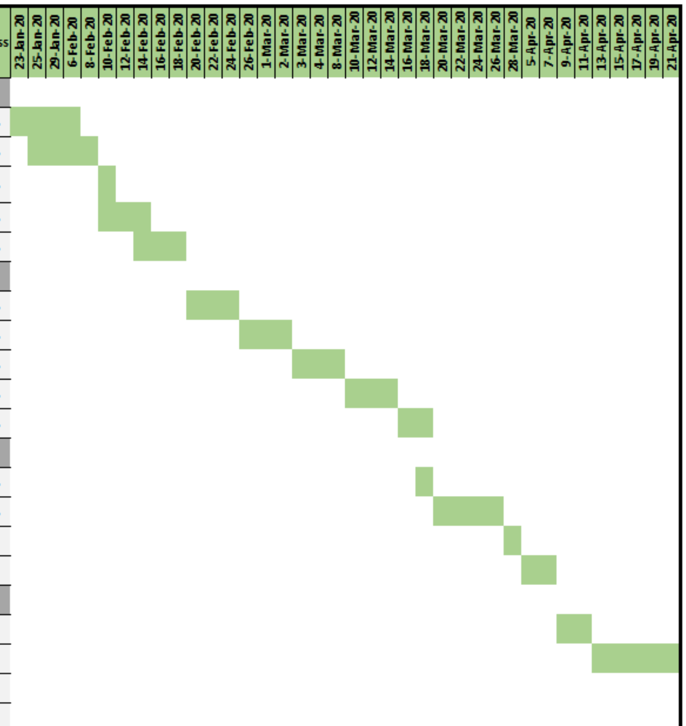

Figure 16. Gantt Chart

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Appendix A: Acknowledgements

The project team would like to express our gratitude to Process Technology International for their guidance and insights throughout the project. We appreciated their willingness to provide us with the needed resources and availability throughout the duration of the project. Our ability to complete this project is a direct result of the suggestions and freedom provided by the PTI team.

- Andres Gomez, Mechanical Engineer/Spare Parts Manager, PTI
- Ryan Boardman, Shop Manager, PTI
- Michael Overbeck, Head of Engineering, PTI
- Danielle Chandler, Inventory Control Manager, PTI
- Kevin Borrego, Procurement Specialist, PTI
- Kwame Weems, Welder, PTI
- Dave Carpenter, Operator, PTI
- Termarco Brantley, Welder, PTI

We would also like to acknowledge Dr. Amin Esmaeli of the KSU ISYE department for his assistance with the EOQ calculations and insights on how to apply these. Finally, we would like to thank Thriptee Bhaskar for providing a designer's guidance for the figures and tables and overall structure of the paper.

Appendix B: Contact Information

Name	Title	Email	Phone
Juan Sanchez	Project Manager	Juanfernando.sanchez0414@gmail.com	678-221-6684
Jordan Nash	Project Coordinator	Jordan.nash@a3bs.com	678-405-5801
Enis Ormanci	Technical Analyst	Enisburak1996@gmail.com	470-257-7268
Erion Tafa	Design Specialist	tafaerio@gmail.com	404-422-2201

Appendix C: Reflections and Work Overview by Team Member

Jordan Nash: What started as a normal senior design project will forever be remembered by the pandemic that has changed all of our lives. It is a testament to the agility of the KSU faculty and the school's integration of technology that the semester continued as planned; avoiding the derailment that could have been. I am grateful to have had the chance to work on a project like this and to have been able to experience the application of my education in a manufacturing setting. There were setbacks, pandemic notwithstanding, and some pushback along the way, but overcoming the obstacles we faced was probably the most important experience I gained from completing this project.

Enis Ormanci: Last semester was enjoyable for me because I got to apply everything that I had learned to one of the most important projects which was the Senior Design Project for my Senior year. I enjoy calculations and I never get bored of doing them, so my group and I decided that I am going to be a Technical Analyst. Overall, the semester was unforgettable because of the COVID-19 pandemic that occurred. Luckily, we have collected all of our data from PTI before the pandemic started getting more dangerous. Our group was very organized from the start to the end. I enjoyed working with everyone and I loved being a part of this team.

Erion Tafa: From the very beginning of this semester, I knew that this Senior Design Project was intended to put all our hard and soft skills to the test. Adding an unprecedented global pandemic to this dichotomy, made this semester not only more challenging, but uniquely unforgettable. When giving credit to where is due, then most of it should go to KSU's fluid online platforms and staff, and for allowing us to proceed uninterruptedly with this semester. The rest of the credits goes to my team, whom from the very beginning of this project and to the very end, organically displayed a tremendous amount of teamwork, discipline, and organization. This project went through some speed-bumps on its way, but by overcoming those obstacles became the biggest lessons learned while confronting these challenges. It has been an absolute pleasure to work on a project like this, and with a team like this.

Juan Sanchez: Senior design has been like a roller coaster of feelings. In the beginning of the semester I was kind of worried to see who was going to be in my team, and if they were going to be responsible for the project. A long the road I met incredible people who gave their best to accomplish an amazing job. We applied several topics learned throughout this journey, we felt like real engineers applying optimal solutions to real problems in the manufacturing industry, we faced with operators who were resisting to change, but at the end we overcome with a great project. I am very thankful for all my professors and mentors throughout these 4 years at KSU and I hope to be one of the best industrial engineers

Appendix D: Additional Information and Data

Erion Tafa		Enis Ormanci	
Tasks Prior to FDR	93	Tasks Prior to FDR	89
Meeting and Recording	4	Meeting and Recording	4
Creating Slides	6	Creating Video	10
Total	**103**	**Total**	**103**

Juan Sanchez		Jordan Nash	
Tasks Prior to FDR	103	Tasks Prior to FDR	111
Meeting and Recording	4	Meeting and Recording	4
Updating Slides and SOPs	4	Updating and Finalizing Report	1
		Creating Poster	2
Total	**111**	**Total**	**118**

Figure 17. Task Breakdown by Team Member

Carolina Specialty Metals, Inc.
PO Box 7462
Charlotte, NC 28241
(704) 588-5888

CSM ESTIMATE

Quote #	94727
Date	3/9/2020
Rep	DA
FOB	Delivered
Lead Time	1 week
Cust. Ref#	

Bill To:
Inteco PTI, LLC
4950 South Royal Atlanta Drive
Suite A
Tucker, GA 30084

Ship To:
Inteco PTI, LLC
4950 South Royal Atlanta Drive
Suite A
Tucker, GA 30084

Description	Qty	UOM	Price	Total
2"Sch 40 T304 seamless/2@20' 100'---$16.94/foot 160'---$15.92/foot	40	feet	19.94	797.60T
2"Sch 80 T304 welded/2@20' 100'----$15.71/foot 160'----$14.51/foot	40	feet	18.75	750.00T
3"Sch 40 T304 seamless/2@20' 100'----$33.00/foot 160'----$31.25/foot	40	feet	35.00	1,400.00T
2.5"Sch 40 T304 seamless/2@20' 100'----$26.00/foot 160'----$24.80/foot	40	feet	29.00	1,160.00T
2.5"ODx.375"WL T304 /2@20' 100'----$42.00/foot 160'----$40.80/foot	40	feet	45.00	1,800.00T
5"ODx.25"WL seamless T304/2@20' 100'---$57.00/foot 160'---$55.90/foot	40	feet	60.00	2,400.00T
1.5'Sch 40 T304 seamless/2@20' 100'---$15.50/foot 160'---$13.25/foot	40	feet	17.00	680.00T

Comments:		**Total**

Carolina Speialty Metals, Inc. PO Box 7462 Charlotte, NC 28241

Page 1

Figure 18. Cost Estimate Provided by Steel Supplier page 1

Carolina Specialty Metals, Inc.
PO Box 7462
Charlotte, NC 28241
(704) 588-5888

CAROLINA SPECIALTY METALS, INC.

CSM ESTIMATE

Quote #	94727
Date	3/9/2020
Rep	DA
FOB	Delivered
Lead Time	1 week
Cust. Ref#	

Bill To:
Inteco PTI, LLC
4950 South Royal Atlanta Drive
Suite A
Tucker, GA 30084

Ship To:
Inteco PTI, LLC
4950 South Royal Atlanta Drive
Suite A
Tucker, GA 30084

Description	Qty	UOM	Price	Total
2"Sch 80 T304 seamless/2@20'	40	feet	26.00	1,040.00T
100'----$24.00foot				
160'----$22.75/foot				
3.5'Sch 40 T304 seamless/2@20'	40	feet	49.00	1,960.00T
100'---$47.00/foot				
160'---$44.75/foot				
5"ODx.188"Wall T304/2@20'	40	feet	50.00	2,000.00T
100feet----$47.00/foot				
160feet----$45.80/foot				
2'Round T303/2@12'	256	LBS	2.50	640.00T
9@12'--1152#--$2.20/pound				
Sales Tax			0.00	0.00

Comments:

Total $14,627.60

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Page 2

Figure 19. Cost Table Provided by Steel Supplier page 2