A Comparison of Visualization Methods for Design and Analysis of High-Mix-Low-Volume Production Systems

A Paper Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University

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2011

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Background and Objective

A 'Value Stream' is "all the actions (both value-added and non-value-added) currently required to bring a product through the main flows essential to every product" (Rother & Shook, 1999, p. 3). The process of mapping the material and information flows of all components and subassemblies in a value stream that includes manufacturing, suppliers, and distribution to the customer is known as Value Stream Mapping (VSM). VSM has proved effective in identifying and eliminating waste in a facility with similar or identical product routings, such as in assembly facilities. Using VSM, many companies have changed their existing facility layouts, material handling, inventory control, purchasing and scheduling systems to reduce the total throughput times of parts and current levels of work-in-process (WIP) inventories. However, the developers of VSM acknowledge that many value streams have multiple flows that merge. This would typically be the case in Make-To-Order jobshops that make products with complex BOM's, such as welded fabrications, furniture, stamping dies, etc. In order to map multiple flows in a value stream, Rother & Shook suggest to "draw such flows over one another. But do not try to draw every branch if there are too many. Choose the key components first, and get the others later if you need to" (Rother & Shook, 1999, p. 19). This approach, when applied in any high-mix low-volume (HMLV) facility, will:

- Ignore numerous other important Value Streams
- Ignore sharing of common work centers by these "ignored" Value Streams
- Ignore the finite capacity-constraints of bottleneck work centers

- Ignore the need for monitoring, modifying and managing a dynamic production schedule

Instead of this “sampling” step in VSM, this paper offers an alternative approach – Value Network Mapping (VNM). This approach is able to overcome these limitations of VSM to map the complete network of flows in the value stream corresponding to a complex product BOM (Bill Of Material). Our approach integrates basic Industrial Engineering (IE) tools for material flow mapping, such as the Spaghetti Diagram, Flow Process Chart, Modified Multi-Product Process Chart (MM-PPC) and From-To Chart, in addition to IE skills such as Two Sample T-test (Statistical analysis through Minitab), Facilities Design, Work Measurement Study, and Design of Workplace Environment as well as a software package for material flow analysis called “PFAST” (Production Flow Analysis and Simplification Toolkit). In particular, the software is effective for visualization and analysis of multiple flows in a value stream that has *products with dissimilar routings that share common resources*. Also, unlike the standard VSM, the proposed approach helps to view a value stream at any and all levels of assembly in a product BOM. The development and benefits of this approach are demonstrated using results from a project done in a local Tier-1 Automotive forging jobshop supplier and a medical emergency vehicle manufacturer.

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Section 1: Introduction to Value Stream Mapping (VSM)

Value Stream Mapping is a mapping tool that maps material flows, information flows, and value adding time as well as non-value adding time. These are used to signal and control the material flows and communication from the customer through the facility to the supplier. This visual representation facilitates the process of lean implementation by helping to identify the value adding steps in a value stream and eliminating the non-value adding steps, or wastes (*muda*). In addition to that, VSM methodology requires a development of Current State Map and Future State Map through push/pull scheduling, FIFO, supermarket, takt time, cycle time, value adding ratio, etc. Then, according to Rother & Shook, there are seven guidelines, adapted and modified based on the concepts of Lean Thinking, that can be followed when generating the Future State Map for a lean value stream (Rother & Shook, 1999, p. 44-54):

1) Produce to takt time
2) Develop continuous flow
3) Use supermarkets to control production where continuous flow does not extend upstream
4) Schedule based on the pacemaker operation
5) Produce different products at a uniform rate (Level the production mix)
6) Level the production load on the pacemaker process
7) Develop the capability to make "every part every (EPE) <time period>"

Section 2: Industrial Application of VSM in a Forging Job Shop

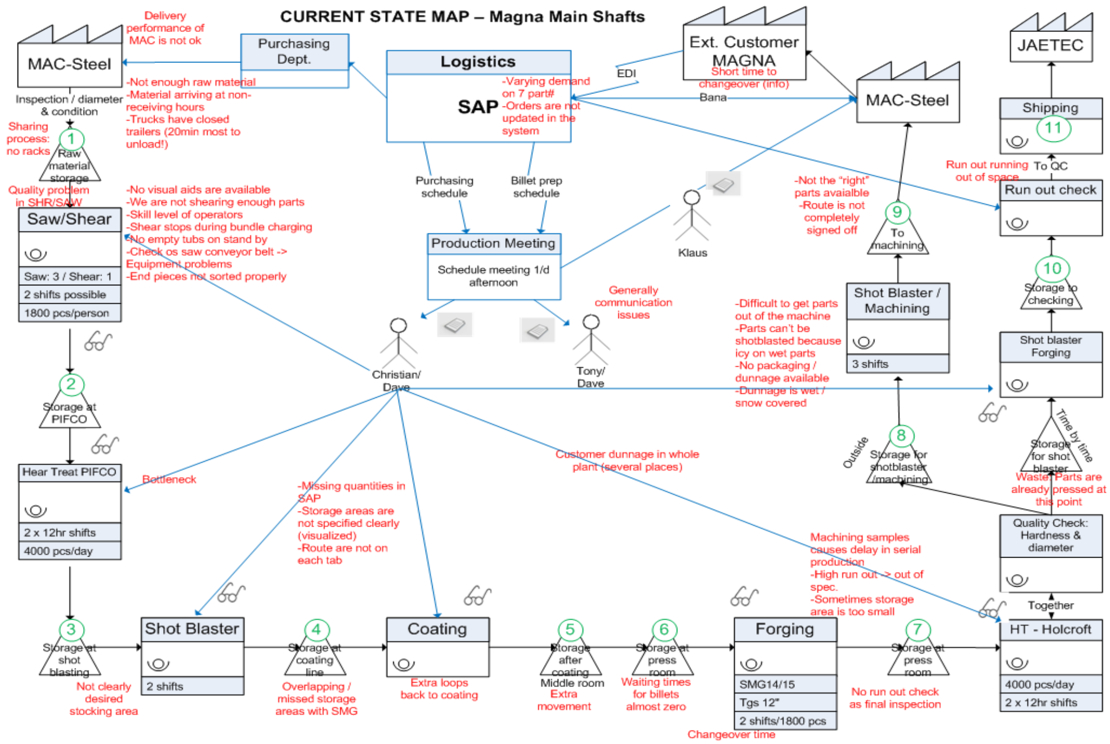
Hirchvogel, Inc. (http://www.hirschvogel.com) is a forging jobshop specializing in the manufacture of precision metal products. The 75,000 sq. ft. facility contains forging and machining equipment. The company produces a variety of products, ranging from hot, cold, warm, and aluminum forging parts to machining parts, component productions, and assemblies. Process capabilities include shearing/sawing, heat treating, shot blasting, coating, forging, cooling, and machining. A typical finished product consists of multiple unique components produced in the Press shop that are forged into a single unit. Hence, the material flow network for any forging product provided the opportunity to study value streams with multiple flow paths that merged into a single path after the forging step.

Despite being a Tier 1 supplier of forgings to the automotive sector, Hirschvogel has to produce 126 different forging parts. During the month of April 2010, Hirschvogel's corporate Lean guru in charge of implementing the "Hirschvogel Production Systems" (HPS) from its mother company in German came to initiate process improvement activities and conducted a standard 3-day Value Stream Mapping kaizen through *Gemba* walk. Four most expensive parts called "Magna Main Shafts" were picked for VSM and the material flow corresponded to 4 (out of 126) parts whose routings were identical.

Current and future state maps were created (Figure 1) and improvement ideas were identified as the results from these three-day activities (Figure 2). The Current state map drawn includes problems identified by the Kaizen team. In addition that, some written notes was put on paper, which comes from experience and with some adoption of ISE 541 students' ideas:

- The needs for a dedicated material handler: A dedicated material handler is needed to be a "water spider" where this person would focus on transporting materials from one machine to another. This is needed since all the presses are monuments.
- Moving coating line to middle room & online weight sorting at the shear (additionally to the existing weight sorter): Having the coating machine in the middle room would make it closer to the press and thus transportation would be shorter. Online weight sorting at the shear is an idea to semi-automate the shear and thus to have fewer resources there. That means, one person could become free and put into the dedicated material handler position.
- Relieve final inspection for main shafts: Relieving the final inspection step for the Magna main shafts is something to look forward, but the process quality control has to be maintained.
- Dedicated storage area for all forging parts (SMG 14, 15, 19, and KB1000): This idea is to centralize the storage areas since there are no dedicated storage areas for all forging parts.

- Dedicated storage areas for FURN6: Having a dedicated area that will go to this furnace.
- Build a wall and bring Tesuna Line from Machining building to Forging building: This idea is mainly to reduce travel from forging building to machining building; thus, Tesuna Line is brought to forging building but a wall has to be built that will make it free from crossing traffic while at the same time making other pathway more crowded.



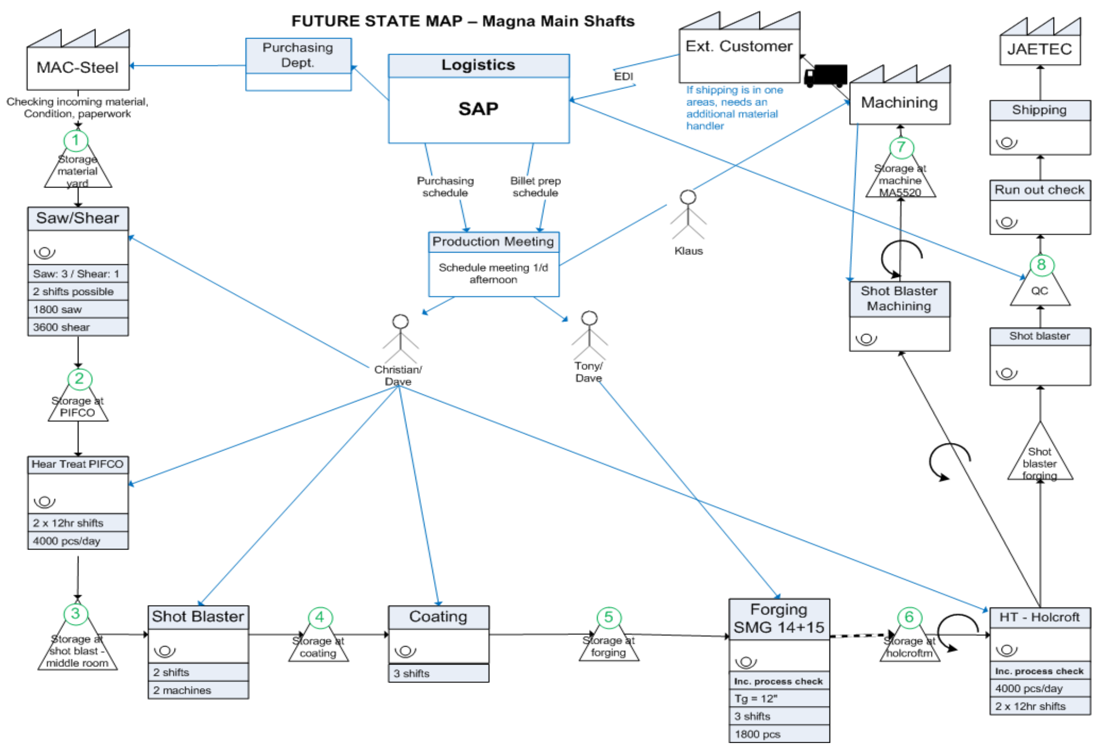


Figure 1: Current State and Future State of Value Stream Maps

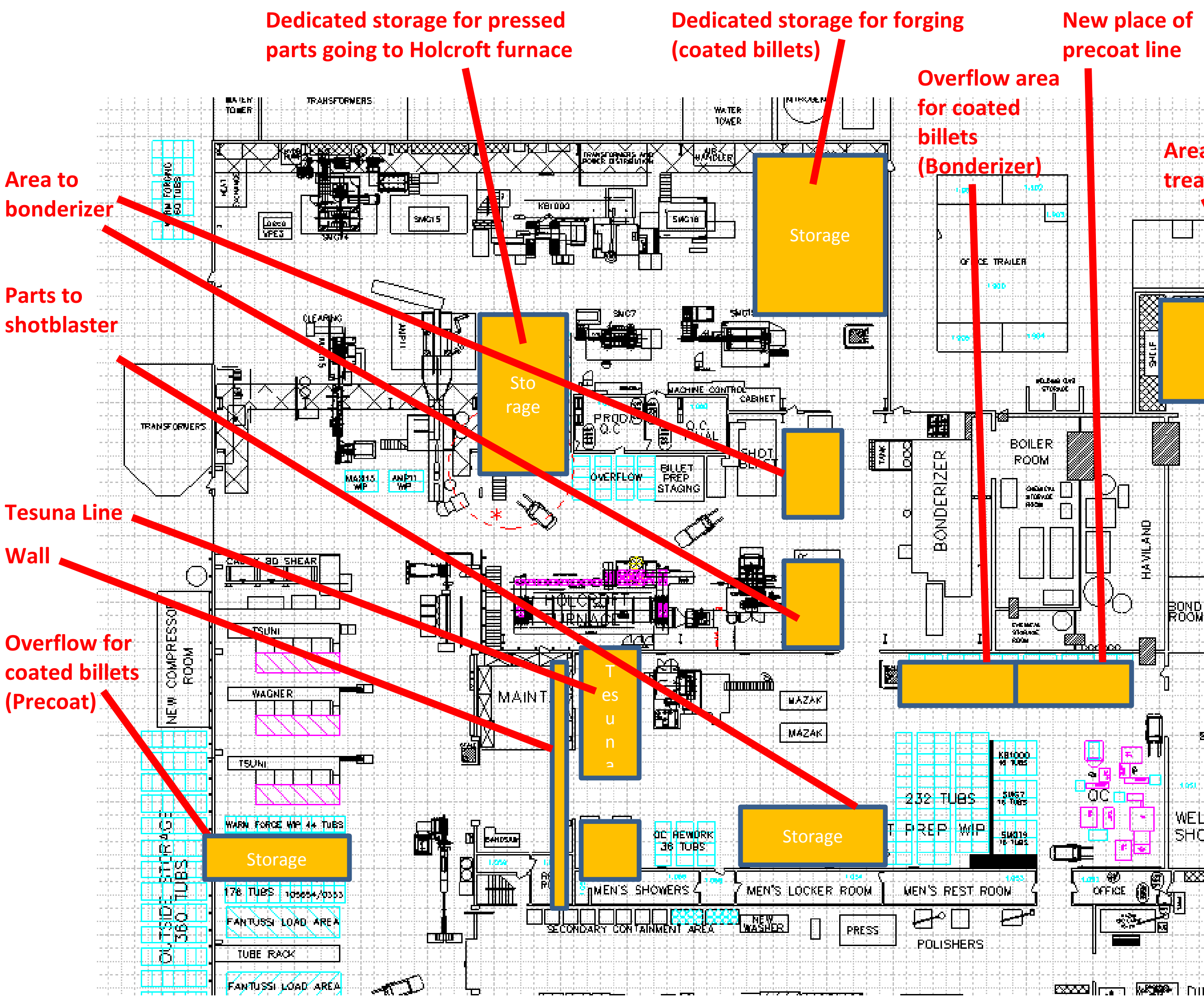


Figure 2: Improvement Ideas produced during Kaizen Event with HPS Lean Guru

In the Future state map, it can be seen that Pull scheduling is utilized on certain areas. However, future state map could only be drawn based on the Current state map which is limited to only "Magna Main Shafts". This becomes the weakness of VSM which is only focused on certain parts which have same/similar certain flow routings as in figure 3 while there are many other machines and storage areas outside this “Magna Main Shafts” parts (Figure 4). More about the limitation of VSM is also described below.

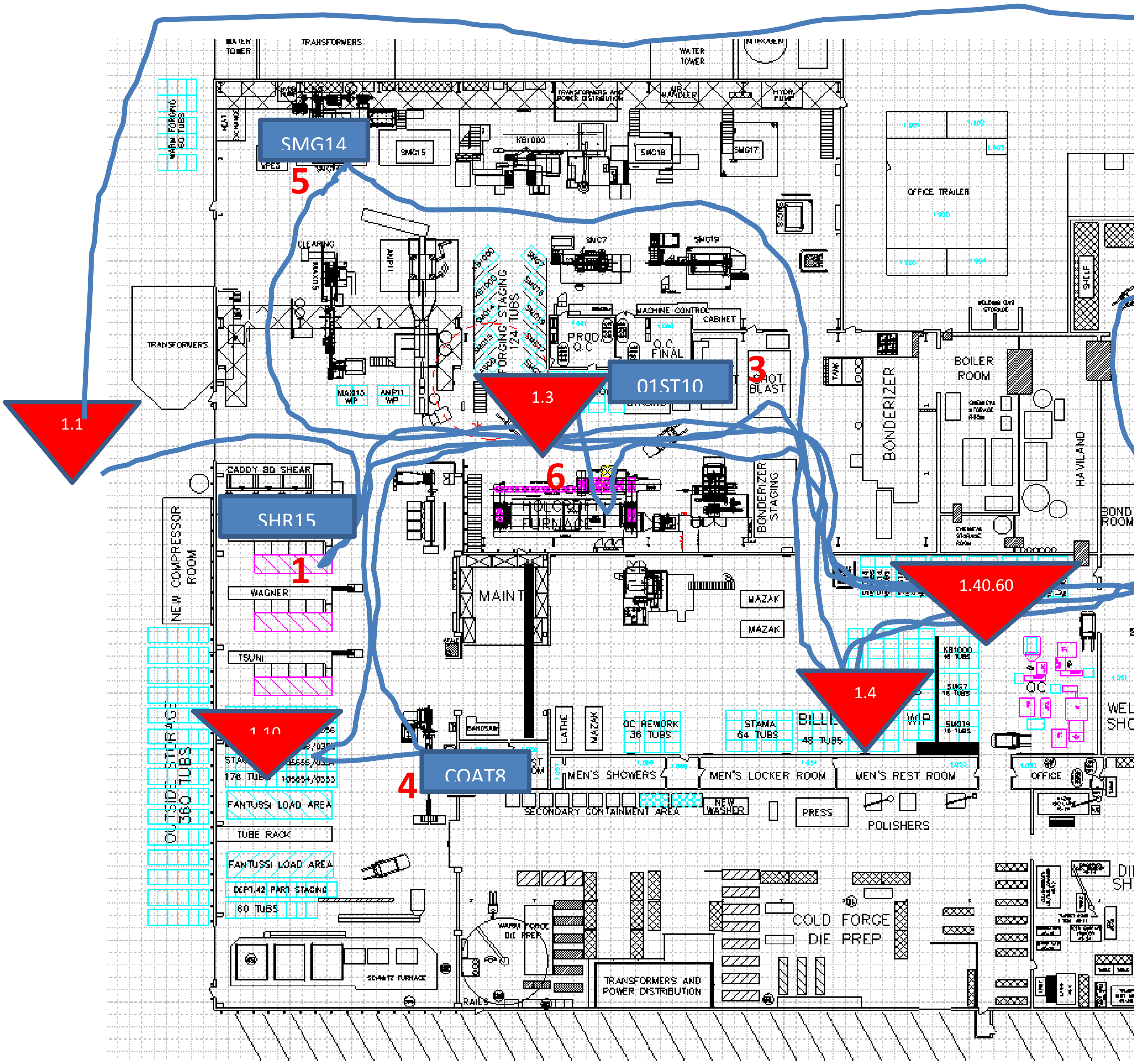


Figure 3: Spaghetti Diagram of “Magna Main Shafts”

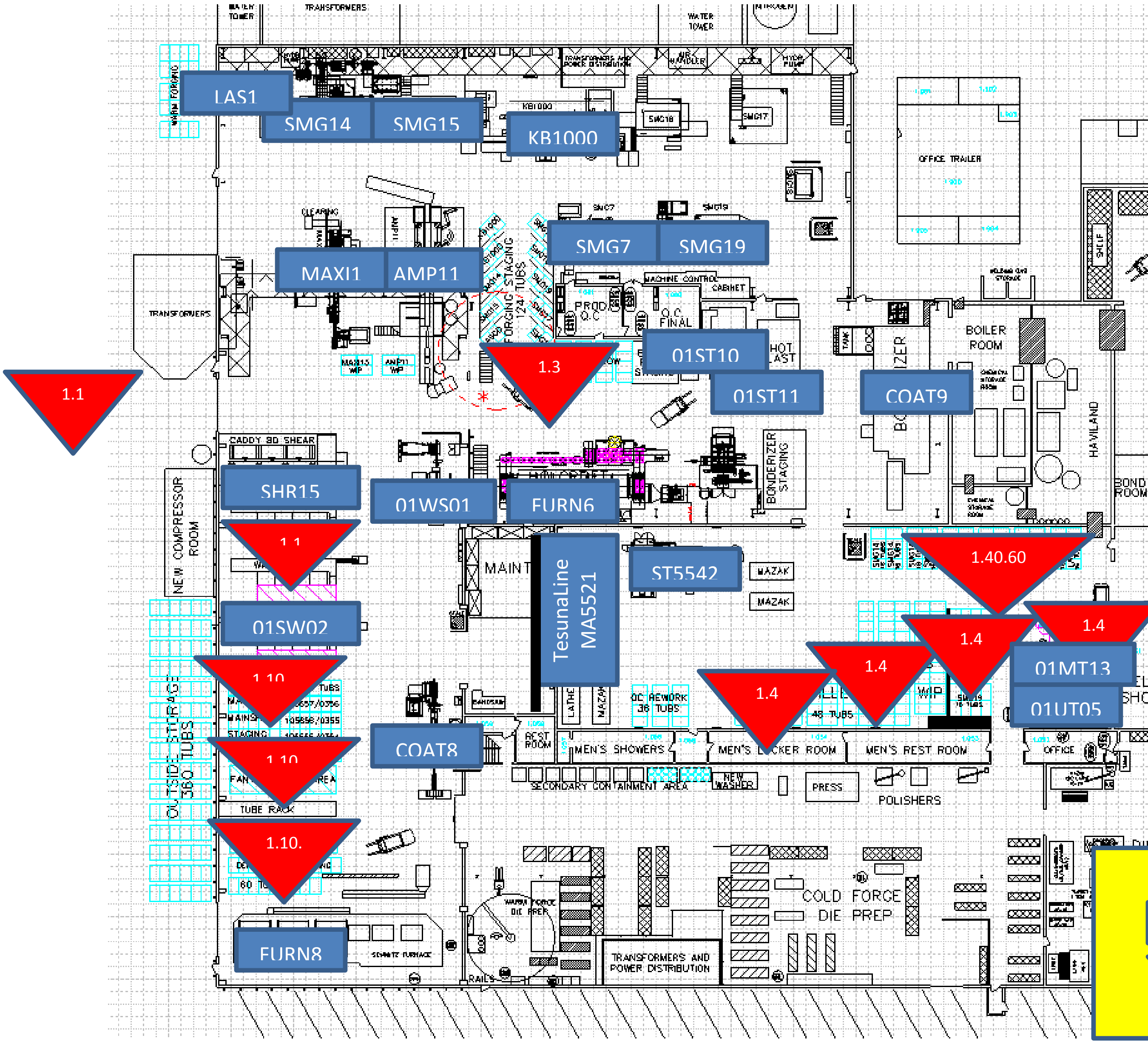


Figure 4: All Work Centers and Storage Areas in the Facility

Limitations of Value Stream Mapping in this Industrial Application

The developers of VSM acknowledge that many value streams have multiple flows that merge. This would typically be the case in Make-To-Order jobshops that make products with complex BOM's, such as welded fabrications, furniture, stamping dies, etc. In order to map multiple flows in a value stream, Rother & Shook suggest to "draw such flows over one another. But do not try to draw every branch if there are too many. Choose the key components first, and get the others later if you need to" (Rother & Shook, 1999, p. 19). This approach, when applied in any high-mix low-volume (HMLV) facility, will:

- Ignore numerous other important Value Streams
- Ignore sharing of common work centers by these "ignored" Value Streams
- Ignore the finite capacity-constraints of bottleneck work centers
- Ignore the need for monitoring, modifying and managing a dynamic production schedule

While VSM could certainly be used to produce good results, VSM however does not deal with large parts or families of parts in a jobshop environment. To use VSM to draw all routings would be inefficient and time consuming, nor effective to show the big picture of what parts the company produces. Thus, VSM cannot provide an idea about how part families can be formed. The traditional VSM method was found inadequate for mapping such a flow network.

Moreover, in forging job shops, where there are many parts sharing resources and equipments, it is important to consider all factors before crafting an improvement that applies only to certain parts. Improving some certain parts only could harm the other parts if the entire product mix is not taken into consideration. In this case, VSM does not show a complete picture of manufacturing product mix. It does not capture production flows of all parts nor does it help readers to see what improvement idea will apply to all parts.

Upon analyzing the revenue and volume of the “Magna Main Shafts”, these parts all together are the most important parts from customer relationship stand-point and the most expensive parts by revenue/part that have the same routings. However, when all product mix was considered, these parts accounted only for about 11% of total sales earned and about 8% of total volume shipped. The decision to use VSM in the Kaizen event does not include the rest of 122 parts nor taking account of 89% of total sales earned and 92% of total volume shipped. Many of the parts have unique sequence of operations that require a large variety of processes.

Based on the above limitations of the standard VSM methodology described in Rother & Shook, some literature on VSM and its application in Jobshop was reviewed. Moreover, an alternative method – Value Network Mapping (VNM) – that extends the current VSM methodology to handle fabricated products with complex BOMs was developed and tested. Specifically, VNM (a) helps to identify and merge multiple flow paths in a value stream that are either identical or similar and (b) considers *all* in-house and outsourced parts that constitute the BOM and assembly structure of the product *instead of focusing on “ the key components first”*. Hence, the proposed approach of Value Network

Mapping (VNM) was applied and tested for general use in a forge and fabrication shop facilities.

Section 3: Introduction to Value Network Mapping (VNM)

This section mostly was adapted from a paper by Khaswala Z.A. & Irani S.A., "Value Network Mapping (VNM): Visualization and Analysis of Multiple Flows in Value Stream Maps".

Value Network Mapping (VNM) was developed to eliminate the limitations imposed on the traditional methodology when "many value streams have multiple flows that merge". A Current State Map for a single component (or assembled product) is built upon the manufacturing routing (or Assembly Operations Process Chart) for the component (or product). Hence, VNM utilizes algorithms for clustering of similar manufacturing routings and design of facility layouts to identify families of similar routings for which a single composite Current State Map could be developed. In addition, these algorithms utilize special data structures that capture the *complete* assembly structure of the product instead of extracting the key components only.

Results obtained from an industrial case study to evaluate this approach are also presented. The steps in the VNM approach are explained below:

1. *Form a Product Family:* VSM defines a product family as "a group of products that pass through similar processing steps and over common equipment in your

downstream processes ” (Rother & Shook, 1999, p. 6). Since VSM is a manual diagramming method, the products that have been studied to date have few components in their BOMs and little or no differences in the manufacturing routings of the components contained in the BOMs. Products manufactured by a typical fabrication jobshop will exhibit the properties such as “multiple flows that merge”, “flows that are identical or differ by at most one or two process steps” and “mulitple branches in the product BOMs. They were found to differ in (a) the components contained in their product BOMs and (b) the manufacturing routings of the components contained in their product BOMs. To form product families, VNM utilizes a combination of the following methods – Product - Process Matrix Clustering, Product - Component Matrix Clustering and PQRS Analysis – that have been computerized using the PFAST (Production Flow Analysis and Simplification Toolkit) package (Irani et al, 2000).

2. *Visualize the Flow:* Using a product BOM and the manufacturing routings of the components in the BOM, the Operations Process Chart for the product can be generated and transformed into a Multi-Product Process Chart (MPPC). When these charts are mapped onto the physical layout of the facility, the Flow Diagram for development of the detailed Value Network Map is generated.
3. *Merge similar routings:* This step in the VNM approach facilitates the placement of the process boxes on the 11x17 sheet of paper when developing the Current State Map without sacrificing the exact assembly structure of the complete product. The merging of similar routings helps to “draw similar flows over one

another" but reduces the number of process boxes to be drawn on the paper. However, it is important not to lose the overall material flows contained in the Operations Process Chart for the product. This is achieved using the Modified Multi-Product Process Chart (MMPPC) derived from the MPPC.

4. *Group Similar Routings into Component Families:* This step in the VNM approach helps to group components with similar manufacturing routings into families. Thereby, one could design multiple component manufacturing cells that would supply parts to the Welding department. This is done using the Machine-Part Matrix Clustering algorithms in PFAST (Irani et al, 2000).

5. *Draw the Current State Map:* When drawing the Current State Map, VSM suggests to "choose key components first, and get the others later if needed" (Rother & Shook, 1999, p. 19). However, this would not be recommended when mapping the flows for a welded structure that requires timely delivery of multiple kits, each consisting of several different parts. Using the VNM approach, this mapping of a large number of different flows could be done at two levels: At Level 1, we would map the flows of a complete product (or a family of products) using the MMPPCs. At Level 2, we would map the flows of components in any family using the MMPPCs and Cluster Analysis dendograms. Both levels of mapping essentially seek to combine/merge several flow paths in order to generate more compact Flow Diagrams without eliminating any components in a product's BOM. For our case study, shows a VNM at Level 1 for the. A unique feature of the VNMs shown in both figures is the material handling information –

distance of travel and equipment used to move parts over that distance – associated with every flow between any pair of machines.

Section 4: Industrial Application of VNM in a Forging Job Shop

When it was suggested to company executives that their improvements were being determined without “seeing the whole”, we were invited to offer an alternative approach. Our approach utilized Product-Process Matrix Analysis which analyzes the entire product mix to find potential families of parts with identical/similar manufacturing routings.

Analysis

Group Technology provides a systematic basis for designing a Flexible and Lean manufacturing system in any high-mix low-volume manufacturing facility. In our analysis through PFAST, we show that the 4 “Magna Main Shafts” parts actually belong to a larger part family which contains 24 parts (Figure 5).

When we look at the big picture of all product mix, there are 126 parts that share many work centers with each other. PFAST identified 7 part families and each one contains a mix of high-$ value (in blue) and low-$ value parts (in white); the one in yellow is the “Magna Main Shafts” part family (Figure 6). Moreover, through Product-Quantity-Revenue (PQ$) Analysis, we found that the high-revenue & high-quantity parts which belong to the 80-80 PQ$ sample spread across all part families and there are only 43 parts there out of 126 parts, despite only 4 parts were chosen to represent the value stream.

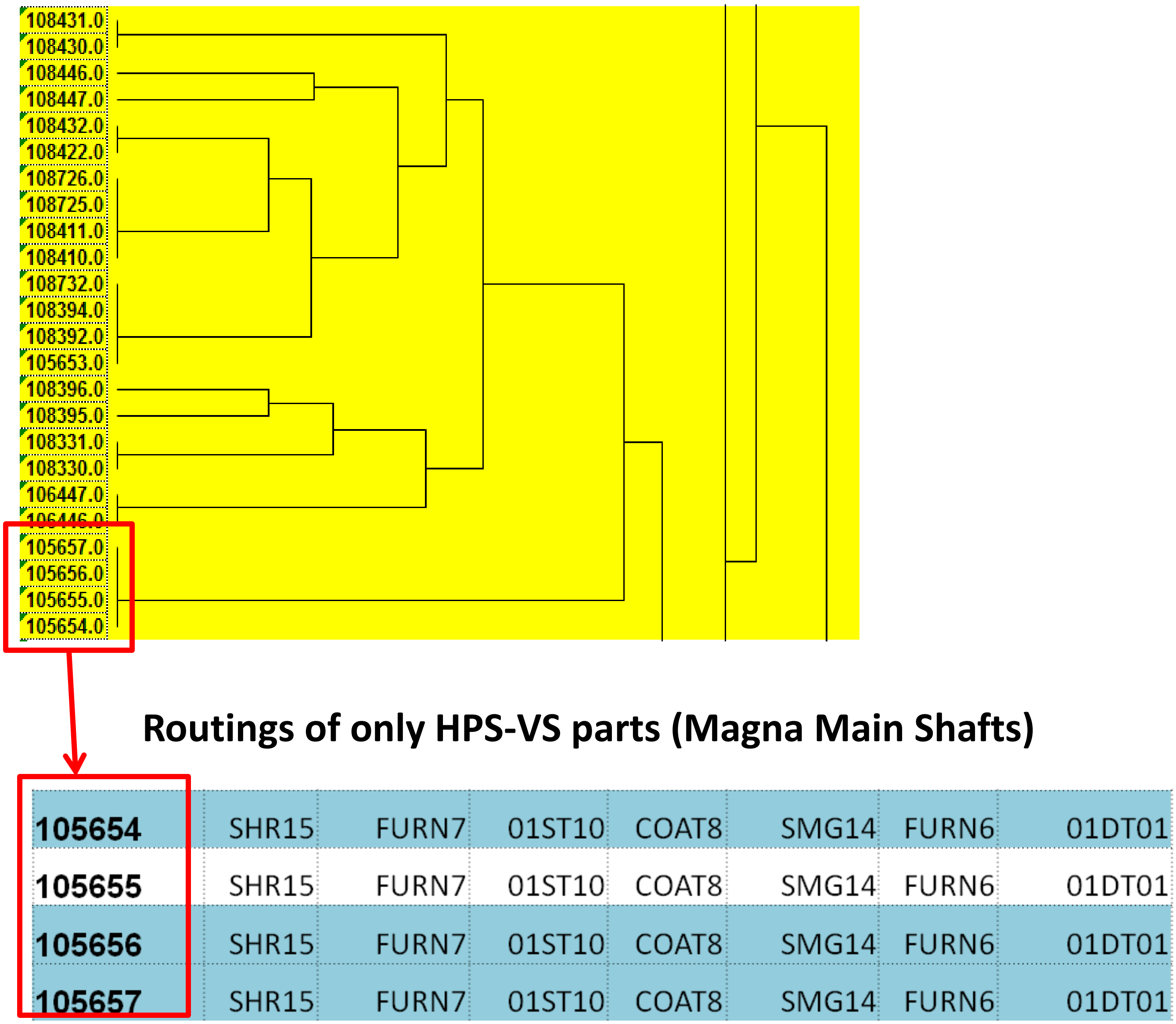


Figure 5: "Magna Main Shafts" Parts Belong to a Larger Part Family

Comparing those 7 part families, it turned out that part family 2, which is the "Magna Main Shafts" part family, has the highest volume and revenue (Figure 7). Together with part family 1, they differ significantly with other 5 part families. In this case, improvements might have to be focused on these 2 part families, but to reach the objective of "seeing the whole" picture and designing a Flexible and Lean manufacturing system, we did not compare Part Families 1 and 2 with the other part families. Instead, we chose to compare three samples of parts:

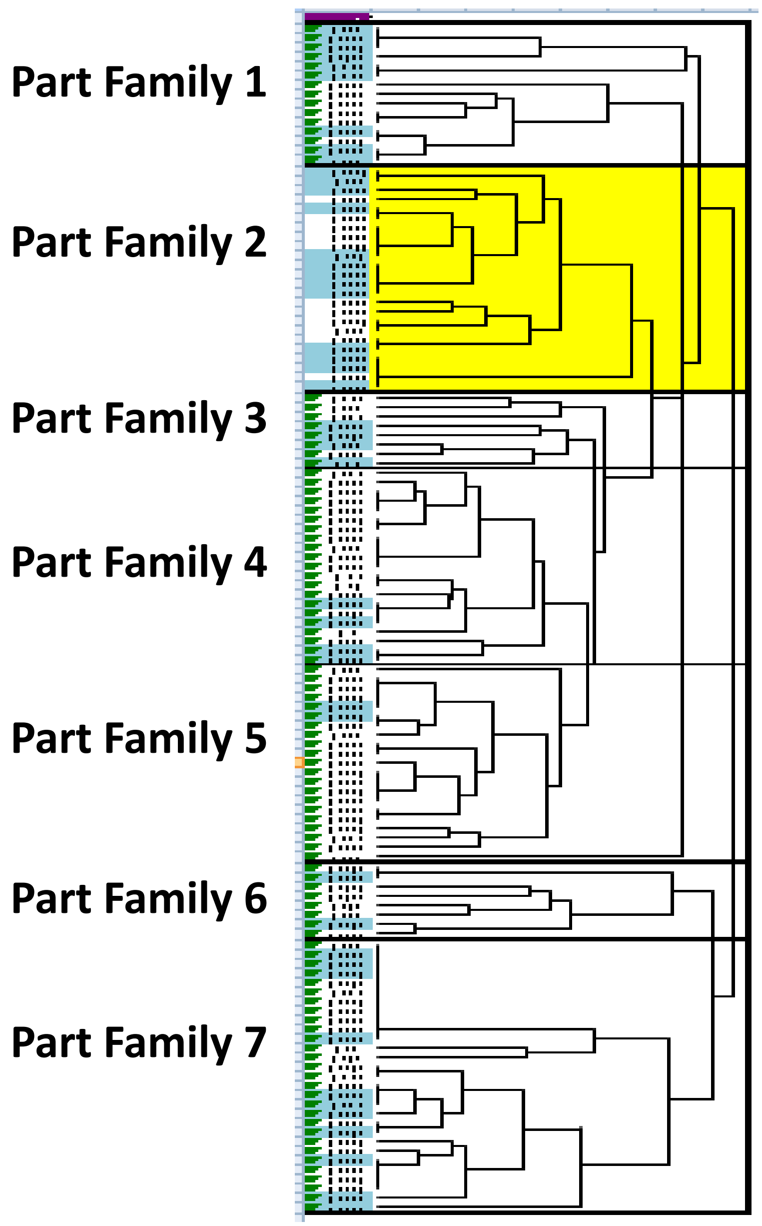
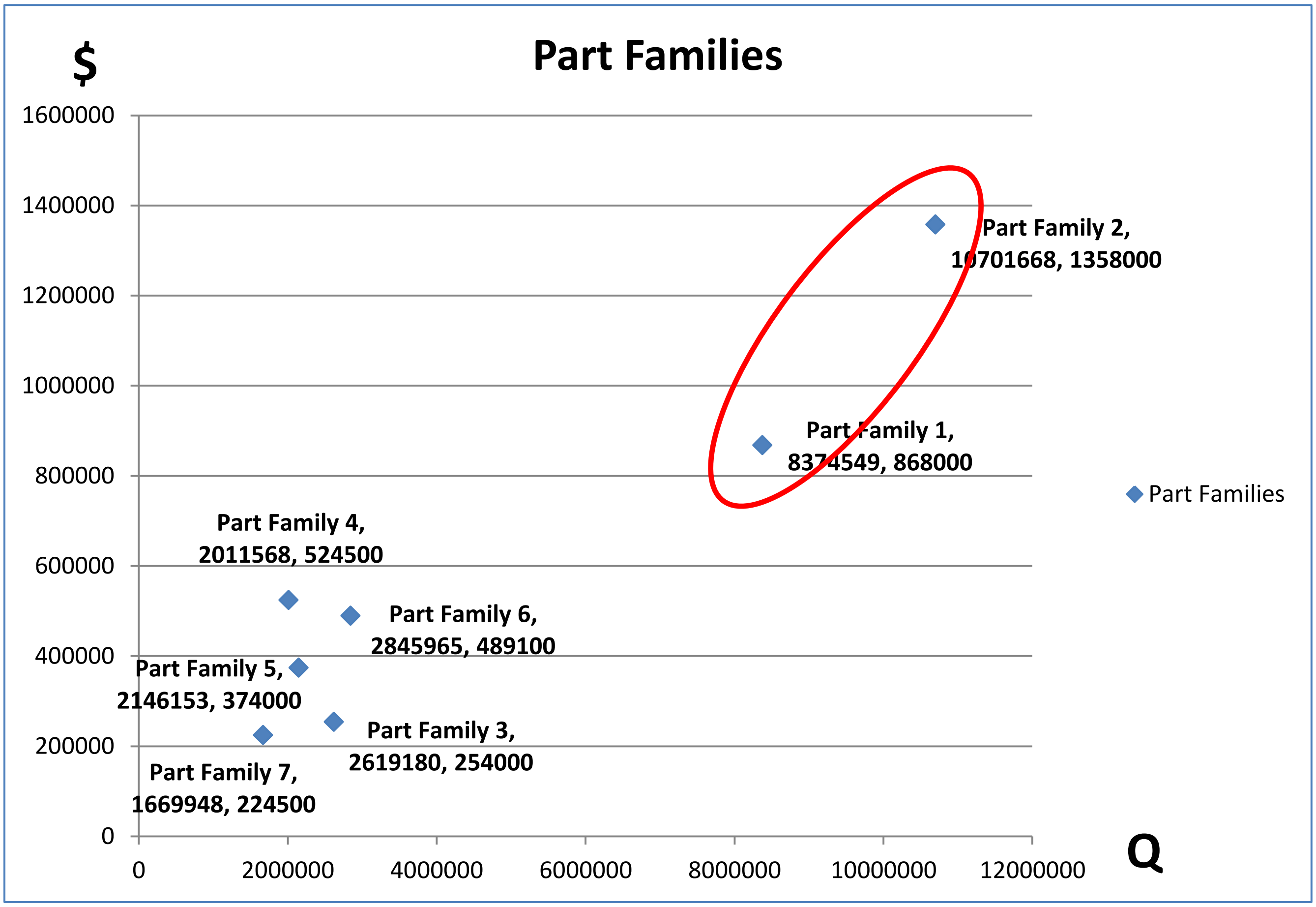


Figure 6: "Magna Main Shafts" Part Family Shares with Other 6 Part Families



Part Family 2 = HPS-VS Part Family

Figure 7: Quantity and Revenue of All 7 Part Families

1. **HPS-VS Parts:** These were the parts that were used for the VSM kaizen which are called "Magna Main Shafts" (11% of Total Sales Earned and about 8% of Total Volume Shipped).
2. **HPS-VS Part Family:** This was the part family that contained the HPS-VS parts and it includes 27% of Total Sales Earned and 25% of Total Volume Shipped.

3. **Complete Product Mix:** This is the entire mix of 126 parts currently being produced by the company. Our studies proved that the VSM kaizen used an extremely limited sample of parts that was not representative of the entire product mix. In contrast, the Product-Process Matrix Analysis made it possible to visualize the manufacturing complexity of each part family and the entire product mix (Figure 8).

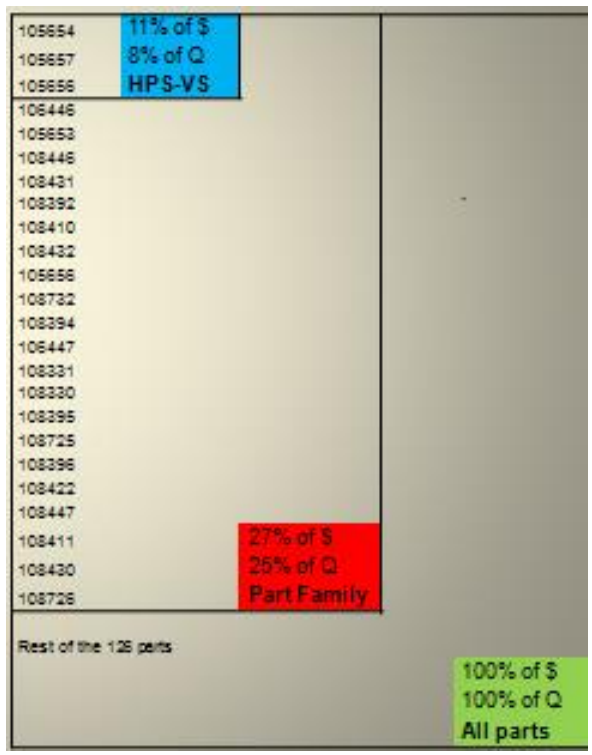


Figure 8: Comparison of HPS-VS Parts, HPS-VS Part Family, and All Parts

The analysis on revenue-based material flows between work center pairs visually shows that improving HPS-VS parts would only improve revenue/reduce cost for small portion of the production, which means there are a lot of parts carrying revenue in the material flow that are not handled. Figure 9 shows that the interaction of all parts between work centers is much more complicated compared to just within the HPS-VS parts.

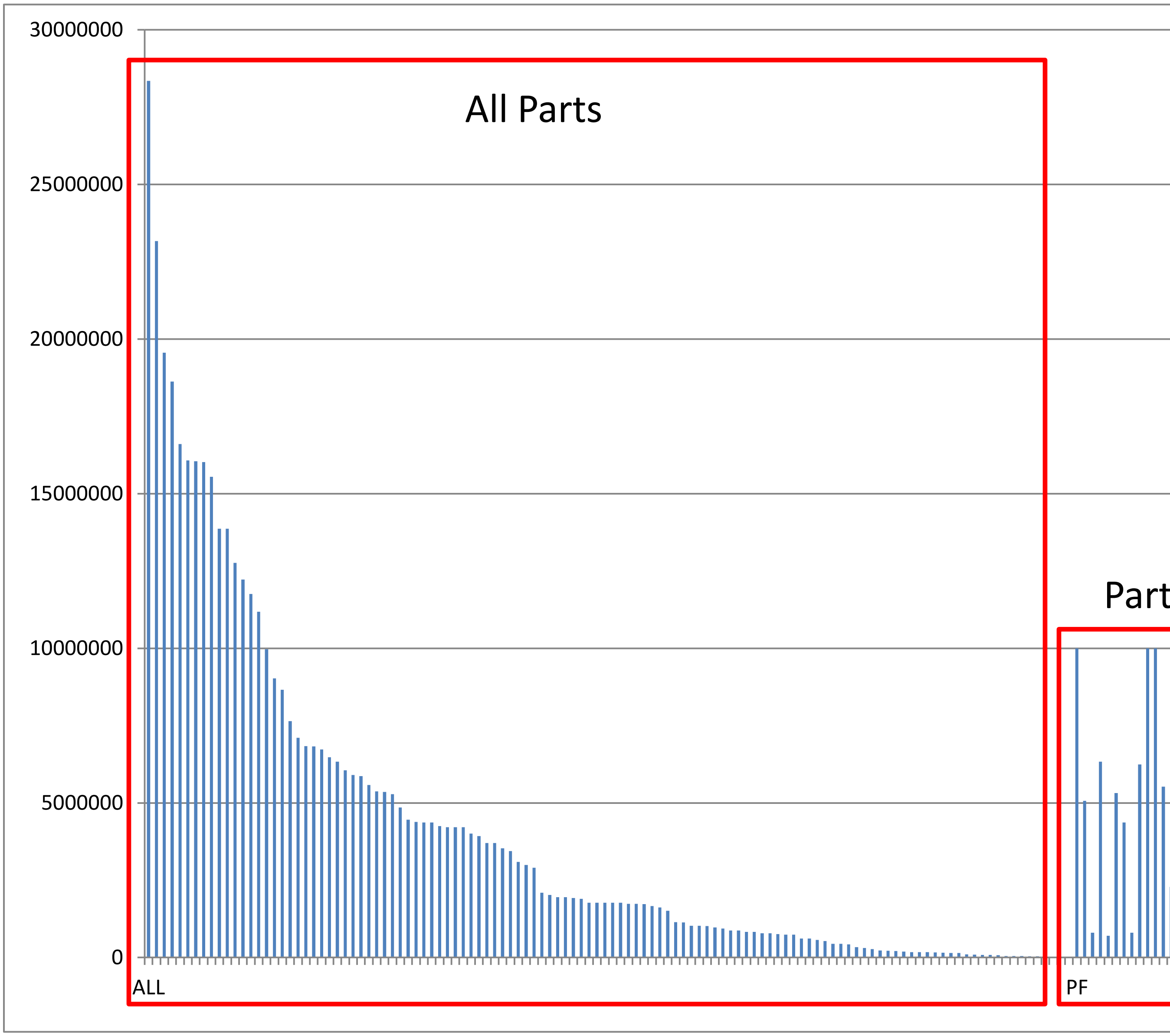


Figure 9: Revenue-Flows between Work Center Pairs

Comparing the material flows between the 3 samples (Figure 10 & 11), we found that the complexity between the samples is significantly different. Improving the HPS-VS parts only without considering the other 2 samples could impact them negatively and scheduling production on any given day would face some prioritization challenges. Figure 10 and 11 also show what we see on paper if using only Value Stream Mapping, which is the flow of HPS-VS parts only, and draw Spaghetti Diagram from it. That means we miss seeing the a lot more issues if we solely use VSM.

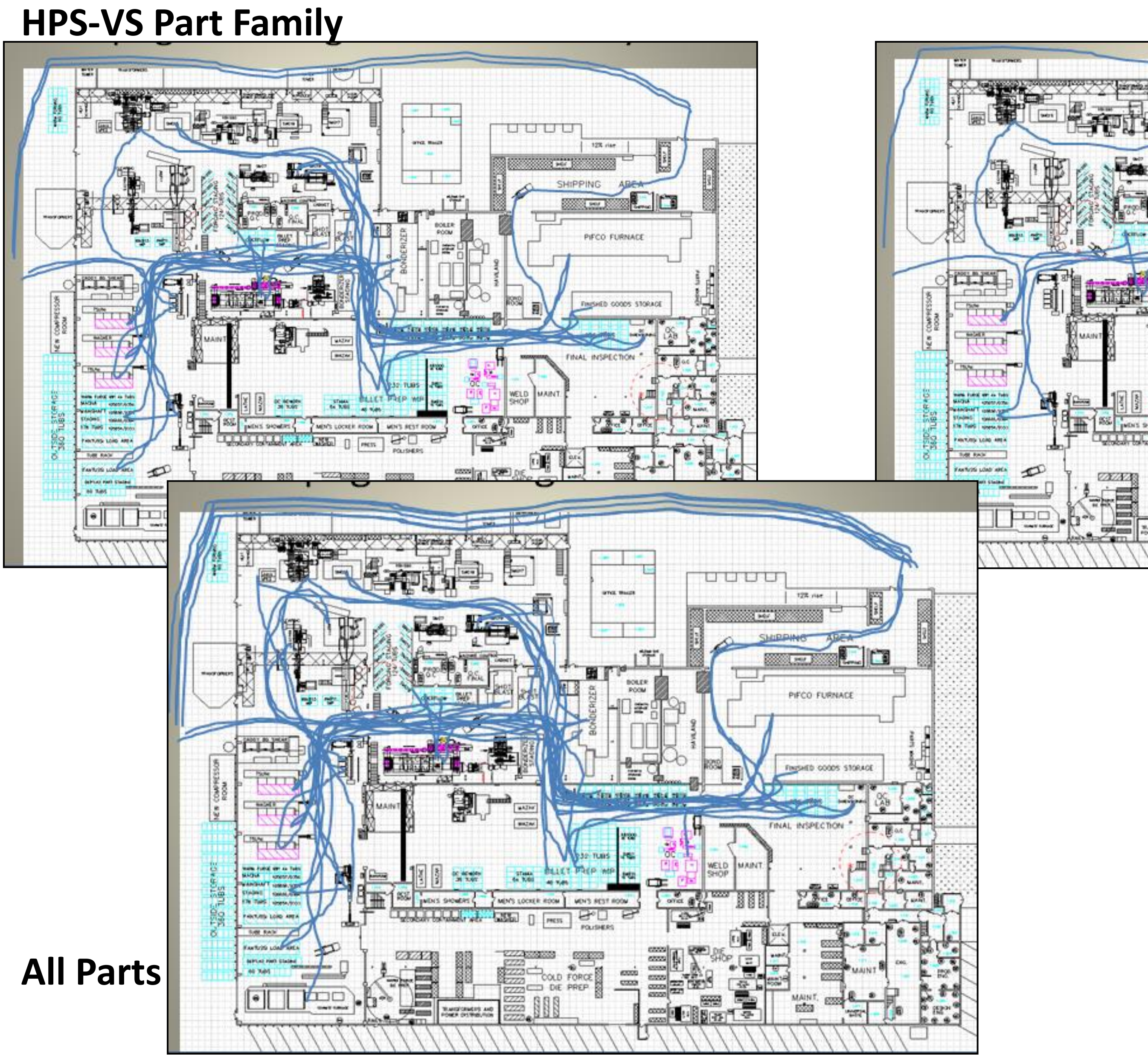


Figure 10: Manual Flow Diagrams of HPS-VS Parts, HPS-VS Part Family, and All Parts

HPS-VS Part Family

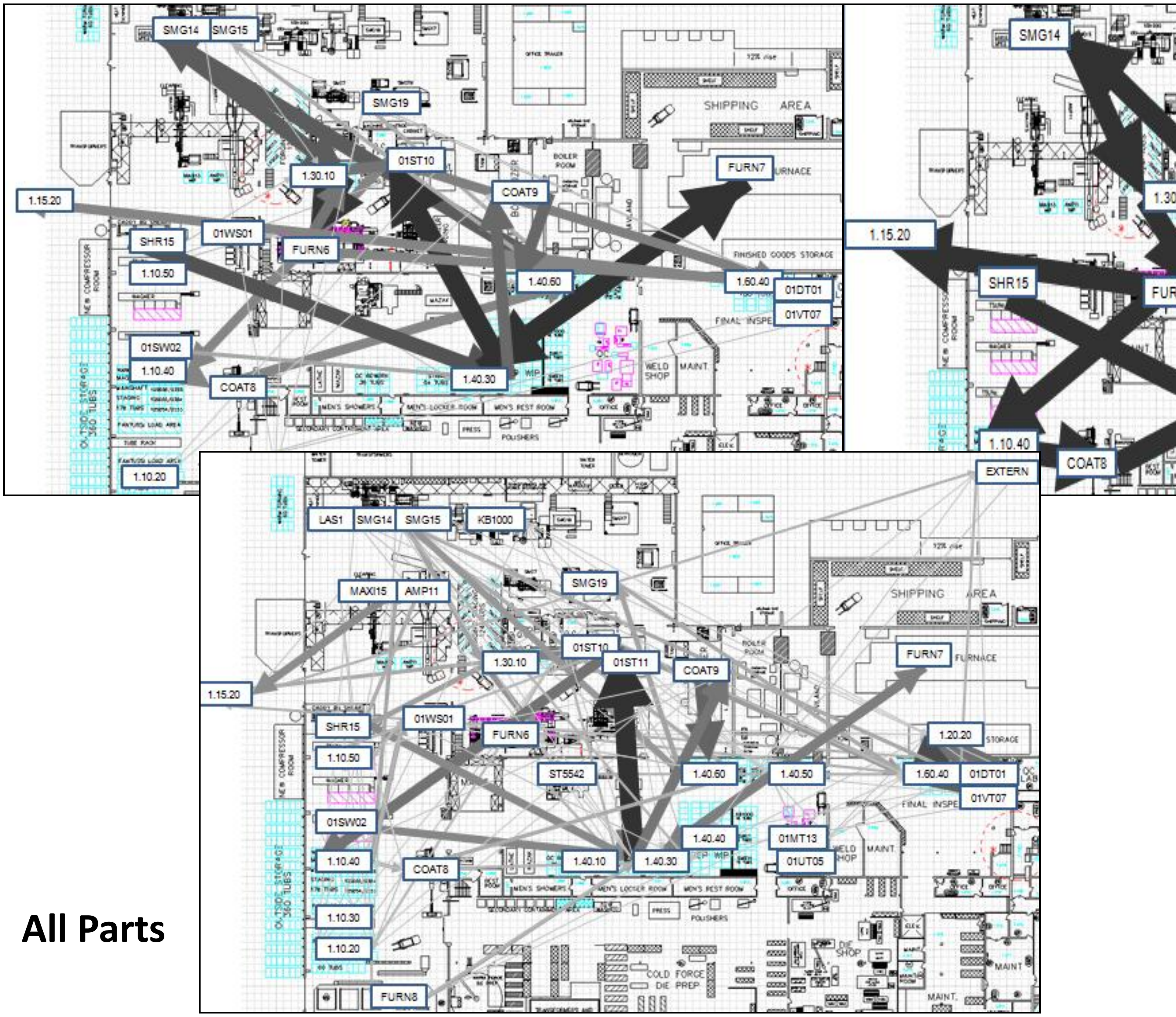


Figure 11: Computer-aided Flow Diagrams of HPS-VS Parts, HPS-VS Part Family, and All Parts

The network map drawn on figure 12 is showing the network complexities and shared work centers. These also show that working on improving HPS-VS parts only could disturb the flows within the value network in addition to differences in which work centers need monitoring requirement.

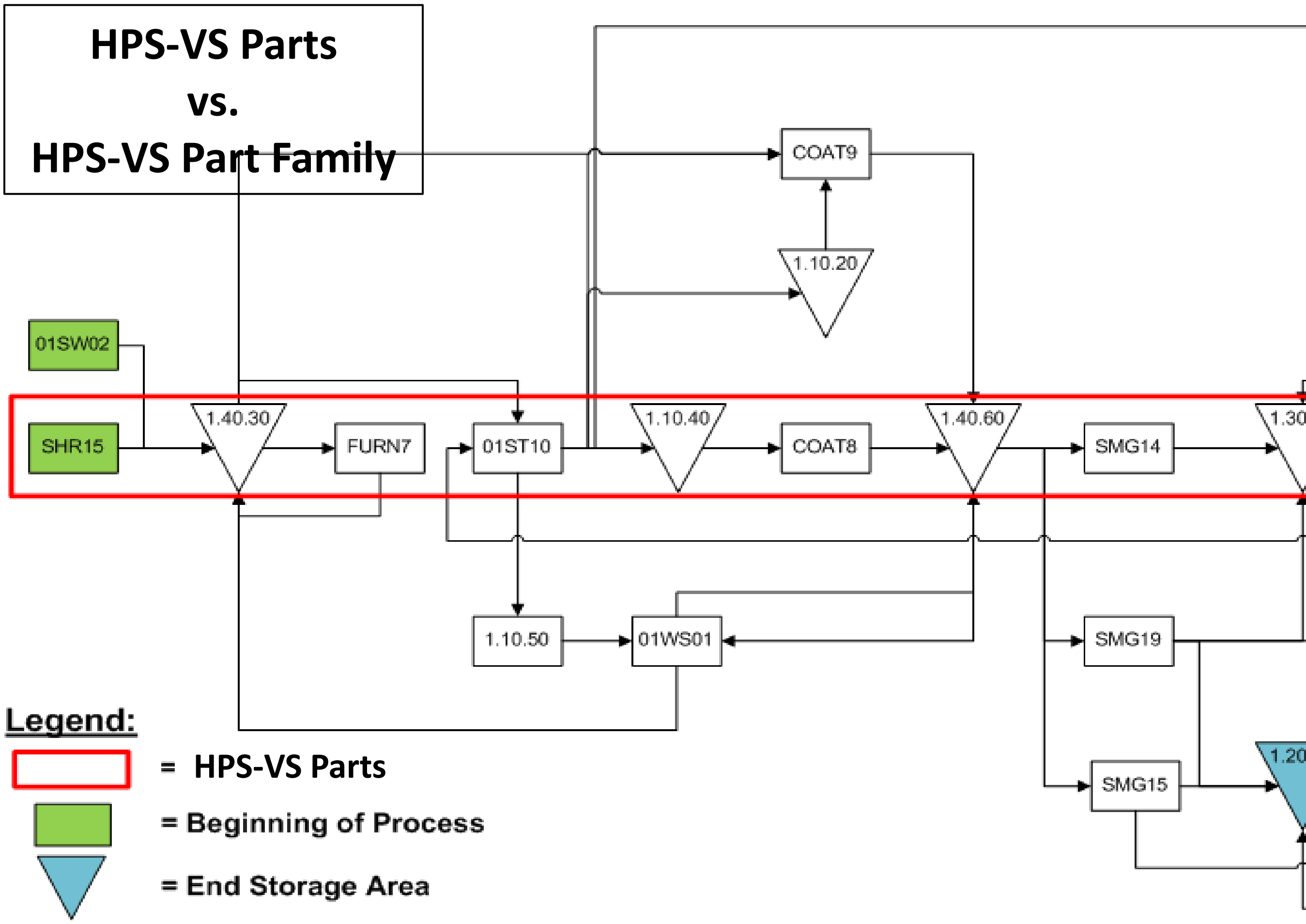


Figure 12: Network Map of HPS-VS Parts and HPS-VS Part Family

Moreover, HPS-VS parts require monitoring of only 7 out of 25 work centers and 5 out of 13 storage areas (Figure 13 and 14). We miss monitoring a lot of $-value at each work center and storage area by focusing only to HPS-VS parts, which is the blue one, compared to the HPS-VS Part Family (red) and All Parts (green). The question becomes why ignoring other work centers and storage areas when making improvements?

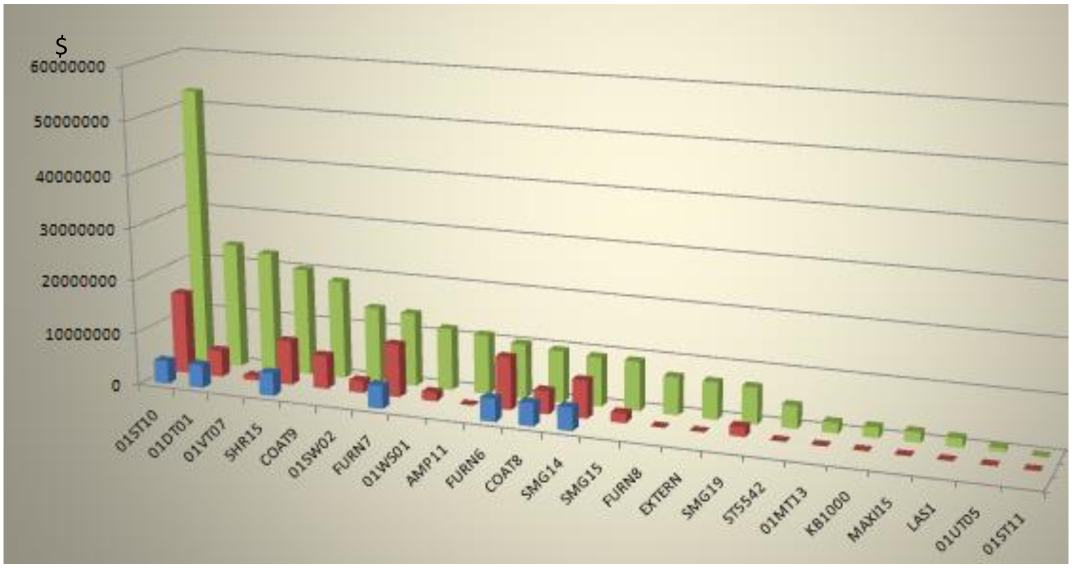


Figure 13: HPS-VS Parts Require Monitoring of Only 7 Work Centers

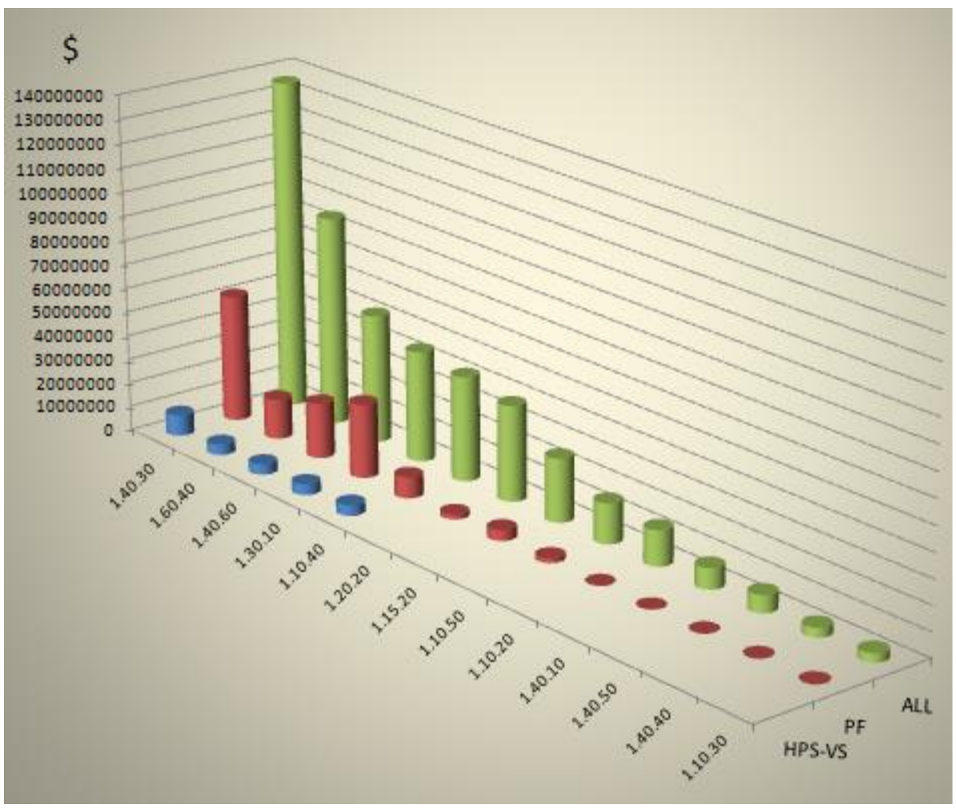


Figure 14: HPS-VS Parts Require Monitoring of Only 5 Storage Areas

The statistical analyses were run between the 3 samples (Figure 15): HPS-VS Parts vs. HPS-VS Part Family, HPS-VS Parts vs. All Parts, and HPS-VS Part Family vs. All Parts. The two sample T-test with total $ flows between all pair of work centers was run as the basis for comparison. All result in 99% confidence interval and p-value = 0.00. This means there is significant differences between the three samples being tested and we cannot assume that improving one sample would also improve the other 2 samples. This support the value network mapping method instead of value stream mapping that just focuses on 1 sample (HPS-VS parts).

Two-Sample T-Test and CI: FT_HPS-VS_$, FT_PF_$

```
Two-sample T for FT_HPS-VS_$ vs FT_PF_$
               N     Mean    StDev  SE Mean
FT_HPS-VS_$  118   481106  1373131   126407
FT_PF_$      118  1181090  2485995   228854
Difference = mu (FT_HPS-VS_$) - mu (FT_PF_$)
Estimate for difference:  -699984
99% CI for difference:  (-1380552, -19415)
T-Test of difference = 0 (vs not =): T-Value = -2.68  P-Value = 0.008  DF =
```

Two-Sample T-Test and CI: FT_PF_$, FT_ALL_$

```
Two-sample T for FT_PF_$ vs FT_ALL_$
            N     Mean    StDev  SE Mean
FT_PF_$   118  1181090  2485995   228854
FT_ALL_$  118  4100444  5468997   503462
Difference = mu (FT_PF_$) - mu (FT_ALL_$)
Estimate for difference:  -2919354
99% CI for difference:  (-4360745, -1477962)
T-Test of difference = 0 (vs not =): T-Value = -5.28  P-Value = 0.000  DF =
```

Two-Sample T-Test and CI: FT_HPS-VS_$, FT_ALL_$

```
Two-sample T for FT_HPS-VS_$ vs FT_ALL_$
               N     Mean    StDev  SE Mean
FT_HPS-VS_$  118   481106  1373131   126407
FT_ALL_$     118  4100444  5468997   503462
Difference = mu (FT_XPS-VS_$) - mu (FT_ALL_$)
Estimate for difference:  -3619337
99% CI for difference:  (-4976172, -2262502)
T-Test of difference = 0 (vs not =): T-Value = -6.97  P-Value = 0.000  DF =
```

Figure 15: Two sample T-test result between the three samples

Recommendation

Using the Value Network Maps for the three samples of parts described earlier, we suggested a variety of improvements that could be pursued, such as:

1. **Change the Shot Blaster machine used for a particular part (as this would eliminate another Shot Blast machine)**

   The current routings in the ERP system shows that only part# 107970 is going to 01ST11 Shot Blaster, while all other parts are going to 01ST10 Shot Blaster (Figure 16). Both Shot Blasters can be used interchangeably and that means there is a scheduling discrepancy in the use of 01ST10 and 01ST11 Shot Blasters. While the capacity for having 2 Shot Blasters is high, but it is not needed. Thus, we propose to change the routing of part# 107970 to use the 01ST10 Shot Blaster and then eliminate 01ST11 Shot Blaster (Figure 17). This will free up floor-space that can be converted into a dedicated storage area for 01ST10 Shot Blaster and COAT9 (Coating Machine).

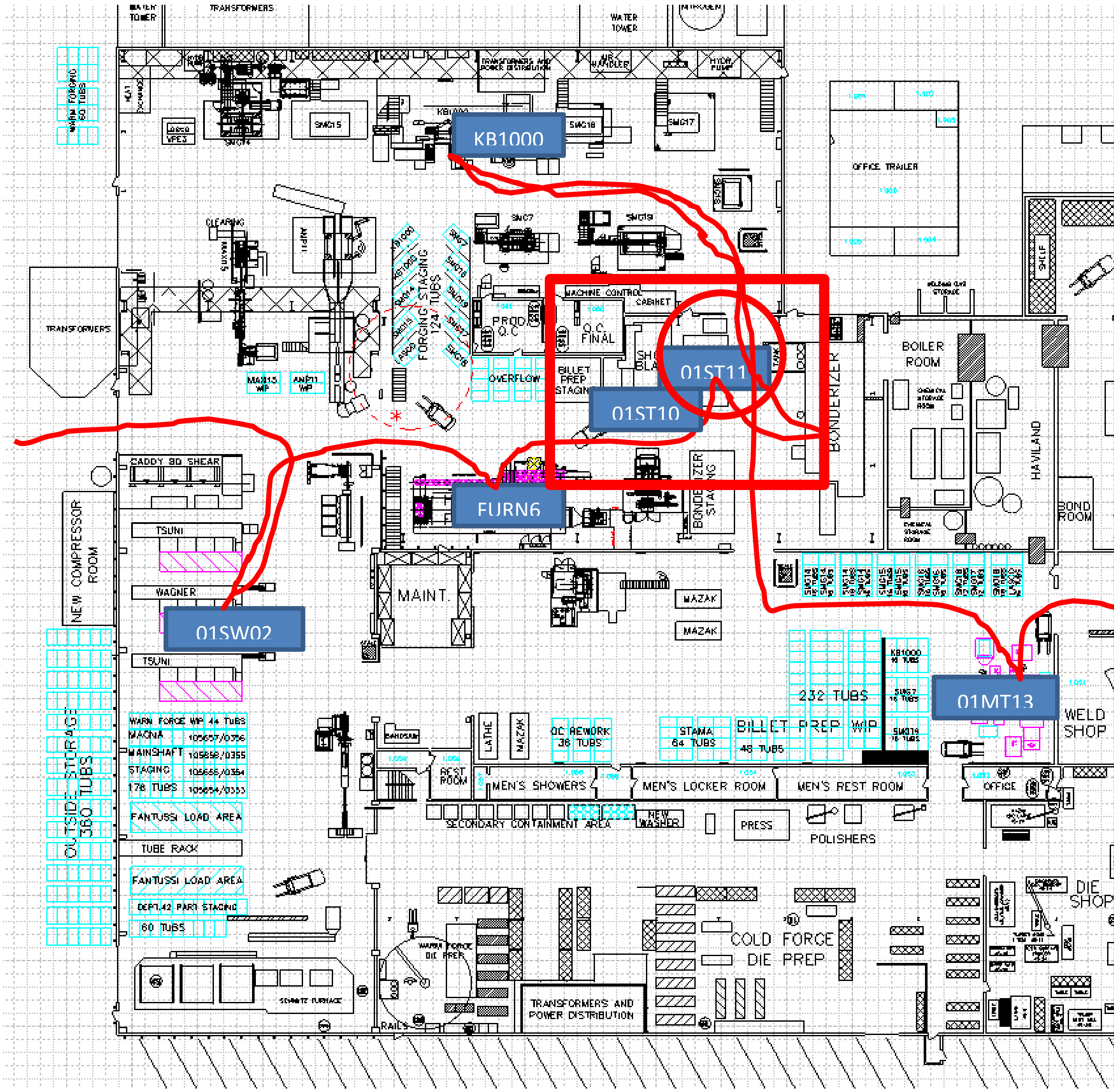


Figure 16: Current Flow Diagram for Part# 107970

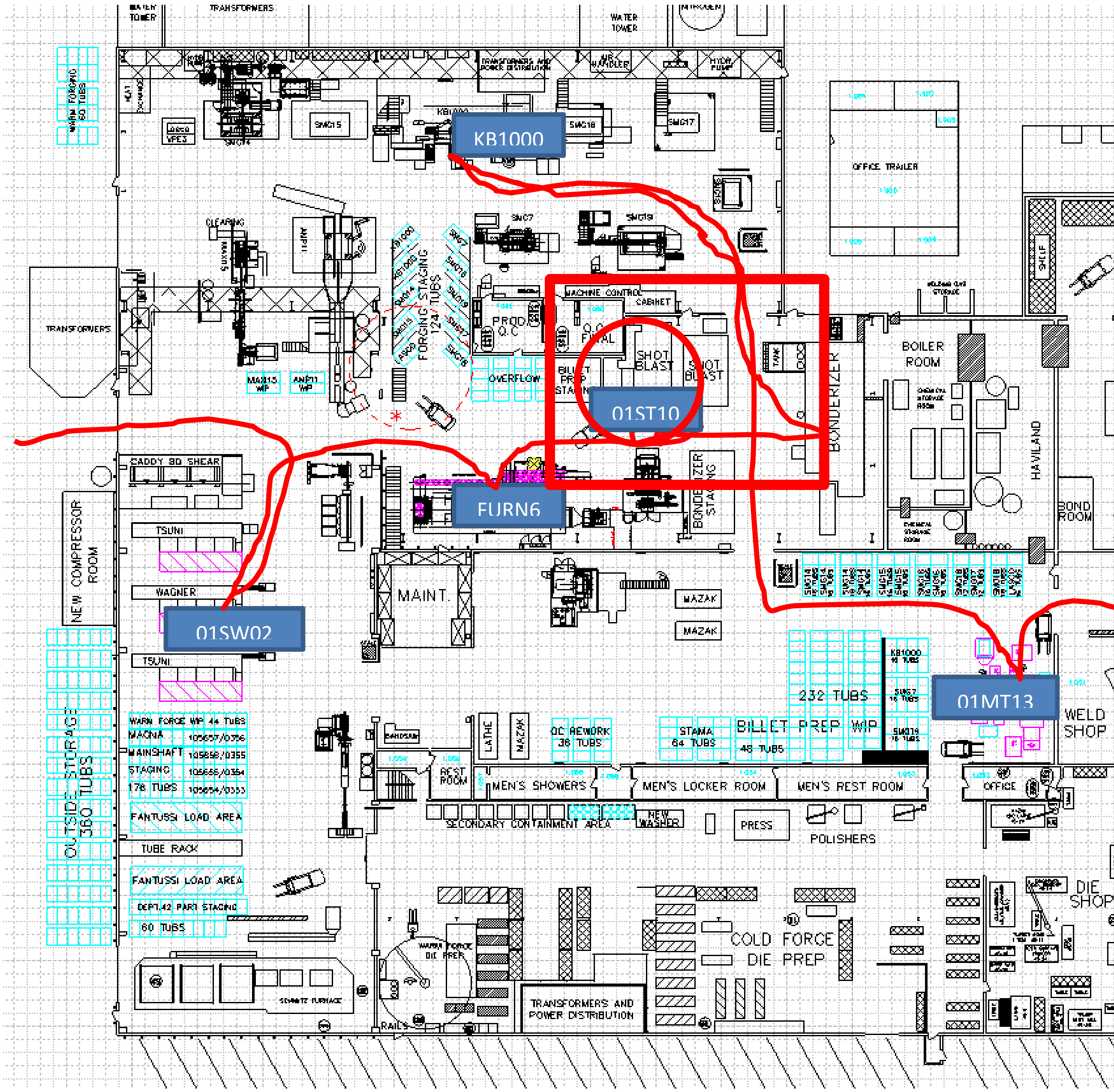


Figure 17: Proposed Flow Diagram for Part# 107970

2. **Improve the lighting and material handling safety in an aisle ("Main Street") that has heavy forklift traffic**

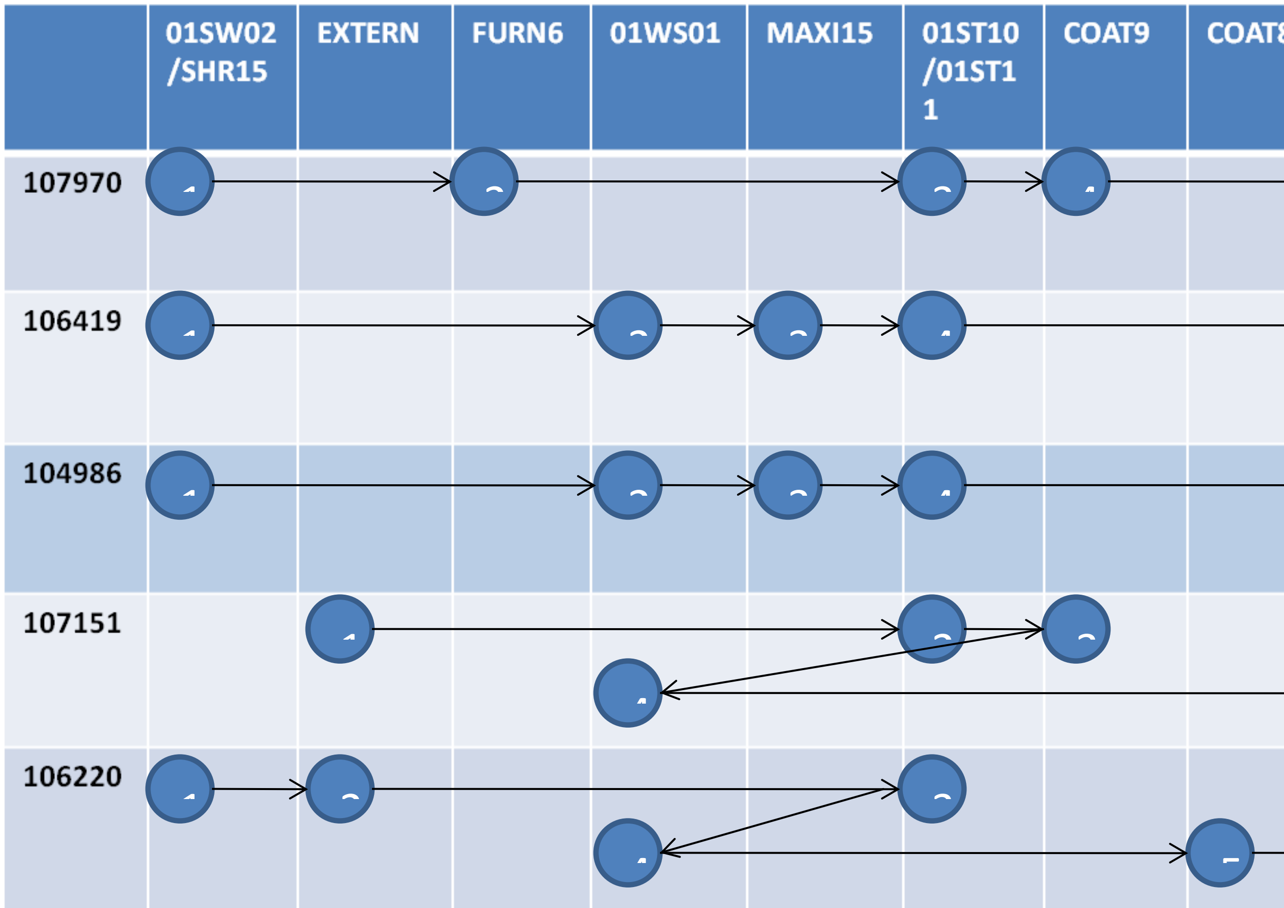
The current pathway between 01WS01 Weight Sorter and COAT9 Coating Machine (Figure 18) is the most crowded area since 01ST10 Shot Blaster is the most utilized machine and forklifts go through this pathway. There are 3 work centers and a storage area along this pathway: 01ST10 and 01ST11 Shot Blasters, FURN6 Furnace, and 01.30.10 storage area. There is no walk way, lighting is the area is dark, noise level is high, and employee’s uniform color is dark blue (Figure 19). Thus, this area has high risk of injury, especially when 4 forklifts are in operation and a person is walking at the same time in this area. In order to increase safety, we propose to change the lighting, create walkway for people, and color code zones for safety. This will benefit the company with better safety, better visual communications, better line of sight, and lower risk of injury and lawsuit. In addition to that, the company will be in good standing with OSHA rules: “Employers have the responsibility to provide a safe workplace. Employers must provide their employees with a workplace that does not have serious hazards and follow all OSHA safety and health standards.”

Figure 18: Most Congested Pathway between 01ST10 and COAT9

Figure 19: Dark area between 01ST10 and COAT9

3. Co-locate Final Inspection, Ultrasonic Inspection, Visual Inspection, and Dimensional Inspection into 1 area

Currently, Final Inspection (01DT01) and Dimensional Inspection (01VT07) are located in one area while Visual Inspection (01MT13) and Ultrasonic Inspection (01UT05) are located in a different area. Upon analyzing the part routings from PFAST outputs, we found that there are consistent forward and backward flows between 01MT13 and 01DT01 and consistent forward flows from 01UT05 to 01DT01 and 01VT07 as shown on figure 20.


01SW02 /SHR15
EXTERN
FURN6
01WS01
MAXI15
01ST10 /01ST1 1
COAT9
107970
106419
104986
107151
106220

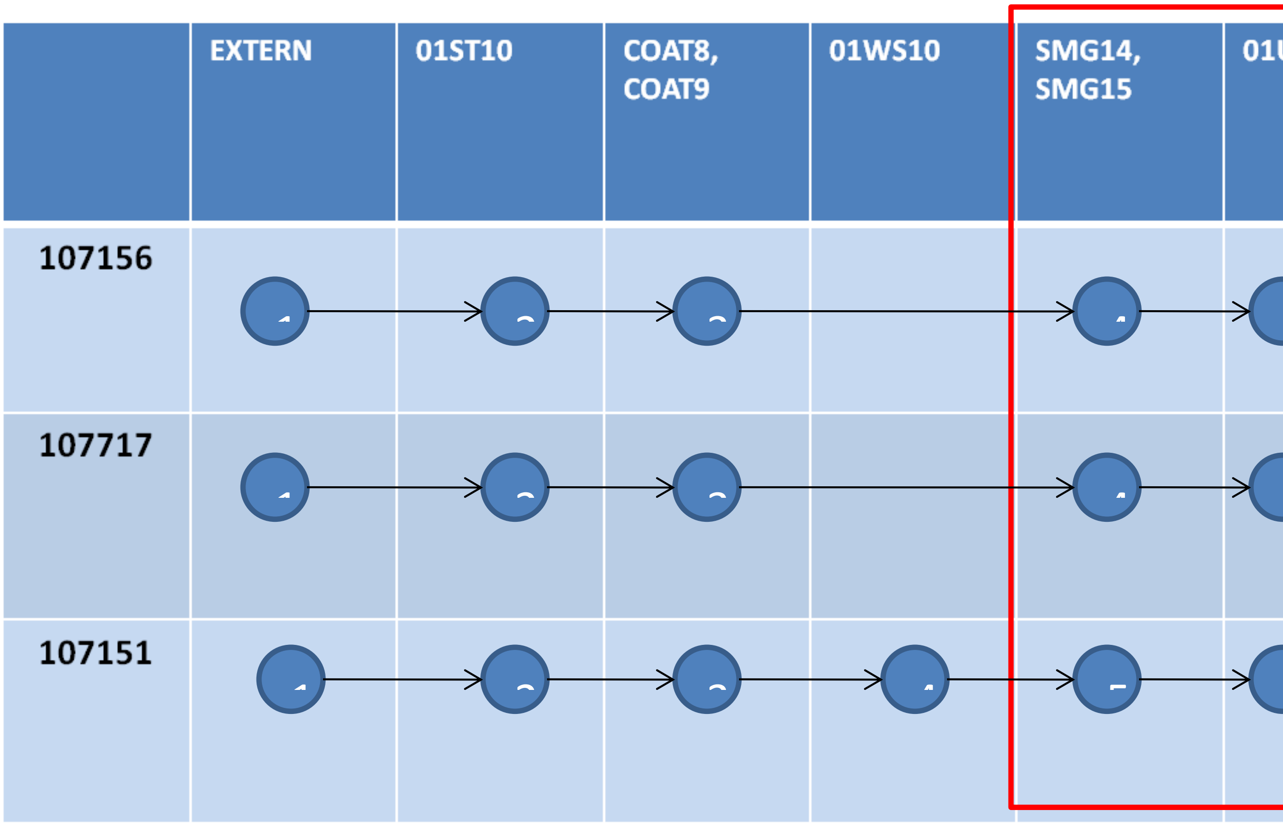


Figure 20: Routings of Parts that Go to Inspection Areas

Thus, we propose to combine all inspection areas into 1 location (Figure 21). This will reduce travel distance by at least 100 feet, reduce 1-way material handling time per trip by at least 15 seconds, and increase line of sight to 100%. Through the shorter distance alone, the company could save about $5635 annually, assuming there are 70% of product mix goes through inspections, there are 5 million of billets per year, 200 billets per bin, employee wages is $17/hour, and forklift travels 5 mph.

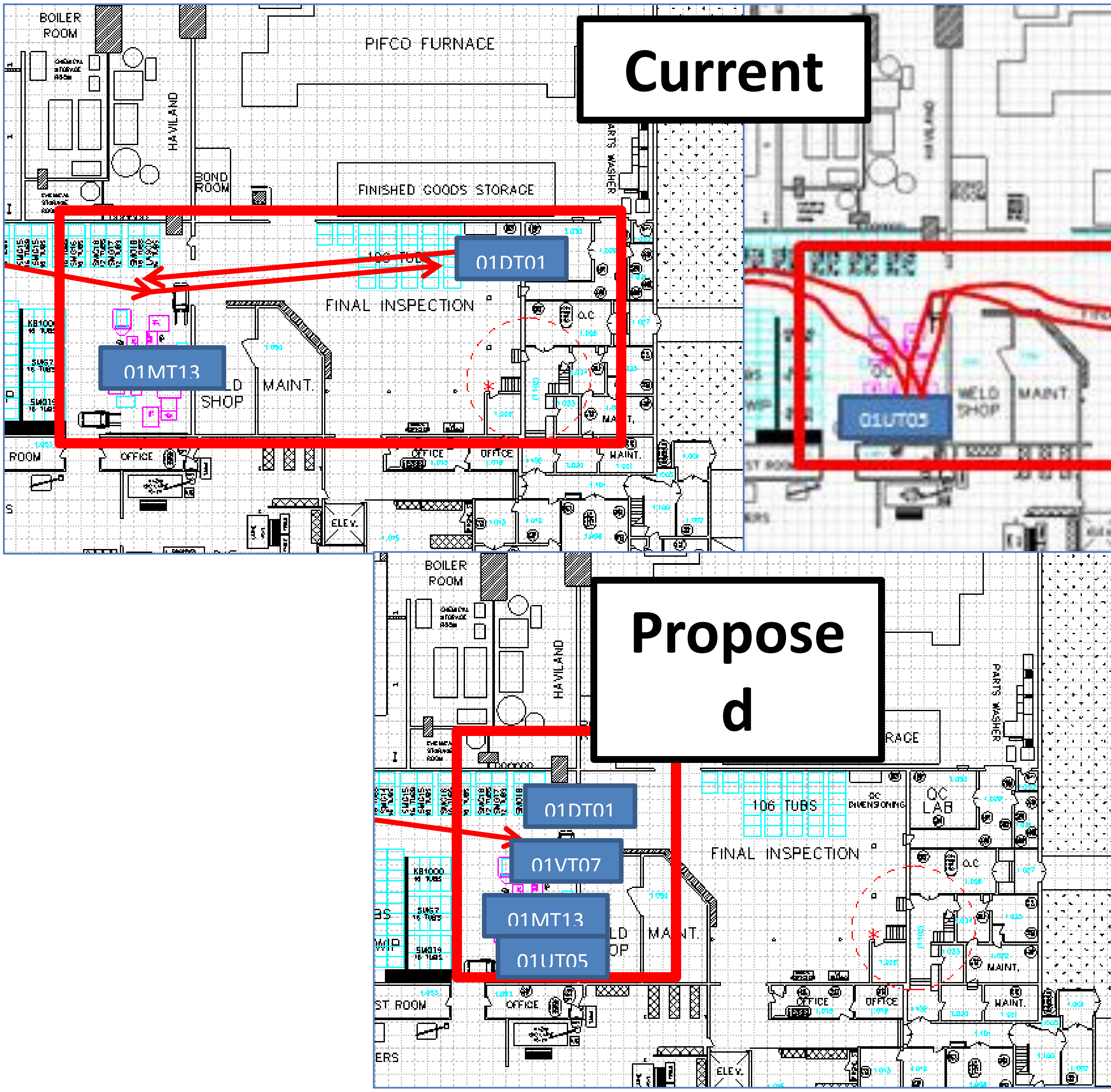


Figure 21: Current and Proposed Flow Diagrams for Inspection Areas

4. **Install a canopy over the external WIP storage areas to protect forgings from rain and snow**

Forging wet billets and accelerating cooling of hot forgings are not allowed because they could alter the billets' microstructure. However, when all storage areas inside the building are full, billets are brought outside for temporary staging. In this case, there is the risk of raining/snowing that could damage the billets and cost a lot to the company. Thus, we propose to use canopy to protect the billets. This canopy is assumed to cost $50,000, but would benefit the company through reduction of damaged billets and thus could save up to $75,000/year through this calculation:

   - 1500 parts/week stored outside for several hours; 50 week/year
   - Raining or snowing once/week (10% scrap due to rain/snow)
   - 1 scrap part costs $7 and labor cost is $3/part
   - Lose = 1500parts/week * 10% * $10/part * 50weeks = $75,000 annually

A sample of canopy can be seen in figure 22.

Figure 22: Sample Canopy for Protecting Billets

5. **Use label stand for storage areas in addition to static hanging label where needed**

   Currently all labels are static and hung above with the intention of having permanent storage areas (Figure 23). This is a good practice, but what if the storage areas cannot hold desired inventory because they are full and what if the container does not face the front and thus forklift driver could see the paperwork? Thus, we propose to use label stand for sorting and picking. The benefits are this kind of label stand is more flexible and can be moved to reflect the right inventory. Also, it can be used to sort and pick parts more accurately.

Figure 23: Static Label above a Storage Area

6. **Consolidate some of the Storage Areas and relocate the remaining Storage Areas at more strategic locations**

   With so many storage areas, it is hard to manage and control them. Thus, we try to consolidate the storage areas to reduce the number of them to make them easily to be managed. By building a p-median model, we want to choose p current storage areas among these n areas. Besides these p median, the other storage areas will be consolidated to the nearest median. The goal of this model is to minimize the total weighted distance between all the storages areas to the median which it is assigned to. The weight is the total avenue each storages area associated with.

The parameters are:

d_{ij} is the distance between each pair of storage areas. If $i \neq j$, $d_{ij}>0$; $d_{ij}=0$, otherwise.

w_i is the avenue the storage area i associate with.

p is the number of the median we want to choose.

n is the number of current storage areas.

The variables are:

$x_{ij}=1$ if storage area j is assigned to the median i; $x_{ij}=0$, otherwise. $i \neq j$.

$x_{ii}=1$ if storage area I is chosen to be one median; $x_{ij}=0$, otherwise.

The mathematical model is on figure 24 below. There are a total of 13 storage areas and each one is equivalent to different revenue levels (due to parts stored in each area). Figure 25 and 26 shows what would be the results if we have a total of 3 or 4 storage areas.

$$\min \sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij} d_{ij} w_i$$

$$s.t. \quad \sum_{i=1}^{n} x_{ii} = p$$

$$\sum_{j=1}^{n} x_{ij} = 1 \quad \forall i$$

$$x_{ij} \leq x_{jj} \quad \forall i,j$$

$$x_{ij} \in \{0,1\} \quad \forall i,j$$

Figure 24: Mathematical Model for Consolidating Storage Areas

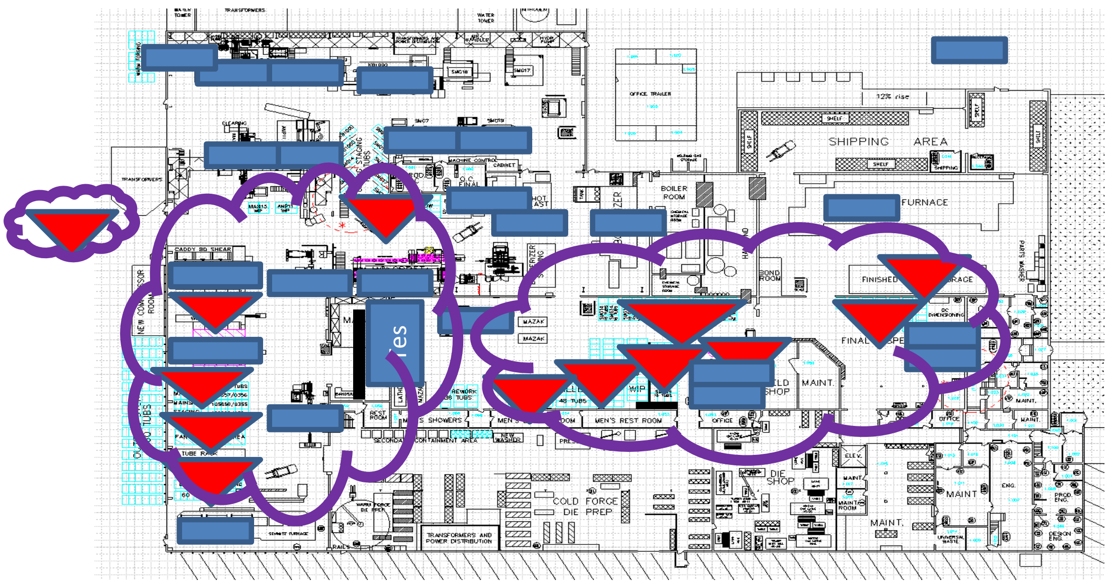


Figure 25: Consolidated Storage Areas with a Total of 3 Storage Areas

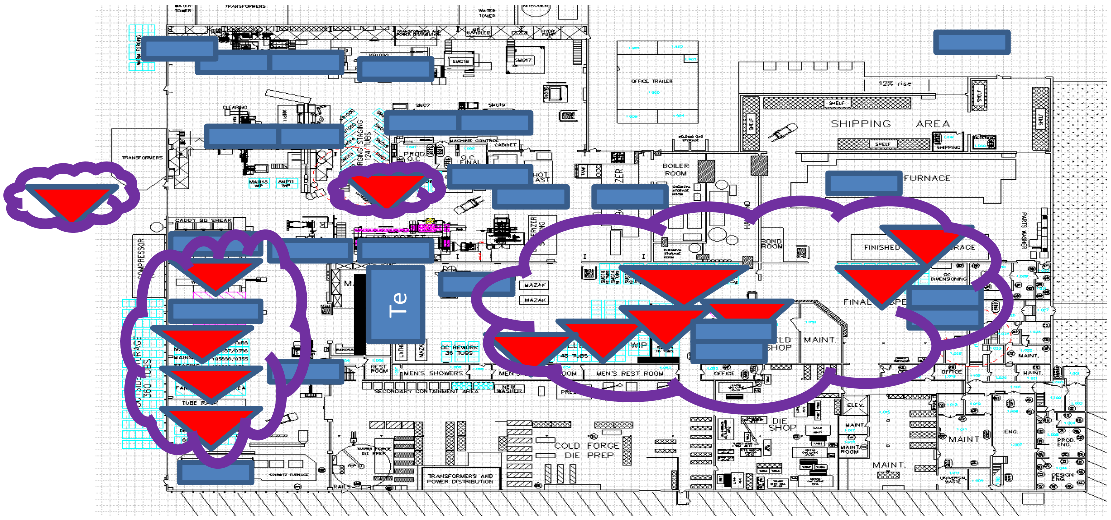


Figure 26: Consolidated Storage Areas with a Total of 4 Storage Areas

7. Co-locate COAT8 (Coating machine) to 01.40.60 area, closer to 01ST10 (Shot Blaster)

Upon analyzing part flows through PFAST output, it turns out that 23 parts travel redundantly from COAT8 to WIP area and then to the Press area where SMG14, SMG15, KB1000, and MAXI15 are located (Figure 27 and 28). Parts travel 950 feet from 01ST10 to a storage area to COAT8 to a storage area to Press area. Moreover, this travel also makes the pathway between 01WS10 and COAT9 a lot more congested. Thus, we propose to move the COAT8 to 01.40.60 storage area which is closer to 01ST10 and Press area (Figure 29). This would result in 525 feet less travel with no redundant travel from/to COAT8 as well as less congested area between 01WS10 and COAT9. This would save $1700 annually from transportation cost, assuming we use same calculation as above with the exception of 20% product mix.

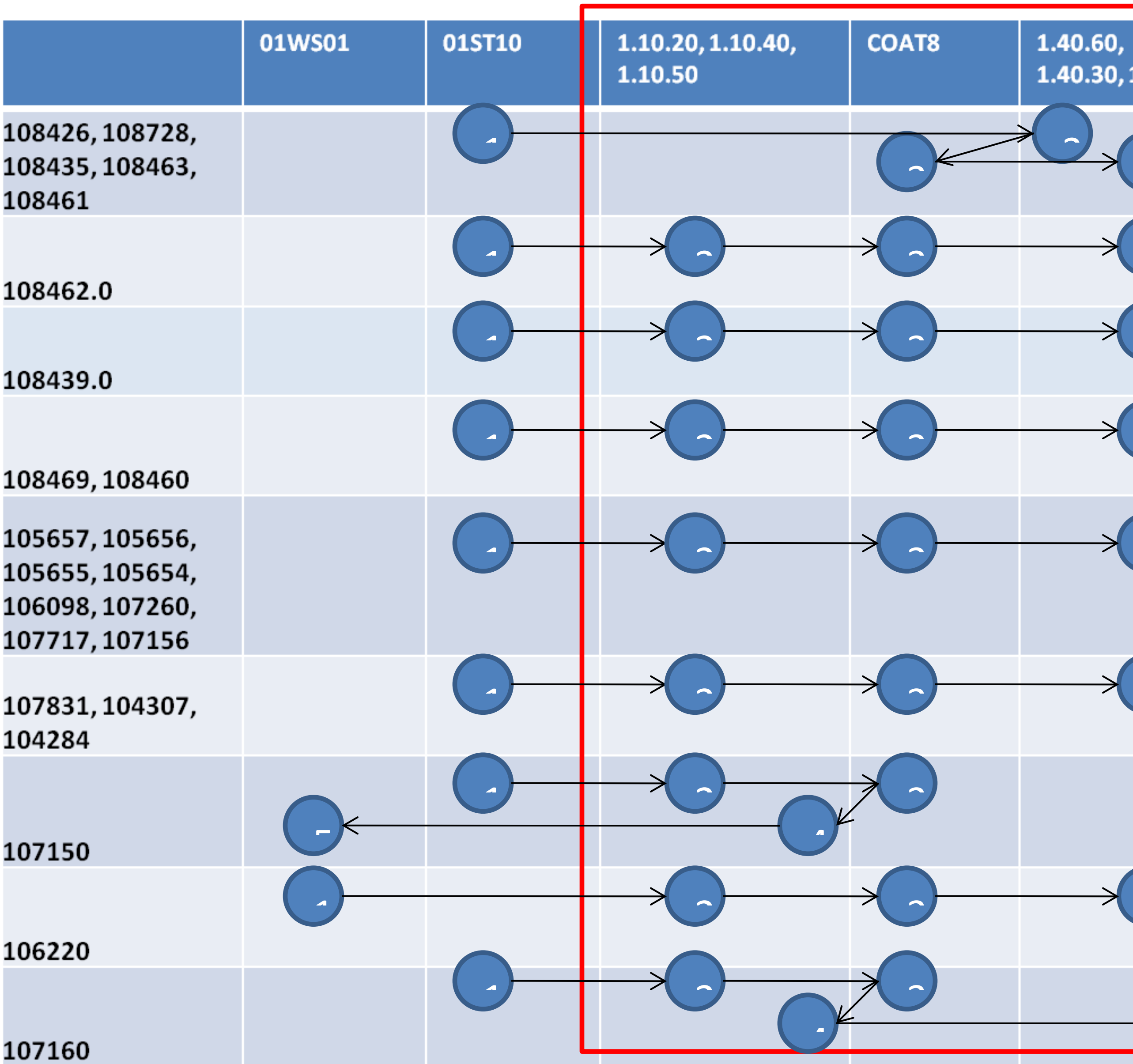


Figure 27: Current Part Routings from 01ST10 to Press area from PFAST

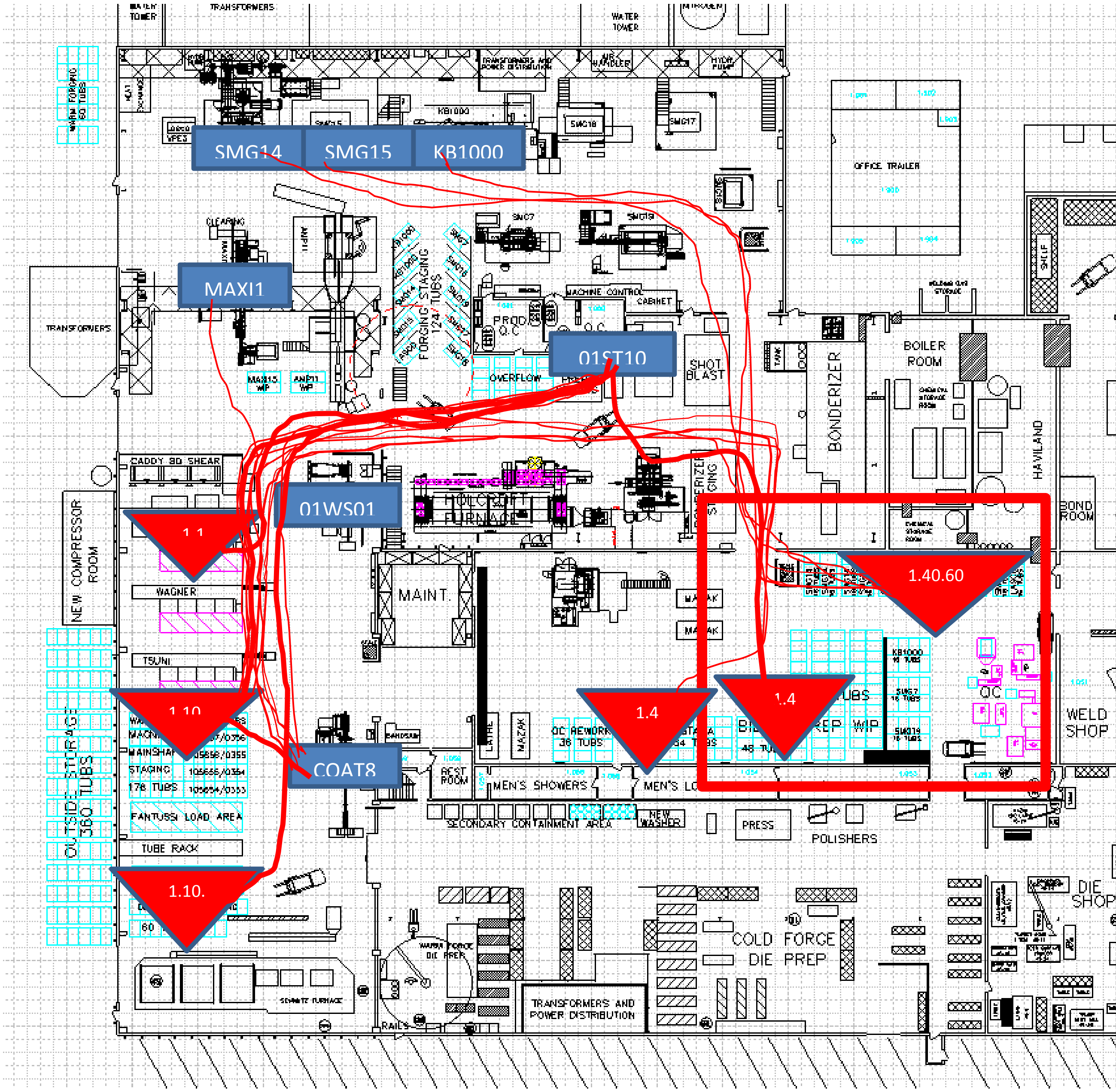


Figure 28: Current Part Routings from 01ST10 to Press area on Layout

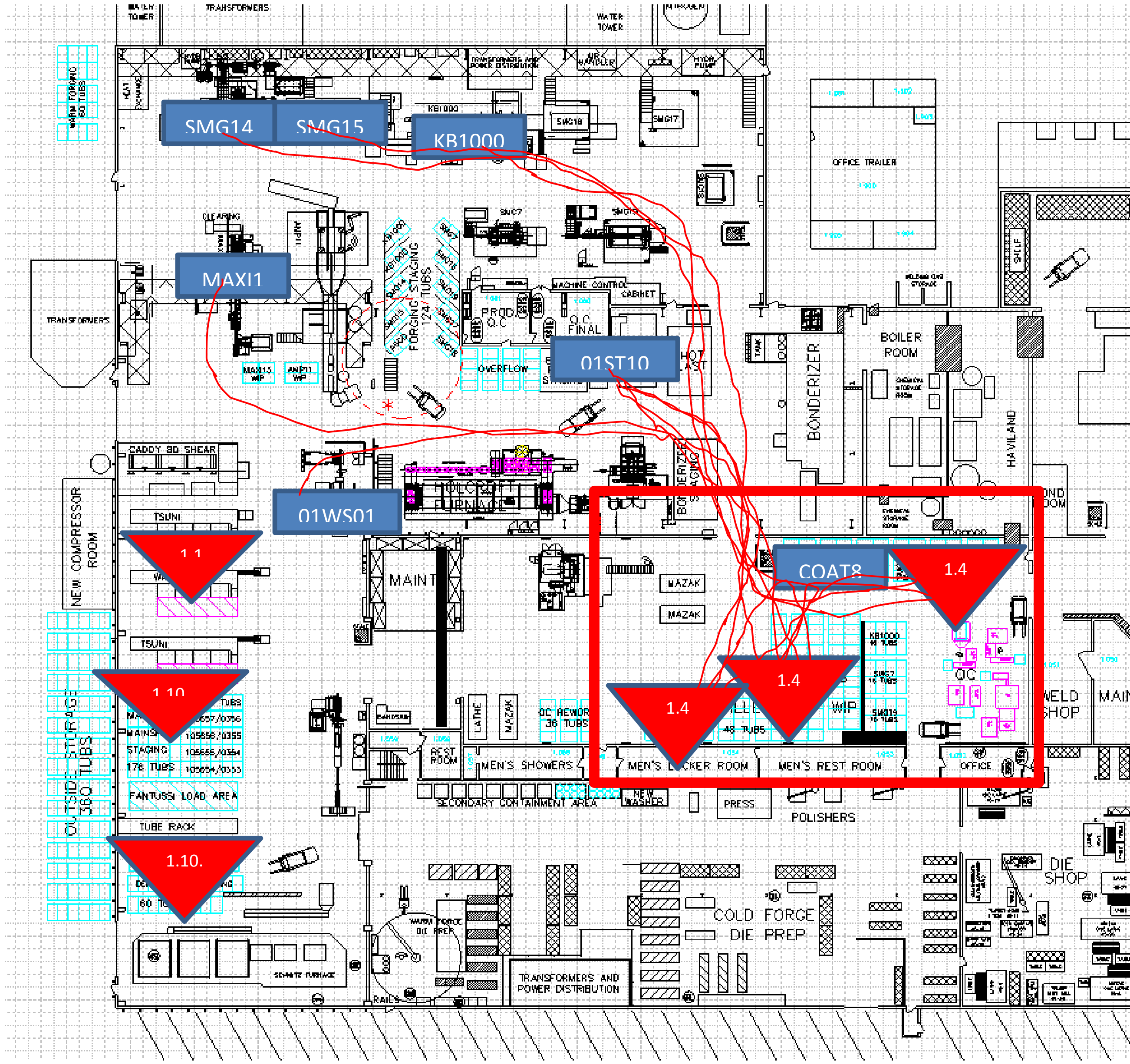


Figure 29: Proposed Part Routings from 01ST10 to Press area on Layout

8. Change the Furnace used to heat treat certain parts

FURN6 (Furnace) is currently being used by 2 low volume parts (Part# 107970 and 108462) outside the HPS-VS Part Family while other parts that use this furnace is the high volume parts. Setups and other operations of the HPS-VS Part Family might be interrupted by the low volume parts. Thus, we propose to dedicate this furnace to only HPS-VS Part Family and let the 2 low volume parts use FURN8 (Furnace) (Figure 30). This would potentially increase utilization and efficiency of FURN6, but at the same time travel distance for those 2 parts would increase by 60 feet per trip to FURN8.

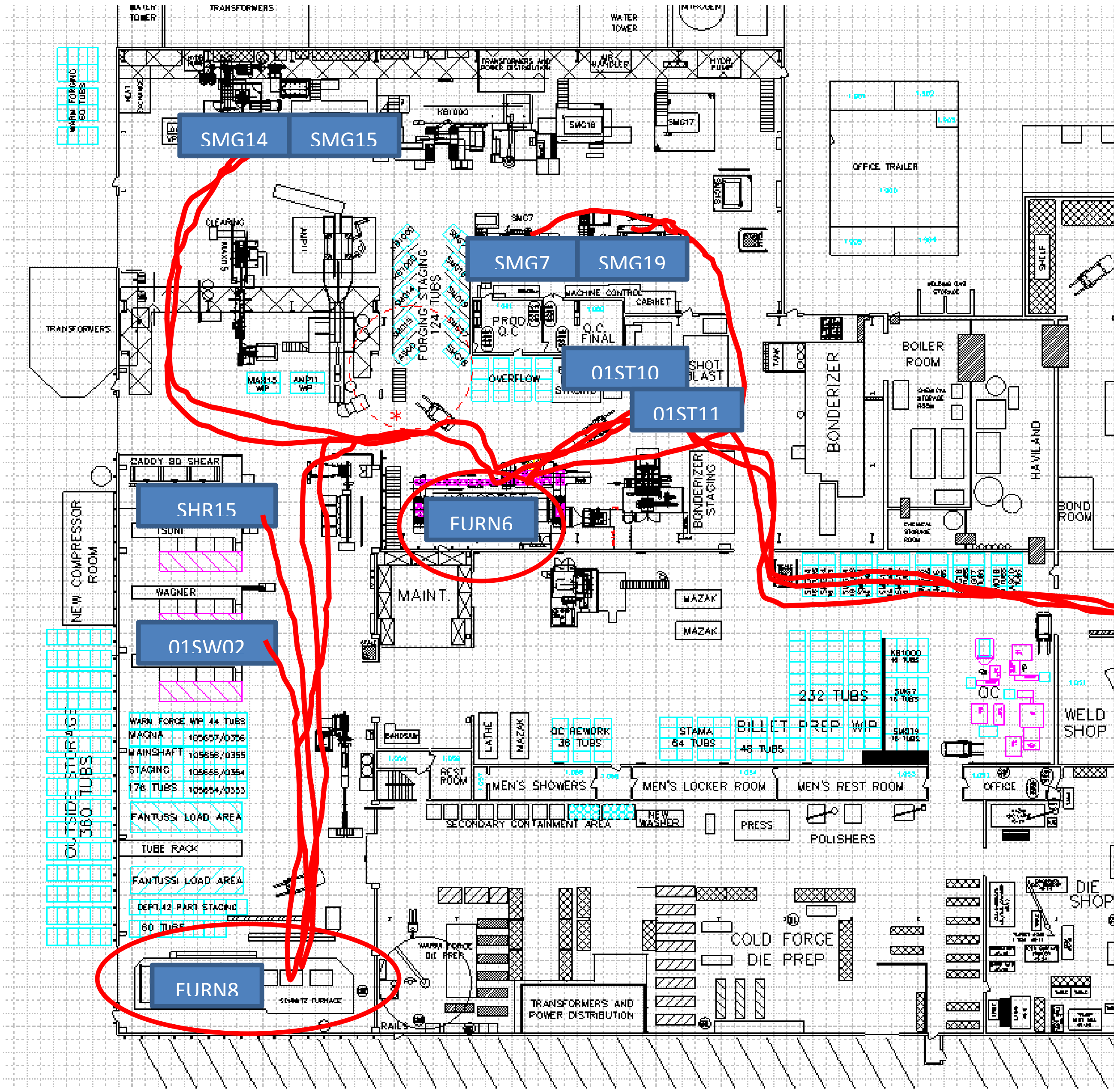


Figure 30: Two Low Volume Parts Are Diverted to FURN8 While Dedicating FURN6 to HPS-VS Part Family

9. Consider the cancellation, or strategic outsourcing, of a large number of parts that are "cats and dogs"

Looking at all current product mix, there are 13 complex parts which contribute to low unit profit (Figure 31). These parts belong to the low volume and low unit profit category, and use 11 to 13 storage areas, 19 to 23 work centers, and 11 to 15 process steps for each part. Thus, these parts are restricting current efficiency; more setups needed and higher queue variability exists. Moreover, revenue earned/hour of capacity on constrained machines is low and cost burden of material handling is high despite low profitability. In order to be more efficient and profitable, we propose to consider cancellation, or outsourcing, of these complex parts and dedicate production capacity, labor, and material handling for more profitable parts.

PART#	Revenue	Quantity	Unit Profit	$-percentage(%)	Q-percentage(%)
108439	41020	5000	**8.204**	0.102473	0.090627
107970	51500	25000	**2.06**	0.128653	0.453137
106419	190820	28000	**6.815**	0.47669	0.507513
107151	120125	25000	**4.805**	0.300086	0.453137
107154	141180	30000	**4.706**	0.352684	0.543764
106220	6920	1000	**6.92**	0.017287	0.018125
107156	76860	15000	**5.124**	0.192005	0.271882
107160	144800	40000	**3.62**	0.361727	0.725019
107914	218020	20000	10.901	0.544639	0.362509
108065	249260	20000	12.463	0.62268	0.362509
104447	227310	30000	7.577	0.567846	0.543764
107442	17674	2000	**8.837**	0.044152	0.036251
107150	187950	30000	**6.265**	0.469520	0.543763

Total $ = 40,030,204 Total Q = 5,517,100

Figure 31: List of Complex Parts with Their Revenue, Quantity, and Unit Profit

10. Utilize portable/mobile inspection

Currently almost all parts travel to the inspection areas. Those parts travel about 70 feet to get there by forklifts and a forklift can only bring 2 bins at a time. Thus, we propose to have a portable inspection where an inspector would travel to storage areas and inspect the parts. This would eliminates the NNVA travel time to inspection areas and the company would get immediate feedback on the parts.

Implementation

In this section, we discuss if the recommendations are implemented, not implemented, or is taken into consideration for future implementation. The list is ordered based on the recommendations above.

1. **Change the Shot Blast machine used for a particular part (as this would eliminate another Shot Blast machine)**

   Idea was implemented. 01ST11 Shot Blaster was removed from the facility and thus 15’ x 20’ space was freed up. This space is now used as a dedicated storage areas for 01ST10 and COAT9 (Figure 32).

Figure 32: New Storage Area for 01ST10 and COAT9

2. **Improve the lighting and material handling safety in an aisle ("Main Street") that has heavy forklift traffic**

   Idea was implemented. New lighting was put in place for safety and thus line of sight is improved and risk of injury is reduced (Figure 33).

Figure 33: New Lighting was put in Place for Safety

3. **Co-locate Final Inspection, Ultrasonic Inspection, Visual Inspection, and Dimensional Inspection into 1 area**

   Idea was implemented at a different location. Inspections were consolidated into one area (Figure 34).

Figure 34: New Consolidated Inspection Area

4. **Install a canopy over the external WIP storage areas to protect forgings from rain and snow**

Idea was implemented differently. Instead of canopy, truck container is used to protect billets from rain/snow (Figure 35). The reason why to use truck container is that it is cheap to rent it. They would increase the use of the container in the future.

Figure 35: Truck Containers Used to Protect Billets

5. **Use label stand for storage areas in addition to static hanging label where necessary**

   Idea was implemented differently. The label stand is for outside storage area to organize parts while it is used inside only for temporary storage when an area is not accurately marked (Figure 36). In addition to that, Hirschvogel made new static labels that are big and clear to read.

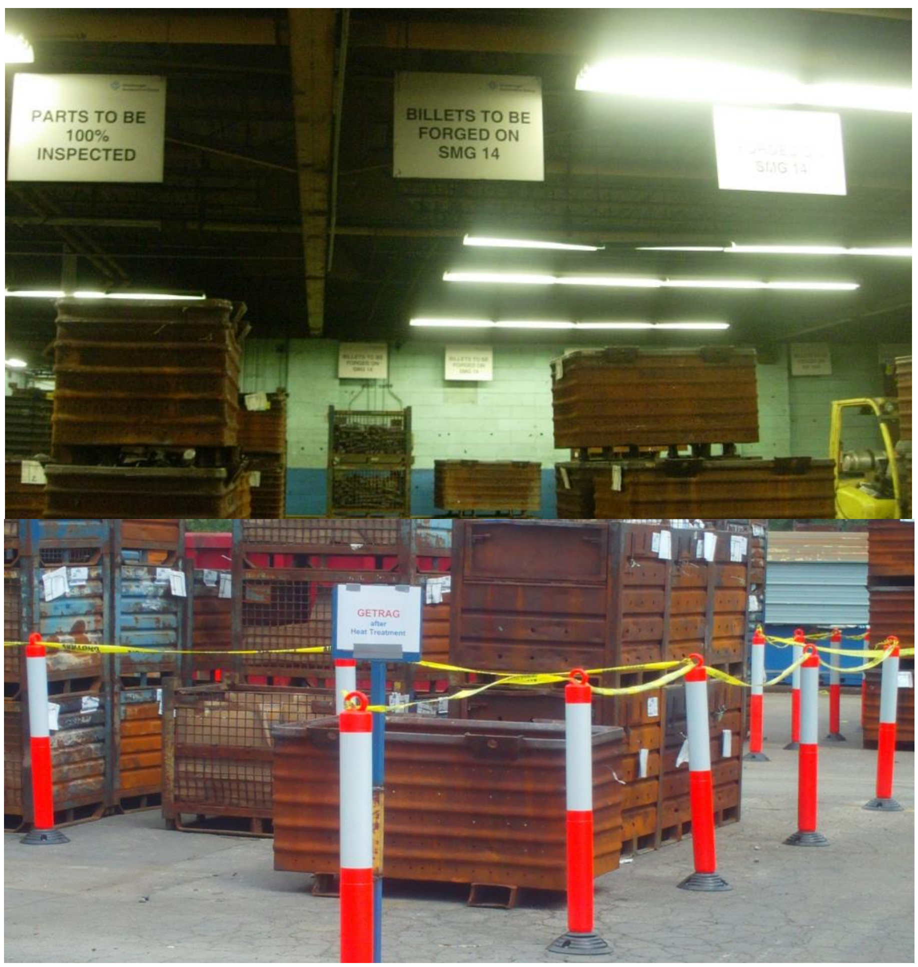


Figure 36: Label Stand at Outside Storage Area and New Static Label Hung

6. **Consolidate some of the Storage Areas and relocate the remaining Storage Areas at more strategic locations**

   Idea was implemented differently. Storage areas are not consolidated, but dedicated WIP areas were created (Figure 37). In addition to that, new system is put in place:

   - No WIP staged after an operation. WIP is always moved to next operation or staged at next WIP location
   - If next WIP area is full, production stops; storing parts outside after heat treatment might cool parts down faster

Figure 37: Creation of Dedicated WIP Areas

7. **Co-locate COAT8 (Coating machine) to 1.40.60 area, closer to 01ST10 (Shot Blaster**)

Idea will be implemented at a different location if approved by management of Hirschvogel mother company. Figure 38 shows the future location for COAT8 and Inline Weighting System.

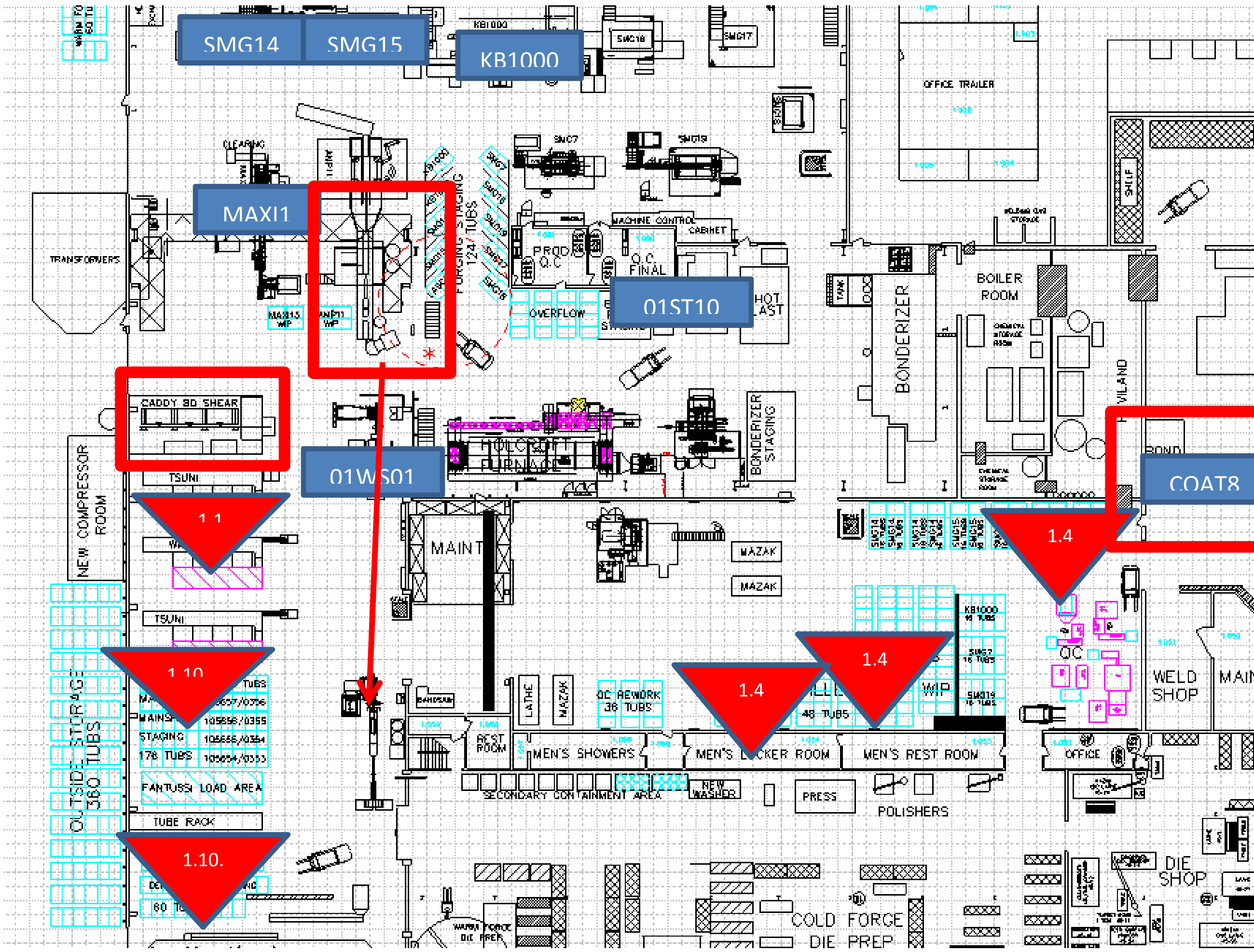


Figure 38: Future Layout of COAT8 with Inline Weighting System in Place

8. **Change the Furnace used to heat treat certain parts**

Idea was not implemented. Furnaces are not as flexible as thought.

9. Consider the cancellation, or strategic outsourcing, of a large number of parts that are “cats and dogs”

Idea was not implemented. Low volume parts have become high volume today and we cannot refuse low volume parts to customers while accepting high volume parts from them. Hirschvogel would lose customers if they accept only high volume parts from customers.

10. Utilize portable/mobile inspection

Idea was not implemented due to impracticality. Billets are hot after forging and they need to cool down for few house before inspection. Thus, it is not practical to inspect billets with portable inspection.

Conclusion

In conclusion, we believe that Value Network Mapping provides a more comprehensive view of the entire jobshop than does VSM. Almost always, when used in a jobshop, VSM tends to focus attention on a few highvolume parts, thereby ignoring the rest of the product mix produced in that jobshop. With suitable training to “learn to see” what is captured in Value Network Maps, Lean implementation teams in jobshops can “see the whole" and plan improvements that would impact entire families of parts, if not the entire shop, and not just a few parts.

Future Work

Acknowledgement

I want to thank my parents for their support and encouragement to pursue and complete a Master degree in Industrial and Systems Engineering. I want to thank my advisor very much, Dr. Shahrukh Irani, for all his time, full support, guidance, and dedication to this research throughout the years. I want to thank my colleagues, Sachin Shah, Shijie Huang, and Chen Xie, for their friendship and help along the way. I also want to thank Minjiao Zhang for her support and her improvement idea to the storage areas in the case study. I am also indebted very much to Mr. Klaus Juergen Schmitt (Production Analyst, Hirschvogel Inc.) for his continuous support and commitment to the Value Network Mapping project.

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