

The Application of Lean Manufacturing Principles in a High Mix Low Volume Environment

By

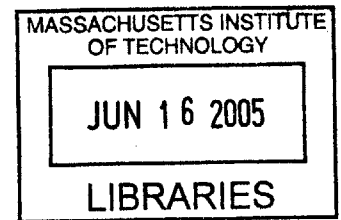
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Submitted to the Department of Mechanical Engineering and the
Sloan School of Management
In Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
Master of Science in Mechanical Engineering

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Abstract

This thesis studies the opportunities for the application of lean manufacturing tools in a high-mix, low-volume traditional manufacturing factory floor setting. Value stream mapping and associated analytical tools are used to explore the opportunities to streamline the flow of products on the floor with a focus on reducing inventory and improving quality. To complement the analysis, this thesis also examines the impact of improved floor employee involvement. It considers several aspects including the increased empowerment of the direct labor staff, stronger team participation, and a greater focus on solutions specifically tailored to area. Based on the results of the research, the recommendation is an increased focus on developing team skills and empowerment, specifically within the direct labor staff.

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1.0 Overview of the Problem

This thesis looks at the application of Lean Manufacturing principles in a highly complex environment. While the processes are primarily traditional machining operations, there is part complexity with more than 400 part numbers, scheduling complexity with demand unpredictability and the need to accommodate new product and process development, and processing complexity with tolerances that stretch the capabilities of the processes. Three analytical tools examined the area, including value stream mapping primarily for flow improvement, Pareto analysis and the development of a product-process matrix to organize the parts into families, and stochastic simulation to understand the impact of different dispatching and work prioritization choices. Additionally, this thesis discusses the results of greater team involvement by the production-level staff.

1.1 First Impressions

When I first walked into the High Tolerance Machining Area (HTMA), it was very clear that this area was different from the rest of the factory. There were very few clear paths and enormous machines and tall cabinets dominated the floor space. Desks and workbenches were tucked into corners and I saw very few people. Those that I did see were very intent on what they were doing or at least intent on not talking with me. There were racks full of tooling, problem pieces, and WIP. I was still confused about the layout after spending a week walking the floor. It was exacerbated, though, because we were walking the production process of a part number which looped around, apparently endlessly.

It soon became clear that there was also a team within a team as the assembly area was managed and run completely separately from the area where the details of the assemblies were machined.

I informally used Goodson’s Rapid Plant Assessment rating sheet at that time and Table 1 below shows the results¹. With a score of 27 out of a possible 121, there was potential to improve their use of Lean Manufacturing techniques. I interned in this area for 6-months with their Value Stream Mapping team to help coach them along the path to Lean.

Table 1. RPA Rating Sheet for HTMA²

		poor (1)	below average (3)	average (5)	above average (7)	excellent (9)	best in class (11)	category score
1	Customer Satisfaction		x					3
2	Safety, environment, cleanliness, and order		x					3
3	Visual management system	x						1
4	Scheduling system	x						1
5	Use of space, movement of materials, and product line flow		x					3
6	Levels of inventory and work in process	x						1
7	Teamwork and motivation	x						1
8	Condition and maintenance of equipment and tools	x						1
9	Management of complexity and variability		x					3
10	Supply chain integration			x				5
11	Commitment to quality			x				5
Total score (11-121)								27

¹ Goodson, R. Eugene, “ToolKit, Read a Plant – Fast”, Harvard Business Review, May 2002, pg. 105

² Goodson, R. Eugene, “ToolKit, Read a Plant – Fast”, Harvard Business Review, May 2002, pg. 105

1.2 Approach

I approached the challenge with a two-pronged process. The first was to focus on applying the traditional analytical tools of Lean Manufacturing as described in *Learning to See*³ and *Creating Mixed Model Value Streams*⁴. The tools of the analysis included value stream mapping, a Pareto analysis, and developing a product-process matrix to organize the product flow. Additionally, I developed a discrete event simulation in an attempt to determine the appropriate process management of the area.

The second part of the research focused on the team dynamics within the HTMA. Lean Manufacturing techniques had been introduced in this area several times previously with good initial success that declined as time went past. While the local staff briefly adopted Lean principles in the area, and even apparently accepted them, few if any were still in use. A hypothesis was that the method of implementation, specifically the team structure and dynamics at the floor level, would have the greatest impact on the success of Lean. The tools used to investigate and involve the team members of the area included individual empowerment and accountability, true full team consensus and participation, and a relentless focus on new process sustainability.

1.3 Organization of the Thesis

This thesis is organized around the two-prong approach of the research. Following the outline of the problem in Chapter 1, Chapter 2 provides a more complete view into the business structure and setting of this problem. It provides an overview of the industry and history of the facility as well as some of the recent dynamics that have brought this situation to the forefront. Chapter 3 outlines the product line analysis. The value stream mapping process is introduced

³ Womack, James P. and Daniel T. Jones, *Lean Thinking*, New York: Simon & Schuster, 2003, pg. 3

⁴ Duggan, Kevin J, *Creating Mixed Model Value Streams*, New York: Productivity Press, 2002, pg. 7

and the 80-20 analysis and product-process matrixes are detailed. Additionally, it discusses the simulation development and results. In Chapter 4, it describes an attempt at a more empirical approach to Lean Manufacturing, focusing on team-based activities. Finally, Chapter 5 will present an overview of the conclusions and recommendations for future work.

2.0 Introduction: Rutherford Aerospace Corporate Background

2.1 Corporate Structure

Rutherford Aerospace is a company facing many of the same challenges as other traditional American manufacturing companies. Serving primarily the aerospace industry, Rutherford has more than 20 manufacturing and repair sites located worldwide, employing more than 12,000 people. Domestically, they have several manufacturing locations staffed by a mix of union and non-union personnel.

The airline component industry as a whole has suffered significantly over the past decade due to the increasing commoditization from global competition. The competition was compounded by a reduction in demand precipitated by the events of September 11, 2001. This has put a lot of stress on Rutherford to reduce overhead and improve the operating efficiency of all of their operations. In response, there have been significant layoffs and a reduction in the support staff to operator ratio. Additionally, a recent significant merger has required major facility and product line rationalization.

2.2 History of Ravenna Facility

Rutherford's Ravenna facility manufactures aircraft components for both commercial and military customers. Rutherford's aircraft component roots start in the early days of air flight. Since then, the company has grown both organically and through merger and acquisition to develop into an integrated system provider. The Ravenna facility, established in 1952, is the world headquarters for Rutherford and is served by the International Association of Machinists and Aerospace Workers Union. The primary products produced by this unit are complex and complete systems sourced directly from the aircraft manufacturers. The facility also provides

support functions with thermo-chemical processing and precision machining, provided by the HTMA.

The HTMA has been a discrete part of the Ravenna facility since its construction in 1952. There are three primary customers for the HTMA: internal OEM, external OEM, and spare parts. One external bar stock distributor supplies the area. Senior machinists, most with more than 15 years seniority served exclusively within the HTMA, staff the area almost entirely. The facility is divided into two main functions: the detail area that blanks the part from bar steel and brings it almost to its finished state, and the assembly area that completes the final details of the sets. There are approximately 75 operators working two shifts directly supported by two area supervisors, three manufacturing engineers and a production planner. They produce more than 300 part numbers in lots of about 20 pieces in the detail area and 5 pieces in the assembly area. They produce high volume part numbers as frequently as once every two weeks.

2.3 Internship Objectives

Rutherford has had several waves of Lean Manufacturing implementations focusing on various techniques. The first introduction of Lean Manufacturing to the HTMA area occurred in the late 1980's under the leadership of internal experts. At that time, the area was moved and laid out into work cells with resources and part numbers dedicated to those cells. Over time, the cell structure broke down as new products were introduced to the mix that did not follow the processes within the cells and the Lean oriented team structure became diluted due to layoffs and belt tightening. There have followed company-wide policies of further implementations of increasing sophistication with the most recent introduction occurring during the internship focusing on pitch and interval.

The assignment was to improve the standard metrics of the HTMA using Value Stream Mapping and Lean Manufacturing techniques. The HTMA was no longer the preferred supplier of valves for internal OEM production due to on-time delivery, delivered quality, and total product cost issues. These three metrics were targeted for improvement.

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3.0 Lean Production Modeling

3.1 Process Review

The analytical model at the base of this product line analysis was the same outlined in Learning to See and Creating Mixed Model Value Streams. Learning to See, initially published by the Lean Enterprise Institute in 1998, was the first book published with clear step-by step instructions for analyzing an entire value stream as a whole. The process it describes involves identifying a product family, identifying the customers and suppliers and mapping the current state of the value stream using a clearly established set of criteria and iconography. A target future state map is then constructed using targeted questions and incorporating customer requirements and process capabilities⁵.

Creating Mixed Model Value Streams advances on the process developed in Learning to See. Using the structure, criteria, and processes developed in the previous book, Kevin Duggan in Creating Mixed Model Value Streams addresses the challenges of the additional complexity of analyzing a value stream that is comprised of several product lines and shared resources. Of particular interest to this thesis, it suggests methodologies to help identify appropriate product families and assess the effects of these product families on the capacity and scheduling of work in a value stream.⁶

The process used began with the model proposed in Learning to See. A facility-wide Value Stream Mapping (VSM) event had identified the need to improve the processing of a specific part family so a local VSM event was already scheduled for the HTMA. However, after the creation of the Current State Map, it became clear that a closer analysis of the product mix on

⁵ Rother, Mike and John Shook, Learning to See, Brookline, MA: Lean Enterprise Institute, Version 1.3, 2003, pg. 58

⁶ Duggan, Kevin J, Creating Mixed Model Value Streams, New York: Productivity Press, 2002, pg. 31.

the floor would be necessary to implement the target future state map because of the introduction of new parts to the original part families. Consequently, the team then executed the product family analysis suggested by Duggan.

3.2 Value Stream Mapping

The process the HTMA VSM team used to put together the Current State Map was based on the general model from Learning to See⁷, though streamlined. After approximately 3 hours of basic training, the team documented the fundamentals of the map. The team identified customers and their requirements, documented the suppliers and their delivery schedule, and mapped out the information flow. The team then headed out to the floor to walk the process backwards, starting at the point where the product leaves for the customer.

At each step along the way, each team member recorded the inventory located at that location, the process time, the cycle time, the changeover time, the approximate yield of the process, the uptime of the work center, the number of operators needed, and the number of shifts per day that process is staffed. Additionally, each team member asked about and recorded any suggestions or problems with the work center, the process, or barriers to getting the work done efficiently. The final question at each step along the way was to find out where the piece came from. Surprisingly, the machinist often did not know, though when pressed they were able to determine it from the paperwork that accompanied the parts.

⁷ Rother, Mike and John Shook, Learning to See, Brookline, MA: Lean Enterprise Institute, Version 1.3, 2003, pg. 13

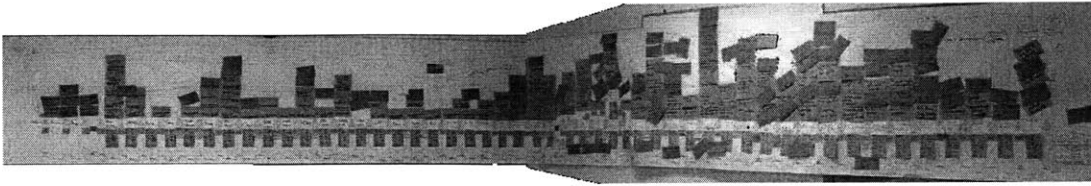


Figure 1. Current State Value Stream Map

When they had recorded all of the data, the team discussed their results and posted the information on the Current State Map, shown above in Figure 1. The continuous light line across the lower third of the map is the string of operations separated by the inventory markers. The darker intermittent squares below call out the metrics of each process. The uneven mass of dark postings above the operations were the problems and suggestions mentioned at each work center. Figure 2, below, shows a closer view of part of the map.

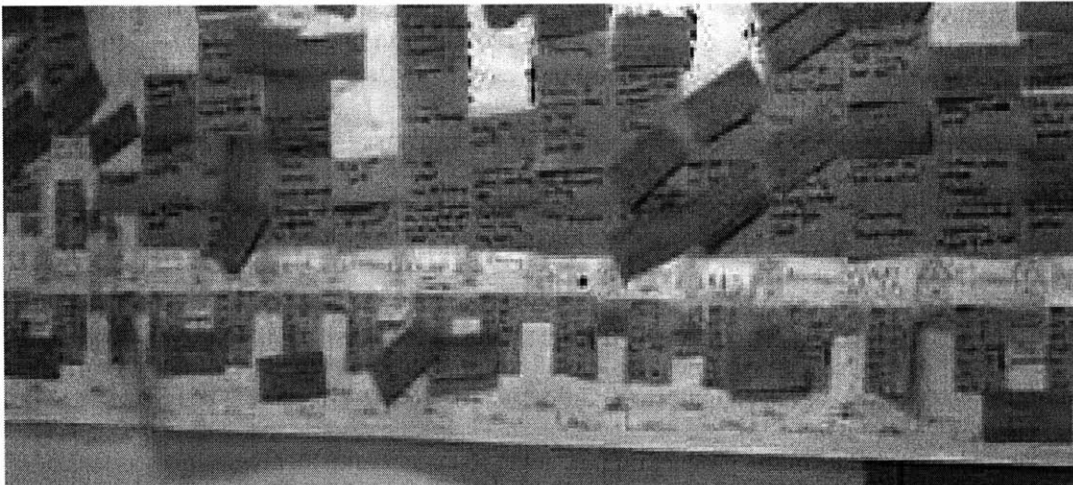


Figure 2. Current State Map - Closer View

There were 49 process steps identified, where a process step is defined as the activities that occur between the points where inventory can accumulate. The size of inventory at a given location was the estimated time it would take to start work on a new piece placed at the end of the current queue. Finally, we constructed a lead-time ladder across the base of the map to

determine the effective lead-time of the process including both queuing time and cycle time.

The total lead-time identified for the process was 1419 hours.

The next step in the process was to construct the Future State Map. Applying the questions in Table 2, below, the team was able to construct a map for a new process. The goal was to aim for changes that we could implement in the next 6-9 months.

Table 2. Key Questions for the Future State⁸

1) <u>What is the takt time</u> , based on the available working time of your downstream processes that are closest to the customer?
2) <u>Will you build to a finished goods supermarket from which the customer pulls, or directly to shipping?</u> (The answer to this question depends on several factors such as customer buying patterns, the reliability of your processes, and the characteristics of your product. Building directly to shipping will require either a reliable, short-lead-time, order-to-delivery stream, or more safety stock. Fortunately, your order-to-delivery lead time involves only those processes from the pacemaker process downstream to delivery.)
3) <u>Where can you use continuous flow processing?</u>
4) <u>Where will you need to use supermarket pull systems</u> in order to control production of upstream processes?
5) <u>At what single point in the production chain (the “pacemaker process”) will you schedule production?</u> (Remember that all material transfers downstream of the pacemaker process need to occur as a flow.)
6) <u>How will you level the production mix</u> at the pacemaker process?
7) <u>What increment of work will you consistently release</u> and take away at the pacemaker process?
8) <u>What process improvements will be necessary</u> for the value stream to flow as your future-state design specifies? (This is the place to note any equipment and procedural improvements that will be necessary, such as reducing changeover time or improving machine uptime. We use the kaizen lightning burst icon to indicate these points in the process.)

⁸ Rother, Mike and John Shook, Learning to See, Brookline, MA: Lean Enterprise Institute, Version 1.3, 2003, pg. 58

The Future State Map shown below in Figure 3 documents the new process. Since the team primarily focused on increasing flow, several batch operations were combined into single-piece flow lines rather than cellurization or significant process modification. The future state map removes multiple point scheduling and replaces it with a pull system and a grocery store at the joint between detail and assembly. The new process has a lead-time of 757 hours and 22 process steps. Once this map had been 70% implemented, the area would have another value stream mapping event to further improve the process.

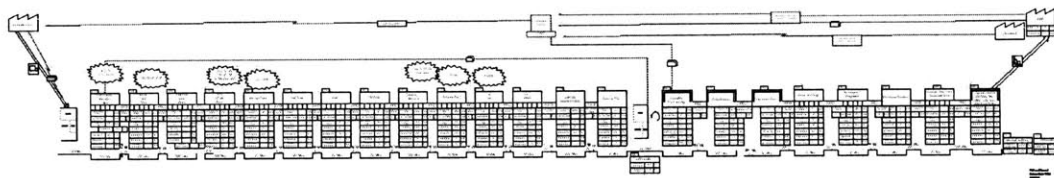


Figure 3. Future State Value Stream Map

Each task necessary to transition from the current state to the future state was recorded. To prioritize the tasks, the team used a methodology from work developed by Gates for his thesis in the same industry⁹. A sample prioritization form is shown in Appendix B. Each team member rated the importance of all 154 tasks, grouped by process step, in six weighted categories: Ease of Implementation, Speed of Implementation, Reduction of Inventory/Cycle Time, Increase to Customer Satisfaction, Increase to Safety, and Cost/Benefit Ratio. The spreadsheet multiplied the scores by the weight for the category and added across the category to arrive at the importance of the task. The tasks were then ranked in order of decreasing importance.

⁹ Gates, Matthew, "Lean Manufacturing System Design and Value Stream Management in a High-Mix, Low-Volume Environment", (Masters Thesis, Massachusetts Institute of Technology, 2004), 42-45.

It rapidly became obvious that there were several problems as the team started to implement the highest ranked tasks. Firstly, since there were many tasks that some team members knew very little about, they neglected to score those tasks. This significantly reduced the rank of those tasks. Secondly, the ranking method does not include sequencing of the tasks. It was not possible to execute some higher ranked tasks before some lower priority tasks were addressed. Finally, several tasks were either complementary or contradictory. If they were complementary, all of the tasks in that subgroup were easiest to complete together. However, some tasks outlined different ways to solve related problems. The team needed some mechanism to resolve the chosen path. To do this, further part family analysis was necessary.

3.3 Pareto Analysis

At this point, it was necessary to use some mechanism to reduce the quantity of part numbers to focus on. It simply was not possible to deal with all of the part numbers at the level of detail necessary to design appropriate flows for the area. The part family analysis will work with a sample of part numbers to identify families and then later examine the remaining part numbers to determine which family they were best suited for. The simulation will work with the same sample to predict the general behavior of the production process since it is not feasible to exactly model the processing of all the part numbers. The task then is to determine a sample that will drive the greatest benefits for these analyses.

The Pareto Principle states that the vast majority of the problems can be accounted for by a “vital few” of the factors¹⁰. The team applied this principle to volume on the floor to discover which parts are critical to focus on. The HTMA area works on more than 400 part numbers,

¹⁰ <http://erc.msh.org/quality/pstools/pspareto.cfm>

though many of those parts are made infrequently (fewer than 3 times a year) and in very small volumes (less than 20 pieces per year).

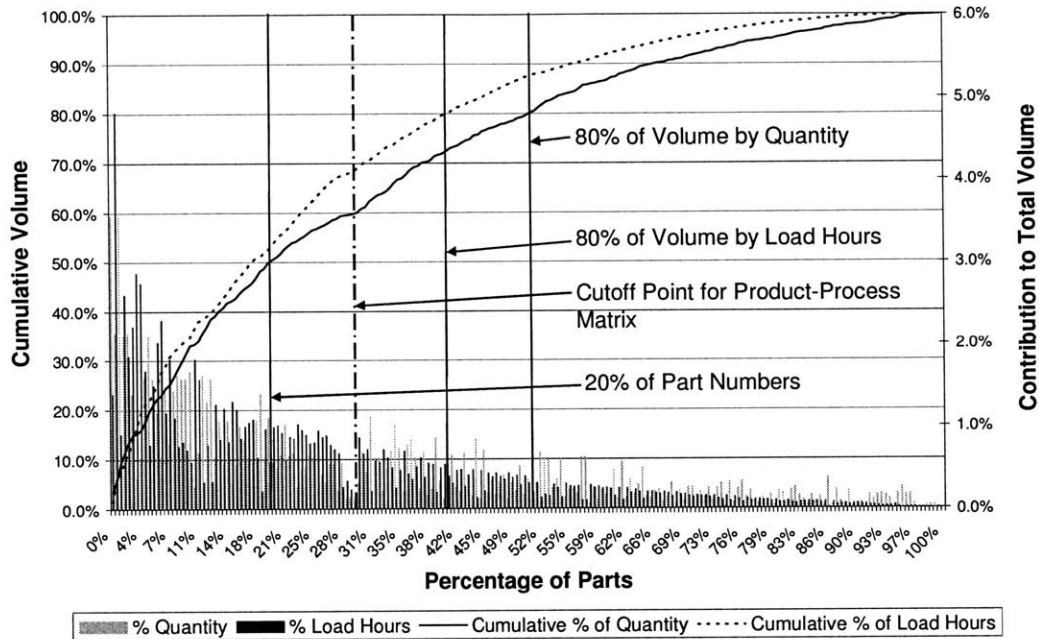


Figure 4. Detail Area Part Volume Analysis

Load-hours, or processing time, was the most important factor for choosing the sample parts. However, because of the nature of the assemblies, there were several important parts that had lower processing time but much higher volumes. To insure these parts were included, I developed a theoretical measure called load factor. This purpose of the load factor is only to rank the relative impact a given part number would have on the floor relative to other part numbers. It focuses primarily on the percentage of load-hours the part number contributes to the total load-hours in the area, but insures that none of the high volume but relatively low load-hour parts were neglected. The heuristic determined was:

$$LF = \frac{Q^2}{200} + H$$

Where:

LF = Load Factor

Q = Quantity of pieces required over the forecast period

H = Number of hours required to run all of the pieces required over the forecast period

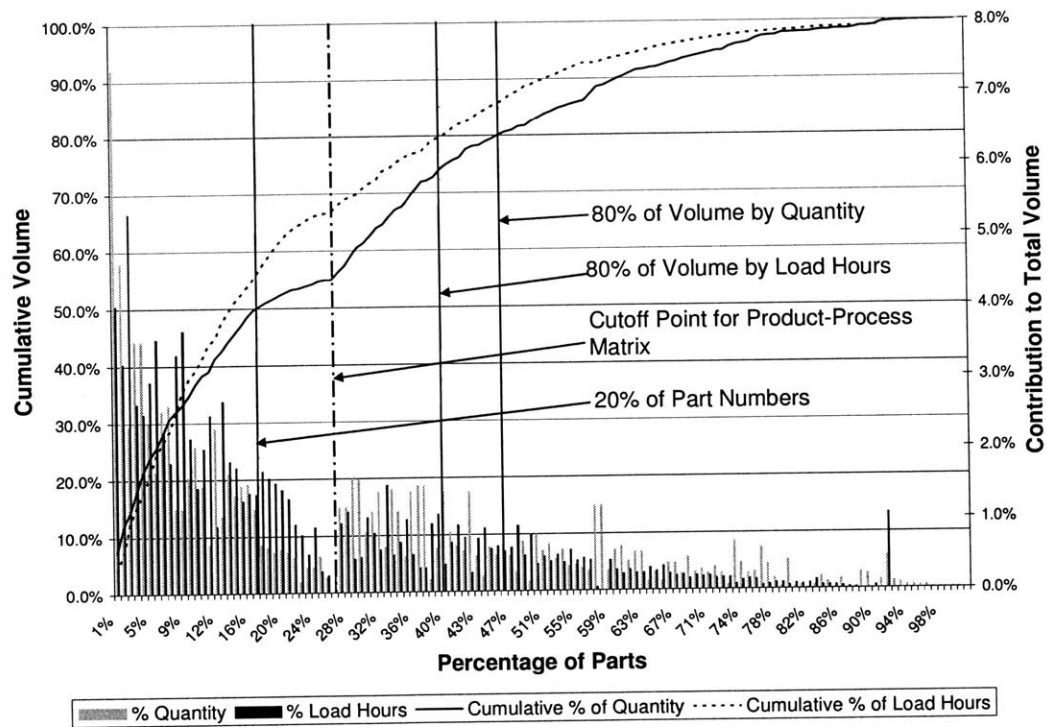


Figure 5. Assembly Area Part Volume Analysis

This heuristic was selected because the load-hours dominated the ranking unless the number required was very large. Using the demand data for the next twelve months to determine Q and H for each part number, the load factors were calculated and the part numbers were ranked.

Figure 4, above, shows the results for the detail area and

Figure 5 for the assembly area.

There was some manual adjustment of the cutoff point for the 80/20 sort due to spare parts requirements. While spare parts usage is forecast, that forecast data was not available to be incorporated into this analysis. Consequently, the high volume spare part numbers were forced manually higher in the rankings.

3.4 Product/Process Matrix

Once we had identified the critical parts to focus on, the team developed a product-process matrix for both areas¹¹. The matrix is laid out with part numbers listed vertically and operations horizontally. The processes are put in order so that as you move across a row for a given part number, a mark is put in the box if that part goes through the operation listed in the column in the order that it is presented. If the part goes through the operation in a different order, a new column must be added so that the order of operations remains sequential.

The image shows a highly detailed and dense grid representing a Product-Process Matrix. The title at the top of the grid is "Product-Process Matrix Detail Line: Blend of Quantity and Load Through 2005: Cleaning and Deburr Operations Not Included". The grid consists of numerous rows and columns, with some cells shaded to indicate process assignments. The shading is most prominent in the first few rows and columns, suggesting that many parts go through the initial operations. The grid is too small to read individual cell contents, but the overall pattern shows a complex relationship between parts and processes.

Figure 6. Product-Process Matrix for Detail Parts

¹¹ Duggan, Kevin J, Creating Mixed Model Value Streams, New York: Productivity Press, 2002, pg. 32

3.5 Simulation

Due to the complexity of the processes, it was determined that a simulation may be able to add insight into the potential results of dedicated flow lines or other work management techniques since there was little value in dividing parts into families. Queuing theory predicts that lead-time and throughput are dependent on the number of open work orders (work in process) on the floor. The expected response of lead-time is shown below in Figure 8. The corresponding throughput is shown in Figure 9. The simulation was developed to attempt to predict the optimal value of open work orders to maximize throughput for a required lead-time.

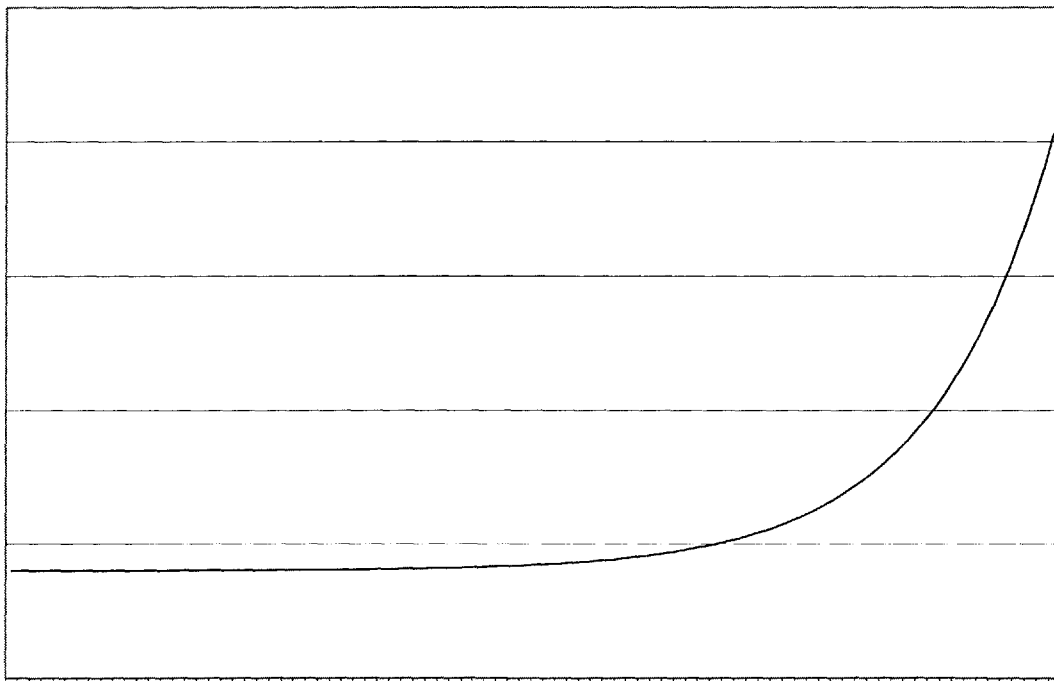


Figure 8. Lead-Time as a Function of Open Work Orders

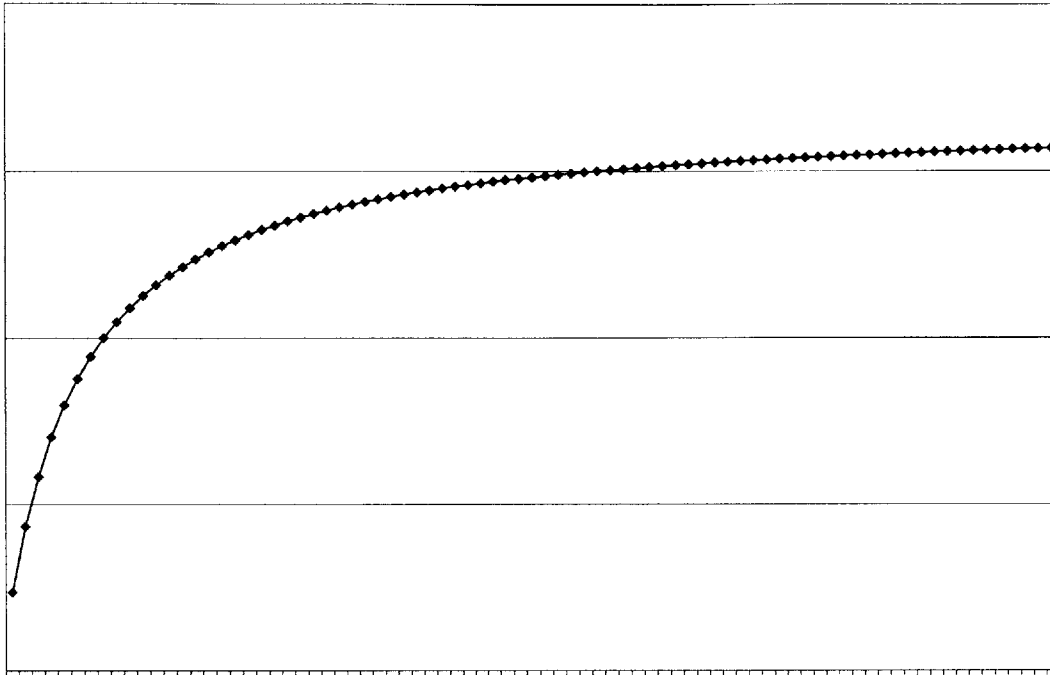


Figure 9. Throughput as a Function of Open Work Orders

The goal was to build a simulation, validate it against the current state, and then modify it to represent the alternative work patterns. The first step was data collection. For each of the 26 parts resulting from the Pareto sort of the assembly area, a processing path was determined. Three sample part processing paths (Job Matrixes) are shown in Appendix C. Each path includes the workstations the work passes through along with the processing times at each workstation. Due to the large number of operations, variations in processing times were not included. Additionally, it was known that the time standards were not accurate for many processes and so the average of the time clocked against an operation was used whenever possible to improve the accuracy of the model. Finally, the loading of the simulation was modeled based on the demand data collected for the Pareto analysis performed earlier.

The construction of the model was completed in Simul8 and is shown below in Figure 10. Icon definition and further details of the model are shown in Appendix D. Each part is loaded separately on the left in a stochastic process and is then routed into a general queue. Then the part moves into a pacing workcenter, Shop Floor Control, because one work management system of interest has level loading (pitch and interval) while another maintains a maximum number of open work orders on the floor. From this point, the work moves to the dispatch workcenter.

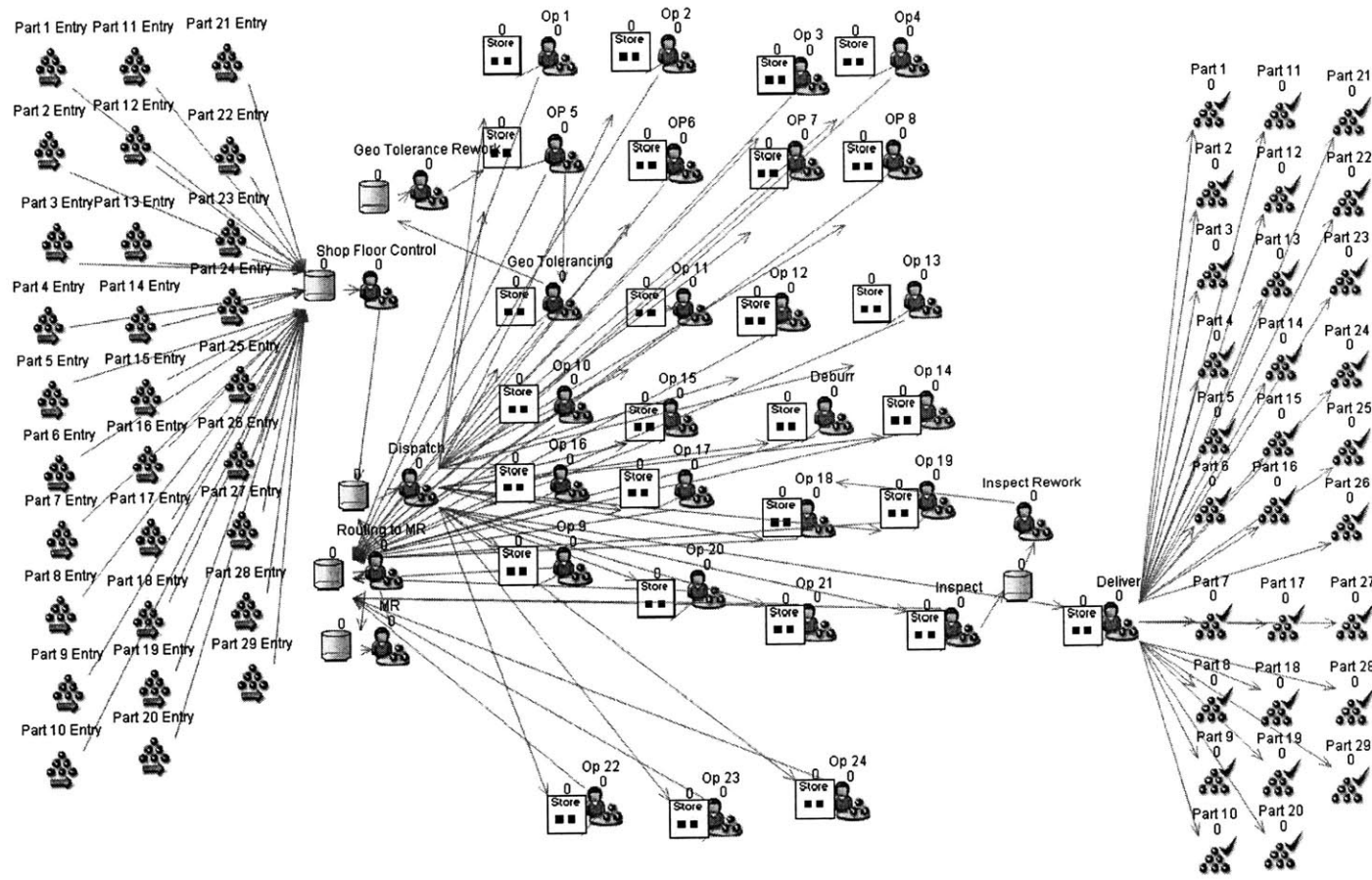


Figure 10. Assembly Area Model Showing Routing

In the model, the dispatch workcenter is merely a routing function and takes no time. It is connected directly to the queue of all workcenters in the model. The mechanism chosen to deal with the complexity of the routing and variance in processing times in Simul8 is the Job Matrix. The dispatch workcenter looks to the Job Matrix to route the workpiece based on the process number. The workpiece is then routed to the appropriate queue and, when the workpiece reaches the workcenter, the Job Matrix is referenced to determine the appropriate processing time. When the workstation completes the process on the workpiece, the process number is decremented and the workpiece is returned to the dispatch queue.

After the initial construction of the model, an attempt was made to validate it. The loading predicted by the model was much lower than the actual loading observed on the floor. To be more representative of the actual process, three re-work loops were added. One rework loop was added specifically between Inspection and Deburr to represent the known defect rate there. Another rework loop was added between a geometric tolerancing station and the preceding machining operation to represent that known defect rate. Finally, a less specific rework loop was added to represent the non-conformance process that existed while the rate for that process was estimated based on area expert opinion. A workstation was added to route a percentage of all workpieces into the third rework loop. At this point, the model was somewhat representative of the actual load on the floor, though there were still major qualitative differences.

Moderate experimentation with alternative management techniques was conducted. The number of open work orders allowed (number allowed in the system) was simulated at values ranging from unlimited to 5. The starvation point is the point in Figure 9 where the throughput

rates to the left of it decline sharply while the values to the right of it stay pretty level. At any value above the starvation point (approximately 30), the system gradually declined in performance. Different queuing disciplines were employed (first in first out for the immediate queue, first in first out for the overall system, last in first out for the overall system, and last in first out for the immediate queue). The difference between these systems was minimal assuming the system was not starved.

Further efforts were made to improve the model by constraining it with resource availability. It did not significantly improve the model. Two factors probably have significant impact on the effectiveness of the model: the fixed operation timing and the overtime policy in place in the HTMA. At this time, there is unlimited overtime offered to employees of the area. Because this overtime is not scheduled, it is extremely stochastic and would have significant impact on the model. Additionally, each process has variability in its timing and this has also not been included due to the large number

Further development of the model at this time is not viewed as valuable. The results of the model are highly dependent on product mix run through the area. While demand was initially based on the next 12 months of demand, the actual part mix historically varies significantly from year to year while the individual part number demand varies significantly within that time period. Due to this variability, the usefulness of the model for future area development needs to be better understood.

3.6 Results

Despite the lack of formal results, the lean analytical process produced many important discoveries. As was discussed earlier, the value stream maps did not adequately incorporate the

full product family and were not able to be directly implemented. However, the value stream mapping process was very useful as a discovery tool in two ways. The most direct discoveries of the VSM team were the day-to-day challenges that had to be accommodated at each step to ship product. These challenges varied from the frequency of changing priorities and broken setups to time spent finding gauging and operation instructions. The process of walking the floor and talking with each operator resulted in what the team referred to as “the pink snowfall” because the large number of problems and suggestions raised, recorded on pink paper, visually dominated the record of the process on the current state map.

The VSM process also started a dialogue on the floor between all of the stakeholders in the process and encouraged teamwork between the various specialties. It raised awareness of the connections between the processes and improved communications. It also signaled how important the area was to management and their intentions to improve the process.

The prioritization process reinforced the scale of the challenge the area faced. Trying to sort through the tasks forced the team to directly confront what would become a continuing theme of the project: how to make forward progress in the face of extreme complexity. Throughout the process, it was extremely difficult to focus on just one aspect of the problem. Just as it was not feasible to sort the parts into smaller families, it was not feasible to focus on just one task at a time, or one solution without addressing other problems at the same time. Collecting data, modifying a process, or rearranging a workspace often required making assumptions that simplified a situation almost beyond the usefulness of the data. For example, when collecting data for the simulation, it was known that the processing times and, in many cases, even the processes were not accurate. However, in order to proceed with the model in a timely fashion, the available data had to be used with less than satisfactory results. The team’s response to this

level of complexity, as will be further discussed in Chapter 4, was a determination to focus on tasks that would primarily act to simplify to daily floor operations.

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4.0 Empirical Experimentation

A team of stakeholders was selected to improve the operations of the HTMA as a Value Stream Mapping (VSM) team. It was co-led by the two area supervisors and was originally comprised of several senior machinists from the detail and assembly areas, an inspector, a manufacturing engineer, shop floor control, a team coach from outside the area and myself. The team coach role was rapidly transitioned to me.

The theory employed in increasing the empowerment of the hourly workforce was to harness their talents to implement targeted improvements. As Womack and Jones state it in *Lean Thinking*, "...there is a higher form of craft, which is to proactively anticipate problems in a team context and to prevent them while constantly rethinking the organization of work and flow of value to remove *muda*. ... Thus the direct worker and the work team subsume many of the traditional activities of "management" while improving activities at a far more rapid rate than management alone ever could."¹³

Shiba and Walden discuss five necessary conditions for teamwork¹⁴. They are:

1. Shared commitment to mission
2. Personal responsibility and accountability
3. Individual skills
4. Substantive coordinated action, and
5. A problem solving process

The composition of the team already assured that the team was composed of members with the necessary process skill and the analytical work discussed in Chapter 3 provided a process to

¹³ Rother, Mike and John Shook, Learning to See, Brookline, MA: Lean Enterprise Institute, Version 1.3, 2003, pg. 207

¹⁴ Shiba, Shoji and David Walden, Four Practical Revolutions in Management, Portland, OR: Productivity Press, Cambridge, MA: Center for Quality Management, 2001, pg. 400-402

address some of the process. However, it was necessary to assure all five of the conditions were met to develop a successful team. As coach of the team, I targeted three main areas to encourage improved productivity and continuous improvement. These areas are: increased empowerment, improved stakeholder participation, and simplified sustainability. Increased empowerment generated a sense of personal responsibility and accountability and helped reawaken a true commitment to the mission. Improved stakeholder participation required substantive coordinated action. Focus on simplified sustainability provided a framework to use the existing corporate problem solving process that was motivating to the entire team.

4.1 Increased Empowerment

As it stood when the internship began, the machinists believed their responsibility was to discover the problems and report them to either their supervisor or an ME. Support staff (management and engineering) was overwhelmed with the volume of problems and falling farther and farther behind in addressing the problems of the area. The operators were frustrated at the lack of change and came to believe that management did not care about their problems.

The HTMA VSM team, while led by supervisors, was primarily composed of floor level personnel. Several specific actions were taken to increase their empowerment and corresponding sense of responsibility for the productivity of the area. The three tools used to create this sense of responsibility were The Wall, Team Norms, and the Living Process Map. These were supported by specific behaviors: improved transparency to the decision processes, addressing problems without blame, decision by consensus, and creating an open forum to discuss problems that arise throughout the process.

The first tool implemented for and by the team was to identify and set up a dedicated VSM project area that was dubbed 'The Wall' by team members. This area served to provide a central and accessible location for all project information and a meeting space for the HTMA VSM team. The Wall had two regions, planning and working. The planning area was included to help the team stay on target and displayed the current and future state maps. The key components of the working area included the Team Norms, the standard VSM project report, the team calendar, the Living Process Map, and a whiteboard for suggestions. Additionally, a small table was located in the area for meeting supplies and a copy of The Goal and Learning to See for reference.

There were several goals addressed in setting up the area. Strategically, the first goal of the team area was to signal the serious intent to change the area. The Wall was large and located near one of the primary entrances to the HTMA so the entire staff of the HTMA regularly passed through it. The goals and plans of the VSM team were explicitly stated in the FSM and the VSM project report. The actions taken to reach those goals were clearly shown in the Living Process Map. The process remained very visible to the entire HTMA as the team continued to meet out in the open at The Wall. Occasionally, HTMA staff that was not members of the core team would stand in on meetings if they had questions or concerns.

The location served another goal of the area: to maximize the communication among all of the stakeholders. Email and other computer based communication tools were not available to everyone in the HTMA and general meetings were already crowded with information. There were several bulletin boards scattered throughout the HTMA but they had sporadic use and were not updated in a systematic fashion. Putting together The Wall and meeting there served

to centralize the information for easy consumption. Additionally, it was automatically updated as the team used the various components, particularly the Living Process Map.

Some aspects of The Wall worked better than others. Chairs were not located at The Wall to encourage shorter meetings. This was both moderately ineffective and counterproductive to other goals of the project. One of the primary behaviors we were working to encourage was consensus-based team decisions. This type of decision takes longer to make than simple direction from a single team lead or even a majority rule vote.

The next tool that was developed to improve full-team commitment and participation was the HTMA VSM Team Norm document. The goal of the document was set communication expectations in four key areas: general team behavior, meetings directly affecting the team's actions, interactions with people outside the core team, and the mechanism to incorporate continued suggestions. The complete document is attached in Appendix E.

These expectations were intended for all of the stakeholder groups: VSM team members, other HTMA staff, and management not participating on the VSM team as well as any external personnel involved in the process. There were several concerns and questions raised in the initial stages of the project that encouraged the development of the Team Norm document. Some team members were concerned about decisions made by management in meetings that floor level personnel were not invited to. Some HTMA personnel were concerned that the VSM team would make changes that impacted them without talking to them first. This concern was particularly relevant to second-shift personnel. The Manufacturing Engineers were concerned that they and facilities would be overwhelmed by each VSM team member independently contacting them and causing confusion and excessive work. Management was concerned that

VSM activity would negatively impact the productivity of the floor since several team members were floor level.

While each of these concerns is addressed in the Team Norm document with the accompanying team calendar, the overall tone of the document is intended to encourage an entrepreneurial spirit in the team. Everyone in the HTMA will be involved and everyone is encouraged to take action themselves if they can. Open communication was also emphasized since, "All stakeholders (everyone who will be in any way impacted by a change) need to be at least communicated with before the change is made. If possible, everyone should be asked for input at a stage where the input can be incorporated."

Posting Team Norms on the wall and discussing them among team members is very different than making them happen. Different team members adopted the norms to differing degrees at different speeds. There was some stress when implementing the entrepreneurial aspects of the team norms. The floor supervisors were uncertain and uncomfortable managing this type of behavior. They had not developed the skills or expectations among their staff. Additionally, some of their direct reports were still requiring more explicit direction while others were becoming more self-directed and independent. There was stress, too, on the part of the newly empowered. They had to learn project management skills and were uncertain how to deal with the responsibility of decision making. One of the greatest stresses to the direct production staff was the implied responsibility they had to garner their peers' support or compliance with processes they developed.

Implementing the communication team norms proved to be a process of discovery in itself. It was difficult to develop the desired behavior of transparency for a variety of reasons. One of the

biggest issues was that some of the required meetings were too long delayed or simply stopped occurring. The area-wide meetings were the biggest candidate for long delay. However, the pressure of curiosity and frustration from the floor-level staff eventually forced these meetings to occur. However, the project never achieved a close connection with upper management and the regular meeting with the value stream owner dropped away.

4.2 Improved Stakeholder Participation

One of the challenges the VSM team had with communication was the lack of practice the area had with consensus-based decisions. Some stakeholders confused consensus with unanimous decisions and became angry when their suggestions were not incorporated. Some of the team members lost patience with the process and made changes without garnering enough support to sustain them. Other team members tried to use the decision process as a mechanism to delay progress.

The primary tool used to drive the team and encourage individual leadership was the Living Process Map. This tool is based on a scheduling tool suggested by Mark Stover, LFM 2005. A picture of the map is shown below in Figure 11. Each member of the HTMA VSM team chose a task or two from the priority list to complete. The task would be written on a sticky note and posted under the date when they planned on completing the task. If a deadline had to be extended, the original location was circled and a line was drawn to the new location on the map. As each task was completed, the task would receive a green check and another task would go up on a sticky note. Each team member was assigned a line on the map and, during team meetings, was responsible for reporting on the progress that had been made against that task. Everyone was encouraged to voice uncertainties or problems they had encountered while working.



Figure 11. Living Process Map

Several difficulties around with the prioritization method as the tasks were chosen by the team members. The first was that many of the team members did not have direct understanding of a task or the area impacted by the task. The team members felt it was awkward and inefficient to lead an effort when they had less knowledge than others in the area. While they acknowledged that there was value in learning about different aspects of the area, they were already stretching themselves outside their comfort zone. Consequently, team members were encouraged to choose tasks that were both important and in their area of knowledge. While this method of prioritization appears random, since it had been completed after the previous prioritization method, everyone was aware of the tradeoffs and benefits of each individual task. Additionally,

it focused efforts on tasks that were viewed as important by production-level staff and helped generate general support for the project.

Another challenge that the team faced was the complex nature of many of the tasks. Most of the team members had no project management training or skill sets. Consequently, they found tasks like “Create flow through End Process” or even “Determine system to decide who does the work at packaging” too complex to plan. It took several months for many of the team members to become comfortable with fully defining a large, vaguely worded task and then breaking it down into manageable chunks.

During the first several months of the project, the individual team members improved their sense of individual commitment and learned a new framework to interact with their peers. They learned to take responsibility for initiating and completing tasks as well as working with others to resolve problems that arose along the way. Eventually the team began to express the desire to involve more of the HTMA staff with the team’s activities.

The HTMA VSM team had developed a sense of responsibility for making sure the area ran smoothly and had started to implement some new policies. Policing those policies became a challenge, though. It wasn’t possible for the area supervisors to constantly monitor for compliance since they were scrambling as much as ever to keep production moving. The team had only scratched the surface of the challenges the area faced. So in many cases, it was left to the team members to try and convince their peers to comply.

Several suggestions were made to integrate the bulk of the HTMA staff. Many of the suggestions revolved around participation in the VSM team itself and included developing a rotating membership position on the team or a term of team membership. These suggestions

were not implemented for two primary reasons: they would not involve enough of the staff quickly enough to have a significant impact and it is very disruptive to team dynamics to change the composition of the team.

Instead, VSM team members were encouraged to develop teams to help them accomplish some of the larger tasks of the VSM effort. In effect, the VSM team became the clearinghouse or coordinator of all of the improvement efforts in the HTMA. A high level quality team was formed to better understand the overall situation in the area and provide a coordinated data collection and analysis system. Three focused quality teams were born to address specific fallout problems. A functional team was formed to share best practices and to facilitate process development and the integration of new technologies throughout the area. These teams met regularly and their teammates on the VSM team were able to help coordinate their actions.

4.3 Simplified Sustainability

As discussed previously, there had been several attempts to implement Lean principles in the HTMA with little long-term sustainability. Consequently, most of the team members were reluctant to spend time and effort of something they considered another “flavor of the month”. One way this resistance was countered was by encouraging them to work on problems they thought were important. The other, which will be further discussed in this section, was to develop techniques to implement Lean that everyone agreed would be sustainable. The main criterion that the team agreed on was that it had to be as simple as possible, preferably automatic.

The first system the team tackled was the queuing system for work waiting for an operation. While the future state map indicated the location of queues, the mechanics of implementation

were up to the team to determine. The system currently in place was a 'hot list' – a list of urgent part numbers required immediately or overdue to the customer. Dispatchers would expedite anything on the hot list, breaking setups when necessary, and then prioritize the rest of the work based on delivery.

This system had several problems that the team identified. First, breaking a setup meant that the partially completed job had to be set up again. This could often take between 2-4 hours of direct setup time and additional time as the process is re-tuned to peak efficiency. Additionally, the first couple pieces after a setup are the most likely to develop quality problems as the process settles. Constantly shifting priorities also caused other efficiency problems for the operators. They were unable to adequately prepare for jobs by acquiring gauging and tooling while the current job was running. If the appropriate gauge or tool was not immediately available, there was generally a delay of at least 30 minutes. This was particularly key on second shift when gauging and tooling availability was a significant problem. From a pure logistics standpoint, it required each operator as they were completing a job to go find the dispatcher to ask what they should be doing next.

All of these legitimate reasons for delay were compounded by personal priorities. It gave the dispatcher enormous power on the floor since the dispatcher could choose to order jobs to favor one operator over another. Additionally, the floor level staff were paid by the hour and granted as much overtime as they chose to take. This naturally encourages them to take as much time as possible on a given operation. Even when a machinist could reasonably figure out what the next job should be, the legitimate reasons for delay were often exaggerated well beyond the point of credibility. This strained the relationship between management and the floor staff. Most critically, though, it discredited valid concerns voiced by the floor staff.

Implementing a simpler, less labor intensive, and more predictable prioritization method quickly became a high priority for the VSM team. It was also used to help the team learn to solve problems in a team setting and discover a solution that meets the needs of many diverse stakeholders. The team agreed that we would use first-in-first-out (FIFO), the queuing system used to maximize throughput in *The Goal*¹⁵ and the recommended method from *Learning to See*¹⁶. The question was how to implement it.

Over a period of approximately 3 months, several different systems were developed. The first and most simple FIFO lane was a small narrow rack that had space for only 4 jobs and was well suited to the assembly area. The instructions were designed to be as explicit and obvious as possible. The diagram of the FIFO lane is a drawing of the actual rack used. The team decided that there would be two conditions when the FIFO lane would be skipped. The first is when an emergency build at a customer's location was delayed due to a specific part. This is termed an AOG and it is the only condition where an operator should break a setup to run a part. The second condition where a job would not wait its turn in line was if the job was sent back to the previous operation for rework. Once the rework was completed, it automatically went to the head of the line.

This small rack did not work for some areas, though. Some queues fed multiple work centers and so required more space and bigger racks. The team experimented with rack size and a number of gravity feed systems. All of the gravity feed systems were discarded due to the complexity; they confused staff more than the existing system. Eventually, a scaled version of the initial system was adopted. Each area was able to adapt it easily to whatever size worked

¹⁵ Goldratt, Eliyahu M, *The Goal*, Great Barrington, MA: The North River Press, 1984, pg. 305

¹⁶ Rother, Mike and John Shook, *Learning to See*, Brookline, MA: Lean Enterprise Institute, Version 1.3, 2003, pg. 48

best for them. There were several other variations due to part size and specialized skills that were similarly accommodated.

To accommodate shared work centers, a technique used elsewhere in the factory was implemented: Turn Boards (also known as Lap Boards). The historical loading at the work center was analyzed and each area was allocated a specific number of turns proportional to their normal load. For example, in the Turn Board shown in Appendix F, Assembly accounted for twice as much work through Op 17 than Detail did so they had two turns for each one for Detail. Appendix F also includes a full set of FIFO Lane instructions for a larger work center queue.

4.4 Results

When the project began, it was unclear how much compartmentalized information there was. A process of discovery began as the team walked the floor together to build state map and continued on throughout the project. As each stakeholder learned more about their partners' problems, constraints and goals, the rate of improvement and the efficiency of meetings increased. For example, when the future state map was first put together, it took the team a long time to put together a map that in the end, while a valuable tool for collecting information, the team had very limited success in implementing. The map included too many assumptions and misunderstandings that made it impossible. However, four months into the process, the same VSM team sat down to address the maintenance of the area's 5S system and developed a system that was well-tailored to the area, sustainable, and extremely effective. These are just two small examples that only touch on the progress that the area made in many regards.

The single most valuable result is also the one that is hardest to quantify. The morale in the area improved enormously. Second shift staff had more regular access to information and was able

to have their concerns addressed by solutions. The problems that the hourly staff voiced were recorded and many were actually addressed. This reassured the area that management was concerned about them and their welfare. A forum was developed between Detail and Assembly where they were able to discuss issues and resolve them. Most importantly, people felt like their individual contributions were making the area a better and more productive place to work.

Many business processes were improved. All three quality teams made changes in the processes that will have lasting impact on the quality of the product and the robustness of the process. One of the quality teams also made significant safety improvements in the way raw material was handled. The functional team reworked the process for their highest volume part to radically improve first time yield and process robustness. The implementation of the FIFO lanes reduced queuing inefficiencies significantly. On-time delivery increased from 90% to 96% over the period of the internship while scrap, rework, and repair costs dropped more than 10% on average over the internship compared with the previous 6 months with fairly constant inventory levels.

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5.0 Going Forward

5.1 Conclusions

The High Tolerance Machining Area of Rutherford Aerospace's Ravenna facility afforded an excellent opportunity for a Lean Manufacturing implementation. There was significant improvement potential in several areas. The value stream mapping event was a very useful tool for identifying many of these areas. Many of the issues raised during the mapping event were similar to the results of Goodson's Rapid Plant Assessment. The issues that the team chose to tackle included nearly every category considered in that assessment.

While the results of the analysis of the product lines did not indicate any clear improvement potential for continuous flow, this was not surprising in such a high-mix, low-volume environment. It did not preclude the implementation of other Lean product flow techniques. The most common one, first-in-first-out product queuing proved a very effective mechanism to both reduce confusion on the floor and resolve competing prioritizations. This policy change has an intrinsic barrier to acceptance since it removes authority from the very individuals who are responsible for enforcing it, the dispatchers. Previously, they had been able to have a large impact on the work processes across the floor because of their choices about work order. Now that work order is determined independently, removing their influence. The area has to address this issue before the system will be able to sustain itself.

The greatest benefits reaped in the area were primarily a result of the more general team-focused activities rather than the more prescriptive techniques. While the Value Stream Mapping technique, the task prioritization, and the generation of the product-process matrix all generated useful information, they also proved frustrating for the team. The Current State Map was probably the most productive of the tools since it documented many of the problems that

needed resolution. The Future State Map was a source of frustration for the team as they worked to implement a map that was not possible, as the product analysis rapidly highlighted. The product-process matrix required a huge effort by extremely knowledgeable individuals and primarily served to prove what the dispatchers had tried to communicate from the beginning of the process: that there was simply too much variation between the parts and the processes were too intertwined to derive much value from separating them into part families.

The more general team-focused activities, however, made significant strides in addressing several of the weakest points in the Rapid Plant Assessment. They started with one of the most fundamental aspects of Lean Manufacturing: safety, environment, cleanliness, and order. The FIFO system developed by the team, even when it was not working properly as a scheduling system, worked well as a visual management system. The data highlighted the importance of equipment and tooling availability and increased the focus on preventative maintenance and tooling access and organization. Most importantly, all of these activities shifted the focus from listing barriers of progress to the creation of solutions. The teamwork and motivation of the area saw a marked increase.

5.2 Recommendations

The greatest barrier to the implementation of flow in the HTMA was the enormous variety of parts and processes required. It is not likely that any meaningful product flow will be possible in the HTMA unless some of the complexity is removed. The coordination of product design and process development with production could produce significant benefits by focusing their efforts to reduce the complexity of the process. Additionally, many of the most complex parts come from external customers. A stronger communication loop with their external customers to

help them understand the impact of their design decisions has the potential to drive significant quality improvements and cost savings.

Going forward, I would recommend the development of a systematic method to develop and implement team skills throughout the organization. So much of Lean Manufacturing is dependent on the increased communication and continuing improvement that full team participation is critical for. Previous management methods did not require the development of the skills necessary to either run or participate in an active way on teams. Area groups need to adopt team skills in order to truly incorporate Lean Manufacturing in a sustainable fashion.

Part of the systematic method to develop and implement team skills would need to be an adjustment to the area metrics. Since people will tend to perform to maximize the metrics that they are evaluated against, a metric will need to be developed to encourage and reward the development and deployment of empowered teams. There was a significant amount of stress and resistance to the initial formation and functioning of the HTMA VSM team. A solid metric that continues to be monitored over time will be required to insure that teams adopt appropriate behaviors and continue to perform in a unified way.

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Appendix A. Terms and Acronyms

HTMA:	High Tolerance Machining Area
ME:	Manufacturing Engineer
WIP:	Work In Process
VSM:	Value Stream Mapping
CSM:	Current State Map
FSM:	Future State Map
FIFO:	First In First Out

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Appendix B. Sample Prioritization Worksheet and Instructions

Instructions

Each row in the matrix represents a Kaizen burst from the future state map. The gray shaded cell gives the process step, while the unshaded cell is the Kaizen name.

For example,

Fab & Weld	Create Continuous Flow
------------	------------------------

The Kaizen burst is "Create Continuous Flow" and it was generated for the process "Fab & Weld". There may be a similar Kaizen burst in two or more process steps, so it is important when ranking to think of the Kaizen burst specifically in relation to the given process step.

Please rank each Kaizen burst **on a scale from 1 to 5** for the six criteria given at the top of the matrix where 5 is the most favorable rating. The weightings for the six different criteria are given at the top of the matrix for your reference. You do not need to worry about these weightings when you rank each Kaizen.

Please select the sheet with your name on it, fill it out as completely as you can, and return it to the coordinator.

An example ranking for the first Kaizen burst is shown below:

		Ease of Implementation	Speed of Implementation	Reduction of Inventory Cycle Time	Increase to Customer Satisfaction	Increase to Safety	Cost/Benefit Ratio
Weight		8	6	10	5	5	10
Fab & Weld	Create Continuous Flow	3	2	5	4	3	5

Figure 12. Prioritization Worksheet Instructions

**HTMA End-to-End Value Stream Future State
Kaizen Prioritization**

		Ease of Implementation	Speed of Implementation	Reduction of Inventory Cycle Time	Increase to Customer Satisfaction	Increase to Safety	Cost/Benefit Ratio
Weight		8	6	10	5	5	10
General	Determine system to decide who does the work (priority)	4	3	5	3	3	5
General	Stabilize temp between all areas of HTMA	4	3	3	4	3	3
General	New data collection system	4	4	5	5	3	5
General	Cross-training	2	2	4	3	4	4
General	Document all undocumented processes	2	3	3	4	3	4
General	RRC gauging availability	2	3	5	3	3	5
Packaging	New packaging area for higher quality and efficiencies	4	3	4	4	3	3
Packaging	Signal method needed	4	5	3	3	3	3

Figure 13. Sample Prioritization Worksheet

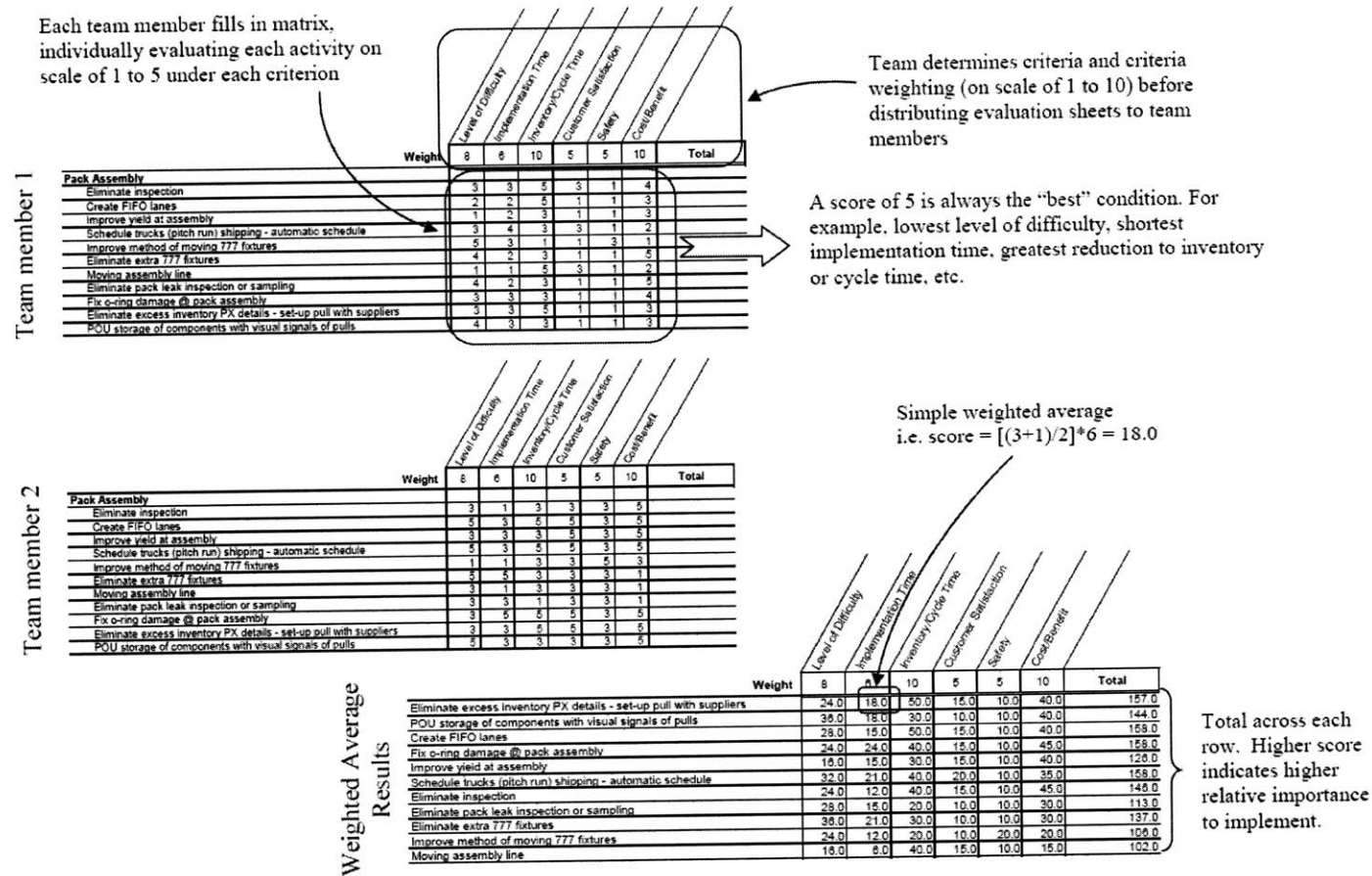


Figure 14. Description of Prioritization Process¹⁷

¹⁷ Gates, Matthew, "Lean Manufacturing System Design and Value Stream Management in a High-Mix, Low-Volume Environment", (Masters Thesis, Massachusetts Institute of Technology, 2004), 45.

Appendix C. Sample Part Processing Paths

Table 3 shows the processing paths of three part numbers.. The Work Type is the variable used by the Dispatch work center to determine the routing of the work piece. The dispatch function routes the work piece to the station in the location column. That station then waits the indicated changeover time and then processes the piece for the time located in the Timing column. This simulation does not use the Job column.

Table 3. Sample Part Processing Paths

Part Number	Work Type	Job	Location	Timing	Change Over
1	9932	1	Station 1	0.0	0.0
1	9931	1	Station 2	23.4	4.2
1	9930	1	Station 3	13.9	25.1
1	9929	1	Station 3	16.3	14.0
1	9928	1	Station 3	13.6	23.4
1	9927	1	Station 4	51.2	67.2
1	9926	1	Station 8	19.7	11.7
1	9925	1	Station 8	105.4	12.3
1	9924	1	Station 4	74.1	64.8
1	9923	1	Station 4	31.1	41.8
1	9922	1	Station 5	73.9	4.2
1	9921	1	Station 4	135.3	45.9
1	9920	1	Station 6	88.8	92.0
1	9919	1	Station 6	55.6	21.8
1	9918	1	Station 6	18.8	1.2
1	9917	1	Station 9	26.8	19.7
1	9916	1	Station 9	32.4	41.7
1	9915	1	Station 9	12.2	12.6
1	9914	1	Station 9	18.9	7.6
1	9913	1	Station 8	49.2	28.6
1	9912	1	Station 8	44.7	16.9
1	9911	1	Station 6	10.7	36.0
1	9910	1	Station 2	27.4	0.7
1	9909	1	Station 10	173.7	44.5
1	9908	1	Station 17	0.0	0.0
1	9907	1	Station 17	0.6	0.0
1	9906	1	Station 2	51.0	22.6

1	9905	1	Station 14	120.0	180.0
1	9904	1	Station 14	30.4	0.0
1	9903	1	Station 15	288.0	0.0
1	9902	1	Station 14	829.2	0.0
1	9901	1	Station 16	0.0	0.0
2	9824	1	Station 1	0.0	0.0
2	9823	1	Station 2	17.7	10.0
2	9822	1	Station 3	9.5	17.4
2	9821	1	Station 25	27.8	48.6
2	9820	1	Station 25	30.4	29.6
2	9819	1	Station 5	0.3	20.9
2	9818	1	Station 6	59.4	18.2
2	9817	1	Station 7	107.2	36.2
2	9816	1	Station 2	29.2	2.4
2	9815	1	Station 12	54.6	9.8
2	9814	1	Station 8	96.9	17.8
2	9813	1	Station 10	74.5	29.0
2	9812	1	Station 2	9.8	14.4
2	9811	1	Station 14	0.0	0.0
2	9810	1	Station 13	43.9	1.2
2	9809	1	Station 13	14.5	1.4
2	9808	1	Station 13	109.7	1.2
2	9807	1	Station 22	2.8	1.8
2	9806	1	Station 11	1.2	1.2
2	9805	1	Station 2	11.6	1.8
2	9804	1	Station 14	0.0	0.0
2	9803	1	Station 15	17.1	0.0
2	9802	1	Station 14	38.6	0.0
2	9801	1	Station 16	0.0	0.0
3	9724	1	Station 1	0.0	0.0
3	9723	1	Station 2	11.6	11.8
3	9722	1	Station 11	26.3	27.7
3	9721	1	Station 26	66.1	13.1
3	9720	1	Station 8	122.6	15.9
3	9719	1	Station 4	103.7	60.4
3	9718	1	Station 5	39.3	1.1
3	9717	1	Station 6	16.0	1.3
3	9716	1	Station 2	13.2	3.8
3	9715	1	Station 12	40.5	18.1
3	9714	1	Station 10	153.3	13.0
3	9713	1	Station 11	60.9	1.3
3	9712	1	Station 11	59.0	1.3
3	9711	1	Station 11	57.5	1.1

3	9710	1	Station 14	0.0	0.0
3	9709	1	Station 13	43.3	2.1
3	9708	1	Station 13	63.3	8.9
3	9707	1	Station 11	41.9	7.0
3	9706	1	Station 11	8.7	1.3
3	9705	1	Station 2	13.7	2.4
3	9704	1	Station 14	0.0	0.0
3	9703	1	Station 11	11.8	0.0
3	9702	1	Station 14	36.1	0.0
3	9701	1	Station 16	0.0	0.0

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Appendix D. Icon Definition and Further Details of Simul8 Model

Part 1 Entry



- Part Entry Point



- Queue Icons when Empty

2



- Queue Icon with Work Waiting

Op 1

0



- Workcenter Icon

Part 1

0



- Part Completion Icon

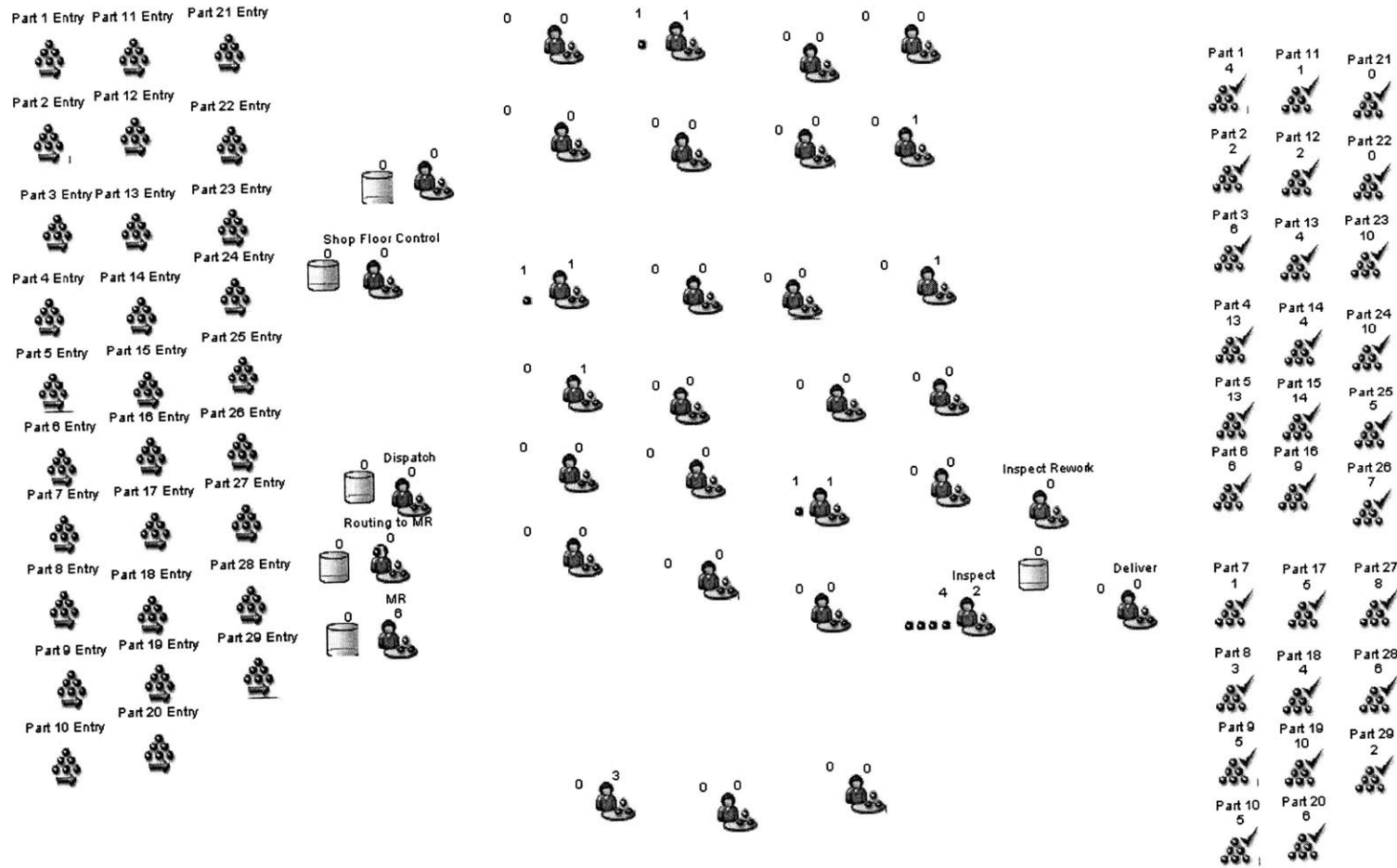


Figure 15. Simul8 Model of Assembly Area during a Run

Appendix E. HTMA VSM Team Norms

Continuing Suggestions/Concerns

- Collect ideas on whiteboard
- Record ideas into priority list once a week
- Reprioritize as needed but at least once a month

Meetings

Any HTMA member is welcome at any VSM meeting

- Core Team
 - Frequency: Weekly on Monday at 2:30 until the action plan is determined, then on Monday, Wednesday, Friday at 3:15 ongoing
 - Time Allotted: Monday meetings – 1 hour, MWF meetings – 15 minutes
 - Goals
 - Develop work plan
 - Keep entire team current on all actions
 - Share ideas/techniques
- Leadership Team
 - Frequency: Daily at 11am
 - Time Allotted: 30 minutes
 - Goals
 - Provide ongoing support to team
 - Discuss foreseeable obstacles and action plans to address
- Management Team
 - Frequency: Every two weeks
 - Time Allotted: 15 minutes
 - Goals
 - Communicate ongoing progress
 - Ensure team support
- Operations Transformation Update
 - Frequency: Monthly
 - Time Allotted: 10 minutes
 - Goals
 - Communicate ongoing progress
 - Ensure team support
 - Communicate successes
 - Increase visibility
- HTMA Wide Town Hall
 - Frequency: Every other month
 - Time Allotted: 60 minutes
 - Goals
 - Communicate ongoing progress
 - Discuss foreseeable obstacles and suggestions to address

- Ensure team support
- Communicate successes

Non-core Team Participation

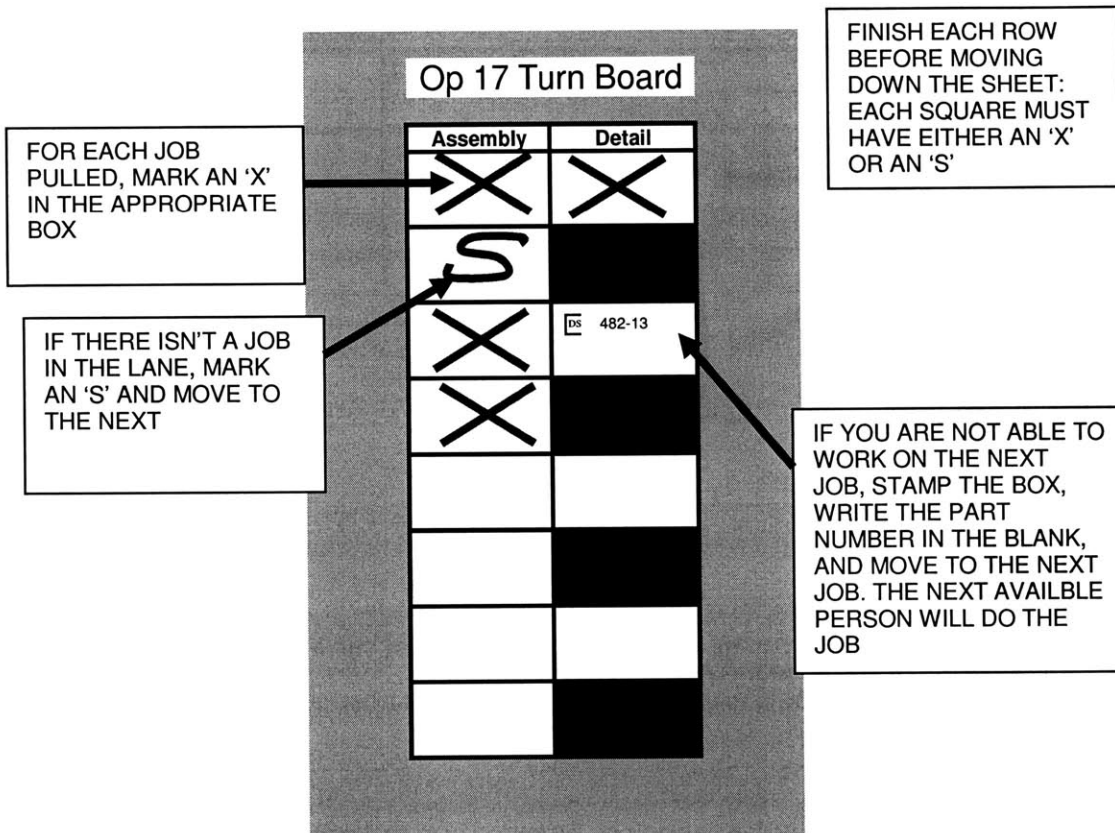
- Internal to the HTMA
 - Input:
 - Required whenever changes affect them, their area, or an area immediately up or downstream from them
 - Requested any time they have a suggestion/improvement
 - Expectation is that every HTMA member will participate at some point
 - Limits:
 - Production must continue
 - Priority list must be respected; new action items will be added but current activities must be closed
- External to the HTMA
 - Process of Involvement
 - If you can do it yourself efficiently, do it.
 - If you know the right person to go to, ask them first. Go up the ladder only if they need higher authority.
 - If you don't know how to get something done, ask the team.
 - If someone on the team has frequent contact with the person outside the HTMA, try and funnel communication through them to reduce confusion. If this will cause delay, talk to them yourself.
 - Facilities point of contact: Lewis Smith

General

- Take a picture of the area/task you are working on. We will post this on the project map to help communicate with the rest of the HTMA. We will also take a picture when we are done to show the progress we have made.
- All stakeholders (everyone who will be in any way impacted by a change) need to be at least communicated with before the change is made. If possible, everyone should be asked for input at a stage where the input can be incorporated.

Appendix F. FIFO Lane Instruction with Turn Board

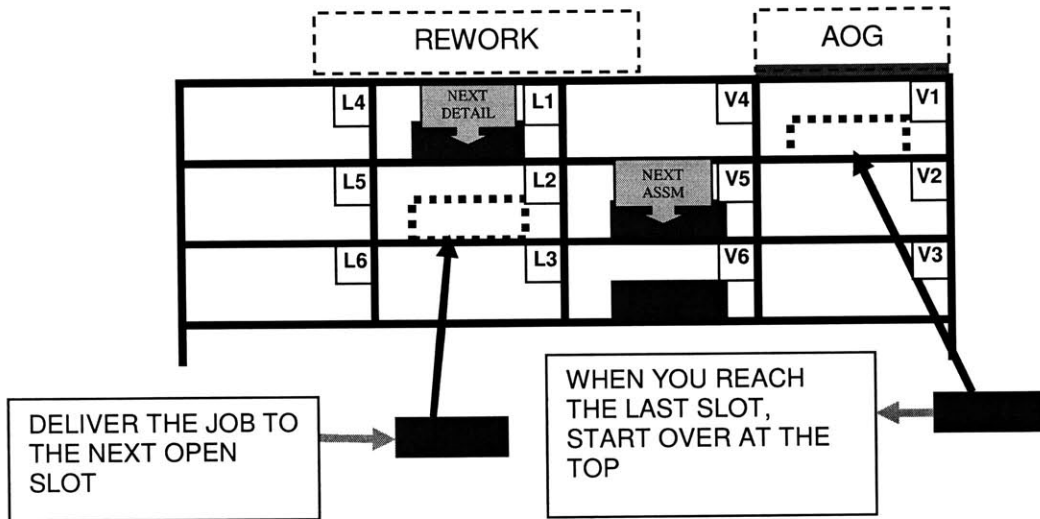
TURN BOARD STANDARD WORK



FIFO LANE STANDARD WORK

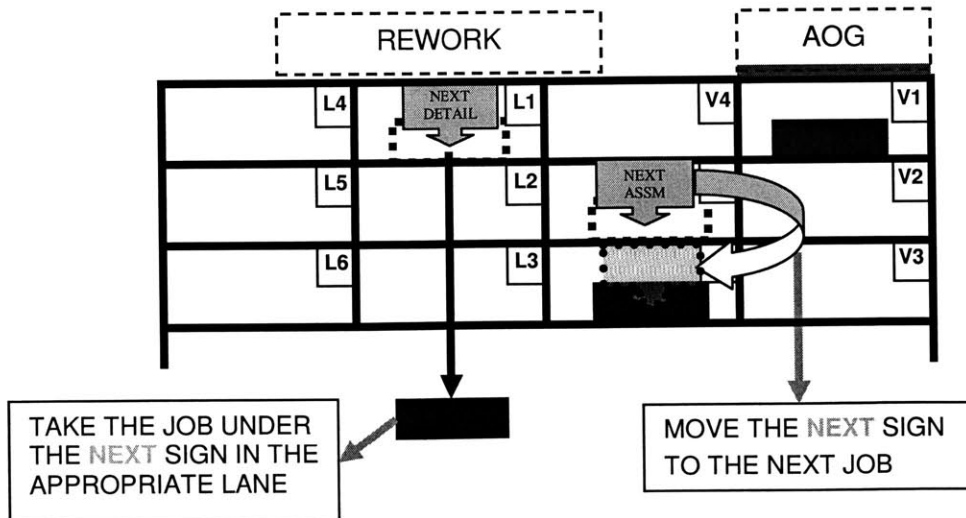
DELIVERING JOBS

1. IF YOU FILL THE LAST AVAILABLE SLOT, NOTIFY BOTH THE LANE MANAGER AND THE LANE OWNER
2. IF THE JOB IS TOO BIG TO FIT IN THE SLOT, PUT THE PINK SLIP IN A TRAY IN THE SLOT AND PUT THE JOB NEXT TO THE RACK ON A CART



TAKING JOBS

1. IF A JOB IS DELIVERED TO THE AOG SLOT, BREAK YOUR SETUP AND DO IT
2. DO REWORK BEFORE TAKING FROM A FIFO LANE
3. USE TURN BOARD TO DETERMINE WHICH LANE TO PULL FROM, 'ASSM' OR 'DETAIL'



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