A Proposed Hybrid-Dynamic Transition Phase for High Mix Low Volume Manufacturers

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Abstract

SMEs with high-mix and low-volume (HMLV) operations face special challenges when implementing lean manufacturing practices due to scarcity of resources and ever-changing market conditions. This is especially critical for manufacturers that need to deliver orders to a high variety of customers with varying time response requirements. The objective of this study is to present a systemic approach to design hybrid-dynamic manufacturing systems (HDMS) for HMLV SMEs. The HDMS is introduced in this paper as a case-study, based on an Oregon-based laboratory equipment manufacturer (and HMLV SME). The HDMS was utilized to incorporate hybrid lead times using an express line for high running products that would run in parallel with the regular production stream. The performance of the designed express line is modeled and validated with historic system performance. The simulation results indicate that the lead time of identified product models can be reduced without affecting the rest of the production flow. The case study shows that for HMLV SME manufacturers, a HDMS design can provide a solution to implement hybrid lead times into their production lines.

Keywords

Lean manufacturing, hybrid-dynamic manufacturing systems (HDMS), small-to-medium enterprise (SME), high-mix low-volume (HMLV) manufacturing

1. Introduction

Small-and-medium enterprises (SMEs) are increasingly more prevalent in the United States and globally, and are a vital component of the economy. In the 2014 State of the Union Address by President Obama, it was noted that 98% of exporters from the United States are small businesses [1]. According to surveys conducted by the Small Business Administration (SBA), approximately 99% of all manufacturing companies in the United States are SMEs [2]. A small to medium-sized enterprise (SME), for a manufacturing or non-exporting service firm, is defined as one that employs fewer than 250 persons and has an annual revenue not exceeding $25 million [3]. As an SME often services a relatively small portion of an industry compared to a larger corporation, they face unique challenges that may be overlooked in broader research. Creating a solution for one SME manufacturer may not apply to all or benefit a large number of companies.

High-mix low-volume (HMLV) manufacturing provides an environment where the products made vary in application, lot size, and production process [4]. SMEs with an HMLV product offering face several unique challenges in enhancing manufacturing productivity. It is difficult to establish a flow within the company due to three main types of variance: (1) Variance of products: it is difficult for companies to establish product flow as there is a large variety of products which require different raw materials, various processing times, and procedures; (2) Variance of routings: with a low volume of each of the products from a wide variety, it is difficult to create consistency on the line, as batching products or creating a back-log of inventory is not ideal or even possible (each product may not pass through all process steps); and (3) Variance of cycle times at each process: with many products it is difficult to create a balanced line, as each product has a varying cycle time at each process step [5].
The objective of this study to propose and develop a Hybrid Dynamic Manufacturing System (HDMS) that can adapt to varying customer demands by accommodating higher volume products and providing a scheduling method for standard products. As introduced here, an HDMS incorporates multiple product flow approaches and is able to adapt to customer demand levels and company manufacturing requirements. It incorporates small changes to the process flow which can incrementally improve operations. An HDMS influences changes in material flow within a facility, rather than changes to the physical plant layout. This ensures that often limited financial resources can be allocated to direct production activities. An HDMS specifically developed for HMLV SMEs addresses issues of long customer lead times and balancing unpredictable customer demand. The work reported presents a systemic approach to hybrid-dynamic manufacturing system (HDMS) design for HMLV SMEs. The approach is illustrated with a case study conducted in collaboration with a small Oregon-based HMLV laboratory equipment manufacturer.

2. Background

Selected prior research for SMEs with a HMLV of products is reviewed in the following section. There is a fair amount of recent research done related to SMEs. SMEs have many resources available to implement lean management techniques into their manufacturing. These opportunities which will investigated relate specifically to individual ways to value stream map (VSM) the facility, facilities layout, product mix planning and lot size optimization. The brief literature reviewed herein is intended to provide an sampled overview into the problems faced by SMEs specifically with HMLV products, as well as some of the most commonly used methods for solving these issues with lean techniques.

Value stream mapping (VSM) is a lean management technique used to analyze the flow of materials and information to create a product or service. A VSM is created by mapping the material and information flows for components and sub-assemblies, which includes manufacturing, supplier and distribution information [6]. Another VSM approach for HMLV manufacturers incorporates the Toyota Way learn principles, value network mapping and Made to Order Lean visual management production control elements [5]. This approach maps the entire production system in one VSM and the box size for each process is proportional to the percentage of associated demand [5]. While this approach creates a basis for Value Stream Mapping of an HMLV facility and could be used as a resource for the HDMS design, it does not address the issues faced when dealing with an HMLV product offering.

An SME with an HMLV product offering can benefit greatly by considering the facility layout or redesigning their current flow. Two methods of facility layout are introduced in [7], which are modular layout and hybrid flow shop layout. The first of these options, modular layout, is an ideal situation, where individual modules separate products or groups of products to allow for material batching, reduce material travel distance and create more predictable cycle times within a given module. The second layout type discussed in [7] is a hybrid flow shop layout which aims to create a single direction flow and reduce backtracking. These layout alternatives for SMEs with HMLV product offerings aim to simplify the material flow into more predictable and manageable subsections. This solution provides long-term benefits, but may not feasible with the small budgets at many SMEs.

Product mix planning is essential at an SME with HMLV manufacturing to reduce changeover costs and time, in addition to increasing equipment efficiency. As SMEs with HMLV product offerings must hold a lot of raw materials to produce the diverse products, they often see high inventory costs. Additionally, to offer a wide mix of products, changeover time and costs are typically high. To combat these issues, an optimization technique for inventory lot sizing for sets of machines with high replenishment costs was created in [8]. This method suggests calculating lot sizes for part families which share set-ups and using these values to create the production schedule. This method will reduce product changeover costs and increase machine efficiencies by reducing downtime due to machine changeover, but is inflexible in the long-term. The calculations would need to be performed for each new product family that is introduced and for varying demand.

Currently, the research and case studies which exist for SMEs with an HMLV product offering, as introduced above, do not address the unique situations which they face due to limited resources, highly unpredictable demand, large varieties of inventories and difficulties with creating material flow. Thus, we propose the HDMS design approach can be used as an alternative solution to improving production efficiency for SMEs.
3. Methodology
To combat the issues of greater cycle times than customer desired delivery dates and excessive finished goods inventories at SMEs with a HMLV of products, a systematic approach is developed in this study. This methodology is designed for HMLV SMEs in which management is willing and committed to implementing lean principles. While they are willing to implement lean, the biggest impact will be seen at a SME which is early in the lean implementation process. Management or personnel should have a basic understanding of lean concepts (e.g., understand a Kanban system, just-in-time production, and Muda) or be willing to acquire the resources to gain this knowledge.

As demand is highly unpredictable in SMEs with a HMLV of products, implementing a single change will not be beneficial once product demand and mix change. Thus, a HDMS is ideal as it can accommodate these changes because while it requires new methods, these can change with varying product and market demand. Additionally, a focus on lean manufacturing is essential at a SME with a HMLV of products. With the issue of limited resources, both monetary and personnel, which SMEs often face, it is more feasible for SMEs to focus on continuous improvement and waste reduction instead of an immediate large change.

The general methodology which can be used at a SME with HMLV to implement a HDMS is shown in Figure 1.

![Figure 1: Methodology to Implement an HDMS at an SME with an HMLV Product Offering](image)

The HDMS design incorporates both creating the express line and scheduling for the standard products. The design phase is ongoing and continues onto the testing portion until a working model is ready to be implemented. This is shown in Figure 1 with the dashed box. The approach is described in detail in the subsequent sections.

3.1 Current State Identification
To begin, an SME should understand its current state by creating a value stream map (VSM), performing a root cause analysis (RCA), a fishbone diagram, asking the five whys, or employing other methods for identifying production bottlenecks and problems. Once an understanding of the current state is gained, an understanding of the current behaviors must be reached. SMEs at the initial state of implementing lean often lack standardized documentation, such as standard operating procedures (SOPs). To understand how employees currently operate, direct observation of the manufacturing floor and interviews with personnel can be conducted. Example questions that should be answered from these two methods should include:

- How does an operator select which product to process next?
- Approximately how many products are waiting to be processed at each step at any given time?
- What steps go into a machine changeover for a certain model?
- What training is provided to an operator to learn how to produce a given product?

From the current state and behavior understanding, steps can then be identified as value-added, non-value added but essential or non-value-added (waste). Value-added activities add market form or function to the product [9] and are
things which the customer is willing to pay for. Non-value added but essential activities are those which do not add market form or function to the product but are necessary for the finished product. These processes ensure the value-added steps are completed properly [9]. These should be reduced in cycle time, if possible. Non-value-added behaviors can be defined as any which does not add market form or function to the product [9] or items which the customer is willing to pay for. Those which are non-value-added should be sought to be eliminated.

Once the personnel understand the current state, behaviors and have identified non-value-added and support activities, they can begin to move towards the creation of a solution.

3.2 Current State Simulation Creation
The first step assists with identifying problem areas and moving an SME towards a better lean state but more analysis is needed with a dynamic simulation. A software simulation can be updated for new products, fluctuating demand and varying process times. Simulation helps to identify current issues and how a change will affect the manufacturing line. A simulation of the current state with processing times and machine capabilities gathered for the VSM and from direct observation can be created. This simulation also serves as a benchmark for the HDMS design simulation. The benefits gained from the HDMS design will be able to be seen in comparing the current state simulation with the HDMS design simulation.

3.3 HDMS Design
An HDMS can account for an HMLV of products with varying processing times and manufacturing steps with minimal-to-no adjustments to the facility layout. The HDMS is divided into two subsections: the express line for comparatively high weekly demand and shorter cycle times and the standard line for all other products. This design is to create a flexible manufacturing production of both high-running products and non-high-running products.

Express line design: The current and future state simulations lend themselves to the implementation of a system with an express line of products. To create the system, first, the products for the express line should be identified. These products should have comparatively high weekly demand and comparatively low cycle times. Once the products have been identified, processing information (e.g., process time, specifications, operation procedures) and machine information (e.g., capacity) need to be gathered for scheduling of the express line products.

Standard product scheduling: The second component of the HDMS is the scheduling for the standard products. The technique will need to adapt to the current scheduling software (if one exists) and the available resources. Each SME is unique and an example of one scheduling technique will be presented in the case study, however, these general guidelines should be adhered to for optimal results. First, the scheduling system should be resilient and better adapt the fluctuating customer demand. Second, this scheduling system should use a decision support heuristic which walks the scheduler through the process. The heuristic will require trial and error to better fit the company’s needs. The third important component of the schedule is it should be created for as close to one-piece flow as possible. With the HMLV of products, it is often not possible to group identical products therefore similar products get grouped together which then creates issues of products waiting to move onto the next process step. Finally, components which are not part of the main assembly or can be assembled aside from the main product flow should be done so before the main assembly reaches that process step.

3.4 HDMS Simulation Testing
Prior to implementing the express line and standard product scheduling, both should be tested to create a smoother implementation process. A simulation can be created for the HDMS system. As the same data from the first simulation (current state simulation before HDMS) can be used for machine processing times and machine changeover times this will demonstrate the benefits and areas for the improvement in the HDMS. Through a process of trial and error, a decision support heuristic for the daily scheduling system and the express line design should be ready to be implemented at the SME.

3.5 HDMS Implementation
Once the design and simulation testing are completed, the physical implementation of the HDMS should occur. This phase may take up to a couple of months depending on how it occurs: in phases or all at once. Implementation in phases would make for a smoother transition with less disruption to production; however, the full results will not be seen until complete implementation is finished. One such option for implementation in phases is to first begin with
changing the production scheduling system. Then, once the scheduling change has been executed, the express line can be implemented.

3.6 HDMS Validation
As mentioned previously, the purpose of an HDMS is to be able to adapt to varying customer demand and an HMLV of products. This adaptability means that when new products are added to the manufacturing line or a product has steady, increased demand, the HDMS should change to meet these needs. Thus, the validation phase will be ongoing for the life of the HDMS, as shown in Figure 1. One such example is if a product is seeing high weekly demand on the standard line on a consistent basis and has a comparatively low cycle time, the company should look at adding the product or exchanging it for another product on the express line.

4. Case Study
In this section, the proposed systemic approach to design the Hybrid Dynamic Manufacturing System (HDMS) is illustrated for the case of a small Oregon-based laboratory equipment HMLV manufacturer.

4.1 Current State Identification
The company designs and manufactures constant temperature equipment [10] with over 100 different models. There is a lack of standardization across the products. Two models may be similar in shape or size, but the components which make up the assembly are not the same. This increases the materials on hand. With a wide variety of customers, each has different product expectations and varying time response requirements. Currently the average lead time for products is approximately three weeks. To shorten lead time, the company holds finished goods inventory which helps with customer relationships. However, if a product undergoes a design change, the items in the finished goods inventory will have to be modified to meet customer specifications. This additional processing can lead to increased manufacturing costs and increased lead time. The manufacturing floor is divided into two sides: the metal shop and the assembly shop. There are approximately 60 personnel who operate the facility. To better comprehend the current state of the manufacturer, a value stream map (VSM) of their entire production system was created. A portion of this VSM is shown in Figure 2.

Figure 2 is the VSM for the case study company for the first three processes: punching, bending, and welding. Only a portion of the VSM is included, as it is highly detailed. The VSM provides information on the number of shifts for
each process, the cycle time at each, the number of operators, and number of machines. On the bottom of Figure 2, the values are the value and non-value added times for a given process, as labeled on the left of the figure.

4.1.1 Metal Shop Processes
On the metal shop side, there are four main processes: punching, bending, welding, and painting. In the welding process, there are several sub-processes including spot welding, and grinding. The manufacturing process begins with metal sheets as the raw material. The raw material ordering system is represented in Figure 2 in the upper left corner. As shown, the metal sheets are ordered using a Kanban system, where a certain amount of each metal type is stored in house. To start, there are approximately eighty different metal variations which range in size, gauge, metal type, and several other specifications. These metal sheets first are processed at one of three punch machines. From here, metal pieces then pass to three brake machines for bending. The bending process involves clamping the work piece between a matching punch and die to bend the piece to a pre-determined radius. Once the metal pieces have been bent, they go to the welding area. Here, parts can be welded manually, by the robotic welder, or by a spot-welding machine. Next, parts are ground and sent to the painting area. Paint jobs are batched by color.

4.1.2 Assembly Shop Processes
On the assembly shop side, there are three main process steps: assembly, quality assurance, and packing and shipping. The shop includes four assembly lines. Each assembly line is designated for specific product types based upon size or industry. Once products have been assembled, the next process step is quality assurance (QA). Here, products are inspected to ensure they conform to quality standards. If there is a defect in the product, it must be reworked or replaced. After QA, products must be packaged. Finally, products which have been ordered by a customer are shipped. Alternatively, those which are built to create a finished goods inventory are stored on shelving units, ready to be shipped when the demand arises.

4.1.3 Production Scheduling
The production manager is the central controller of material flow. A production schedule is created at the beginning of each week for the entire week of production. The orders are released electronically which determines the flow of materials through the shop. The production manager schedules production based upon the delivery date requested and the anticipated availability of the four assembly lines. Once products have been released, they must be uniquely identified and tracked. Products are assigned to a job with like products. Currently, there is no computerized inventory tracking system in place. Once products are assigned to a job, a router is printed. The router specifies which processes are required for this product, a description of the processes and the required quantity and due date for the respective processes. Additionally, each job has a unique identifier comprised of a three-digit number and a letter. The first two digits identify which week of the year the material began processing, the third digit signifies which of the four assembly lines the products will run on and the letter identifies what color paper the router is. The color creates a visual distinction between jobs.

This push production system conforms to the needs of the customer. When an order is received, the production manager determines how to incorporate that order into the line. However, as some products have longer cycle times than the lead times requested by the customer, the company holds certain products in finished goods inventory to be able to meet their customers’ needs. With this current method, issues arise when these products become obsolete and must be reworked before they can be sold.

4.2 Current State Simulation Creation
As described above, products have approximately seven main processing steps. The processing steps have fairly low levels of complexity and require manual processing especially at the welding, assembly, and quality assurance steps. The company had little documentation of product routings, product cycle times, or machine changeover times, therefore this material needed to be acquired. As there was no electronic tracking system, this information had to be gathered by hand through time studies, direct observation, and interviews with the operators. For the express line products, information was mainly gathered by time studies. The manufacturing line was examined at each process step, individually providing more detailed information. This information was compiled to approximate average wait times, processing times and machine changeover times. Upon gathering the product information, a simulation of the current state of the facility was created using Arena simulation software.
In Figure 3, each box represents a process. The seven processes contain sub-processes which include decision heuristics to guide the material as it would be processed in real-life. For instance, the assembly lines at the case study company are scheduled by product size and industry type. To ensure that the material flows in the same manner as it does as the company, the simulation contains decisions which step the material through each assembly line until it reaches the one which it would be assigned to.

Products at the company are processed on a first-in/first-out basis, and this is reflected in the simulation. There are not any products that are given precedence for processing. Material is batched with like items, not necessarily the same model but in the same family. This batching is reflected in the simulation with batches of three units. In the simulation, one week of production time is considered to be 64 hours. This is because, on average, the company operates four days a week and 16 hours per day between two overlapping 10-hour shifts. The results from the current state simulation highlighted in Figure 1 are shown in Table 1.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Average Cycle Time (hrs.)</th>
<th>Average Cycle Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>296.25</td>
<td>18.52</td>
</tr>
<tr>
<td>2</td>
<td>259.73</td>
<td>16.23</td>
</tr>
<tr>
<td>3</td>
<td>259.16</td>
<td>16.20</td>
</tr>
<tr>
<td>4</td>
<td>267.90</td>
<td>16.74</td>
</tr>
<tr>
<td>5</td>
<td>255.15</td>
<td>15.95</td>
</tr>
<tr>
<td>Average</td>
<td>267.64</td>
<td>16.73</td>
</tr>
</tbody>
</table>

In Table 1, each entity represents a specific product which the company produces. The cycle time of each product is shown in the second column in hours, which is pulled directly from the simulation. The third column shows the cycle time in days. The cycle times are on average 16.73 days or around 2.5 weeks. This is very similar to actual cycle times at the company as the packing and shipping processes were not included in the simulation. In addition to the quantitative results shown in Table 1, other observations were made from the simulation. The company has the practice of only starting material at the beginning of each day for a process. Therefore, material that arrives throughout the day sits in queue until the following day. Furthermore, material at the weld station only begins on the first day of the work week, Monday. From the simulation, it was observed that the time in queue was large although machine utilization results indicated they were not being fully utilized.

4.3 HDMS Design
To design a HDMS, the following steps have been applied to this study:

4.3.1 Express Line Creation
The products that run on the express line are high-running and comparatively low cycle time. Current and forecasted demand levels in addition to the insight of the production manager and continuous improvement manager were used.
to determine the products. Five products were selected, out of approximately 100 product offerings at the company, approximately 5% of their total product offerings. While demand fluctuates based upon customer orders, historical data provided insight into approximate weekly quantities. The five products and corresponding approximate demand are shown in Table 2.

Table 2: Express Line Models with Product Description and Estimated Weekly Demand

<table>
<thead>
<tr>
<th>Model</th>
<th>Product Description</th>
<th>Weekly Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Incubator A</td>
<td>4-6 units</td>
</tr>
<tr>
<td>2</td>
<td>Incubator B</td>
<td>5-7 units</td>
</tr>
<tr>
<td>3</td>
<td>Incubator C</td>
<td>12-15 units</td>
</tr>
<tr>
<td>4</td>
<td>Oven A</td>
<td>8-11 units</td>
</tr>
<tr>
<td>5</td>
<td>Oven B</td>
<td>10-12 units</td>
</tr>
</tbody>
</table>

Multiple iterations of the express line product list were created and can change again in the future to accommodate changing demand. For these five products, general information needed to be gathered to understanding their impact on the company’s success and on the manufacturing operations. Information was gathered on the raw materials required (i.e. metal type, gauge and sheet size; and electrical components), the components which compromise each model and the quantity of each component.

4.3.2 Standard Product Scheduling System
The standard scheduling system will use a set of logic and rules which seek to address the issues currently faced by their facility. For instance, there are currently issues with perception that products can only start in certain departments at the beginning of the week. This decision support heuristic will seek to eliminate these concerns and address the root issues. Through the trial and error process of creating the decision support heuristic, a Gantt chart with each of the products listed was monitored to look at effect of logic changes on product cycle time.

4.4 HDMS Simulation Testing
Once the design of the HDMS was completed, it was necessary to test the design using simulation software. The same software, Arena, was used for the future and current state simulations. The HDMS simulation focused on the five high-running products while still incorporating the standard products. The design differences in the future state simulation will be described in this section.

4.4.1 Product Designations and Divisions
Each of the five products were created individually with specific processing and machine changeover times. In addition to the five products, three other products were created which represented the standard products divided into low, medium and high processing times. These processing times were gathered from compiling, analyzing and averaging sales data for the company from the past six months. The three product categories also simulated the demand level data gathered from the past six months.

4.4.2 Material Processing
In this HDMS simulation, material processing was updated in three ways: product order processing decision making, continuous manufacturing and one-piece material flow. The product order processing decisions differ from those of the current state. As the HDMS simulation incorporates the standard and express line products, material must be processed accordingly. The products in the express line will take precedence for processing at any given process step. At each process, the queue has two tiers: the first being for the express line products and the second for standard products. Standard products are selected to begin being processed only when there are no express line products in the queue.

In addition to changes to the order of product processing, the simulation is designed such that material is continuously manufactured. Thus it is processed at any time of day, should it be at the top of the queue. This eliminates the added cycle time, which resulted from waiting to process products, at a new step until the next morning or the beginning of the week.
Third, the HDMS design simulation processes material one at a time, removing the batching that was present in the current state simulation. The one-piece flow moves the company towards a leaner environment. Removing batching allows for improved flexibility and reduced work-in-process (WIP) inventory.

### 4.5 HDMS Design Simulation Comparative Results

The results obtained from the simulation of the HDMS design are compared to those which were obtained from the current state simulation. A focus was placed on the changes for the express line products as the cycle times of these products was a main objective of the research. A comparison of cycle times between the two simulations is shown in Table 3.

<table>
<thead>
<tr>
<th>Express Line Product</th>
<th>Average Current State Cycle Time (days)</th>
<th>Average HDMS Design Cycle Times (days)</th>
<th>Cycle Time Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.52</td>
<td>2.80</td>
<td>85%</td>
</tr>
<tr>
<td>2</td>
<td>16.23</td>
<td>3.00</td>
<td>82%</td>
</tr>
<tr>
<td>3</td>
<td>16.20</td>
<td>3.15</td>
<td>81%</td>
</tr>
<tr>
<td>4</td>
<td>16.74</td>
<td>3.45</td>
<td>79%</td>
</tr>
<tr>
<td>5</td>
<td>15.95</td>
<td>2.78</td>
<td>83%</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>16.73</strong></td>
<td><strong>3.04</strong></td>
<td><strong>82%</strong></td>
</tr>
</tbody>
</table>

A comparison between the two shows a cycle time reduction of around 80% for all five of the express line products. The cycle times for the HDMS design are on average 3.04 days or ¾ of a work week for the company, as they only operate four days of the week on average. As noted previously, the simulation does not account for the pack and ship processes. Therefore, the cycle time of 3.04 days would allow one day for those two processes to be completed.

### 4.5 Implementation and Results

Now that this revision of the simulation is completed, the next step is to implement the hybrid dynamic manufacturing system at the company. In addition to the demonstrated cycle time reductions for products, the simulation highlighted changes which will help the company. Implementation of an updated scheduling system, one-piece flow and continuous manufacturing will help the SME towards reducing cycle times for all products.

As stated previously, a HDMS can adapt to changing market conditions and is expected to evolve over time. It is a closed loop system, as shown in Figure 1, and results will help to revise future iterations of the HDMS.

### 5. Discussion

SMEs face special challenges when implementing lean manufacturing practices as there is often a scarcity of resources. SMEs with a HMLV of products have an even more difficult time implementing lean principles due to the wide variety of products they create. Additionally, SMEs tend to feel the effects of ever-changing market demand more closely than a large corporation. The hybrid dynamic manufacturing system approach proposed in this research provides one solution for HMLV SMEs to be flexible to these conditions.

The use of a systemic approach to the HDMS design demonstrated many opportunities for future research. In the short term, future research will investigate scheduling interactions between express line products and non-express line products. For instance, alternative methods to create the weekly production schedule or different methods of material processing. Further, with this HDMS transition system, how the manufacturer can improve their manufacturing performance from the gained implications also needs to be studied. The goal for such manufacturing system is to eventually reduce unnecessary product varieties by standardizing products and manufacturing components. While these two opportunities are in the short-term, long-term this research can lend itself to creating a mathematical model for scheduling optimization for SMEs with a HMLV of products. While the current method of scheduling is robust and adapts to changes in customer demand, this method can be verified mathematically to ensure that it is the optimal solution. If it is not, the scheduling system can be updated based upon what is optimal.

### 6. Acknowledgement

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