Improving Throughput at a Hydraulic Pump Assembly Facility

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Abstract

This paper presents a systematic approach followed by a group of industrial and systems engineering students to complete their capstone project at a pump assembly facility to gain efficiencies in the build process. The objective of this research was to design a mixed model linear flow assembly line that can build high volume hydraulic pumps efficiently to meet the growth in customer demand. There were five U-shaped cells used to assemble a variety of hydraulic pumps. The U-shaped cells were inefficient and the throughput was lower than the customer demand rate. Using clustering algorithms, the pump assemblies were classified into families. As the existing time standards were inaccurate, new time studies were conducted to benchmark the current state. Line balancing techniques were used to compute the optimal number of workstations and appropriate manning levels to have a line with high balance efficiency. The new line is designed to assemble multiple styles of pumps which account in total for 80% of the total demand. Several process improvements were recommended and implemented. As a result of all the recent initiatives, the throughput of the new line was much higher than the five U-shaped lines combined.

Keywords: Industrial engineering, lean manufacturing, mixed model assembly

1. Introduction

This project was conducted at a hydraulic pump manufacturing company. A wide variety of pumps are assembled on different production lines based on their specifications and functionality. The pumps are typically used in construction, energy, automotive industries and sold to OEMs. The project team comprised of two seniors and one faculty mentor from industrial and systems engineering.

The pump assembly considered for this study offers over 300 unique models that are primarily used to power the car lifts in automotive shops and operate plows on snow trucks. These models operating range is typically between 3,000 and 5,000 psi. Altogether five U-shaped cells were used to assemble all 300 models. Each of these U-shaped cells consists of four stations: assembly, testing, trim, and packaging. The assembly station is responsible for assembling all components of the build prior to testing. After the unit is assembled; it is passed to the test station. The test station is where the pressure, voltage and current of the unit are tested based on the tolerance provided on the blueprint. The testing equipment used at the test station differs depending on the model type. After passing the test, the unit moves to the trim station where it is wiped down and all post-test plumbing is attached. Once the unit is completely assembled, it is moved to the final station (i.e. packaging). The unit is then strapped to a piece of cardboard or plywood and placed in a cardboard box, ready to be shipped out to the customer.

In 2012, the company produced over 48,000 units comprised of over 300 unique models. All five cells were used to meet the customer demand. These five cells combined take up approximately 3,934 ft² of floor space. Operators currently build using batch production with batch sizes ranging from 4 to 8 depending on what aspect of the build is being assembled. The majority of common small parts are kept on the workbenches. Having bench stock can cause operators to waste time searching for the appropriate part or can lead to poor quality or defective finished units in the case where the wrong part is used. Large parts are presented to each work cell in their original packaging. During the assembly process operators are responsible for removing all the cardboard and plastic that the motors and tanks are delivered to the factory in. This significantly reduces the amount of time that operators actually spend assembling.

2. Problem Statement

Due to the high variation and inefficiencies in the build process the factory has been consistently falling short of daily demand. With the current layout and build process an average of 177 units can be built per day, which alone is
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not enough to meet annual demand. The work content within the work cells is neither balanced nor standardized. This lack of standardization leads to variation in the cycle time per station because every operator has a unique method for assembling the units.

The project objective was to design a mixed model assembly line capable of handling a variety of models and facilitating a single piece flow (instead of batch assembly). Based on preliminary data analysis from 2012, 80% of the demand is comprised of 77 unique models. The goal is to design the new line such that a majority of these 77 models can be assembled on the new line and the remaining on a different line. In developing the new line, the following considerations were also taken into account:

1. Change assembly methods from batch production to one piece flow.
2. Condense the current U-shaped work cells into a linear mixed model assembly line, reducing the amount of floor space required.
3. Minimize the amount of travel done by operators.
4. Balance the work content at each station to reach a 3 minute cycle time goal at each station.
5. Create high level standard work instructions.
6. Standardize the assembly process through the development of product families based on component similarity.

3. Current State Analysis and Solution Approach

Nearly two weeks were spent observing the existing manufacturing cells. Through observations cycle times, inefficiencies in part presentation, waste in travel and motion, etc. were tabulated.

3.1. Time Studies

During the observations of the factory floor, preliminary cycle times were recorded for the production cell. This was important in order to establish a benchmark for the station times. The results are shown in Table 1. Along with the spreadsheet, video recordings of the operators were taken in order to obtain data that can be further broken down to the micro level. Even though this data was only for one model, the assumption that all models within a product family had relatively similar assembly times allowed this data to represent all models within the product family. The data was used to understand which stations in the process take the most time, which led to the identification of bottlenecks or stations with the most operator idle time.

<table>
<thead>
<tr>
<th></th>
<th>Assembly 1</th>
<th>Assembly 2</th>
<th>Testing</th>
<th>Trim</th>
<th>Packaging</th>
<th>Total</th>
</tr>
</thead>
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<td>1:01</td>
<td>2:36</td>
<td>5:36</td>
<td>3:48</td>
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<tr>
<td>Standard Deviation</td>
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<td>0:06</td>
<td>0:39</td>
<td>1:24</td>
<td>1:01</td>
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</tr>
<tr>
<td>(min:sec)</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Number of Observations</td>
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<td>16</td>
<td>23</td>
<td>11</td>
<td>15</td>
<td>N/A</td>
</tr>
</tbody>
</table>

3.2. Spaghetti Diagram

A spaghetti diagram aided in determining how much waste was attributed to transportation. Figure 1 shows the spaghetti diagram for a work cell in the current state. Within the confines of the work cell, two operators walk back and forth between each work station to complete tasks. Hellman, Lindahl and Malmberg [1] discuss the benefits of a U-shaped design layout. Ideally there is less material handling needed along with a reduction in floor space which corresponds to a reduction in travel [1]. The distance shown in the spaghetti diagram did not appear to be large due to the cell’s U-shape design, which is one of its claimed benefits. This is not entirely true when the excess travel of a single operator between the work stations is compared to the almost stationary operator on a linear assembly line allocated to one workstation. Data was collected for a one operator sample. The data showed for each 4 piece batch, the operator walks approximately 149 feet. With a goal of approximately 20 units per day, operators walked 745 feet per shift, or 35 miles per operator within the cell in a given year. With increase in demand, the amount of time wasted in travel is expected to increase significantly. The linear mixed model assembly line designed eliminated this
unnecessary travel by incorporating conveyors to convey builds from one station to another. More details on this can be found in section 5.

Figure 1: Spaghetti Diagram

3.3. Clustering to form Product Families
The company intends to use the high volume assembly line to assemble the models that make up the top 80% of their annual demand. In order to determine the high volume models, Pareto Analysis was performed on the 2012 sales data. An assumption was made that this sales data is an accurate way of forecasting future demand, so whichever models had the highest demand in 2012 were the focus of the analysis. Figure 2 shows the Pareto Analysis Chart for the 2012 sales data for each model. The chart is made up of over 300 unique models, each represented by a bar based on the amount sold in 2012. The specific names of each model are hidden in the figure below to maintain confidentiality. There were 77 high volume models that made up 80% annual demand. These 77 models were the focus of this project.

Figure 2: Pareto Analysis Chart for 2012 Sales Data

The 77 models that made up 80% of annual demand were broken down into six product families. These product families were established based on the similarities within the build process. Clustering algorithms in Minitab were used to form families. The similarity was determined based on the parts or components used in the build process of each model. Due to the slight variation in part numbers of otherwise seemingly identical parts, the similarity within each product family was initially very low. Using the assumption that functionally similar parts are the same no
matter what their unique names are; all same parts were combined under a general name. The Minitab results are shown in Figure 3. The similarity between models that fall under the top two product families was 42.26% and 37.64%, respectively. The product families were further classified into sub families by applying the clustering algorithms to each family independently. As a result, family 1 had seven sub families and the second family had eight sub families. There were some sub families which were 100% similar. Interactions with the management helped us to also take into account certain design features while classifying the families and sub families. The percentage of annual demand that each product family accounted for is shown in Figure 4.

![High Volume Models Dendrogram](image)

**Figure 3: High Volume Models Dendrogram**

![Product Family](image)

**Figure 4: High Volume Product Families**

### 3.4. Line Balancing, Manning Levels, and Standard Work

With established product families and an acquired basic understanding of the system, the stations needed for the new linear assembly line and specific work content at each station was determined. Operator input was a logical starting point, because aside from the floor manager nobody knows the system better than the operators. The operators
explained the stations at each work cell and how the work is currently divided in order to meet their expected throughput per hour. In the current state, each cell included one assembly station, one test station, and then a trim and packaging station. At the assembly station the operator assembles 4 to 8 units for one batch. The unit is then moved along the bench to the test station. The test stand is capable of testing one unit at a time. After testing, the unit is moved to the trim station where further mechanical assembly is carried out. Finally at the packaging station the unit is placed in a box and pushed to an automatic tapping machine. The boxed units were then placed on a pallet. When two operators work on the line, one operator builds and tests the unit; the second operator works at the trim and packing station. From the preliminary data gathered, this is not an efficient way of balancing the line. The building and testing stations have a combined average cycle time of approximately 6 minutes and 34 seconds, whereas the trim and packaging stations have a combined average cycle time of approximately 9 minutes and 24 seconds.

In the current state there are 5 distinct U-shaped work cells, each operated by 1-2 assemblers. The exact number of assemblers scheduled fluctuates depending on assembler availability and the current product demand. When running a mixed model assembly line, theoretical minimum number of workers needed can be determined using equation (1) to determine how many operators are minimally required to run the line and meet the customer demand [2]. The major variables in the equation are the rate of production \( R_{pj} \) for each model, which can be determined by the annual demand for that model and the available work time. The other major variable is total work content time \( T_{wCj} \) required for that same model \( (j) \). Other factors that can affect the number of operators required are the number of shifts, number of hours in the shift, the number of unique models \( (n) \), and the efficiency of the assembly line \( (E) \). An industry standard is to use anywhere from 85-90% efficiency when calculating labor requirements, because it accounts for operator error, failure/rework time, and unscheduled breaks. Using the time study results from the pilot tests and 2012’s sales data for demand, the theoretical minimum number of operators required to meet the demand was found to be 6. In reality the future state line will operate with either 6 or 7 operators, depending on the specific models being run at the time. The results from the calculations validate the design of the future line.

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minimum \text{ workers} = \frac{\sum_{l=1}^{n} R_{pl} T_{wCj}}{60 \times E}
\]  

Based on the work content and the precedence relationship between different work elements, the work content of assembly station was divided into three stations to balance the line. Testing, trim and packaging each had one operator. In order to prove the proposed solution is feasible and effective, pilot tests were run with different models from each product family.

4. Pilot Test

The company dedicated a Greenfield area within the factory for the development of the future high volume line. Pilot tests were conducted to determine whether or not the stations can meet the expected 3 minute cycle time given the suggested division in work content. Within the Greenfield, 3 sample work benches were assembled and used to simulate the workstations in the future state line; 3 assembly stations. Many of the lean principles found in the literature were followed to ensure the benches were properly organized [3]. The benches were fit with air-pressure lines and electrical outlets to power the tools necessary to build the pumps. After consultation with the floor manager, several models were chosen as candidates for the pilot study. In some pilot tests, two orders were run back-to-back to simulate a changeover between models. When running two different models, data for 10 samples of each model was collected in a single pilot run.

There were several issues in the way parts were presented in the current state. Operators were losing time opening bagged parts, sorting different parts delivered to the line, walking frequently to prepare the batch, etc. Hence, a concerted effort was made to improve part presentation for the new line designed. For every model run on the pilot line a work order was created and picked completely by the picking team. The parts were individually bagged and labeled and delivered to the Greenfield in a large box on a pallet. All small bags of parts were sorted by station and set up in a pre-determined presentation method. This involved filling and labeling medium-sized compartmentalized gray bins with the required small parts. The gray bins worked well for presenting medium-sized parts because operators could easily grab them out of the bins. The challenge with parts presentation was determining how to present the small parts such as screws and nuts. The advantage of running these pilots was being able to test different methods of presenting parts with varying success. The team collaborated with the picking team and the
consensus seemed to be that using compartmentalized bins would be the most efficient way of balancing the picking aspect of the work and the lean presentation of parts to the workstation.

The established rules for the pilot study were that each operator may build only one piece at time. They could only begin to build the next part if there was no more than one finished piece waiting to be assembled at the next station. Each operator could only assemble the components of the build that are allocated to that work station. Those steps were explained in the work instructions presented at each station. Operators were told to work at a steady pace keeping in mind that their pace would need to be maintained for an eight hour shift.

During the pilot tests there was a minimum of 1 observer per station that recorded cycle times per operation and noted any downtime, defects, or possible improvement suggestions. The purpose of running the pilot tests was to gather data and demonstrate that the newly designed line yields higher throughput. The initial results from the time studies conducted during the pilot tests showed that the line was unbalanced. Figure 5 is a bar chart with cycle times for each station for several models built. Variances in the cycle times occurred at different stations, which indicated the work content needed to be analyzed and rebalanced. In order for the high volume assembly line to flow smoothly, every station needs to have similar cycle times.

There were two methods used to balance the work content between the stations. In the first method, a flexible operator was assigned to the line. This operator was shared between the test station and one of the assembly stations. In the second method, a modular operation list was created to list each operation and its relative cycle time. Knowing the work elements and how long they take at each station allowed the identification of which work elements could be shifted upstream or downstream. The only concern with this method was whether or not materials would be double handled, and whether or not certain elements could be shifted based on precedence. Figure 6 shows the total work content for each model at each station after the lines were rebalanced. The original results from the pilot tests resulted in a total line efficiency of 67%. Moving the work content around and introducing the flexible operator improved the efficiency to 76%.
5. Future State
The objective of this project was to convert the current assembly line into a new high volume mixed model linear assembly line. Figure 7 below shows the layout of the future line proposed. The new line has 6 distinct work stations that are connected via an automated conveyor belt. In their article, Dattatray and Kavade [3] discuss the basic types manufacturing layouts. Their description of the product layout fits best with the needs of a high variable product assembly line, which arranges the work stations in sequential steps in the order the product is assembled [3]. This is also an optimal design for a mixed model assembly line. A linear line with a belt-style conveyor used to transport parts will result in a significant reduction in travel distances and an increase in operator utilization. There are three basic principles to consider when implementing a conveyor system. These principles include uniformly distributing parts over the length of the conveyor, having carrying capacity greater than the intended maximum throughput, and monitoring the speed of the conveyor for loading and unloading purposes [4]. All of these principles are built into the new conveyor system. Each workstation is evenly spaced so that each part is placed at an even distance throughout the belt. The conveyor also has the capacity to hold and transport the heaviest models built on the assembly line. Lastly, in order to control the speed of the conveyor photo-eyes are set up so that the belt will stop once the part reaches its destination allowing the assembly line to operate with one piece flow. There are two test stands; the second test stand will only be needed for some pumps with a lengthy test time. Staffing the future state line with 1-2 operators per station will result in the utilization of the same number of operators used in the current state, while eliminating the need for overtime. A simulation model was constructed in Arena to determine performance metrics such as throughput. The time studies from the pilot tests, in conjunction with the results from the simulation model, show that each station will be able to maintain a 3 minute cycle time. High level work instructions, created using Microsoft PowerPoint, will be displayed at each station to help operators know what specific tasks need to be performed, along with a computer screen containing the model’s blueprint. The reason it is important to have both is because there are slight variations in the orientation of parts within the same product families that can only be seen on the blueprint. Additionally, the test stand needs to be able to read the engineering specifications for metrics such as pressure, voltage, and current, and the only way to have that specific information easily available is by utilizing the blueprint. The goal of the future state line will be to produce approximately 160 units in an 8 hour work day, which will match the current demand levels and exceed current throughput when supplemented by the assembly line producing the models not categorized into the high volume product families.
6. Cost Analysis

Building the new high volume assembly line has certain costs and benefits associated with it. With regards to savings, the 5 U-shaped work cells take up 3,934 ft² and there is an opportunity cost of $6 per ft² year. The two future state lines combined only occupy 1,946 ft², which results in a savings of $11,928. The second savings from implementing the future state line is the reduction of overtime hours for the operators. In order to meet the 2012 demand, operators worked 1,665 hours of overtime. The new line will be able to match the current throughput and eliminate the need for overtime hours. The cost of having operators work a single overtime hour is $37. Through the elimination of overtime, the company will see an annual savings of $61,771.

There are of course costs associated with developing this new line. The most significant costs associated with the new line are purchasing new work benches and a new conveyor belt as well as redesigning the two test stands. Updating the current test stands to allow the flexibility to run both types of units down the same line is a very significant cost, both in materials and in labor. The combined cost of materials for the benches, conveyor belt, new tools, and test stands is roughly $40,000. The cost associated with moving the tools over from the current state and the labor involved in building the new line is approximately $8,000. The total cost was budgeted with management for $48,400. This will result in a first year savings of $25,299. Additionally, every year the line runs with no overtime will see a savings in the labor costs.

7. Conclusions

The newly designed mixed model assembly line was fully functional beginning in June 2013. There are still two of U-shaped cells that are operational on each. These cells are used to run the lower volume and more challenging units. After a couple weeks of sorting through the loose ends, the mixed model assembly line was running as intended. Orders for each job are completely picked, excluding a select handful of inexpensive common parts that are currently located near the line in a supermarket. Bench stock has also been eliminated. Large parts are delivered on carts separated out by their designated work station in the build process. There is also a scoreboard that compares the operators’ actual throughput with the goal for the day to calculate efficiency in real time. In October 2013 the line broke a record and built 202 units in a single day with 7 operators on the line. Since then, the mixed model assembly line has produced over 220 units in a single day, bringing the total average daily throughput to
approximately 230 units. This is approximately a 23% increase in throughput using the same number of operators compared with their previous layout throughput. Due to the success of the high volume mixed model assembly line, further investigation has begun to implement these lean techniques on other assembly lines within the factory.

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References