VALUE STREAM MAPPING MICROPANEL ASSEMBLY WITH CLUSTERING TO IMPROVE FLOW IN A SHIPYARD

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Abstract: The micro-panel assembly process produces approximately 20% of the components that are assembled in a typical commercial ship and improvements made to assembling these interim products will reap savings for shipyards. Micro-panels can be considered transverses, brackets, and unit panels stiffened with profiles. Value stream mapping is useful in illustrating the flow during assembly processes. In this paper a value stream mapping case study of an automated micro-panel and robotic micro-panel assembly line is made. Then the clustering technique is applied to the different micropanels assembled in order to demonstrate which micropanels should be assembled together. Then a methodology for an improved state of a combined automated and robotic micro-panel assembly line is made, with all the benefits illustrated. This includes duration time, man-hours, configuration improvement and space savings. The importance of kaizen or continual improvement is demonstrated in order for shipyards to achieve and maintain competitiveness.

Introduction

The production processes in a typical shipyard are becoming more and more complicated since the interim products continue to increase in variation between one another and it is difficult to create simple and repetitive processes. For this reason the shipbuilding industry is different and unique from most other industries where there is much more repetitiveness in manufacturing. Even though the interim products of a ship vary between each other it is still possible to make improvements and streamline the manufacturing processes by using lean manufacturing principles. An important step is to map the value stream of the production processes in order to readily visualize where there is waste so that it can be eliminated. It then becomes possible to create a future value stream map (VSM), which improves upon the present production facilities. Assembly steps that create value are maintained whereas non-added value steps and waste are eliminated, thus creating a more efficient production system. Since there are many different types of interim products with different processes assembling them, it is helpful to cluster them together in a way, which is not readily apparent for engineers. This can be done through cluster analysis. Upon cluster analysis, it is possible to ascertain which interim products even though different in appearance should be grouped together in the same production lines. The benefit of this is that the number of production lines decreases and the important lean principle of one-piece flow is enhanced.

Then it becomes feasible to analyze steps and draw up an action plan for creating a future VSM that is leaner and more productive. In this paper, a methodology for the mapping and improvement of the micro-panel assembly processes is developed. The key steps developed by the authors include VSM of the current micro-panel assembly processes, data mining (clustering) analysis, and finally a future improved lean VSM.

Literature review

The use of value stream mapping (VSM) in the shipbuilding industry is existent over the past decade. For instance the analysis of the entire shipbuilding project from conceptual design to the detailed design was analyzed and improved [1]. The VSM has been used to analyze and improve the shipbuilding organization with the development of lean tools [2]. A production line of a specific shipyard was analyzed with VSM and a future improved map was developed as well [3]. Analysis has been made concerning clustering analysis used to classify interim products in a shipyard [4,5]. Clustering was also used to form product families to aid in grouping interim products in compliance with group technology [6]. However, the use of clustering analysis integrated with VSM in order to streamline shipyard-manufacturing processes is lacking.

Background

Value stream mapping is part of lean manufacturing. The first two principles of lean are specifying value and identifying the value stream, which is the first step of VSM. The third and fourth principles of lean are the creation of flow and pull. This is in contrast to a push system or one in which large batches of intermediate products are made which wait for days in temporary storage areas before being applied in the downstream assembly processes. The fifth and final principle is kaizen, a Japanese word for perfection, which in shipyard production process translates to meaning that each process can continually be improved upon. This allows for competitiveness within the shipyard and with other shipyards [7,8].

The use of value stream mapping is prevalent in the automobile and aerospace industries. However, the use of VSM to decrease waste in shipbuilding processes is lacking. The differences between the shipbuilding and automotive industries are the production volume differences. Whereas Hyundai produces roughly 60 vessels a year, up to 6000 vehicles are produced daily. Therefore the repetitive character of the industries is significantly different. The automotive industry is thoroughly treated with regards to lean manufacturing especially with regards to Toyota [9]. Nonetheless, it is still possible to reap advantage of repetitiveness in the assembly of ship interim products. The micro-panel is one such interim product, which consists of between 15-20 percent of ship weight. Therefore, a VSM analysis is due in this area. According to (Schroer, 2004) lean manufacturing is useful in process improvement [10]. The use of simulation is helpful in understanding lean concepts such as developing pull as opposed to push systems. A close view of shipbuilding processes will show that push as opposed to pull is prevalent in most processes [11]. Since pull will bring about greater efficiency in production, it is necessary to transform push processes to pull ones.
Cluster Analysis

Since the existence of many different types of interim products as well as many tuples of data it is helpful to use a data mining approach of cluster analysis to determine how to cluster the interim products together. This input will enhance the creation of an improved VSM, because of a logical and simpler way of grouping the interim products, which do not readily appear to be grouped readily. The goal of clustering is to minimize the equation below (see Equation 1) in order to form homogenous clusters. There is no straightforward way to minimize this expression. Hence, we use an iterative algorithm to minimize this and this iterative algorithm is called k-means:

$$\text{SSE}(C) = \sum_{i=1}^{K} N_i \sum_{j=1}^{n} \| x_{ij} - \bar{x}_i \|^2,$$

where \( \text{SSE}(C) \) is the sum of squared errors within each cluster, \( K \) is the number of clusters, \( \bar{x}_i \) is the mean vector related to the \( k \)-th cluster, and \( x_{ij} \) is assigned to exactly one cluster only, whereas \( i \) represents a tuple of data [12]. In order to determine the optimal number for \( K \) or the number of clusters, it is reasonable to make two considerations. The first is creating a scree plot, which illustrates how the percentage of variance changes as the number of clusters increases. The second is considering the importance of one-piece flow. Ideally, in lean manufacturing it is advantageous to have as few clusters as possible during production.

Problem Description and Approach

The problem with shipbuilding manufacturing processes is that due to the high variety of interim products there are a large number of processes as well. In the case of the panel production, there are four production areas. These include large panels (P), semi-automated panels (CA), robotically assembled panels (CR) and manually assembled panels (CR). For the production workers and engineers of the shipyard it appears logical to continue to produce these interim products on four different assembly lines. However, in order to decrease duration time and man-hours through simplifying production it is necessary to create a VSM of the present state of assembly and then perform a cluster analysis to determine which interim products to cluster on the same production line, and then finally based upon this determine a new and transformed process which combines some of the existing processes into one process.

The first step is to map the present micro-panel assembly processes. This is evident in Fig. 1 where the two micro-panel processes CR and CA are mapped. For both processes the steel plates and stiffeners arrive from storage and are placed in interim storage represented by yellow triangles. Afterwards the steel is pushed to the first workstation where they are laid out and fitted together and tack welded manually by workers. The takt time, the changeover time (C/T) and the number of operators are listed under each workstation, including the robot which then completes the welding operations independently. The completed micro-panel is then transferred to the robot which then completes the welding operations independently. The completed micro-panel is then transferred to interim storage. The main problem with this current VSM is that there is much waste with interim storage, pushing and redundant processes between what are actually similar micro-panels. Therefore it is necessary to create a new VSM. Likewise it becomes possible not only to identify waste but also to implement lean principles such as one-piece flow and balanced takt time in developing the improved future state. The use of VSM methodology and Concept Draw Pro tools is used in conjunction with clustering analysis to determine the optimal lean configuration of the integrated micro-panel assembly process.

Results and Discussion

In order to determine the optimal number for \( K \) or the number of clusters, it is reasonable to take two considerations. The first is creating a scree plot, which illustrates how the percentage of variance changes as the number of clusters increase. The second consideration is the importance of one-piece flow. Ideally, in lean manufacturing it is advantageous to have as few clusters as possible in
production. However, there will always need to be some clusters due to the large dimension differences between the interim products. With relation to the scree plot (Fig. 1), it illustrates that the steepest change in variance occurs between 1 and 2 clusters. Therefore, two clusters is chosen as the correct number and K therefore equals 2.

The clustering analysis was performed on 229 tuples of interim product data using the k-means algorithm in R-Studio. The interim products consisted of semi-automatically assembled panels (P), robotically assembled micro-panels (CR), automatically assembled micro-panels (CA), and manually assembled micropanels (MP). The sub-assembly hall of the shipyard has four different production processes, which takes up space and time. However, with clustering analysis it is determined that instead of the four processes it is rational to reduce it to two (See Table 1). The three micro panel processes CA, CR and MP are integrated into one process known as the integrated micro-panel process (IMP). This reduces the amount of space that is presently taken up in the sub-assembly hall. Likewise the principle of one-piece flow is adhered to. In Fig. 3, the two remaining processes are distinctly different for six of the 11 interim product characteristics of mass, panel length (pan_length), panel width (pan_width), stiffener height (stiff_ht), stiffener length (stiff_length), and stiffener number (stiff_no). Cluster 2 represents the integrated micro-panel line of CR, CA and MP panels, whereas cluster one remains unchanged and represents the larger and heavier panels (P).

Table 1. Clustering Analysis Breakdown of the intermediate products

<table>
<thead>
<tr>
<th>Interim product type present</th>
<th>P - same</th>
<th>IMP future</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>0</td>
<td>99</td>
</tr>
<tr>
<td>CR</td>
<td>0</td>
<td>71</td>
</tr>
<tr>
<td>MP</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>P</td>
<td>27</td>
<td>0</td>
</tr>
</tbody>
</table>

Likewise, the future VSM of the micro-panel processes shown in Fig. 4, illustrates the combination of the micro-panel assembly processes (CA and CR) and adheres to the principle of one-piece flow. As a result, there are significant savings in duration time and man-hours of 24 and 52 percent respectively for CA products. Similarly for CR products the duration savings and the man-hours savings are 25 and 50 percent respectively. Applying the principle of kaizen results in continual improvement to both system configuration and technological improvements. Likewise the third micro-panel process MP, is combined into this IMP process and only elements that require curved, circular or angular welds are welded manually. Please note that the kanban post with the supermarket shelf implementation (Fig. 4) eliminates the need of interim storage (Fig. 1) which means less waste. Likewise the combination of the processes reduces the need for operators since maximum automation is implemented and there is less manual work.
Conclusions

Value stream mapping is a very useful tool, which helps to eliminate waste. Likewise, the application of clustering analysis aids in making decisions for clustering together interim products and therefore manufacturing processes which otherwise would not have been grouped together. This scientifically logical reduction in redundant production lines results in a simpler and more efficient integrated process, which can handle multiple interim products. This is in compliance with the lean principles of one-piece flow as well as kaizen. The advantages of applying clustering analysis prior to creating a new value stream map is that it enhances decisions that would otherwise not be optimal. This results in significant man-hour and duration time savings of 25 percent and 50 percent respectively. Likewise, the elimination of redundant processes yields new availability of invaluable shipyard space. Finally kaizen is implemented in the analysis and is kept as something necessary for constant future improvements. The authors suggest future VSM with clustering should be applied to improve other downstream shipbuilding processes mentioned in the paper such as KP, S and T.

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