Lean approach in a High Mix, Low Volume Manufacturing Environment – Case study

Anees Hussain, Jose Eduardo Munive-Hernandez, Felician Campean
Faculty of Engineering & Informatics
University of Bradford
Bradford, BD7 1DP, UK
A.Hussain286@bradford.ac.uk, J.E.Munive@bradford.ac.uk, F.Campean@bradford.ac.uk

Abstract

Market competition is fierce and has been intensified due to globalization, therefore companies have experienced increase pressure to improve cycle and delivery times and achieve a high level of customization. Lean principles have been designed and implemented to respond to market changes. However, these principles are commonly aimed to aid low-mix high-volume (LMHV) manufacturers. This paper aims to develop a systematic approach to implement a lean framework in a high-mix low-volume (HMLV) manufacturing environment. An HMLV manufacturing environment, currently produces a variety of products which differs in terms of shape and size and different sequence of operation and as a much smaller batch size. Additionally, analysis of the manufacturing assembly shows there is a substantial variation in cycle and changeover time from product to product. In this approach, an action based study has been completed. This study uses data collection methods to be applied in order to calculate timings to be used in a Discrete Event Simulation (DES). The simulation uses lean tools to study material movement and facility layout to minimize bottlenecks and eliminate waste from the process. An introduction of lean supermarket is considered within the simulation whereby an operator withdraws products in an specific amount needed by a downstream process before introducing it across the assembly floor and an action plan is created. As a result, a lean manufacturing simulation study has been implemented to evaluate the effects of a supermarket concept within the current manufacturing environment. Initial results show a variation within the cycle and setup times for each of the different products due to the nature of the process. The paper, is limited to applying the approach to a singular production line and a singular manufacturing plant. The practical implications to implement this approach into a manufacturing environment is that there should be a need from the company. This approach should be driven by senior members within the organization as the resistance to change would increase the risk of failure. Another implication of the proposed approach is to ensure the accuracy of the data collected and to introduce a series of briefs within each stage of the approach. This is important as all stakeholders would need to be kept up-to-date with the project. However, the approach is applicable to any organization and can be applied to any sector. This paper, develops a systematic approach to implement a lean framework in a high-mix low-volume (HMLV) manufacturing environment. The approach is validated in an automotive manufacturing organization competing in global markets.

Keywords
Lean, Discrete Event Simulation, Supermarket concept, Action Research and Modelling.

1. Introduction

Manufacturing is the key economic driver for growth and provides added value through the transformation of materials into products. Within the EU, manufacturing is responsible for 80%+ of exports and 80% of private research and innovation therefore it is one of the key elements of sustainable economic growth (European Union, 2015). Initially developed to minimize costs, lean manufacturing has been accepted as the philosophy for management and improvement of systems by significantly shifting the trade-off between productivity and quality. It has also led to rethinking of a wide range of manufacturing and service operations beyond the high-volume repetitive manufacturing environment (Holweg, 2007).

As increasing demand for customization within today's markets and developments in the area of manufacturing strategy have led to the term "Agile manufacturing" (Buetfering, et al., 2016). Agile manufacturing refers to modern advances in manufacturing methodology that has led to reduced costs and quicker response time. It is about the ability to design production processes in ways which they can be changed quickly based on the demands of the customer (Ingram, 2013).

This paper aims to produce a systematic approach to implement a lean framework into a high-mix low-volume (HMLV) manufacturing organization. This methodology incorporates the DMAIC, which is a data-driven improvement cycle used for improving, optimizing and stabilizing business processes and designs along with Discrete event simulation in order to understand the current state of the manufacturing assembly prior to making changes (Henshall, 2017). The proposed methodology is validated within a UK based manufacturing facility that produces parts for the automotive sector. This approach will allow decision makers to understand the variation from product to product as well as understanding how schedules and line layout effects the cycle and setup time. The approach includes the necessary steps to gain the trust of operators and managers in order to effectively collect and improve current manufacturing processes. (Hussain, et al., 2019), has established an methodology to evaluate the current state of the organization in which this paper uses to establish an improved state.

The paper reviews literature based on Lean, Lean thinking, Discrete event simulation and introduces the supermarket concept. The paper continues with the development of Discrete Event Simulation methodology, including the application of process improvement techniques relevant to the DMAIC improvement cycle, producing process maps and constructing a Discrete event simulation model. The paper also highlight action research and its advantages as well as highlighting the limitations of using Discrete event simulation when actual timings are unknown. Finally, The paper presents results from the simulation and discusses the advantages and disadvantages of changing the current manufacturing process.

2. Literature Review

2.1. Lean manufacturing

Lean is an process improvement philosophy is aimed at eliminating waste, that does not add value to the product, and/or prevents the process of receiving incremental improvement. Therefore, by elimination of waste, there is an improvement in the flow of processes and employees work, decreasing the production lead time and making the customer more flexible to meet market demands (Domingos, 2014).

Rebelato et al (2009, cited in Domingos 2009) states that value is generated within the activities of the supply chain flow of product to the end customer. In this process of identifying activities with the greatest potential to add value, the company focuses on eliminating processes that avoid the company to achieve greater productivity and better quality. It is also important to identify activities which do not generate value (non-value add), from a customer perspective which would allow companies to establish leaner operations.

Within lean; a data driven methodology DMAIC (Define, Measure, Improve and Control) is used. DMAIC is formally known to be part of a six sigma philosophy, but in general in can be implemented as part of process improvement initiatives such as lean (ASQ, 2019) The steps in brief are (Kakkad & Makwana, 2017) (Hussain, et al., 2019):

- Define – Define the problem statement
- Measure - Collect data for the processes involved
- Analyze – Understand the root causes and identify the key process variables
- Improve – Implement measures to reduce the defects and create a 'future state'
- Control – Ensure on-going compliance and continuous improvement resulting from the implementation

Within the lean methodology, waste can be defined as any step that is not required to complete the process successfully or anything which the customer is not willing to pay for. Womack & Jones (1996), define waste as:

- Waiting – Long periods of inactivity for people, information or goods, resulting in long lead times
- Overproduction – Producing more than what is needed
- Defects – All aspects of the product that is not in accordance with the customer requirements

- Motion – Moving people, products and information more than what is required
- Over processing – Performing any activity, which the customer is not willing to pay
- Unnecessary inventory – Holding information or material ahead of requirements
- Excessive transportation – Moving unnecessary materials throughout the process flow

There are three types of activities that define waste within an organization (Hines & Taylor, 2000).

1. Value adding activity: those activities that make the product more valuable in the eyes of the customer and if the customer willing to pay for it.
2. Non value added activity: those activities that do not make the product more valuable and are not necessary even under current circumstances. These activities are clearly identified as waste and should therefore be the target of immediate removal.
3. Necessary non value adding activity: activities which do not make a product or service more valuable but are necessary unless the existing process is radically changed. This type of waste is difficult to remove short term and should be a target of long term improvement.

(Hines & Taylor, 2000) Define five essential principles to eliminate waste.

1. Specify which tasks create value from a customer's perspective
2. Identify all the required steps to produce a product; highlight the non-value added activities
3. Take actions to create a value stream without interruptions, delays or waste
4. Only produce parts that is ordered by the customer
5. Repeat previous principles until a state of perfection, with zero waste is achieved.

2.2. High Variety / Low volume

Recently, lean implementation has been aimed at High volume/ Low variety products. The designation of a small batch production identified the production of low quantity of similar parts. The formal definition given by Buetfering, et al. (2016) is "High variety, low-volume production environments include the one of-a-kind as well as the small batch production environments." Therefore, the complexity of the production environement significantly impacts the performance of Lean implementation in a LV/HV environment. The different characteristics between low and high volume production systems are shown in Table 1.

Table 1 - Comparison between high and low-volume production system **(Bhattacharya & Walton, 1997)**

Characteristic	High-volume production	Low-volume production
Typical annual volume	From 100,000 to 1,000,000+ units per year	From 20-500 and 5,000 – 20,000 units per year
Product variety and complexity	Medium with no bespoke products, specialist products are seperated into dedicated plants	Very high, some bespoke products are delivered also. All manufacturing in the same plant
Manufacturing planing system	Stabilized by a degree of make to stock with primarily assemble to order	Low-volume with full make to order
Order winning criteria	Variety, delivery speed, "All in" product features	Varitery, bespoke products, "Extra features", delivery speed

2.3. Supermarket

Within lean, the word supermarket describes a central location for a group of products which are often held in Kanban's. The concept is used in an Pull system to store materials according to demand. The analogy is a retail supermarket, where items are held in a single location. Although the aim of lean thinking is to make things flow, in many industries constant flow is not possible as the supply is not directly linked to the demand. Hence, supermarkets can be considered a necessary evil and should not be confused with buffer stock that is withheld in the production chain (Visser, 2012) (O'Rourke, 2019).

2.4. Discrete Event Modelling

Decision regarding manufacturing development, optimization or reorganization are driven by factors that are often costly, with the benefits hard to justify prior to implementation (Heshmat, et al., 2013). Therefore, specific processes can be modelled and simulated to provide cost effective analysis. Discrete event simulation is used when a state of a model changes at only a discrete, but possibly random set of time points. A DES model replicates the performance of a present system and can provide an insight when the system is altered. However, to achieve an accurate model the model requires accurate data or estimates on the characteristics of the proposed system.

DES is the process of codifying the behavior of a complex system as an ordered sequence of well-defined events therefore it heavily relies on process maps or flow charts. In this context, each event on the simulation model embraces a specific change in the systems state at a specific point in time.

An effective DES process must include the following characteristics (Rouse, 2012):

- Fixed starting and ending points, which can be events
- A method of keeping track of time that has elapsed since the process began
- A list of events that have occurred since the process began
- A list of events pending or expected until the process ends
- A graphical, statistical or tabular record of each function for which the DES uses

3. Methodology

The methodology used for this project is by applying the DMAIC (Define, Measure, Analyze, Improve and Control) method. It is one of the tools which has a similar approach as plan-do-check-act (PDCA) to solve problems. The DMAIC methodology is designed to establish a group of members to improve the quality and process via a step by step approach (Zulkifli & Shanmugam, 2019).

This approach uses action research which is an observed research method designed to solve real world problems whilst studying the experience of solving the problem (Adelman, 1993). Once the research structure is defined, an action research strategy is established in order to improve the current process. Action research is an endless cycle which involves seven steps (Sagor, 2000):

(1) Selecting a focus
(2) Clarifying theories
(3) Identifying research questions
(4) Collecting data
(5) Analyzing data
(6) Reporting results
(7) Taking informed action.

Within this project, action research is combined with gemba walk and process stapling in order to gather information regarding the current process. The project also involves working closely with operators and managers to provide accurate estimations and differences between each model and process. A major aspect of this project will include understanding the current system and providing an improved layout whereby manufacturing conditions will vary.

3.1 Gemba walk

Gemba walk is an important aspect of the lean philosophy. Its purpose is to allow leaders and managers to observe the actual work process, engage with employees and gain knowledge about the current working process. The term gemba means the real place in Japanese and is the most important place for a team as it where the work happens. The Gemba walk is a concept generated by Taiichi Ohno, who is often considered the father of JIT (Just-in-time production). There are 3 main elements of this lean tool (Kanbanize, 2019):

- Go and see – Take regular walks around the manufacturing floor to be involved in finding wasteful activities
- Ask why – Explore value streams in detail and problems through active communication
- Respect the people – Collaborate with teams and find problems together. Focus on the weak spots of the process and not on the people.

3.2 Process Stapling

Another method used within this project is process stapling. This is a popular method used in Lean Six Sigma to understand the current state of the manufacturing process. In order to do this it is important to follow the part from the start of the process to the end rather than following what the operator is doing.

3.3 Process flow
Once the previous method of process stapling is carried out; a process flow document is created. This is a method of visually documenting stages within the process. This process flow is then shown to operators to allow for changes. Within this project; the process flow is considered for all part numbers within the same model.

3.4 Measure
Once the process flow is created and validated then start measuring each aspect of the process. It is essential to setup meetings with operators prior to this phase of the project. This phase consists of people and change management as opinions of operators will differ if they are not convinced of the improvement objectives of the project. Operators will tend to over-estimate timings of processes which will therefore have a significant effect on the simulation for an improved state.

3.5 Modelling the future state
The use of the Discrete Event Simulation model is defined in previous literature (Hussain, et al., 2019). This defines how the simulation is created and the processes needed to create the current manufacturing state. The simulation uses key processes from the current state and uses various assumptions/estimations to create an accurate model of the future manufacturing state therefore it is very important to gain the trust of operators and complete accurate studied of the previous methods used in this project.

4. Results
There are many assumptions to be taken into account to complete the redesign of the manufacturing facility. As shown in (Hussain, et al., 2019), the current assembly is organized to a single piece flow. Table 2, shows the measured timings taken for each operation and Figure 1 shows this on a current state value stream map. From Table 2, it is visible that there is a high cycle time for process 3 in comparison to the other processes. However, it is also visible that process 2 has a large changeover time. As the measurements have been taken for a single model type, the argument is raised as to why the layout should be changed as the time taken for changeover at process 2 would allow process 3 to 'catch-up'. This presents a tough challenge in order to change from a single piece flow concept into a supermarket concept as the latter would effectively reduce the bottleneck at process 3 but can increase the 'waste' in terms of storage and transportation. Therefore, the following assumptions should be included in order to create a future state map:

- Method to transport materials to the assembly
- Time taken for transportation
- Storage space
- How many models/parts would be stored
- Would it be beneficial
- How to resolve quality issues

Table 2 - Stopwatch timings for each processes

Stopwatch analysis			
Process Number	**Cycle time**	**Value added time**	**Changeover time**
1	40	33	300
2	55	45	1200
3	100	85	900
4	60	50	900

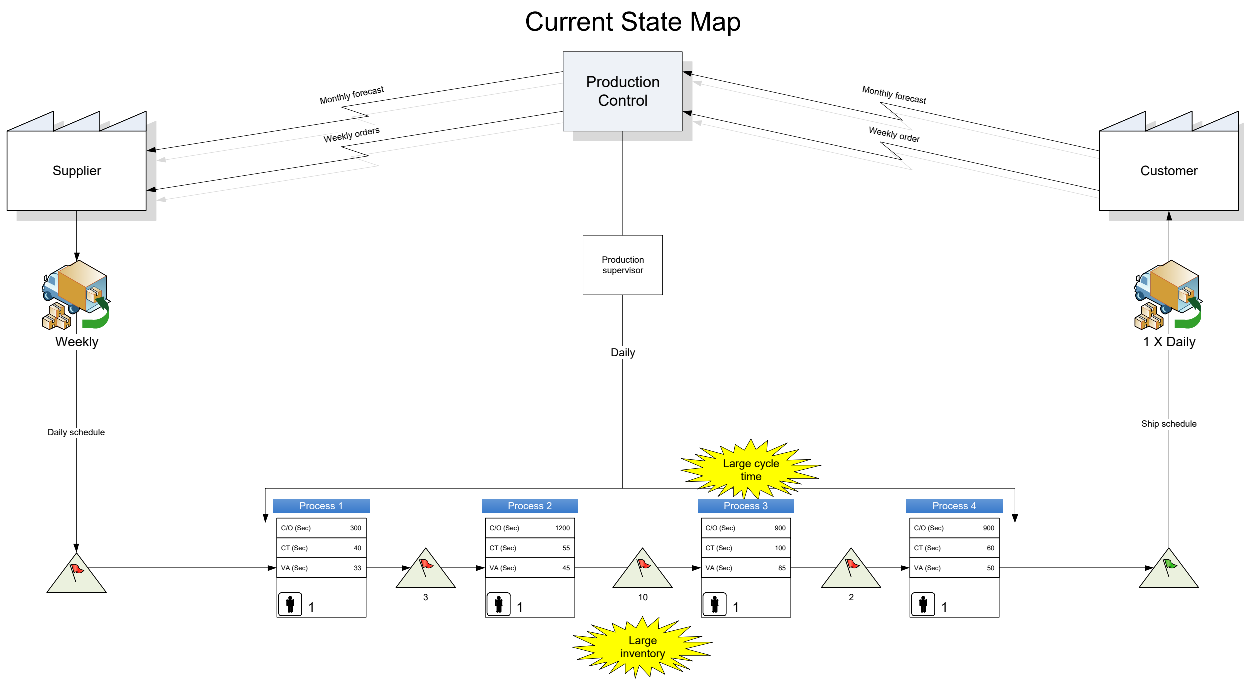

Figure 1 - Current state map

5. Conclusion

This paper presents a lean approach in a high mix low volume manufacturing facility. This proposal includes arguments for and against the need to change from a single piece flow into a supermarket concept. This paper would show decision makers that by reducing the size of bottlenecks they may have to compromise on transportation and storage which could increase costs. Therefore, this paper will help them to be better informed to support decision in improving the manufacturing facility. The VSM is constructed by using the DMAIC improvement cycle and using stopwatch analysis to measure operators over a various shifts.

The paper applies action research, gemba walk and process stapling to create a current value stream map. This would then need to be validated with stakeholders before introducing estimations to create a future state map that would include a supermarket concept.

The paper applies action research to validate the proposed methodology in a British manufacturing organization competing in global markets. Thus, the analysis, development and validation of the current value stream map and analysis to change the layout into a supermarket is very beneficial. The process of using the supermarket concept to validate the benefits within the organization could be further enhanced:

- Including of CAD software and Discrete event simulation
- Running trials for various scenarios.
- Further action research is needed to analyze and implement the methodology in other assembly lines and collecting data considering a longer period of time.
- Validate the DES methodology with data collected from other assembly lines.
- Create a detailed action plan for the implementation of improvements.

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Biographies

Anees Hussain is currently a postgraduate research student within faculty of Engineering and informatics at the University of Bradford. He received his MSc in Mechanical Engineering in 2019, whilst working as a process improvement engineer for an automotive manufacturer. His research interests include application of modelling techniques, such as Discrete and Dynamic Event Simulation to support the implementation of lean and six sigma methodologies within manufacturing, supply chain management and big data systems.

Dr J. Eduardo Munive-Hernandez is a Lecturer in Advanced Manufacturing Engineering at the Faculty of Engineering and Informatics, University of Bradford. He received his PhD in Total Technology from the University of Manchester Institute of Science and Technology in 2003. He has industrial experience in the manufacturing sector and in the automotive industry. His research interests include application of modelling techniques, such as System Dynamics and Discreet Event Simulation, to support analysis and performance measurement, process improvement and lean initiatives for sustainable operations and supply chain management. He is also interested in the analysis, development and implementation of strategic knowledge management systems to support those improvement initiatives.

Felician Campean is a Professor in Automotive Reliability Engineering and Director of the Automotive Research Centre at the University of Bradford. He holds a PhD in Reliability from Brunel University (1998) and a Mechanical / Manufacturing Engineering Degree from Transylvania University (1990). Worked in the bearings industry before joining Academia as a lecturer in manufacturing automation. Has joined University of Bradford in 1998 as a Research Fellow, and progressed to Senior Research Fellow (2000), Senior Lecturer in Competitive Design (2005), and Professor in 2011. Current research interests revolve around modelling complex systems, including model based methods for systems engineering, reliability, robustness and resilience analysis for multi-disciplinary complex systems, big data analytics methods for systems design and lifecycle management, multi-disciplinary design optimization applied to complex systems, modelling complex manufacturing and product development processes.