Applying Lean Principles to Production Scheduling

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Abstract

When exploring the Lean issue, literature appears to have countless definitions to describe that individual topic, causing misinterpretations between academics and professionals alike. The mainstream Lean implementation ventures are merely a compilation of tools and methods that are forced down the organisational hierarchy from higher tiers, due to other organisations publicising lean in improving their enterprise's effectiveness and efficiency. However, lean implementations have often undesirable outcomes. Firstly, organisations either do not achieve the levels of success they initially yearned. This leads to management either deserting their lean efforts or seeking aimlessly for a new buzz word to adopt. Secondly, an enterprise may find it difficult to sustain the lean improvements, and thus rushing to conclude lean as incompatible with their industry, or unsuited for their organisational structure. These shortcomings can be easily avoided by recognising lean not only as a collection of tools but also a philosophy. The Lean philosophy needs to be applied companywide, with both management and employees onboard, to tackle business issues as they arise with a united way of thinking. In turn, this means that when opportunities or problems occur, and traditional lean tools fail short, the shared way of thinking by the organisation can be used to derive and develop new tailored solutions to address the issue directly. This paper aims to illustrate the possibilities of lean tools being applied in complex production environment, and introduce two case studies supporting the findings. In particular, we argue that the full potential of planning and scheduling in a manufacturing setting can only benefit from the utilisation of lean principles and the support of quantitative modelling.

1. Introduction

While there are many methodologies to increase the efficiency of production operations, it is often the case that there is a need to apply a combination of tools to achieve the desired objectives. It is with that in mind that this paper intends to enlighten the merits of applying lean principles to production scheduling.

The argument presented here consists of two parts; firstly, it is concerned with the adoption of Lean in an appropriate manner and not attempting to imitate other organisations or tracing their footsteps, as this has shown to be a common explanation for companies failing to realise or achieve Lean success. Secondly, Lean can venture beyond its automobile origin, known to be Toyota in Japan, to benefit other industries and market sectors. Here the concept of applying Lean to production scheduling is investigated in more detail. Lean tools that can be adapted to scheduling are explained and analysed to help highlight the agenda. This is further emphasised by presenting two case studies, where Lean tools and techniques are implemented to enhance the scheduling effectiveness. The first case study shows the impact 'leaning' (particularly, buffer reduction) has on the scheduling process and how quantitative modelling can be used to examine this. The second case study investigates the support of day-to-day operations in a Lean-centric cellular manufacturing environment.

The remainder of the text is structured as follows. The next section briefly summarises the Lean philosophy, followed in Section 3 by a review of scheduling, accompanied by Lean-tools of interest to scheduling. Then, in Section 4, the two case studies are presented. The paper closes with a discussion and conclusion.

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2. LEAN PRODUCTION

The term *Lean* was first used by Krafick [1] in 1988, a principle researcher in the International Motor Vehicle Program (IMVP) at Massachusetts Institute of Technology (MIT), to describe what today is known as the Lean Manufacturing or Lean Production paradigm [2]. A major output of the IMVP research efforts was the publication of the book *'The Machine that Changed the World: The story of lean production'* [3]. This book documented the evolution of the automotive industry from Craft Production, through Mass Production to ultimately Lean Production. The book argues that the Lean paradigm follows in the footsteps of its peers, but only by combining their advantages, while trying to evade the high costs of craft producers, and the rigidity of mass producers. Lean is a philosophy that seeks to improve activities by exposing and eliminating all types of waste from the system, may it be a value stream, a manufacturing process, or even a routine job. It makes use of its tools to strive for zero inventories, zero downtimes, zero defects, and zero delays in the production process. Waste can be described as the opposite side of value on a Lean coin. Value is all the aspects of a product that a customer is willing to spend his/her money on [4]. Lean emphasises the need for an organisation to develop a culture of continuous improvement in quality, cost, delivery and design [5]. Lean has been described as a quest for "brilliant process management" [6]. Lean asks an organisation to consider all activities as a series of processes that can be optimised and aligned to continuous improvement programmes.

2.1. THE TOYOTA PRODUCTION SYSTEM, JUST-IN-TIME AND LEAN PRODUCTION

A point of confusion for both academic researchers and industrial practitioners is the relationship between the Toyota Production System, Just-In-Time and Lean Production. Sugimori et al. [7] describe TPS as comprising two main concepts; 'Cost reduction through the elimination of waste', and 'Full utilization of worker's capabilities'. Cost reduction is primarily achieved through the use of Just-In-Time production (Kanban, one-piece flow and levelling) and Jidoka; operators have authorisation to stop the line to prevent defective work being transferred to the next station [8, 9, 10]. TPS achieves full utilisation of worker's capabilities by promoting respect for individuals through minimising employee movements, emphasising employee safety, valuing and encouraging employee involvement, and increasing employee responsibilities [11].

Some authors argue that Lean Production is an improvement or descendant of TPS and JIT [12], while others argue that it is merely a Westernised version of TPS and JIT [13]. Papadopoulou & Özbayrak [2] argue that evidence from the literature suggests that Lean Production and JIT should not be considered as systems, rather as philosophies that have a broad scope and are continually under development and "have neither exact nor sole definition nor obvious boarders". However, when they compared the American Production and Inventory Control Society (APICS) Dictionary definitions of JIT and Lean they concluded that the similarities in the definitions far outweigh the differences, thereby, giving support to the idea that Lean is a descendant of the JIT philosophy.

Lander and Liker [11] identified that many organisations struggle with understanding how Lean Production principles can be applied to them. When they look at Toyota, they see highly repetitive, standardised manufacturing processes and have great difficulty in seeing how they can transfer this to their organisations, which may build-to-order, involve highly engineered products or they may be service providers. Lander and Liker [11] argue that these companies are approaching Lean Production from the wrong perspective. What is required to transfer the benefits of Lean to environments where they have yet to be applied is to adopt the same principles and thought processes that Toyota used to develop TPS, rather than direct implementation of a set of tools and techniques from a toolkit. Viewed in this light TPS is not a production philosophy, but rather an example of the application of JIT and Lean philosophies to one organisation in the automotive sector.

Lean offers opportunities for many organisations, to increase productivity, reduce waiting times, lower costs and improve services, if it can be successfully applied in their business sector. The literature on Lean is rich with case studies on the successful application of Lean in a variety of sectors worldwide (e.g. Liker, 1998; Drickhamer, 2000; Siekman, 2000; Zimmer, 2000; Lewis, 2001; Prizinsky, 2001; Strozniak, 2001; Bateman, 2002; Rea, 2002; Teresko, 2002; Trombly, 2002; Parker, 2003).

2.2. THE ELEMENTS OF LEAN

One of the trademark features of Lean is its reliance on visual and simple mechanical aids to improve manufacturing effectiveness. Most fundamentals of Lean; Value Stream Mapping [13, 14], Kaizen [15], Kanban [10]; can be implemented without any major investment in automation. Kaizen is a Japanese term that means continuous improvement. Kaizen Blitz or Kaizen Events are a common activity on the journey towards leanness where a group of trained lean experts target and review one or more production processes in the quest to identify opportunities for improvement. Value Stream Mapping is a technique used in Lean Manufacturing that maps the flow of material and data, and associated time requirements. It begins from the initial supplier to end at the customer for a given business process. It can be used to define improvement areas and sources of waste. Kanban is a method of flagging up the need for more parts on an assembly line by using signal cards at workstations, first used at Toyota and associated with the Just-In-Time technique. However, the implementation and deployment of these tools is not in itself Lean.

Womack and Jones [4] identified the five basic principles underpinning Lean Thinking as:

1. specify value by product;
2. identify the value stream for each product;
3. make value flow without interruptions;
4. pull value from the manufacturer; and
5. pursue perfection.

Bhasin and Burcher [5] identified that the Lean paradigm has two important requirements; technical requirements and cultural requirements. With respect to the technical requirements, they suggest that instead of focusing on one or two tools of lean in isolation that it is important that companies practice most, if not all, of the following: Kaizen (continuous improvement), Cellular Manufacturing, Kanban, Single-Piece Flow, Process Mapping, Single Minute Exchange of Dies (SMED), Kaikaku (radical activity improvements), Supplier Development, Supplier Base Reduction, 5S, Total Productivity Maintenance, and focus on Value and the Seven Wastes (overproduction, waiting, transportation, inappropriate processing, inventory, unnecessary motions and defects). In addition to these technical requirements, Bhasin and Burcher [5] identified thirteen changes that are required in corporate culture to ensure successful implementation of Lean. These include, decision making at the lowest level, clarity of vision, strategy of change with clear communication of how the goals will be achieved, clear roles and responsibilities, develop supplier relationships based on trust and mutual respect, nurture a learning environment, focus on the customer, promote lean leadership at all levels with clear lean metrics, maintain the challenge of existing processes, maximise stability by reducing schedule changes, program restructures and procurement quality changes, access the fraction of employees operating under lean conditions, observe the proportion of departments pursuing lean and long-term commitment. Karlson and Ahlstrom [16] presented a conceptual model of Lean Production that argues that the paradigm ranges from Lean Product Development, to Lean Procurement, to Lean Manufacturing to Lean Distribution. Womack et al [3] used the term Lean Enterprise to describe the application of Lean Thinking outside the boundaries of the organisation.

Krishnamurthy and Yauch [17] summarise lean, therefore, as "a methodology of developing a value stream for all products that eliminates waste in waiting time, transport, inventories, and defects, and focuses on a level production schedule".

3. SCHEDULING

Production scheduling is a critical activity in manufacturing. It concerns the distribution of scarce resources, usually machines, to tasks over time [18]. Scheduling is defined as a decision making query that entails optimisation of one or more scheduling conditions. Due to it combinatorial nature, scheduling problems are computationally very intricate and complicated to solve. Therefore, it is not always possible to find the best possible solution in a reasonable time frame. Assortments of heuristic methods have been developed in order to find near-optimal solutions in comparatively short periods of time. However, often heuristics applied in practice are dispatching rules that have minimal computational complexity and are simple to implement [19]. Production scheduling is important to manufacturing organisations for a number of reasons. J Younger a pioneering author in the field of scheduling had the following view on the matter:

> *"Well-organized and carefully executed work routing, scheduling and dispatching are necessary to bring production through in the required quantity, of the required quality, at the required time, and at the most reasonable cost."* [20]

Cost objectives, quality targets, delivery concerns, and quantity goals are the key elements and evident reasons why scheduling is performed by organisations. It also provides the basic background for the formulation of mathematical structures and computer systems architectures that simulate and generate schedules.

In most situations a production schedule will never be executed precisely. Disruptions are a certainty and modifications are inevitable to allow execution, and perhaps facilitate improvements in dealing with the situation encountered. This process of altering the original schedule to handle disruption from uncertain varying factors is generally referred to as rescheduling or reactive scheduling. Manufacturing operations can encounter a wide range of uncertainties. Therefore, the objectives of scheduling are to accommodate and anticipate these uncertainties before they occur or have a recipe to counteract them [21]. Different sources of uncertainty are inherent in real life production scenarios. The interruption that has been most often dealt with in the literature is machine breakdown. Scheduling research has so far been unable to properly address the general issue of uncertainty, making the impact of scheduling research less influential on industrial practice [21]. However, uncertainty is not the only dimension in scheduling, and research efforts need to be redirected to look at different aspects that effect scheduling.

3.1. Scheduling in a Lean Environment

Production planning in a lean environment requires smoothing out the peaks and valleys in the production schedule. This aids to maximise the utilisation of the production facility. Levelled production aims to run a constant quantity of all the operations, hence without the levelling system, there would be great difficulty in dealing with uncertain demand fluctuations. Unless there is a surplus of labour, capacity and large quantities of inventory, the concept of a levelled schedule is required. The benefits of this constant production and levelled schedule are reduced overall waste. This can be in the form of less operators standing ideal while waiting for work, or machines and tools that require high investment sitting unused [22]. In order to gain a better understanding on how Lean effects scheduling, it is worth while exploring the main tools and concepts that may have an impact [23].

3.1.1. Takt time:

Takt time is the basic rate of production, also referred to as the drumbeat for the process of production. Takt time is equal to the operating time available divided by the customer’s required quantity, and uses the language of supply and demand, where it attempt to allow for the supply to meet or even exceed the demand in order to ensure that the customer order is fulfilled and avoid disappointment. Takt time is usually calculated prior to generating a schedule, the rest of the operations have to be aligned with the Takt time in order to avoid delays or shortages. However, instances where a production facility is faced with uncertainties such as the arrival of urgent orders, unpredictable machine breakdown or resource shortages may have an impact on the Takt time calculated. In such cases the Takt time needs to be recalculated incorporating remedial actions in order to revamp the schedule.

3.1.2. The Pacemaker Process and Heijunka:

When scheduling in a lean environment, the pacemaker must be initially identified, as this operation will determine the pace of the rest of the value chain. The pacemaker is usually a critical operation with limited recourses or capacity. Scheduling at this one point will result in a pulling effect on work from upstream processes and flowing product through the subsequent processes to the customer. The scheduled volume and product mix at the pacemaker typically corresponds to what is known as the master schedule. Master schedules are established in synchronisation with the Takt time for all items that go through the pacemaker process. The entire system depends on an elementary lean principle of levelled production called Heijunka [2, 22, 24, 25], which involves the levelling of production by both volume and product mix. Products are not manufacturer in accordance with the sequence of customer orders; rather Heijunka calculates the total volume of orders in a period and levels them out so the same amount and mix are manufactured each shift/day. Small-scale Lean organisations use spreadsheets to schedule their production in order to create Heijunka. However, IT systems are a crucial addition for most organisations and yield significant benefits. With the addition of the Internet, this has exploded its potential [26]. The spreadsheet approach can be helpful in a pilot context or small scale entities, but it is questionable whether spreadsheets are a scalable technology in larger organisations, as it’s known that they encounter issues with data reliability when used in isolation. Hence, there is a requirement to enable the scheduling method to integrate with an organisation’s Enterprise Resources Planning (ERP) or Supply Chain Management (SCM) systems.

3.1.3. Finished goods supermarkets:

Producing to customer orders only is, when possible, the best practice. However, producing a constant small inventory maybe more desirable than flexing plant resources to meet day-to-day order variations. In a lean operating plant, products are often produced to a buffer called the finished goods supermarket, rather than directly to customer orders. The stability and reliability of customers' ordering frequency will mandate the size of the supermarket required. Another dependent factor for the size of the supermarket is the replenishment time for the finished goods.

3.1.4. PULL TO THE CUSTOMER / KANBAN:

A common standard in lean manufacturing is the principle of pull, which emphasises only replenishing what is used. Pull replenishment works on the basis of segmenting the Work-In-Process (WIP) or finished goods supermarkets into equal units referred to as Kanbans. Once a certain predetermined quantity of Kanban units is consumed, a signal is generated to indicate the requirement to schedule production or authorise a new order for replenishment. In order to allow for a Kanban system to be productively implemented, a few prerequisites are needed:

1. Demand for the items must be steady and continuous.
2. Replenishment time must be relatively short in comparison to order lead time.
3. Raw material needs to be readily available to allow immediate production to commence once a signal is generated.

When demand is not steady and continuous, quantitative modelling techniques such as discrete event simulation or queuing network models can provide decision makers with the means to optimise the parameters of the system, such as the number of items in Kanban bins or the number of Kanbans to be allocated to workstations.

4. CASE STUDIES

To illustrate the benefit, if not the need, in introducing customised Lean tools to assist scheduling in complex production environments, two case studies are reviewed in this section. The case studies provide insights on the benefits of using analytical models to support scheduling in an integrated push-pull environment and in a cellular manufacturing environment, respectively.

4.1. CASE STUDY 1: SCHEDULING IN AN INTEGRATED PUSH-PULL ENVIRONMENT

The first case study involves a global supplier of eye healthcare products. In particular, the division of focus here is dedicated to the production of contact lenses. Contact lenses are produced over a two-step process in standard sized batches. The initial step involved the production of moulds for the lens. For each contact lens two moulds are required. The second step entails the injection of lens material into the mould cavity to produce the contact lens. The associated complications with this procedure are well identified. The moulds have a specific curing time to stabilise their structure. In addition moulds have a relatively short shelf life wherein they must be consumed to ensure the quality of the lenses. The moulds are destroyed during the second step and cannot be reused.

The company was aiming to overhaul their contact lens operation to accomplish higher value by reducing waste. This is a typical Lean Kaizen innovation. An ideal way to achieve a reduction in waste is by striving for zero inventories. However this was not considered possible in this case, due to the curing times involved. Hence, a reduction in the buffer stock between the two processes was sought. During that process, the company still emphasised the importance of maintaining the robustness of the system; problems with the production of moulds should not have immediate impact on the production of lenses. Engineers at the facility were unable to predict the consequences of changes their buffer strategy, and hence could not adequately evaluate the trade-off between balancing inventory quantities and maximising service level. They required a quantitative model to represent system and simulate different scenarios.

For the purposes of developing the model, the main area of interest was bound by the two production processes and the intermediary buffer mentioned above. In order to apply Lean scheduling techniques, *Takt time* is normally the initial computation, as the rest of the operations have to be aligned with this rate in order to avoid delays or shortages. However, in this instance, the production facility is faced with a variety of uncertainties such as the arrival of urgent orders, machine breakdowns and possible resource shortages, resulting in difficulties to determine a Takt time. Therefore, the factory here does not explicitly operate on the Takt time basis. Weekly forecasts are used to generate an efficient weekly schedule to produce the lenses. The schedule accounts for machine maintenance and also quarterly forecasts. The latter enables some smoothing to take place, distributing the load of heavier periods over less loaded periods. The model, therefore, utilises an elementary Lean principle, Heijunka (levelling production).

The intermediary buffer operates on a pull principle; this is a result of the second production process being the pacemaker. The second production process is the pacemaker due to resource and capacity limitations at that operation. To assess the buffer's capacity, different Kanban levels were used to determine adequate batch sizes of moulds required to produce a certain number of lenses. Depending on the replenishment level being tested, it can either operate in a tightly coupled fashion (a minimal buffer is used, and stocks are replenished as soon as moulds are taken from the stock) or more loosely coupled (the buffer has enough moulds for several batches, and only after a number of batches are taken out, the moulds are replenished).This integration of both Push (in this case of lenses to the customer) and Pull (of moulds to the casting stage) is proposed in the Lean literature by e.g. Hodgson and Wang [27, 28] and Cochran and Kim [29]. Both place specific significance on requiring quantitative analysis to determine the parameters of such integration. Here, a form of quantitative modelling called Constraint-based Scheduling was used to perform the analysis [30].

The model had sufficient levels of functionality in statistical analysis, which were used for determining the most suitable levels of stock to be held at the buffer and also display the effect of different levels on the resulting schedule. This helped the engineers in weighing the savings gained by smoothing and quicker casting against higher stock levels for different scenarios. Due to the flexibility of the tool, additional scenarios were investigated. These included the addition and removal of machines to and from the facility, and also evaluating alternative materials to use for producing the moulds. In essence, this tool has provided the company with enhanced visibility of the scheduling process and improved knowledge of the scheduling consequences on modifying factory operations, concluding to be an invaluable tool in the company's Lean journey.

4.2. Case Study 2: Scheduling in a Cellular Layout

The second case study deals with Alcatel-Lucent, a global telecommunication giant. In particular, the focus is around their base station fabrication facility. As these wireless infrastructures vary widely in configuration, the company practises a build-to-order strategy. The fabrication of these base stations consists of three major processes; assembly, wiring and testing. Due to the complex nature of the wiring and testing procedures, the company decided to implement a Lean driven cell-based workstation layout for Wiring and Testing. Dedicated cells were designed to handle limited number of product groups. The intention of the restructured shop floor layout was to improve the wiring quality and reduce the testing times. However, as a result of the dedicated work cells, the scheduling pattern will have a direct impact on the workload levels of each station. Planning errors can result in starving certain cells, or tail-backing already overloaded cells. Hence, the use of an analytical scheduling tool was required [31].

The site was already implementing a number of Lean tools and practices before reshaping into a cell-based layout. Working in a synchronised fashion tailored the production to a predefined Takt time, allowing the company to produce in a Just-In-Time mode. The principle extended over the entire production line, with each step ideally handing over goods as the succeeding station frees up. Workload durations are standardised across the assembly lines, but due to the reconfiguration, items will spend multiple durations of the beat at each of the new cells. Therefore, one assembly line can be feeding multiple cells. Natural production cycles at the plant have shown patterns of low demand early in quarter and peaks nearing the end of each quarter. This prompted implementing a levelling regime to smooth the production, however resulting in a quantity of orders being produced ahead of schedule.

The quantitative scheduling support tool developed here was able to account for most of the variables involved and for resource limitations. The final results from the model where localised smoothing at each cell and a reasonable levelled production rate of the assembly stations feeding in. It is difficult to display the direct benefits of the scheduling tool, as it converged into the overall new style of production at the facility. However the engineers have observed significant improvements in the manufacturing interval, work in process inventory, first test yields, head count, and quality of the delivered performance. Although these benefits are mainly achieved because of the reformed cell layout, the scheduling tool is crucial in realising its full potential. As a result, the company has considered extending the cell-based shop floor concept to other areas of the factory, and obviously continue to avail of quantitative modelling as part of the extension.

5. Discussion and Conclusion

The Lean manufacturing toolbox has been standardised to its pure elements, and will at all times require adjustment and customisation to the individual organisation. The tools themselves are not that complicated to use, the difficulty resides at choosing the right tools for the situation being dealt with. Implementing Lean should not be managed as a project, but rather a new way of conducting business. The first improvements will usually be soon visible, but companies should not have high expectations for the first months. Lean takes time and demands resources to become a success. This is not referring to high capital investment, but when attempting to change the whole organisation's way of working, this will take time.

Scheduling and planning are important for an enterprise to foresee and be able to control or adapt for its future. Anticipating what may take place, allows management to modify or adjust their actions in order to control the outcomes. There are many commercially available tools for use in the scheduling effort. Some are quite generic, but others concentrate on a specific business model. However, most of them share some fundamental similarities that include cost and resource utilisation as primary targets. This involves the delivery of orders to customers in the shortest feasible time span and at a price margin that is accepted by both manufacturer and consumer. Scheduling operations in a Lean environment, therefore, plays two important roles. Firstly, it has a role in developing improved strategies for dealing with chaotic uncertain demand. The aim is to reduce variability by using Kanban supermarkets, finish-to-order or make-to-order strategies in order to dampen the impact of fluctuating orders received at the plant. The second role of scheduling in a Lean environment is the levelling of the schedule, in order to allow the plant to balance production to a constant beat (Takt time) and not overstress or underutilise the facility and resources available.

Scheduling can greatly benefit from the addition of lean principles; this was demonstrated in both case studies presented in Section 4. The use of quantitative modelling added the advantage of allowing the user to forecast the outcomes of such implementations and helped in supporting the decision making process. Thus, it is a significant addition to the lean toolset as it allows predicting the outcomes of strategic decisions and aids the rescheduling process in the event of any interruptions. The application of quantitative modelling techniques to support decision making in lean environments, in particular with respect to scheduling, provides the possibility to employ statistical analysis to a much greater advantage than demonstrated in the above case studies. It allows the decision makers to account for uncertainties, more significantly, multiple uncertainties simultaneously. This is done by allowing decision makers and users to tease out relationships and variables that might have been masked by other factors. The systematic nature of statistics can ease efforts at replication and extension; however, there are also disadvantages. It could encourage engineers to act as if they can ignore whatever they have yet to learn how to measure, which can lead to rouge conclusions and impair the research target.

The important point to note is that Lean should be seen as a direction, rather than as a status to be achieved after a certain time period. Therefore, the focus should lie on what the organisation seeks to achieve, and not what each Lean tool can achieve for them. It should also be noted that not all the tools, in the Lean toolbox, are adaptable to any situation. There could be instances where conflicting signals are sent. Thus, with this in mind, the application of such tools as quantitative modelling should be in a supportive role for practitioners to ensure that they are not diverging from their initial goals.

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