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How Lean transformation affects scheduling

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ABSTRACT

The Lean paradigm transforms a production company from utilisation-centric planning into a system in which other operating conditions such as short flow times, local control, reduction in variation, and first-in-first-out control are weighted as well. This paper studies how the scheduling of production changes when the above four conditions are implemented. Their effects are studied by constructing an optimisation model for the scheduling of a flow shop. The optimisation model is based on the following ideas. First, when the flow time is emphasised, the objective of the scheduling changes from utilisation to a short flow time. Second, if local control is used, it means that the optimisation is performed locally, i.e. individually at each station, and it concerns the makespan at the station. Third, if the variation is reduced, the processing times and arrival times have less variation and, fourth, the scheduling can force the flow times to have less variation by using *first-in-first-out* (FIFO) sequencing. The experimental results achieved using the model describe how and in which order the operating conditions under study should be implemented in the scheduling. For example, if utilisation is important, local control and FIFO should not be used before variation is reduced.

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1. Introduction

When companies undergo Lean transformation, they start to use different techniques, such as Single Minute Exchange of Die (SMED), Kanban, Kaizen, and Heijunka, to streamline their production. Different Lean techniques affect production through different mechanisms. These mechanisms can be grouped on the basis of the type of effect they have on the operating principle of the system and operating conditions. Some methods focus on reducing flow time, some increase the flexibility of the production, e.g. by using local control, and some permanently reduce disturbances and thus variation. The purpose of this paper is to study how these methods should be used when scheduling is considered. The paper is a revised and extended version of a conference paper [1]. In this extended version, the content is updated and, in particular, the numerical experiments section is made broader so that it now studies the usefulness of Lean methods in the case of different numbers of jobs and machines.

In the literature, it is often emphasised that all the Lean techniques should be used if Lean is applied, or otherwise production does not improve significantly. Focusing on just a single technique is often seen as the main problem in Lean implementation (see e.g. [2, p. 10]). However, it might be that some techniques are more relevant than others because of the way they change operating conditions and consequently different measures of performance. For example, the Toyota production system, on which Lean is based, has two pillars, which are autonomation (i.e. smart automation) and just-in-time [3, p. 77]. As described in Ref. [2, p. 32], these pillars stand on stability, which is the foundation for all the other methods. Above the pillars, there are the targets: costs, delivery times and quality. Fig. 1 illustrates this so-called House-of-Lean. In other words, the figure shows that variation should be reduced first, and only after that can the processes be automated and the material flow balanced. Following these ideas, this paper tries to find out how important different operating conditions are when the scheduling of a flow shop is considered. The emphasis is put on finding out what kinds of changes to operating conditions are required and in which order they should be implemented when a Lean transformation occurs.

Lean itself is a buzzword that combines multiple ideas that aim to reduce waste in production. As stated by Liker [2, p. 20], many ideas come from the pioneering work done by Ford [4] and Ohno [5]. Lean has been studied quite extensively during the last few decades (see e.g. [6]). However, as recently reviewed by Powell et al. [7], studies describing a sequential process for Lean implementation, which is in focus in this paper, are at least scattered if not few. One such study, by Åhlström [8], concludes, on the basis of a case study conducted at a Sweden-based company, that management should put simultaneous effort into all aspects of production, beginning with the quality issues, and then, after the quality issues are resolved, the managers should shift to the continuous improvement initiatives. This is related to the original

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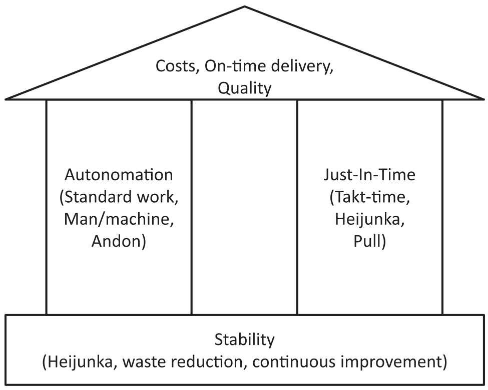

Fig. 1. House of Lean describes the order in which different Lean methods should be used.

pillar idea described in the above paragraph. Chen et al. [9] have a case study in which the order of Lean transformation is the following. First, the value-stream mapping is used to reveal the current state of the system, then, second, the 5 s method was first applied to reveal the root causes for the problems and, third, machining parameters were optimised using Taguchi method to reduce variation in process. After that, rabbit chasing was used to increase flexibility. They also state that Lean transformation should occur in small increments. Brown et al. [10] have a similar paper to the previous one. They state that Lean transformation should first define the status of the system using value-stream mapping, then employ shop floor kaizen methods and finally use quality improvements.

Although the sequence in Lean transformation is not studied often, the importance of different aspects of Lean is. Worley and Doolen [11] found that management support play a role in Lean implementation. A recent literature review done in the paper by Belekoukias [12] reviews papers about the Leanness of companies. They show how different Lean methods affect differently the performance of the companies. In their actual study, they conclude that just-in-time (JIT) methods have most impact on improvement of the companies. This suggest that in order to increase performance management should focus on lead time reduction. In general, Lean techniques improve flow times by making WIP low, but on the other hand they also improve the utilisation of the system by reducing variation and increasing capacity. This complexity makes it hard to study Lean methods together quantitatively, and thus they are often studied one at a time. For example, in a review by Kumar and Panneerselvam [13] studies dealing with Kanban-based methods are common.

This paper presents a quantitative optimisation model to study the potential effects of Lean transformation on scheduling a flow shop. Scheduling itself is broadly studied in the literature. The reader who is unfamiliar with scheduling and optimisation may study e.g. the books by Conway et al. [14] and Pinedo [15]. In short, the scheduling arranges jobs for the different resources, with the objective being e.g. to balance the utilisation of the machines and the flow time of the jobs. The scheduling problem becomes complex when the system consists of multiple machines. This is also a case in which Lean transformation often seems to be effective. A special case of multiple machines, a flow shop, is studied in this paper. In a flow shop, the jobs are always processed on the machines in the same order. This kind of production process is common in manufacturing industry. The scheduling of a flow shop has been considered earlier from the Lean perspective (see e.g. [16–18]), but according to our knowledge, the performance of scheduling in different phases of Lean transformation has not been studied before. In this paper, the scheduling problem is approached using a mixed-integer linear programming (MILP) optimisation model and optimising it using CPLEX optimisation tool. In the numerical experiments, number of different scenarios are generated, each scenario is optimised separately and average results are studied. This is better way than stochastic optimisation as in the reality the processing times are often known or at least they can be estimated. Complete optimisation is used instead of heuristics such as genetic algorithms or simulated annealing.

The paper is organised as follows. Section 2 first discusses how the four operating conditions studied, i.e. flow time, local control, variation reduction, and first-in-first-out (FIFO) control, relate to Lean techniques, and second, describes an optimisation model constructed to study the effect of these operating conditions on flow shop scheduling. In Section 3, the model is used in numerical experiments to study how the weights on the operating conditions affect the performance of the scheduling. The results are discussed in Section 4, and they suggest that if the utilisation is important, flow time can start to be reduced immediately, local control only when the process is somewhat stable, and FIFO control only if the processing times of the process are stable. Finally, Section 5 presents final conclusions.

2. The Lean operating conditions in scheduling

2.1. Lean techniques and operating conditions

Our paper studies four types of operating conditions that lie behind the use of Lean techniques. These are short flow times, local control, variation reduction, and first-in-first-out (FIFO) control. When a Lean transformation takes place, these four operating conditions are realised at the planning level. Next, we point out how these operating conditions are achieved using different Lean techniques. A more complete analysis of Lean techniques, or actually the techniques in its predecessor philosophy JIT (just-in-time), has been performed by Bartezzaghi and Turco [19].

The first operating condition to be studied, *Short flow time,* is achieved in Lean by limiting work-in-process (WIP), reducing batch sizes, and increasing capacity. First, limiting WIP reduces flow time in production. In production where utilisation is high, it is almost impossible for an increase in WIP to increase throughput without increasing the flow time. Thus the opposite is also true. If the utilisation is high, a decrease in WIP will reduce the flow time. An example of a Lean technique that reduces WIP is Kanban, a control system based on cards that start the production and are released from the downstream of the production. It reduces WIP by limiting the number of parts in process to the number of the cards. A second way of reducing flow time is reducing lot sizes. For a single machine, if there is a batch of N items and setup time S and processing time t, the flow time is $N^{*}t+S$. One-piece flow could reduce the flow time in this case. However, it increases the need for setups, which have to be shortened in order to be efficient. This is achieved in Lean by using the SMED (Single Minute Exchange of Die) technique. A third way to reduce the flow time is to have extra capacity or more flexible capacity. This reduces the flow time, simply because the capacity is available.

The second operating condition that is studied, *Local control,* allows simplified decentralised production control. This is not a very new idea as locally applied solutions are often used in practise. The problem with local control is that it might impair the overall control of the production. This is often seen in a functionally working company, where the utilisation of single machines is important, but the whole picture is not so clear. However, the production controllers usually push global targets, and thus may find local control secondary from their point of view. Kanban and 5S are examples of Lean methods that are typically implemented just

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