Reducing the EPEI-Time Using Discrete Event Simulation

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ABSTRACT

One of the cornerstones in LEAN production is 'make to order', which requires small batch sizes and, thus, short Every Part Every Interval (EPEI) times. EPEI-time is defined as the time it takes to produce all product variants, before the first variant in the cycle returns in the schedule. However, many companies are reluctant to reduce their EPEI-times due to the increased number of set-ups. This skepticism is also supported by parts of existing theory, while other research contributions mean that companies often can reduce batch-sizes without affecting productivity. This paper presents a case study which uses discrete event simulation (DES) to evaluate the relation between EPEI-time and productivity. The results show that it is possible to reduce the EPEI-time and still maintain productivity and service levels to customers, without any investments. Increased variation in the production schedule evened out the load among the machines and, hence, the time lost in set-ups was gained in more parallel work.

KEYWORDS: Discrete event simulation, DES, LEAN, EPEI-time

1. INTRODUCTION

LEAN production specialists claim that companies can reduce factory space and man-hours by 50% and inventory levels by even more [1]. This, in combination with the ability to produce a greater variety of products, contributes to the fact that many companies nowadays try to embrace the LEAN philosophy. One of the key components in LEAN production is to get a flexible production with production to order instead of on forecasts as the primary goal. To reach this goal, it is important to reduce the Every Part Every Interval (EPEI) time.

The EPEI-time is defined as the time it takes to produce all variants in high variety production, before the first variant in the cycle returns in the schedule. Hence, short EPEI-time leads to small batch-sizes while increasing EPEI-time equals larger batches. Therefore it is important to keep the EPEI-time low according to a LEAN philosophy, since smaller batch-sizes results in a more flexible production, lower inventory levels and shorter delivery lead-time to customers.

On the other hand, longer EPEI-times reduce the number of set-ups and give more available time for production. This is why many companies are reluctant to reduce their EPEI-times. It is often easier to quantify the benefits of few set-ups than to estimate the advantage of increased flexibility. However, the problem with large batches is the difficulty to keep high service levels without having a lot of products in stock.

To investigate this state of opposition, the impact of EPEI-times on productivity is investigated in a case study at a Swedish component manufacturer. The company has a long-going lean philosophy but the production cell in this study has problems to produce solely to order, given the promised lead-time to customer of 15 days; see Fig 1. The 15 days total lead-time implies a restriction of the cell's production lead-time and EPEI-time (hereafter called combined lead-time) to seven days compared to the current situation, which is 13 days. The other eight days are required for other process steps (assembly and heat treatment) in the product's complete value stream.

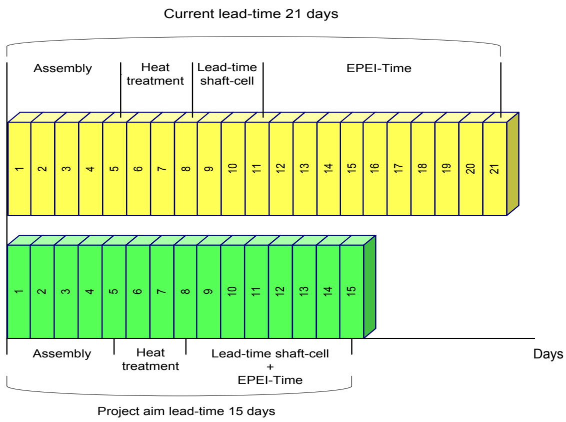

Fig 1: Current state at the case study company versus desired situation to be able to keep the promised lead-time to customers.

The aim of this paper is to evaluate the relation between EPEI-time and productivity by investigating necessary production improvements that are necessary to reduce the combined lead-time to seven days with maintained productivity.

2. METHOD

In this paper, Discrete Event Simulation (DES) is used for evaluation By using DES it is possible to run combinations of various EPEI-times and different production improvements (e.g. decreased set-up times and machine investments) and study these factors' interrelations and their impact on productivity.

DES is used mainly since the experimental object is a product flow in a production cell, where real-world experiments cannot be performed without affecting the production. Using a model of the cell enables more efficient and agile design of experiments and the results are available at a much shorter time [7]. Furthermore, the production cell is a very complex system with many different factors affecting the cell behavior. This makes it hard or even impossible to use common sense or analytical evaluation methods successfully [2]. The vast amount of data produced by the simulation together with easy-to-use statistical tools makes DES a proper tool in this application.

Additionally, DES' capability to mimic dynamic aspects of production systems is very important in this case, since shorter EPEI-times lead to more flexible and dynamic flow of products. It is possible that small batches can even out the load among the machine.Other analysis methods such as static calculations are not able to study this possible phenomenon.

The DES software AutoMod 12.2 [3] is used to model and analyze the production cell (see Fig. 2)

2.1. Validation

In order to gain confidence for the experimental results from a DES study, it is vital to perform a proper validation process. This ensures sufficient conformity between the model and the real world system. Sargent [4] stresses the importance of a valid model with regard to each question that the model is designed to answer. Moreover, the same publication describes several useful validation techniques.

The first validation technique applied in this case study is *face validation,* which means that overall behavior of the simulation model is studied and approved of people with great knowledge of the system [4]. This is preferably performed continuously throughout the model building process.

Secondly, to achieve a relevant abstraction of reality, several assumptions are made in during the creation of the simulation model. These assumptions were all validated by confirmation from involved process experts and decision makers. This also includes ensuring the validity of statistical distribution representation of input data, which is achieved using goodness-of-fit tests [5] performed in the statistical software ExpertFit® [6].

Thirdly, a historical data validation of the output from the production cell is performed using a Student's t-test [7]. This technique shows how well the model output conforms to the real system output using identical input data. The null hypothesis, assuming that there is no difference in mean value between the outputs from the model and the real world system is:

$$H_0: \boldsymbol{\mu}_0=0$$

This hypothesis is tested versus the alternative of significant difference:

$$H_1: \boldsymbol{\mu}_0\neq 0$$

At this point the statistic t_0 is computed using equation (1).

$$t_0 = \frac{\bar{d} - \mu_0}{S_d / \sqrt{K}} \quad (1)$$

Where:

- $\bar{d}$ is the mean from the observed difference between model output and real system output.
- S_d is the standard deviation of the observed difference
- $\boldsymbol{\mu}_0$ is the mean of the difference d_j distribution

  With $\boldsymbol{\mu}_0$= 0 the critical value $t_{\alpha/2,K-1}$ is provided from the table provided by Banks [4] where α is the significance of the test and K-1 are the degrees of freedom. If $|t_0| < t_{\alpha/2,K-1}$ it is not possible to reject the null hypothesis and conclude that the model is not inadequate; i.e. the model can be considered validated regarding historical output data comparison.

2.2. Case Study Description

The mapping of the EPEI-time's influence on productivity is performed in a real world scenario from a case study in a machining production cell at Parker Hannifin. The production cell produces shafts for hydraulic pumps and motors. It consists of two milling machines (1), one multi operational machine (2), four grinding machines (3) and one hard-turning machine (4). The flow within the cell is dependent on what features the shaft is supposed to have e.g. splines or keyway or if it is supposed to be a part of a variable angle machine (see Fig. 2). There is also one extra milling machine (Makino, 5), which is included when simulating future scenarios.

For material planning, the company uses a periodic run-out-time planning. Prior to an upcoming planning period, the length of which is referred to as EPEI-time or cover time, all material needed for the period is ordered from the supplier. In order to minimize set-ups, all orders concerning the same variant of shaft is combined to make one larger batch. The material is then delivered consecutively day by day to the factory. When the shafts are finished in the production cell they are sent, by daily transport, to heat treatment at another facility.

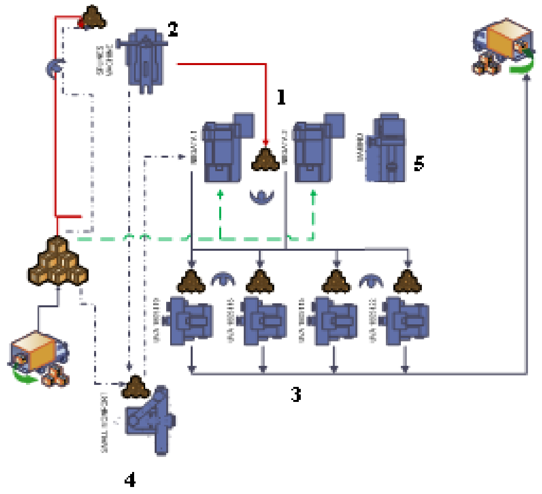

Fig. 2 Conceptual model of the production cell

3. FRAME OF REFERENCE

LEAN manufacturers are striving towards very robust production systems, where it is central to be able to adjust capacity with regard to fluctuations. Standridge and Marvel [8] mention that the LEAN philosophy and its deterministic tools such as value stream mapping are necessary to fulfil these objectives. However, they also conclude that many random and structural variations cannot be identified by the regular lean measures, and present a list of situations where simulation provides a powerful supplemental tool. If any of the questions below is answered by a "Yes", simulation in conjunction with lean makes up for a profound understanding of the production system.

1. Are multiple part types produced?
2. Are parts shipped on days when they are not produced?
3. Are some operations performed off-site?
4. Does the customer return shipping containers that need to be re-used by the production system?
5. Is there significant downtime or any other significant disruption in any production operation?
6. Is the production process ever starved due to a lack of raw material?
7. Is inventory storage space highly restricted?

Shorter EPEI-time leads to smaller batches. Furthermore, according to a study by Carlson et al. [9], reduced batch-sizes give a more flexible and rapid production and, thus, much shorter lead-times. In that study, simulation is used to understand the real system and to allow users to explore alternatives. In addition to help understanding the impact of batch-sizes and variability on system performance, the results also demonstrates the importance of buffers to protect system performance. As a conclusion, Carlson et al. [9] mean that the batch-sizes could generally be reduced a lot until the output is affected significantly.

Furniture manufacturing is an industry where the lead-time and retail inventory are critical to sales. In a case study at Grubb Furniture Manufacturing, Keller et al. [10] studied the problem that if customers want a particular item that is not in stock at the retailer, they still want it now or as soon as possible. If the lead-time from the manufacturer is 8 weeks or more in this particular case, customers may go elsewhere. A simulation study led to the conclusion that production in small batches contributes significantly by offering less lead-time with more product variations. This study indicates that a shorter EPEI-time might have significant benefits on the production lead-time.

Moreover, Ekrena et al. [11] presents another study stating that smaller batch-sizes lead to more set-ups. If the batch-size is reduced to the extent that the production output is affected this could be compensated by reducing the set-up times.

Furthermore, in an article by Dolcemascolo [12], it is proposed that the primary reason for implementation of shorter set-up times through Single Minute Exchange of Die (SMED) projects is to be able to shorten the EPEI-time and thereby also decrease the batch-sizes. Furthermore, the same study mean that many companies of today have far too long EPEI-times, resulting in high levels of work in progress (WIP), large inventory costs and a lack of flexibility towards customers.

4. RESULTS

This section firstly presents how the model is validated. Secondly, the experimental plan and the results from the experiments are presented.

4.1. Validation

The first step of validation is to show the model to the line production managers (the project contact persons) and determine whether the model behaves according to the real system. The mentioned managers argue that the proposed model with its machines and material flows shows a satisfactory behavior. Secondly, the statistical representation of all input parameters is validated using the goodness-of-fit-tests available in ExpertFit® 6.01 [6].

The last part of validation is to run the model using the historical input data, see chapter 2.1. The contact person at the manufacturing company chose a test period where production levels and orders quantities have been stable. The period covers September 2008 to November 2008 and the same orders that were run through the real production cell are run through the model.

According to the contact person at Parker Hannifin the all-time-high production rate is approximately 1900 shafts per week and the average lead-time is approximately 3 days. During the first test runs the model produced too many shafts compared to the real system. Together with the contact person a decision was taken to implement allowances of 13% of the working day in the staff schedule, according to union negotiations. This modification lowered the output of the model to a level similar to the real output. The runs also showed significant dependencies between large buffer sizes and long lead-time.

The validated model output is 7% less (see Table 1) than the real systems output in the same period. This deviation is within the confidence interval in the hypothesis test (see Table 2) and therefore reasonable enough to be able to use the model as a base for experiments. To get the model output closer to the real system more accurate data is needed for performance of manual labor in production. The assumed lead-time in the real cell is 3 days according to our contact person; this corresponds well to the production lead-time in the model.

Table 1 Production output from base model

	Base Model	Real System
Shafts produced from Week 36 to 48, 2008 (14 weeks)	19397	20744
Production Lead-time	3.2 days	~3 days

The hypothesis test (student t-test) described in chapter 2.1 is performed during the weeks in the test period. For the results shown in Table 2, it is not possible to reject the null hypothesis and, hence, the model is considered valid also for this test.

4.2. Experimental plan

The analysis of the model is performed in a sequence of steps and Parker Hannifin provides the scenarios tested in the simulation models. Improvement proposals other than the ones from Parker Hannifin are not included in this case study.

The input to the model is:

- Real orders from a period with stable demand from customers.
- Production data such as machine cycle times, breakdowns and scheduling of personnel and machines.

The output from the model is:

- Production rates
- Process lead-time
- Set-up counters
- Utility of machines and personal

Three experiments will be run:

- EPEI-time reduction: By reducing EPEI-time in the model more set-ups is expected. This test will show how much extra set-up there will be and how much impact it has on productivity.
- An additional machine: The Manufacturing company has a old spare multi-operations machine that works in the same way as the two machines currently in use. The new machine can process all variable products that arrive from the previous turning process. This will decrease the workload on one of the multi-operations machines and increase the overall capacity. The machine that processed variable products earlier will get a new tower for a specific product family.
- Set-up time reduction: If the productivity decreases when lowering the EPEI-time it can be compensated by lowering the set-up times according to Carlson et al. [9].

4.3. EPEI-time reduction

Several tests are run with various EPEI-times. The model does not show any correlation between any changes in production output and a shorter EPEI-time. Even though it is also showed that the number of set-ups is increasing with a shorter EPEI-time the output remains approximately the same. This is shown in Fig. 3 where the thinner bars (displaying the output) are constant while the thicker bars (number of setups) are varied.

Table 2 Validation results of null hypothesis test

Input Data Sets (K)	System Output (Z_{ij})	Model Output (W_{ij})	Observed Difference (d_j)	Mean $\bar{d}$	Squared Deviation from Mean	S^2	S	$\lvert t_0 \rvert$	α	Critical Value t_0	Test Result
1	1605	1440	165	77.92	7617.26	101836.13	319.12	0.068	0.05	2.18	Valid
2	1447	1684	-237		99428.64						
3	1743	1466	277		39472.52						
4	1656	1116	540		213515.08						
5	1140	1641	-501		334920.40						
6	1577	1436	141		4029.32						
7	1505	993	512		188596.45						
8	1676	1243	433		126221.69						
9	1463	1428	35		1842.39						
10	1204	1538	-334		169351.24						
11	1249	1300	-51		16569.63						
12	1410	1314	96		326.78						
13	1460	1524	-64		20142.16						

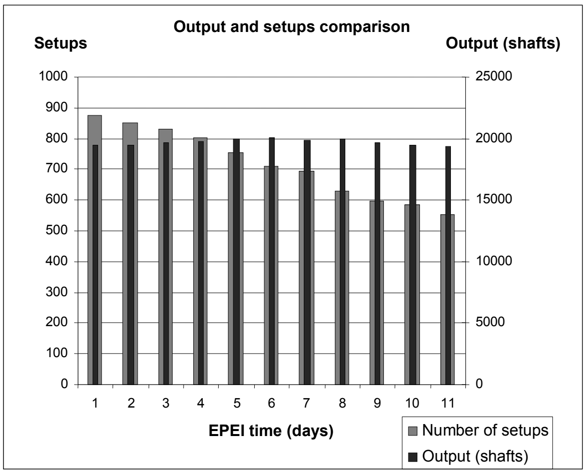

Fig. 3: Output and number of set-ups with different EPEI-times.

4.4. Installation of a multi-operations machine

When implementing the additional multi-operations machine in the simulation model, experimental runs show that the lead-time is reduced by 23.3% and that the output is increased by 3% compared to the base model (see Table 3).

Table 3 Results from simulation with an extra multi-operations machine. The output results are the total from the grinding machines

	Base model	Extra machine	Comparison
Lead-time (days)	3.21	2.46	-23.3%
Output (shafts)	19397	19983	3.0%

4.5. Reduced set-up time

The analysis evaluates the impact of improvements in set-up times by up to 50 % in the milling machine, the turning machine and the four grinding machines. According to Mileham et al. [13] a reduction up to 50 % in set-up time is reasonable in similar processes. The purpose of the test is to show how much impact the setup has on the lead-time and production rates.

Tests show that reduction of set-up times in the milling and the turning machines do not have a significant impact on either lead-time or output. This is due to the low utilization of these machines that was under 10%.

The important results from the experiments are summarized in Table 4. It shows that set-up time reduction can increase output by up to 7 % with a set-up time reduction of 50 % in the grinding machines. At the same time, lead-times are slightly decreased.

Table 4 Results from set-up time reduction in grinding

	Set-up time reduction				
	10%	20%	30%	40%	50%
Lead-time reduction	-2%	-1%	-3%	-5%	-6%
Output improvement	1%	3%	3%	6%	7%

4.6. Combinations of improvements

When installing a new multi-operations machine and doing set-up reduction (at least 40%) on the grinding machines the cell lead-time can be reduced from 3.21 days to 1.96 days. This makes it possible to choose an EPEI-time of 5 days instead of 4 days (see Table 5) and still achieve the 7 days total time (see Table 6). Choosing a longer EPEI-time minimizes the number of set-ups.

Table 5 Different scenarios regarding lead-time and EPEI-time.

Scenario	Lead-time	EPEI-time	Total
A: Base model (0% set-up improvement)	2.91	4	6.91
B: Extra machine model (0% set-up improvement)	2.23	4	6.23
C:Extra machine model (40% set-up improvement)	1.96	5	6.96

Table 6 Scenario A and B results in 4 days EPEI-time. Scenario C will have an EPEI-time of 5 days.

	Days to shipping						
Scenario	9	10	11	12	13	14	15
A & B	Lead-time			EPEI-time			
C	Lead-time		EPEI-time				

5. DISCUSSION

In this case study, EPEI-time reduction does not significantly affect the output from the model despite that more time is spent on set-ups due to the smaller batch-sizes. The set-ups increases by 60% if the EPEI-time is reduced to 1 day but render no production losses. This is an unexpected result when comparing to statements by Ekrena et al. [11] (see chapter 3). The reason for this result is the fact that the higher variation in product mix, due to a shorter EPEI-time and smaller batch-sizes, evens out the load among the different machines. Hence, the time lost in set-ups is gained in more parallel work in the cell.

The results from chapter 4.6 show that the lead-time could be reduced to 2.9 days by just changing the EPEI-time to 4 days. According to the simulation study, this will neither impact the output nor require any major investments. However, if it shows that this will affect the output after implementation in the real-world system, the set-up times will have to be reduced. Reducing set-up times can for example be done by a so called Single Minute Exchange of Die (SMED) analysis (see chapter 3).

According to the simulation model, output will remain steady even though EPEI-times are shortened and set-ups are increasing. This confirms the statement by Carlson [9] that the batch-sizes could be reduced a lot until the output is affected significantly. Making further bottleneck analyses to discover constraints in the system and test shorter EPEI-times would be a future interest for the company.

Furthermore, the smaller batch-sizes give the company several advantages according to Keller et al.[10]. These include a shorter total lead-time to customer which improves customer service level. Moreover, it reduces work in progress as well as inventory, which in turn lead to internal cost reductions.

The list of questions by Standridge & Marvel [8] can indicate when DES is a proper tool. The unexpected results discovered in this simulation show relationships that would not be found otherwise.

To benefit even more from the lean concept and continuous improvement work, it would be a good advice to use DES as a tool to rapidly evaluate proposals from people involved in the improvement work (operators, managers, engineering, maintenance etc.). In other words, DES can be used as a support for evaluating efforts in Kaizen work and, thus, feedback can be presented within a shorter time span.

For future research, it is necessary to evaluate whether the same relation between EPEI-times and productivity appears in other manufacturing companies. Further and more extensive research is necessary to identify which technical and economic factors that should be considered to determine appropriate EPEI-times. Furthermore, based on the findings in this case study and on previous theory, it is likely possible for many companies to reduce EPEI-times without losing productivity. However, a process to determine the threshold value stating how much the EPEI-times can be decreased is not yet developed. In future research DES should definitely be utilized in this process.

6. CONCLUSION

This case study shows that shorter EPEI-times do not necessarily have a negative effect on production output, despite an increased number of set-ups. In this specific study, the EPEI-time was reduced from 11 to 3 days without productivity losses or major investments. This result, in combination with some previous research, indicates that companies can increase responsiveness to customers and reduce inventory levels without significant efforts and setbacks. To some level, productivity seems to gain more from the improved agility than it loses from the increased set-up times.

Throughout the study, DES has shown to be a powerful tool for evaluating the effects of LEAN production efforts. Here, the focus has been on optimizing EPEI-times, which is similar to batch-size reduction. However, the model is also appropriate to evaluate production improvements, both on a continuous basis (Kaizen) and for major investments (Kaikaku).

Additional notation: three months after this study was completed, the company ran real-world tests on reducing the EPEI-time and doubled the number of set-ups. The results are positive and the service rate to customers is reported very close to 100%.

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