MEASURING THE LEVEL OF LEANNESS OF PRODUCTION - USE OF PRODUCTION LEAD TIME

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Abstract: *To manage any company process, it is essential to measure its performance. Lean production as a process of a change in a production, which is one of the main company processes, is no exception. We see that the universal methodology of a practically applicable evaluation of the level of leanness of production is missing. Many authors use some form of qualitative methodology - especially in form of questionnaires. In this paper, we focus on an analysis of possible approach using a quantitative methodology. We take Little's Law formula describing direct correlation between lead time and work in process to use lead time as a main metric to evaluate leanness of production. Thanks to the formula, we know that the shorter the production time is, the less buffers are kept and the more effective and thus the "leaner" the material flow is. As a benchmark for ideal lean company, we use one piece flow representing the top level of lean production.*

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Introduction

All the state economies create one global market. Manufacturing companies can't rely on competitive advance deriving from their local focus. All producers are compared on a global level, where there is a hyper-competition (D'Aveni, 1994). In this comparison, the only ones that can succeed are the ones achieving excellent performance. Only efficient business processes are able to satisfy customers.

One of the key processes is production. Properly functioning production system is a matter of course. But a system that is capable to maximize effectiveness of the production is often the attribute which can help overcome the competitors. Lean production (LP) is one possible approach of how to optimize production processes. Results of the firms which have successfully implemented this methodology bring enormous interest in this matter. This fact is supported by dominant interest of academics from the operations research area (Voss, 1995; Shah and Ward, 2003).

Krafcik named the new approach based on principles of Toyota Production System (TPS) "Lean production" (Krafcik, 1988). Womack with his team firstly described in detail basic principles of the LP in 1990 (Womack et al., 1990). Many other authors focused their research on understanding how LP works, how to successfully implement it and what the limitations of this principle are. Hundreds of scientific articles were written about it. From this point of view it looks like everything around lean production is described and clear, and companies shouldn't have any problem with implementation. But that is not completely true. There are still not many firms that have reached all the positive impacts of this approach. There are even some firms which fail the implementation or resist it. Schipper and Swets made a survey of practioners of lean implementation and found that there is only 30% success rate (Schipper and Swets, 2010).

1 Statement of a problem

Behrouzi and Wong (2011) stated that the lack of an effective implementation methodology, a clear understanding of lean performance and its measurement are significant reasons behind the failure of the lean practices. Main problem is that uniform definition of LP is missing (Bhamu and Sangwan, 2014). Almost every author has their own approach and the variety is huge. Basic principles differ, implementation methodology and tools differ and even goals differ. Another issue is implementation process. Again, there is no uniform methodology and differences between companies are so big, that every implementation is unique. Not often mentioned, but important area is a measurement of the level of leanness. Organizations frequently use generic measures with a little consideration of their relevance to LP (Bhasin, 2008). A few authors tried to develop specialized system of measuring the benefits or the level of leanness, but still none of it was globally accepted and used within the implementation process.

The importance of measurement of the leanness of the production is high. If management of a company has to decide about the implementation of LP, they should understand what the actual level of the leanness is and what the realistic expectations are. Then future goals can be set and expected benefits can be calculated. During the implementation, it is necessary, for the people involved, to continuously measure their approach and if they are on the right track to achieve the goals. After the implementation, it is important to have sustainable system which can be controlled by appropriate performance indicators.

The aim of this article is to review the literature about measuring lean production and to define requirements for the development of the appropriate metric. One possible way to evaluate the level of the leanness of the production will be introduced. The organization of this paper is as follows. Literature review is divided into two parts - lean production and leanness followed by measurement of leanness. Next part will be the introduction into the topics of variability and buffers and Little's Law. Finally, one possible way to measure LP is introduced in discussion and in limitations and future research are presented in conclusion.

2 Methods

For a literature review secondary data research of a scientific papers was used. Articles focused on measurement of lean production from scientific databases like Taylor & Francis, Emerald, ProQuest and others were reviewed.

2.1 Lean production and leanness

Since Krafcik (1988) named for the first time TPS "Lean production" and Womack and his team described in detail principles of TPS (Womack et al., 1990), many other authors have focused on a different definitions of LP. That is why there is no universal definition of lean production (Karlsson and Ahlstrom, 1996; Qing Hu et al., 2015). First differences are in a area of company processes involved in a definition. Some are only production-oriented (Narasimhan et al., 2006), others are enterprise-oriented (Womack and Jones, 1994) and some definitions are wholly supply-chain-oriented (Naylor et al., 1999). Some authors name LP as a philosophy (Liker, 2004), as a system (Hopp and Spearman, 2004), as a process (Womack et al., 1990) or as a tool (Bicheno, 2004).

The most popular definitions are following: “Lean production is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability.” (Shah and Ward, 2007); “Lean production can be described as the elimination of waste.” (Liker, 2004); “Lean production is a strategy or philosophy that promotes the use of practices, such as kanban, total quality management and just-in-time, to minimize waste and enhance firm performance.” (Womack et al., 1990) or “Lean production is a manufacturing strategy, which strives to minimize waste and thereby increase efficiency.” (Hofer et al., 2012). From these definitions, we understand that lean production is a system of tools, which are used to eliminate waste. And waste is a product of variability in the company. Another important thought is that it is a strategy that influences the whole company. This definition sounds quite clear, but it is rather general. Explaining this definition in greater detail can be a problem. Every author understands this definition differently and focuses their research and papers in different ways.

Affiliated problem is implementation process. There are again many frameworks of implementation of LP, but none of them is universally applicable (Bhamu and Sangwan, 2014). Management of a company stands in front of a difficult decision because incorrect application of lean strategies results in inefficiencies of an organization’s resources and reduced employee confidence in lean strategies (Marvel et al., 2009).

Frequently used term connected with LP is “leanness”. There are more definitions of that term. “Leanness refers to the degree of the adoption and implementation of lean philosophy in the organization.” (Wong et al., 2014; Comm and Mathaisel 2000). Naylor et al. (1999) use “leanness” to describe the process of realizing lean principles while introducing the concept of “leagility”. The term “total leanness” was used by McIvor (2001) to imply a perfectly lean state of several key dimensions of lean supply. The leanness level of a system can be defined and measured by comparing the current state with the worst case and the perfect case. Thus, the level of leanness can be quantified (Anvari et al., 2013). For purposes of this article we will identify ourselves with definition of Wan and Frank Chen (2008): “Leanness level refers to the performance level of a value stream compared with perfection.” Therefore, a leanness measure shows “how lean” the system is.

2.2 Measurement of leanness

Lean metrics are performance measures that are used to track the effectiveness of lean implementation (Anvari et al., 2013). There are many different ways of how to measure LP, but there is no universal methodology, that can be used to evaluate LP in every company. The tools for assessing leanness can be basically divided into two types: qualitative and quantitative.

Qualitative tools are based on surveys, checklist and other forms of getting data about how company meets different conditions and prerequisites connected with lean manufacturing. Analysis and evaluation of these data shows the level of leanness. One of the most popular tool is Lean Enterprise Self-Assessment Tool developed by lean aerospace initiative at MIT (Hallam, 2003). The model is made of 36 indicators that are divided in six groups, followed by 101 metrics to match wastes. Seyedhosseini et al. (2011) have investigated the leanness criteria in auto part manufacturing using a Balance Scorecard approach. They have considered five different perspectives: finances, processes, customers, employees, and suppliers; and extracted more than 50 criteria for being lean. Various lean assessment surveys have also been conducted by lean practitioners and researchers to assess the leanness (Fullerton and Wempe, 2009; Karlsson and Ahlstrom, 1996; Soriano-Meier and Forrester, 2002). Most lean assessment tools provide just qualitative analysis and do not provide any clear direction of where the improvement efforts should be directed (Srinivasaraghavan and Allada, 2006).

In comparison of qualitative surveys, quantitative metrics and models provide better leanness score (Karim and Arif-Uz-Zaman, 2013). These tools can be divided into two groups. First group is focused on a techniques of an overall evaluation of the system. For example Srinivasaraghavan and Allada (2006) have measured leanness by calculating the Mahalanobis distance between the current state of the system and the benchmarking performance. In that case, other companies in the market are taken as a benchmark. The outcome depends heavily on the quality of the benchmark. Wan et al. (2007) measured the overall leanness by VSM (Value Stream Mapping) considering cost, time and output values. Fullerton and Wempe (2009) and Agus and Hajinoor (2012) used Structural Equation Modeling (SEM) to establish the relationship between different lean tools and lean production performance. They conducted several surveys to validate the relationships.

Second group is represented by tools, which are more narrowly focused on specific aspects of the leanness. For example the Manufacturing Cycle Efficiency (MCE) index represents leanness level in terms of time-based performance. This index for cycle time reduction compares value-adding time with total cycle time to show the efficiency of a manufacturing process. Fogarty (1992) has developed the Value Added Efficiency (VAE) index to assess leanness from value-added performance perspective. It is defined as the ratio of total run time to the total manufacturing time. Dai and Lee (2009) further expressed it as the ratio of the time in actual production and setup process over the total time in the production area. Wu and Wee (2009) measured overall equipment effectiveness. Swamidass (2007) used the ratio of total inventory to sales as a general performance index to analyze over 14,000 firm-years of lean practitioners. Eroglu and Hofer (2011) used Empirical Leanness Indicator (ELI) for measuring inventory leanness. This indicator measures a firm's deviation from size adjusted within-industry average inventory levels which represents the level of inventory leanness of the company.

Researchers also explored various operational research techniques to measure leanness, such as using Data Envelopment Analysis (DEA) (Wan and Chen 2008). Some researchers used fuzzy logic algorithm to measure the manufacturing leanness, since leanness can be measured considering quantitative as well as qualitative indicators with this algorithm (Bayou and de Korvin, 2008; Behrouzi and Wong, 2011; Vinodh and Balaji 2011). And Detty and Yingling (2000) have utilised simulation models with several performance metrics to quantify leanness level.

3 Problem solving

3.1 Variability and buffers

Variability is one of the main reasons why companies aren't lean. Even definitions of LP by Wacker (2004) or de Treville and Antonakis (2006) discuss variability: "LP can be referred to as an integrated manufacturing system aimed at minimizing inventory levels and maximizing capacity use through the minimization of variability in the system." Formal definition of variability is the quality of nonuniformity of a class of entities and it is a naturally connected with randomness (Hopp and Spearman, 2008). Variability has many different causes. We can divide them into the two groups. First group is an external variability consisting of a causes resulting from the environment outside the company. As an example we can take deviations in a customer orders or natural disasters. For managers, it is hard to influence this type of variability. Its reduction is almost impossible. The only way how to fight with it is some kind of protection against its effects - to have for example bigger stocks of finished goods or insurance against natural disasters.

The second group is an internal variability. Here belong causes arising from the company itself. This variability is created by internal processes and activities. There are two possible ways of how to respond to it. First is the same like with the causes of external variability - to prevent impacts caused by the variability. In production, it means mostly to create buffers. Generally, this is the easier way. Second way is to reduce the variability itself. Quite popular methodology is Six sigma, which is based on work with randomness and variability. Other possibility is to use some LP tools like SMED (Single minute exchange of dies), 5S, TPM (Total productive maintenance) or many others. Its purpose is to eliminate or reduce as many causes of the variability as possible, so the randomness is minimal and the uncertainty becomes certainty. Then there is no need to have any other protection in terms of buffers.

All buffers represents some kind of inefficiency. That is why the company should pay attention to identification of buffers in the system. All buffers cost money and from the customer point of view they don't have any added value and customers aren't willing to pay for them. Since buffers are hidden in the system, it is not easy to identify them. For conventional production systems, it is natural to include these buffers. It is important to find them, because they cover many types of variability in the system the same way as water in the lake hides the rocks at the bottom. Therefore, if you reduce the buffers it will show you the variability like lowering water-level in a lake will show the rocks.

Buffers, built to cover both external and internal variability, consume money and don't generate value added. Within the internal variability, the ineffectiveness of the system or how some authors call it “waste” is hidden. In general, buffers can have 3 major forms (Hopp and Spearman, 2008):

- inventory buffer,
- time buffer,
- capacity buffer.

Inventory buffer means that extra material in the transformation process is kept. This extra material can cover unstable process or other problems in the production. Time buffer means that pieces in advance are produced to cover potential delay in the production. Capacity buffer significate that free capacity is kept and can be used in situation of unplanned problems in production. Without these buffers conventional production systems collapse.

One of the main buffers defending the improvement of the production system is Work In Process (WIP). High level of WIP is a common problem in many companies. It is remnant of the old production systems used in the 20th century. In many cases, it is connected with planning systems. One of the famous planning systems created in the 60's is Material Requirements Planning (MRP), which is surprisingly still the basis for planning processes in modern Enterprise Resource Planning (ERP) systems. MRP and other systems need a high level of WIP for their proper working. When they were created there wasn't such a big pressure on efficiency of production processes, so their inaccuracy and imperfection wasn't a problem. Times have changed and today, this system is a problem for improving the performance of the company.

3.2 Little's Law

Buffers created to protect the company against the variability can significantly influence the dynamic of production. There is a direct correlation between WIP as a main form of a buffers and cycle time which represents total time of a batch in a production. To understand it, it is important to remember Little's Law. This law (1) explains the relationship between WIP measured in number of pieces, throughput (TH) measured in number of pieces per time unit, and cycle time (CT) measured in time units - days usually (Hopp and Spearman, 2008):

$$WIP = TH \times CT \tag{1}$$

Instead of CT which represents actual production time, we can use lead time (LT) as a planned or expected production time. This formula came from queuing theory, when in 1961, John D.C. Little (1961) published his article about a proof of the queuing formula (2):

$$L = \lambda W \tag{2}$$

Here L represents the average number of items in a queuing system, λ stands for the average arrival rate of items to the system and W is the average waiting time of an item in the system. Production systems can be taken as a special form of a queuing system, so we can apply formulas and rules from queuing theory on them. There is only one difference between these two formulas. It is throughput representing output in (1) and arrival rate representing input in (2) (Little, 2011). We can use (1) only in case that WIP meets special conditions, for example if there is a strict adherence to the First-In-First-Out (FIFO) system. Otherwise we should use input rate instead of throughput.

In this formula, we can see the mentioned direct correlation between the amount of WIP and production time. From this relation, it is obvious that the bigger the buffers are the longer it takes to produce a batch of products. The connection between these two parameters is throughput. This parameter is normally defined by the needs of customers and limited by production capacity. Batch size is a parameter that isn't explicitly included in the formula, but can significantly influence both WIP and CT parameters. From this point of view, the decision is about how the TH will be divided into batches. Again, there is a direct correlation. It means the bigger the batch size, the bigger amount of WIP is kept in a system and the longer the production time is.

4 Discussion

Bhamu and Sangwan (2014) stated that measurement of LP is a key topic for future research and development of this methodology. Leanness level or level of implementation of LP or measurement of benefits of LP is often discussed in scientific articles. But since the time Booth (1996) stated that universal way of how to measure level of leanness is missing, not much has changed in this area. Generally, it is critical for proper functioning of every process in the company to measure it. If we take the implementation of LP as a process of a change and we don't measure the results, then we can't expect it to be on a right track. Other problem is to identify the current state of the production process in a company and to set the right goal of the implementation process.

The literature review section showed that there are quite a lot methodologies trying to measure the leanness level of the company. Each has its own way how to do it.

For typical lean assessment tools, questionnaires are developed to survey the degree of adoption of lean principles (Wan and Chen 2008). Questionnaires are quite popular qualitative measurements of the leanness. The problem with these self assessment tools is the nature of subjectivity; the predefined lean indicators of a questionnaire may not fit in every system perfectly (Wong et al., 2014).

Due to these facts, we prefer to use quantitative measurements of the leanness. Many scientists introduced their quantitative methodologies. But still none is generally accepted. Hallam (2003) stated that the right metric should have following characteristics:

- They should be measurable and in-line with the strategic objectives of a company and customer value.
- They should enable control and evaluation of performance.
- They should aid in understanding the current scenario and help identifying improvement opportunities.
- They should be up-to-date and realistic.

We think that there is one main characteristics, which is missing in some methodologies and can be reason why there is no universal metric. It is the problem with complexity of the calculation and affiliated problem with difficulty and repeatability of the calculations. The performance should be measured over periods of time in order to determine whether any substantial improvement has been achieved (Srinivasaraghavan and Allada, 2006). Many metrics are based on a historical data. Although past models are extremely useful, they only provide problem-tool connection without a quantitative measure of leanness (Wong et al., 2014). For the shop floor management it is essential to have a measurement that can be used to evaluate immediate state of the process. Then it is possible to track the improvements and use it as a motivation for the employees.

For the top management it is important to measure the organization's performance, benchmark it against an industry standard, and point to specific direction for future improvements (Srinivasaraghavan and Allada, 2006). The metric should be able to carry the strategic content. Decision about implementation of LP is a long-term goal and whole company must be involved in this process. That is why it is important to set the right target of this change and to be able to measure the progress.

All the characteristics and requirements about measurement of leanness point to the following methodology. To prevent the subjectivity of the metric, it should be quantitative. It is also better while taking into consideration the universal use and ability to benchmark the company. To ensure the simplicity of the calculation, we will use only one metric instead of complex system of indicators to evaluate the whole system. Here, we want to focus only on evaluation of the leanness of the production. The complex performance analysis of the company is different topic, where a lot of methodologies, like for example EFQM model are used. The metric should be calculated from actual data of a company system. This should ensure that the metric can be used on the daily basis. This would be the tool that would be able to track the improvements of the process.

Lead time is the "key" measure of leanness. Short lead times and lead time reduction is such a basic tool in LP that you will find it to be a strong measure of leanness (Naderi et. al, 2009). Although lead time is quite a simple indicator, it represents really strong tool revealing the level of LP. From Little's Law, it is obvious that there is a direct correlation between lead time and WIP. Here WIP represents one of the most common forms of buffers. Buffers are created to cover variability, which is a source of inefficiency of the process. Long lead times represent high level of WIP, which means high level of buffers covering big variability and inefficiency of the production. One of the main characteristic of lean production is to decrease the inefficiency. From this point of view, short lead times represent lower level of variability and pointing out the high level of leanness.

Manufacturing parameters that cause long cycle times also cause high-production costs and factors that cause short cycle time lead to lower production costs. To maintain excessive amount of WIP, extra cash is needed. The turnover of stocks is lower and money are inefficiently utilized. The flexibility of the production is lower and the reaction time to the changes on the market is long. Customers are not willing to pay for any of that. Focus on customers is another important characteristic of lean principles.

Getting data about lead times is quite easy. Each production system should contain start date and finish date of each batch. But how can we set the goal or how can we compare two different companies or even two different material flows? Wan and Chen (2008) stated that ideally a lean manufacturing system runs with one-piece flow without interruption. Using the ideal case as a benchmark, the leanness level of a system can be measured based on the performance of the flow of each work piece. It was already Toyota who set one-piece flow as the top level of LP. All lean initiatives should lead to achieving this goal. This is benchmark for each company. We can calculate lead time in the theoretical case of one-piece flow with no interruption and compare it with the actually achieved cycle time in a production. The difference shows the level of leanness and the potential for improvement.

Conclusion

The real benefits of LP are restricted as Liker summarizes "50 per cent of the auto suppliers are talking Lean, 2 per cent are actually doing it." (Bhasin, 2008). Many organizations around the world have attempted to implement LP but the lack of a clear understanding of the main attributes of leanness, lean performance and its measurement contribute to the failure of lean practices (Anvari et. al, 2013). Lean production is a phenomenon of this age, but still it isn't fully understood. It is a process of a change, which needs to have a clearly defined goal. It is crucial to measure the performance for realizing the benefits of lean practices (Karim and Arif-Uz-Zaman, 2013). All processes in a company must be measured and evaluated. Without it, they can't be managed. Although, there are numerous theoretical and practical studies that address lean tools and techniques, few studies focus systematically on measuring the influence of lean attributes on leanness (Anvari et. al, 2013). Our target was to try to fulfill this research gap. We believe that the use of production lead time could be the way. We successfully tested this indicator on a few production companies with interesting results. Next steps are to make comprehensive research in companies to test the functionality and practical use of this metric.

We see a few limitations of this metric. Firstly, it focuses on production process and production companies. We haven't tried to use it for other company processes or other types of industry, especially services. Other limitation is the narrow focus on evaluation of leanness. Our aim isn't to measure the whole company performance but only the level of leanness. Practical use of this metric and evaluation of the results must be tested. We made a few tests in real companies with positive results, but thorough research is necessary.

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