The Impact of Autonomy on Lean Manufacturing Systems

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Abstract

An increasing number of companies implement lean principles into their production processes due to changing market conditions, a higher market competition and the high success of the Toyota Production System in the 1970s. Since lean manufacturing focus primarily on changes in the process organization, most of these changes do not require complex technologies. Additionally, many companies establish IT systems, e.g. a Manufacturing Execution System (MES) or an Enterprise Resource Planning System (ERP), as well as RFID and sensor technologies, for the improvement and monitoring of their processes. They may enable autonomous production that shifts the decision making from central to decentral.
The question is how human factors, IT systems and smart communication technologies can support the objectives of lean manufacturing. This paper provides an approach for the analysis of the correlation of lean manufacturing and decentrally controlled production by modern technologies, modern software systems as well as human and organisational factors. Thus, the effects of the usage of autonomy for a decentralised production control and benefits for various objectives can be classified. Therefore, the paper introduces a three-layer cluster for the classification of the level of autonomy.

1. Introduction

Changing market conditions, variable customer demands and growing customer requirements are some reasons for manufacturing companies to create flexible and adaptable processes to fulfill the customer demands in a high quality. There are several methods for dealing with the named challenges: lean production, advanced software systems and decentralization of decision making with the help of intelligent autonomous technologies. While lean production focus on the elimination on non-value adding processes, software systems may assist the process by the automatization of decision making due to algorithms. With the help of autonomous technologies - e.g. sensor networks or RFID - it is possible for production objects to proceed the information making and decision execution on their own. This decentralization of production control seems to be an adequate method to deal with the current requirements on production processes.

When regarding autonomy in production processes in literature, there is a clear focus on technology [1, 2]. There are three conditions for autonomous objects: independent information processing, independent decision-making and independent decision-execution [3]. Regarding these three issues, it turns out that there is more needed than technology to enable autonomy in production.

The question is how human factors, IT systems and smart communication technologies can support the objectives of lean manufacturing. This paper firstly presents three enablers of autonomy. The breaking down of the different kinds of waste of lean manufacturing sets the basis for the analysis of the correlation of autonomous and lean production as well as the possible influence of autonomous production control on different process lead times. The paper works out at which level of autonomy the improvements can be categorized. Market surveys among IT system providers and expert interviews serve as validation for the results of this research.

2. Three Enablers of Autonomy

In general autonomy describes the ability of interacting elements to proceed, make decisions and execute these decisions independently [3]. Thereby it is mostly assumed that these elements are machines and other hardware components that are able to communicate with the help of software components. According to the etymology of the term “autonomy“, it is defined as the capacity of a rational individual to make an informed, un-coerced decision [4]. Transferred to production systems, that means that there are - in addition to the definition of autonomy that is

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mainly based on hardware with software related intelligence - two other possibilities to create an autonomous controlled production: autonomy via software and autonomy by human action and organization. All three (hardware, software and human) are able to proceed intelligently, either independently or due to a combination of them. The degree of combination may vary from a high interaction to a nonexistent one.

In order to generate a holistic view on a decentrally controlled production, it is necessary to consider different enablers. Additional to “intelligent“ technologies that are able to make the decision making - in accordance with given targets - on their own, also modern software systems like e.g. MES and ERP can make decisions. Also, a decentrally controlled production can be enabled by human factors. The following section describes the three enablers.

Enabler 1: Human Autonomy

To enable a human autonomy, humans must be capable to make and proceed decisions on their own and in a team respectively. Preconditions for this are among others flat hierarchies, the transfer of responsibility, communication among various persons and departments and suitable organizational structures [5].

Enabler 2: Software Autonomy

There is a wide range of specific software used in production systems [6]. Among the most common are:

- Manufacturing Execution Systems (MES)
- Machine Data Logging
- Operating Data Logging
- Advanced Planning and Scheduling (APS)
- Warehouse Management Systems (WMS)
- Computer Added Quality (CAQ)
- Staff Working Time Logging

Every software system focus on different aspects of production, but there are also some system providers that provide integrated systems and those that include basic functionalities of other systems respectively (e.g. a MES that includes quality management functions [7]). With the help of software systems, it is possible to reduce the system‘s complexity and automatically proceed the decision making by using existing software algorithms. A market research among German MES providers shows that the three most offered lean methods within manufacturing execution systems are Kanban, Kaizen and Total Quality Management [8].

Enabler 3: Machine Autonomy

“Autonomous Control describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions independently. The objective of Autonomous Control is the realization of increased robustness and positive emergence of the entire system due to distributed and flexible coping with dynamics and complexity” [9]. Requirements for Autonomous Control are differentiated in information processing, decision-making and decision-execution [9].

Information processing includes data input, data storage and data aggregation. Relevant data has to be tagged to the production object. Therefore, specific technology is necessary [3]. Examples for such technologies are sensors, e.g. Radio Frequency Identification (RFID) or barcode [10]. Decision making combines the aiming system with predefined rules as well as communication with other production objects. For the decision execution, the communication of different production objects as well as the capability of a production object to performance alternative processes is necessary [3].

Supplemented by organizational aspects that include strategies of organization and concepts of control, an Autonomous System can be modeled. It has elements that are able to make decisions in an autonomous and decentralized way. This would create the opportunity of a production that complies with relevant rules and allows the adoption to changes with a minimum of external intervention. All relevant data is stored, read and evaluated by a given algorithm. Based on this, regulations are proceeded [3].

3. Waste in lean manufacturing

Originally designed for mass production in automotive industry at Toyota, Lean Production took on in importance even for small batch production during the last years. The globalization and the linked changing market conditions are one of the main reasons for this. For many companies, Lean Production becomes the focus of attention. After World War II engineers reconsidered all production processes with the aim of strengthen them. The main aim is the minimization of all waste - a term used in the lean philosophy for all parts of the production process that does not add a customer value to the work piece - in order to streamline the processes. This improves the adherence to delivery and minimize costs. Lean Production distinguishes three kinds of waste - based on Japanese words and called the "Three Mu": Muda (losses due to waste), Mura (losses due to deviation) and Muri (losses due to congestion) [11, 12]. As Muda is the worst waste, this paper will focus this type of waste. They provide the basis for the assignment and analysis of autonomy in manufacturing in order to improve lean processes.

"The basis of the Toyota production system is the absolute elimination of waste." (Taiichi Ohno, 1912 - 1990)

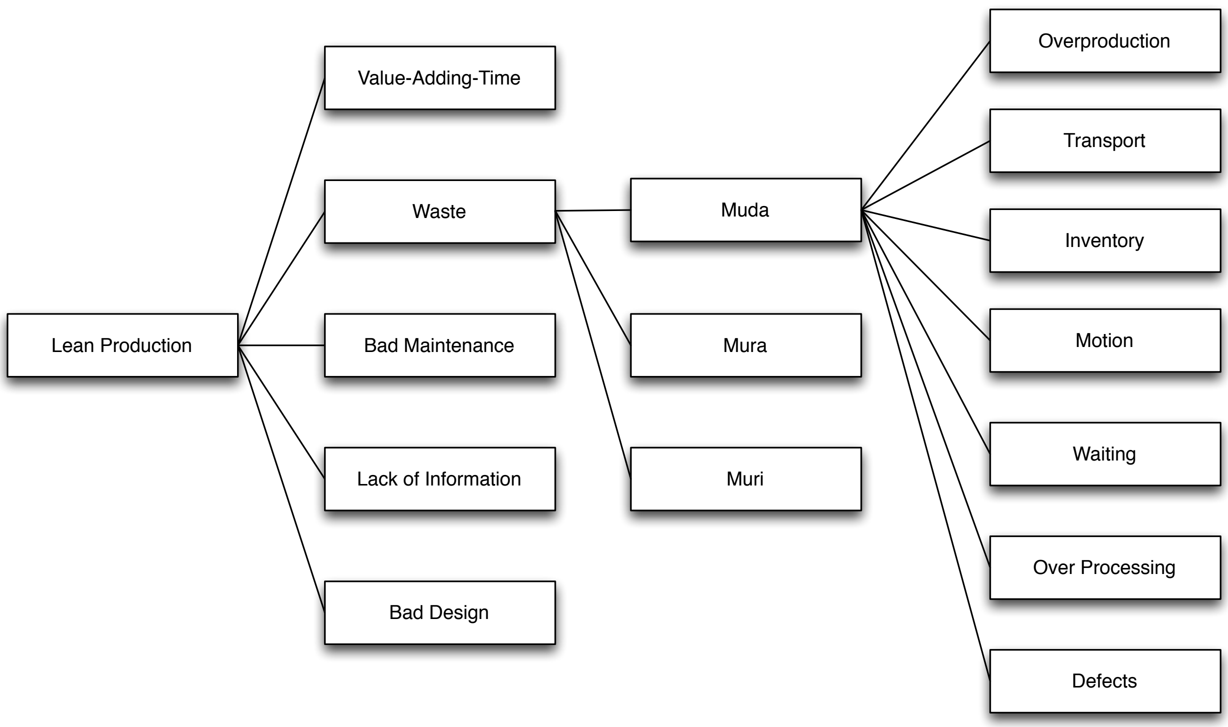

Figure 1: Times and Types of Waste in Lean Production

Figure 1 pictures five different types of time and waste used in lean production. Originally there are seven Muda: Overproduction, transport, inventory, motion, waiting, over processing and defects [13]. The following substantiates them [14, 15, 16, 17]:

3.1. Overproduction

The field of overproduction distinguishes two kinds of waste: the quantitative and the time related. Whilst in the quantitative the produced quantity of goods exceeds the needed quantity, in the time related waste the goods are produced before they are needed for the fulfillment of orders in due time.

Both kinds result in higher stock levels. In case of the quantitive, those products that are not needed at the moment of completion have to be put into storage. Additionally there is the risk of a total loose of the products, meaning that they cannot be sold totally. In this case, all operations for producing and storage that already have been done at the single products are a waste.

For the elimination of overproduction, there are methods like just in time (JIT), just in sequence (JIS) or the productions without stock.

3.2. Transport

This kind of waste occurs in case of avoidable transports, e.g.due to an unfavorable arrangement of machinery or production plants. It causes long transports between the single processes. Additional sources are (long) ways to warehouses, double handling during the work process and the getting of necessary tools and documents. At Toyota, every provision of material that does not serve an immediate assembling is considered to be a waste.

An optimized information flow between production and logistic can help to avoid this kind of waste.

3.3. Inventory

Inventory is defined as the stock of an item on hand at a particular location or business. It is mainly kept in warehouses. The main task is the economical coordination of varying dimensioned flow of goods. Additional functions are speculation, refinement, balancing, protection as well as sorting.

The establishment and maintenance of warehouses causes costs. Products that are in storage, increase the fixed capital of a company. An advantage of storing products is a high flexibility towards customer demands. It is of great significance to determine the best size of storage. Advantages and disadvantages have to be analyzed and balanced.

An excessive warehousing has close links with overproduction. Additional to the already names wastes it causes an increased space requirement which in turn causes costs. Both types of waste may cause other types of wastes. As they often cover the other types of waste, they overlay the linked needs of improvement. Therefore, the elimination of inventory is a central subject in lean production.

3.4. Motion

This waste essentially consists of inefficient movement routines. They can occur if e.g. tools have to be searched or if tools are kept in a bad and un-ergonomic position, e.g. high or on the floor. This category also classifies long distances due to an unfavorable production layout or ways to storages. Muda motion can be reduced by standardization of working processes and 5S - a method that focus cleaning and standardization of the working environment. The elimination of storages eliminates the ways between process and storage. Long distances due to an unfavorable production layout can be reduced by an U-layout arrangement of production processes.

3.5. Waiting

Waiting times may result if a human or a machine hindered from doing value-adding work by interruptions, e.g. long set upon times or waiting times caused by untuned process times. They can include waiting for machines, material, person, transport, tools, the order, information and decision.

3.6. Over Processing

An optimal manufacturing process consists only of value-adding process times. All non-value-adding times are waste and should be eliminated. Long set-up times, unfavorable, incorrect or missing tools and devices as well as poor transport systems are possibilities for disturbing the optimum.

3.7. Defects

Defective products have to be repaired or reworked if the defect occurs during the production. This results in unplanned expenses, e.g.working times of staff, machinery times or additional required material. The later the defect is detected in the process, the more working processes have to be reversed and the more serious this kind of waste is.

4. Correlation of Lean and Autonomy

Based on the different kinds of waste presented in section 3, this section deals with the correlation between autonomy and lean.

4.1. Setup Times

The total set up time can be determined by summing up the products of the duration of a single setup and the number of required setups. The impact of lean production is to reduce the particular setup times using a targeted analysis and improvement. Short setup times enable small lot sizes and frequent setups with a constant total time. The most common method for the reduction is Single Minute Exchange of Die‘ (SMED). It is primarily based on the distinction of internal and external set ups times and constructively design which allows a quick setup (e.g. the use of clamps instead of screws). Internal setup times have to be executed directly on the machine - the machine is blocked for any production work. External setups can be executed while the machine is working. By shifting internal to external setup times, acceleration can be achieved. The sequence of production orders and the thereby linked setup times can be determined by all three enablers of Autonomy. Frequency and the point of time of the planning are the main reasons for differences as both determine the required amount of setups. The duration of a single setup cannot be influenced by autonomy.

In manual planning (enabler human), the determination of the sequence of production orders is usually done in advanced for several days - e.g. on Friday for the entire following week. Suddenly occurring events cannot - or just with a big effort - be considered. As this extra effort often transcends the expected benefit, the process continues with the non-optimal planning.

Due to the possibility of automatization, a MES can drastically reduce the planing horizon - from weekly to daily or even one per working shift. Necessary changes and certain events can be considered much better.

By the use of technologies of the third enabler of autonomy, planning and reaction cycles can be even reduced to a few minutes. Additional to mere planning, they allow a reactive control and regulation. That implies that the sequence of production orders can be determined in respect of the current production situation and upcoming orders. The real-time availability of information can reduce additional waste. As soon as an order is assigned to a certain machine, the necessary external setups can be started.

4.2. Waiting Times

Subsection 3.5 named seven kinds of Muda in which waste occur due to waiting times. Improvements are possible at all three enablers of autonomy.

Human Autonomy can reduce or even eliminate waiting times by different methods of lean manufacturing. SMED helps to reduce set-up times in a drastic way (see 4.1). Multiple machine work and balancing of process times are methods of reducing waiting times to machinery. Total Productive Maintenance (TPM) helps to reduce machine breakdowns by preventive maintenance. Small working teams with a high self-responsibility enable quick decision making due to short ways of decision making.

The second enabler allows additional chances for the improvement. By the use of machinery data acquisition, there are up-to-date information on the machine status and the progress of orders in process. Associated with a high frequented planning of production orders, a contemporary reaction to e.g. machine failures is possible. Re-plannings of orders to alternative machines are one option for an adequate reaction. In conjunction with staff working time logging systems, an additional planning and allocation of staff - e.g. in consideration of the staff‘s qualification - is possible.

Autonomous technologies enable tracking and tracing of objects. In manufacturing, this is particularly valuable for the tracking of material, transport vehicles, orders and tools. Useful information regarding the availability can be obtained. Often, high-quality tools have a limited disposability as they are used at the same time at different working stations and machines. A synchronization of them is essential. Autonomous technologies can achieve improvements.

4.3. Inventory

Autonomous methods affect inventory times only secondary. There are several factors that affect the necessity and duration of the storage of products. The definition of production orders, line balancing and the sequence may are some examples for influential factors. Transparency also has a crucial role. It is difficult to obtain satisfactory results to the necessary of extra storage efficiently if it is not obvious, which product or material is stored at which quantity. It is also essential to know if stored products are available or reserved for other orders.

In the area of the human enabler of autonomy, marking of quantities and the definition of fixed sizes of the storage size can increase the transparency of the currently available material.

Warehouse management systems, as well as MES and ERP systems, are important for the software based enabler. Often they can cause real-time status reports on different storages and the assignment of stored material to future orders. The occurring reservations cause that the material is treated as ‘not available‘.

Autonomous technologies offer the chance to a real-time tracking of every production objects. Sensors that are tagged on the objects allow their localization at every time. Further analytics are possible, due to the information storage for the (planned) availability.

4.4. TRANSPORT TIMES

The determination of transport can be done either manual (human enabler) with the use of algorithms or by the help of software systems. Two problems that may occur are a high complexity of decision making and not up-to-date information of transport vehicles.

Autonomous technologies can reduce the second problem by using a network of sensors that allow up-to-date information of the current location of a transport vehicle, its physical status (e.g. breakdown) as well as their order progress.

4.5. DEFECTS

A fast fault detection highly important. Otherwise, there is the risk that a faulty process produces more faulty products. Besides it may happen, that other processes operate at the product, and in the end the result has to be destroyed because the graveness of the failure. This would generate waste. Robust processes are an essential requirement for gaining a low error ratio. Nevertheless, the measurement of quality is mandatory in most cases.

The safest way of failure checking is a 100 percent test. However, this results in a high effort and causes high costs. Either the employee himself or a quality team check every part after every process. When detecting a failure, the cause of failure has to be examined and eliminated.

Software provides extensive possibilities for the analysis and evaluation of process and product data. A comparison of actual and planed values is possible by the help of an integrated data recording of actual values. Statistical test methods and evaluations, as well as graphical representations, provide the ability for a pursing data analysis and identification of trends [18].

Autonomous technologies enable a self-analysis and self-evaluation of products due to integrated sensor technologies. They can decide by their own, whether the failure can be ignored, a rework or a sorting is required. A warning can be given to the process at the same time. Moreover, there is the opportunity to discover hidden information due to a big amount of data and algorithms.

4.6. CONCLUSION

The paper points out that the consideration of the three different enabler of autonomy is reasonable. As there are various possibilities for the improvement of production and the reduction of non-value-adding times in all three, a comprehensive analysis provides the chance to fulfill the primary objective of the production system.

It shows that - in order to get the best results - especially in the area of technological autonomy it is essential to generate a close linking of the different tasks. A separate consideration and implementation cannot result in a good performance as information about on area may be needed to proceed the information finding in another one. For this reason, it is essential to integrate the information and proceed a comprehensive implementation.

5. OUTLOOK

It is necessary to continue the development of an autonomy model that considers the three different enablers of autonomy. This model clearly has to identify the distinction as well as the communication of the different parts. The model enables the classification of different methods with different objects - e.g. like shown in this paper methods for the elimination of waste - with consideration of autonomy in production. Additionally, it is essential to create key figures that focus on the autonomy of the different enablers as well as such that focus on their interaction. The Autonomy Index AI [19] will provide a reasonable basis for this. In a next step it is necessary to check and verify the methods and their impact in a flexible simulation environment, e.g. the hybrid simulation environment of LUPO laboratory [20, 21], or even implement them in practice.

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