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DEVELOPING AND IMPLEMENTING A LEAN MANUFACTURING SYSTEM

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Abstract: This paper describes the development and implementation of a lean manufacturing system at AO Larti. Lean manufacturing is a broad concept in management aimed at waste elimination and business process improvements: from developing and manufacturing a product to supply chain and sales management. When compared to mass-production, lean production systems allow for a more defect-free and less labour, capital, and land-use intense product to be created. It also helps improve product quality and reduce costs with same level of capital investment (16). In economic context, lean manufacturing organizes production operations in a way that ensures both the high quality of produce and low wastes and costs. This approach leads to a more effective use of financial resources, workforce, materials, and information in the face of different environments and evolving consumer needs, and with rapidly growing scientific and technological knowledge of economic agents, all the above being seen as major factors in modern economy (15). As such, these operations can be grouped into two types of activities: the first create the value desired by the customer while the second are necessary for the production process itself. Lean manufacturing sets the first as a standard and, if possible, eliminates the second (3).

Keywords: lean manufacturing concept, muda, methods, values, tools, 5S system, value-stream mapping, SMED, TPM, SWOT-analysis, benchmarking.

INTRODUCTION

The concept of lean manufacturing is closely related to the concept of muda. Muda is a Japanese term meaning “wastes”, i.e. any resource-consuming activity which does not add value to the product. It should be noted that value is defined by the customer, not the manufacturer (Lean Manufacturing). There are two types of muda in lean process thinking: Muda Type I are non-value-creating activities, which, however, cannot be eliminated immediately. Muda Type II are non-value-creating activities, which can and should be immediately eliminated. Muda Type II includes transport of goods and supplies from production to assembly without any purpose. Type III of muda can also be identified. This is the muda of non-utilized ideas, failure to act, lost prospects and opportunities, in other words, actions that could possibly add value to the product, but were not performed due to reluctance to make changes or out of habit (9).

There are 8 major types of waste:

1. Overproduction. It occurs when a product is made, which: is not required by the customer; is not yet needed; is not needed in the quantities given. Overproduction is a result of push production, when there is no order to make a product on. Subsequently, two problems ensue: overproduction causes redundancy in supplies and remaindered goods piling up; as a result, these goods are distributed at lower costs, often at the expense of the manufacturer; overproduction is generally more prevalent at enterprises that produce goods in big lots (i.e., mass-production enterprises). This type of muda can be countered with an equipment changeover, so as to shift the manufacturing process towards making goods in smaller lots or on order (7).

2. Surplus stock. Storage of excess stock induces additional costs to maintain its value. This activity involves extra floor space being used, servicing of goods, energy and labour costs, etc. And since goods can get damaged, spoil, or grow obsolete, having a surplus in stock may also inflict other wastes.

3. Transport. A transport of parts and goods with no apparent need, e.g.: to a warehouse until they are required in the next stage of production. This type of muda may be combated by aligning production stages in immediate succession, generating a value stream.

4. Waiting. This muda occurs when the production flow is interrupted due to push production taking place, products being held at the previous stage, equipment downtime or failure, low capacity.

5. Over-processing is generally caused by using low-quality tools or the need to adjust a defect component.

6. Unnecessary movement of people. This type of waste was described as early as in the works of Frederick W. Taylor, the father of scientific management, who attempted to increase labour efficiency by cutting down on and eliminating unnecessary movement of workers. This includes all movements that do not add value to the product, but consume time and energy, exhausting the workers. One of the means to combat this type of muda is to create a single standard for workstation and workflow organisation.

7. Defects. A defected product is a compromised item that may or may not be reparable, or that is to be discarded. This type of muda can be eliminated if a defect in an item is immediately reported at the given stage of production, so that it does not move downstream the line. This liberates the manufacturer from the need to employ a special department to deal with defects in the final product (6).

8. Unused human capital. This type of waste results in lost opportunities (e.g.: poor motivation, uncreativeness, non-utilized ideas). This muda is often neglected or even ignored within enterprises, partly because the responsibility for it lies with the management. Human capital frequently remains unused due to management policy and style that disregard a worker's contribution to the overall production process. A

management capable of giving proper training to their staff can prove effective in raising individual contributions to the cause (7).

DEVELOPING A LEAN MANUFACTURING SYSTEM

The adoption of lean manufacturing principles leads to the creation of operation teams, whose role in the production chain is shaped by either external of internal customer satisfaction, and not by cross-department rivalry. Under these circumstances, each individual worker seeks closer cooperation with their colleagues with the joint goal to minimize Waste Type II. The following methods of lean manufacturing should be mentioned in particular: Value Stream Mapping; Pull-Type Mass Production; Continual Improvement (Kaizen); 5S System; Single-Minute Exchange of Dies (SMED) System; Total Productive Maintenance (TPM) System; Just-in-Time (JIT) System; Kanban; Visualization; U-Shaped Cells. Value Stream Mapping is the most common method to identify wastage in the production flow. The underlying principle of lean manufacturing is based on the concept of value. Contrary to popular misconception, while value is created by the manufacturer, it is still defined by the customer, since every good or service is designed to suit the needs of the latter. However, proper customer feedback is often required for the manufacturer to identify the buyer-perceived value of their product. In this context, value stream mapping is used to pinpoint value creation processes, costs that are integral to the production flow, and costs that may be excluded entirely from the production process (12). A value stream map should cover the entire range of processes: from receiving an order to shipping the product to its customer, i.e., accurately describe every activity that takes place at the enterprise. It is used to identify hidden wastes and to determine which processes are value-creating and which are not. To this end, customer surveys are conducted regularly.

Pull-Type Mass Production is a method of production control in which downstream activities signal their need to upstream activities. Each operation in pull production follows these rules: only orders coming from the next activity in the chain are to be filled; production should be stopped if the next activity in the chain does not require upstream work. Thus, every downstream activity pulls the product from the preceding one. The key concept of the Kaizen approach suggests that everything should be flexible and subject to constant revision, while balance is non-existent. Improvements are made continuously, one small step at a time. The purpose of the 5S System is to set the environment into clean, intuitive state with a place for everything and everything in its place. This allows for a more efficient use of workplaces and smoother workflow. 5S includes five interlinked phases: sort; set in order; shine (cleaning the workplace regularly); standardize; sustain-self-discipline (16). Single-Minute Exchange of Dies (SMED) is a set of theoretical and practical methods for reducing equipment downtime during a changeover. SMED is aimed at reducing equipment downtime and defect rates while boosting productivity.

This tool is used to resolve some of the problems mass production enterprises face, when they increase production lot sizes due to complications in converting equipment from running the current product to running a different one. This, in turn, results in inventory surplus. Equipment flexibility, defined by how quickly current equipment can be readjusted, is key to filling more orders with greater efficiency. Total Productive Maintenance (TPM) is a system of comprehensive maintenance of equipment, TMP and 5S being two complementary methods. TPM system relies primarily on equipment operators and maintenance teams. Since the former's job requires routine equipment inspections, they are likely to be the first to detect a malfunction (e.g.: defective output, unwanted sounds, fault reports). If a malfunction is detected, the latter intervene, since a timely repair would cost much less than a full replacement of expensive equipment. As such, operators and maintenance teams must communicate with each other, while the management would oversee routine servicing of equipment. This organisation allows to avoid breakdowns and, consequently, losses from downtime. The key concept in Just-in-Time Manufacturing (JIT) is Cycle Time, measured from the starting point of one product's processing until final product is made. The shorter the cycle time is, the lower are the work-in-process levels, which have direct relation to costs, price, and lead time. Just-in-Time is a system where exact quantities of parts and materials are provided as required in every stage of production, reducing the work-in-process rates. This system creates a continuous workflow while maximizing resources utilization (15).

Kanban in a scheduling method used in conjunction with JIT. A kanban is essentially a card giving information on the quantity of products, methods, numbers, and time of transport, delivery location, storage location, means of transport, package, etc." As a result, Kanban organizes requests for new shipments of resources and various instructions. It involves putting tags on every trolley, folder, machine, toolkit, etc. for data visualization. The Kanban technique helps identify periodic patterns in the workflow, assisting both the workers and the managers in their activities. It should be noted, however, that if this concept is misapplied, it can prove detrimental for the enterprise's performance, since it is woven into the very fundamental production processes. Visualization is a mean of informing somebody on how the work should be conducted. This tool presents information in the form of optical images (e.g.: images and photos, graphs, charts, tables, maps, etc.). U-Shaped Cells refer to a general layout where several production cells are arranged in a U-Shape to minimize unnecessary transport of goods in-between them and reduce floor space. In such an arrangement cells involved in a processing sequence are located close to one another, facilitating the flow of processing parts, documents, etc. either one by one or in small batches of consistent size. To successfully implement a lean manufacturing system as part of the general lean strategy, it must be adapted to Russian conditions and include progressive improvements, made regarding current capacities of an enterprise. With this in mind, we propose a sequence for gradual implementation of key lean manufacturing, as presented in Figure 1.

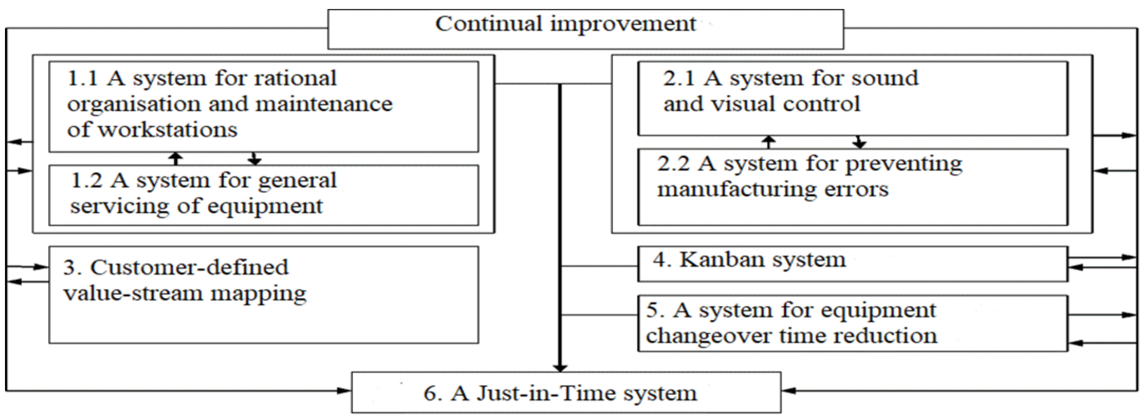

Figure 1. A Sequence for Gradual Implementation of Key Lean Manufacturing Elements.

Implementing lean significantly reduces non-production-related wastes and increases repair processes quality, facilitating a more efficient use of equipment. Lean manufacturing techniques increase the quality of repairs. Putting these tools to use will lead to significant improvements in the enterprise's primary activity effectiveness, namely: reduced design time, faster manufacturing and placing of new products, higher quality of goods and services produced, greater workforce productivity and inventory turnover, lower work-in-progress and unused stocks rates, less occupied floor space and transport and storage costs, etc. This, in turn, will enhance the competitiveness of the enterprise without major investments (3). Six Sigma is a set of methods for measuring and increasing productivity of a company by means of identifying defects in production processes. The term originates from the statistical category of mean square deviator, indicated by Greek letter sigma. The methodology of Six Sigma was introduced at Motorola Corporation in 1986. A six-sigma process is one with only 3.4 defects per million opportunities (or operations) with anything not acceptable to a customer being considered as defect.

Table 1. Lean manufacturing tools

Lean manufacturing tools	Conditions for implementation
Delegates an external or internal expert on transitioning an enterprise to a lean manufacturing system	Appoints one of the senior executives as the internal expert. Confers the external expert with broad authority; whose recommendations are to be complied with
Conducts general employee training on lean manufacturing technology	If the staff lack motivation to accept business changes, the company should consider a dismissal or layoff of some of its employees, particularly of underperforming elderly workers
Sets the goals for making organisational changes	Requires prudency in identifying the reasons for a lean manufacturing transition (e.g.: a financial crisis) and the promptness of such undertakings
Conducts value-stream mapping of every business process	Revises business processes, equipment and workstations; conducts material- and information-flow mapping
Identifies wastes and their causes	Requires a maximum number of employees to be involved in the process
Develops the procedure for value-adding processes lean transition	Requires logistical support to facilitate proper organisation of workstations and equipment, and employee training
Implements Kaizen all along the production chain	Employs small task groups for devising and implementing improvements
Expands lean principles on other processes	Stimulates those employees undertaking work towards these changes
Introduces a new management accounting system	Facilitates pull production at every stage in the chain. Introduces kanban cards
Uses performance indicators to determine compensation for operation teams	Requires transparency in accounting and performance
Gradually replaces outdated equipment with equipment for mass production	Requires additional resources to carry out such a replacement
Promotes the adoption of lean manufacturing among outside vendors and consumers	Gives one's colleagues a demonstration of lean system profitability

The method is as following: at the beginning of each month a designated team of workers is formed in every department to inspect workstations, equipment, tools, inventory, documents, etc. If it is discovered that the item inspected is rarely used, or that it interferes with transport of goods or workers movements, it is marked with a red tag. If the inspection team is uncertain about whether an item is needed, they still tag it (9). In the following days, a different team comes to inspect every item or document once again, deciding on whether they are necessary for the production process or may be put to a more effective use. The items that have been found to be interfering with the production process are either immediately discarded or moved to storage. Improvement teams are to consider all presented ideas and, if possible, put them into effect.

IMPLEMENTING A LEAN MANUFACTURING SYSTEM

Let us look at the key stages in the AO LARTI production system development. In April 2010, the LARTI plant became the first enterprise of AO LARTI to initialize the implementation of a new production system (titled A Lean Manufacturing System). According to the adopted operations plan, the works for implementing the Lean Manufacturing System first started at 7 pilot facilities. The following major tools were used in this process: the 5S System, Value-Stream Mapping, Total Productive Maintenance, ABC-classification. 40% of the employees were taught the basics of the Lean Manufacturing System by internal experts alone. In 2011, a comprehensive SWOT-analysis of strengths and weaknesses was conducted. A Strategic Vision was developed for TVZ (ТВЗ). Additionally, 14 pilot facilities were listed into the operations plan, including a railway carriage assembly line. SWIP, SMED, and Line Balancing tools were utilized. A schedule was developed for the cross-training of employees. 60% of staff were taught the basics of the Lean Manufacturing System. In 2012, the following results were achieved: pilot facilities comprised 50% of the plant; 100% of staff were taught the basics of the Lean Manufacturing System; the line for car body assembly was balanced.

In 2013, the following results were achieved: pilot facilities comprised 80% of the plant; a Model Line project was implemented at the car body assembly line; a digital stand was developed for the technology and production management; a System for Submitting Improvement Proposals was developed and successfully implemented. In 2014, the following results were achieved: X-matrices of L1, L2, and L3 were built for the CEO, the board of directors, and heads of facilities and shop foremen respectively; macro maps were developed for three strategic products (single- and double-deck carriages, an electric locomotive); 100% of primary and auxiliary production managers received standard training under the ZAO TMH (ЗАО ТМХ) programme; a methodology to control, measure, and analyze OEE was adopted. In 2015, the following results were achieved: works began on developing a Production Network project; a calculation for project numbers of assembly line operational workers was made based on the Standard Operating Procedure method; a uniform catalogue of transport containers was created for every department in an assembly line; 100% programmed control of storage facilities.

In 2016, the following results were achieved: the tram production process was value-stream mapped; development of a standard operating procedure compilation project for all assembly lines was started; a digital system for handing out shift plans for blank production was developed; the Production Network project was developed and implemented based on the takt time of all types of products (single- and double-deck carriages, a metro coach, a tram); works started on creating a schedule for the procurements and shipments of OEM items based on the Production Network; a Workstation Organisation in Accordance with the 5S Office System instruction was developed and successfully implemented; a sample product from the Cars for Egypt line was manufactured and its designing process value-stream mapped. In 2017, the following results were achieved: 1. X-matrices of L1, L2, and L3 were developed based on KPI maps. 2. The implementation of the ZAO TMH production system was made a personal goal for every head of department/shop foreman. 3. Value-stream mapping of new products (metro coach bodies, trams) was conducted. 4. An instruction on the 5S Office System was developed. Around 200 employees received training. 5. New criteria for the Model Line project were introduced. 6. A new form for reporting Model Lines was developed with a three-month forecast. 7. OEE calculation methodology covered 100% of CNC equipment and critical equipment. 8. The Guidance for Line Balancing at OOO LARTI was developed.

In 2018, the following results were achieved: 1. X-matrices of L1, L2, and L3 were developed based on the KPI maps adopted by AO LARTI. 2. The implementation of the ZAO TMH production system was made a personal goal for every single head of department/shop foreman. 3. Shop foremen performance goals were aligned with pilot facilities. 4. Value - stream mapping of a new product (electric locomotive) was conducted. 5. Logistic billing system as seen at TMH was adopted at the enterprise. 6. As for 2019, all contracts were ordered to be concluded in accordance with the new logistic billing system. 7. A new form for procurements requests on the OEM items, which requires the supplier to confirm the date of shipment, was developed. 8. An audit was successfully passed on alignment with the OHSAS 18001 international standard. 9. A Provision on Security Warning Cards was introduced at the enterprise (12).

After the results on the Lean Manufacturing project implementation had been received, a need to implement the Lean Changeover (SMED) tool emerged. SMED or Single Minute Exchange of Dies is, essentially, a set of theoretical and practical methods that allow to reduce equipment changeover time down to ten minutes. This system was initially developed to optimize the process of dies replacement and equipment changeover, however, the principles of SMED can be applied to any of the processes. It took Shigeo Shingo 19 years to develop the SMED system. While studying equipment changeover processes, he made two findings that lead to the development of SMED.

Changeovers are made up of two types of elements: Internal changeover elements, that must be completed while the equipment is stopped. Dies, for instance, can only be replaced while the equipment is not running. Internal changeover elements, that can be completed while the equipment is running. For example, bolts for fastening the dies can be selected and sorted while the equipment is still running. Converting as many internal elements to external as possible can dramatically reduce changeover times. Toyota was one the first companies to introduce SMED to its production process, where setup changes on a 1000-tonne press that used to take four hours, were cut down to just three minutes. Changeover time is a big concern for every company that aims to organize its production on the principles of just-in-time and small-lot manufacturing. In this context, shorter changeover times allow to quickly update model ranges and avoid inventory surplus (12). SMED is the most efficient approach to reducing changeover time. This system will allow you to cut down on complicated, time-consuming, and counterproductive changeover activities, if not completely eliminate them. This, in turn, will not only make your personal job easier, but also increase your company's competitiveness (8). The four traditional setup steps are presented in Table 2.

Table 2. Traditional Setup Steps

Setup steps	Share of each step in the overall setup process prior to implementing SMED
1. Preparation, past-installation adjustments, checking materials and tools.	30%
2. Removing and installing fixtures, tools, and parts.	5%
3. Measurements, settings, and calibrations.	15%
4. Trial runs and adjustments	50%

The gross economic effect of implementing this project will amount to roughly 2.1 million roubles annually. Each change's contribution to the overall effect is presented graphically in Figure 2.

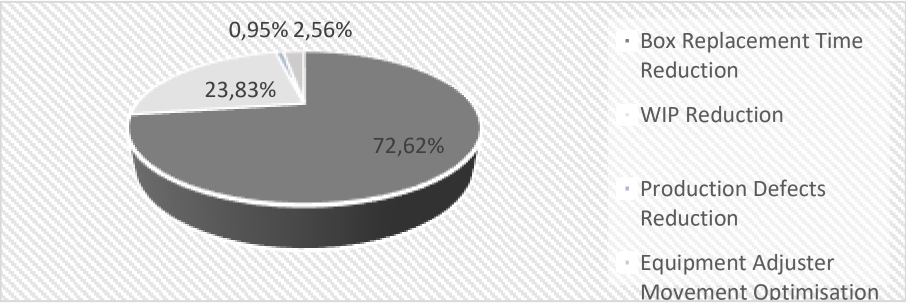

Figure 2. Graphic Presentation of Effectiveness

We also propose to implement a benchmarking system within the Lean Manufacturing project framework. Benchmarking is a powerful tool used to make continuous improvements and scientific and technological advancements by keeping up with best world practices. To facilitate the most efficient, result-yielding, and integrous benchmarking those involved in the exchange of experience should adhere to the rules and principles of the respective Code of Benchmarking (16).

CONCLUSION

The term "lean management" was first introduced to Russia in Lean Thinking, a book by Jim Womack. Lean is often defined as a concept in production management centered around wastes reduction. A lean manufacturing system involves every employee into the business optimisation process and helps achieve the highest levels of client orientation. This concept originated from the interpretation of Toyota's operating model by American researches. The numbers of manufacturers affected by this approach grow every year (3). The critical success factors for implementing a lean system are: full commitment of senior managerial staff, who play an exemplary role in training their subordinates, spreading lean ideas further on; a consistent and well-thought system to establish communication between staff on multiple levels, which would facilitate the implementation of lean; promoting lean ideas among employees and everybody involved in the process by launching pilot projects in every division of a company, yielding quick, significant, and sustainable results; providing effective and timely support from all departments (IT, HR, economy department, marketing department, etc.); centralized management and allocation of sufficient resources to lean projects (usually 1-1.5% of workforce).

SMED (Single Minute Exchange of Dies) is a lean manufacturing tool for reducing losses from equipment downtime and changeovers. It allows to rapidly switch between stages in the production process and, consequently, reduce financial and time expenditures on manufacturing and storing goods. Production of educational resources inevitably causes wastes and losses, invoked by the need to produce and store outdated programmes and educational aids. In the face of changing environment, receivers of education are becoming more and more demanding of educational resources and are less willing to waste their time in wait. Employees no longer want to study their books, since they were spoiled by much simpler means of gaining information, such as newsfeeds and YouTube-channels, where it is presented in a cheerful, fast-paced manner. Regarding the existing generational theory, Gen Z members are soon going to fill in their roles as employees. These people prefer to receive knowledge in 'clips', which, on one hand, allows them to quickly switch between information flows, while on the other hand makes them tired of dry, slow-paced presentation of information quickly.

In this regard, both internal and external trainers are challenged with having to rapidly adjust their teaching methods to meet the evolving needs of their audience. Technologies like AR, VR, and AI systems, that once seemed unattainable and obscure, are now becoming increasingly popular (7). Toyota's best practice in implementing the SMED system has proven that changeover time of a 1000-ton press can be brought down from four hours to just three minutes. Every company working towards implementing Just-in-Time and Small-Lot Production systems should always take its equipment changeover times into account. If SMED is successfully implemented at an enterprise, it can reduce stock surplus and help eliminate outdated produce. The SMED system presents the most productive method to reducing equipment setup time. It boosts your company's competitiveness by removing labour-intensive yet unfavourable activities from the production flow (8).

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