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LOGISTICS IN PRODUCTION PROCESSES

Integration of production planning and logistics is currently becoming more and more widespread in many companies. The role and tasks of production logistics in a company are dependent on many factors as well as on an appropriate definition of logistics. The development of the concept of the supply chain has resulted in a broader view of logistics. The primary goal of production logistics can be formulated as expansion of the capabilities for the implementation and reliability of deliveries with the lowest logistical and production costs. In such an approach production systems are those in which input quantities are temporally and spatially transformed into products. With logistical supply networks at the input and distribution networks at the output of the system, production and logistics are closely linked. The approach proposed within the framework of *Lean enterprises* is interesting. It requires first defining a stream of values, then mapping and improving it. The methods appearing in the literature under the name *Lean toolbox* can be used to improve a company's productivity indices.

1. INTRODUCTION

One quality that characterizes the management of manufacturing enterprises is the constant search for ways to improve the productivity of production processes. It is production that causes the main stream of materials, components, and parts to flow through individual departments and structures of a company. This flow depends on many factors, with the structure of the production system decidedly having the greatest influence on flow processes. In many manufacturing companies, most optimization activities are limited to the area of production. Thus, it is apparent that, from a logistical point of view, the proper control of the stream of materials in a production system should be among the primary logistical tasks [1]. 'Proper control' in this context is to be understood as control that guarantees the continuity of production processes according to the 7R logistical principles: the right product (R1), in the right quantity (R2), of the right quality (R3), which should be delivered to the right place (R4), at the right time (R5), at the right price (R6), to the right customer (R7). The concept of a 'customer' should be understood very broadly. A customer can be the direct recipient of a ready product, but also every stop in the production process (internal supply chain).

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Thus, production logistics encompasses all processes related to supplying the production process with the right goods (raw materials, auxiliary materials and consumables, as well as semi-finished products and purchased parts) and to transferring semi-finished and finished products to the outlet warehouse [2]. The proper approach to production logistics requires a systemic approach to definition of the production system as well as determination of the interactions of the immediate environment (supply system, distribution system) [3].

Possible couplings of production logistics with supply and distribution logistics are dependent on many factors and decisions related to production. Very often, the production technology applied at a production company does not allow for production without stocks. However, if possible, production logistics should propose solutions without buffer warehousing and minimize station and inter-operational storage areas.

From the perspective of the tasks of production logistics, it is worth referring to the definitions contained in the Glossary of Terms of the Council of Supply Chain Management Professionals (CSCMP), which differ from certain European definitions (e.g. ELA). For example, Gudehus [4] writes that … *objects of logistics are physical goods such as raw materials, preliminary products, unfinished and finished goods, packages, parcels, and containers or waste and discarded goods*. However, Taylor [5] identifies logistics management as follows: … *logistics management is the part of supply chain management that plans, implements, and controls the efficient and effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements*.

The development of the concept of the supply chain has resulted in a somewhat different and broader view of logistics. Currently, the key to understanding the operation of an enterprise is the awareness that it functions as a part of a greater whole. Thus, new concepts and tasks of production logistics are appearing. In relation to the supply chain, Nyhuis and Wiendhal [6] write simply that:

The fundamental goal of production logistics can thus be formulated as the pursuit of greater delivery capability and reliability with the lowest possible logistic and production cost.

2. COMPANY LOGISTICAL SYSTEM

A Company Logistical System (CLS) can be written in topological terms as follows (as a supersystem) [1]:

$$CLS = < MFS, MS, IS, R >$$

where:
MFS – materials flow system,
MS – management system,
IS – informational system,
R – relationships between systems and between systems and the environment.

For the purposes of logistics, the approach proposed by Durlik [3] in accordance with engineering management is a very convenient description of a production process. According to Durlik: *a production system* is a specifically designed material, energetic, and informational system that is exploited by people and serves to produce specific products or services for the purpose of satisfying the needs of consumers. By applying the simplest definition of a system in systems theory [7], an expanded form of a production system can be obtained:

$$SP = < \{X, Y, T, Z\}, R > ,$$

where:
$X = (x_1, x_2,... x_i, ...x_n)$ – input elements (materials, parts, equipment, energy, capital, information, personnel),
$Y = (y_1, y_2,... y_j, ...y_m)$ – output elements (ready products, services, waste),
$T = (t_1, t_2,... t_k, ...t_p)$ – elements of the process of converting the input vector into the output process (technological, transportation, warehousing, inspection/control, and service operations); otherwise known as elements of the production process,
$Z = (z_1, z_2,... z_l, ...z_r)$ – elements of the management process (planning, organization, control, inspection),
$R = R_X \times R_Y \times R_T \times R_Z)$ – material and informational couplings (relationships) between elements (X, Y, T, Z) of the system.

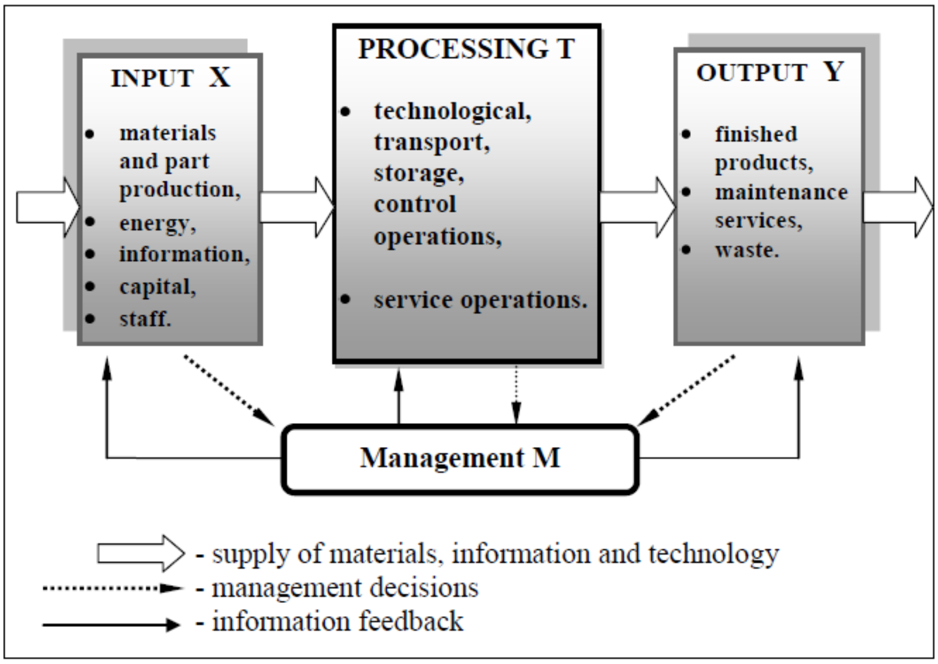

Fig. 1. Simplified structure of a production system (according to [1])

Albers [8] presents a similar approach and defines a production system as an IT system that serves to design production through the continuous generation of goals, their transformation into desired products, and validation of the obtained results. The input quantities of the system are: information, employees, capital, material, and energy. The initial goals of the system are formulated by the operating system based on market information. Indispensable tasks are entered into the matrix of activities, and the resources required for their execution are assigned to them. Specific products are created as a result of process engineering operations, which include the creation of drawings, documentation, and plans. The validation of results has an influence on the operating system, which may generate new goals or, in the case of negative validation (goals have not been achieved), repeat the processes. Figure 1 presents a simplified structure of a production system.

Thus, production costs as well as the reliability and delivery capabilities are decisive for success on the market (in the long term).

Logistical goals related to production processes are also related to key performance indicators (KPIs). There is a clear conflict between KPIs and logistical goals; therefore, in every case, individual consideration of mutual relations is necessary. Three mutually related processes are taken into consideration: production and testing, transportation, and storage and deliveries. Relationships between the level of work in process (WIP), minimization of processing times and passage of materials through equipment, and the level and reliability of deliveries are particularly significant. Figure 2 presents logistical KPIs for production companies proposed by Nyhuis [6].

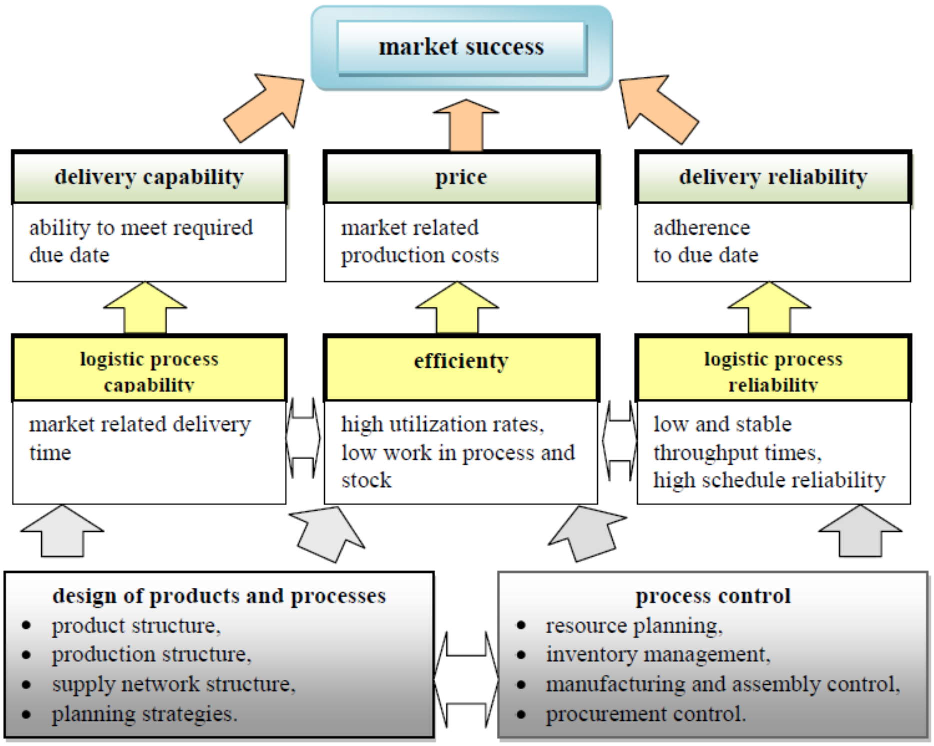

Fig. 2. Logistical KPIs for production companies (according to [6])

Gudehus and Kotzab [4] consider the complexity of the subject of the mutual relations between logistics and production somewhat differently. They treat a production system as a network of interlinked processing stations connected to a transport and storage system.

Production systems are special systems in which input material is transformed into the physical form of products. Production and logistics are strictly related to each other through logistical supply chains (on the input) and distribution networks (output of production systems).

Production planning that does not account for logistics is incomplete, as is logistics that does not account for production engineering. Production systems are complex networks of elementary production cells that are directly related to transportation systems or indirectly through buffers and storage systems. The tasks of production logistics include planning and organization, while technologies and improvement of technical processes are the tasks of production engineering.

From the perspective of the lifetime of a production system, long-term planning is very important. The following procedures are subject to approval [4]:

1. Projects for optimization of an existing production network, with regard to the need to design a new production network.
2. Network structure documentation, specification of the parameters of available production and transport resources, as well as determination of the capacities of required buffers and storage areas.
3. Segmentation of ready products and ordered semi-finished products and parts kept in the warehouse.
4. Definition of the standard of production chains and trees: selection and development of a cost-optimal production chain or tree for other product groups.
5. Specifications and documentation related to production, execution, and warehousing.
6. Organization of production planning: specification of production tasks and schedules.

A new challenge for the logistics of production companies is accounting for supply chains (SCM). According to Taylor [5], logistics has focussed too much on solving the partial problems of a company and not enough on the system of the company as a whole. As a result of the development of supply chain and network theory, a clear increase in the use of the methods, principles, and concepts proposed by SCs (Supply Chains) and SCM (Supply Chain Management) has been observed in recent years. However, neither this increase nor the redefinition of logistics has grasped the proper importance of linking supply chains with manufacturing and production processes. Matters related to product design, operation systems, product life cycle, withdrawal from production, product disposal and recycling also lack proper places in the spectrum offered by modern logistics.

3. IMPROVEMENT OF FLOW CONTINUITY

Womack and Jones [9] have proposed a completely novel approach to the perception of a company in recent years. Even though certain solutions of theirs are controversial and not always possible to implement, they still merit intellectual engagement. Their principles concerning *lean enterprises* are a very good method for production enterprises with an assortment of products and frequent reconfigurations of production lines.

The lean enterprise concept is based on five basic principles:

1. Defining values for every product.

2. Determining the product value stream.
3. Carrying out value flow without disturbances.
4. Enabling the customer to obtain value from the manufacturer.
5. Continuous striving for perfection.

A lean enterprise is therefore an organization that makes it possible for all entities involved in the value production process to hold consultations in an ongoing fashion. The goal of these consultations is to create a channel for the flow of the entire value stream, making it possible to completely eliminate all types of waste. All activities, from concept development through detailed design, up to the time the product appears on the market, must be considered in the lean approach. On the other hand, all activities performed from the time of acceptance of an order and production planning up to fulfillment of the order must be established. Furthermore, it is necessary to describe activities from the time of acquisition of raw materials to the time of delivery of the product directly into the hands of the customer (7R principle).

The essence of the lean approach is transformation of *muda* (Japanese: waste) into value, and thus, determination of value is the first step in the implementation of the lean approach. The opinion has been widely accepted that only the involvement and determination of high-level management in the process of implementing *lean* principles can lead to significant improvement in the effects of a company's activity.

There are a great many methods and techniques that can be used in the production activity of a company. Hence, selection of the ones appropriate for a given company and given processes is sometimes difficult. More and more often, these methods can be found in the subject literature under the title *The Lean Toolbox* [10] and include:

– the VSM method (*Value Stream Mapping*),
– the TPM method (*Total Productive Maintenance*) – comprehensive machine maintenance,
– the 5S method (*5 Pillars of the Visual Workplace*) – workplace organization,
– the SMED method (*Single Minute Exchange of Die*) – fast machine reconfiguration,
– the JiT system (*Just in Time*) – just-in-time flow control,
– the Kanban system – organization and control using cards,
– the 6S method (*Six Sigma*) – proper product quality,
– the 5W1H method (*5 why and 1 how*) – identification of the cause of a problem,
– the 7 M method (*7 Muda, 7 Wastes*) – elimination of losses and waste in processes,
– the Pareto principle – influence of causes on results,
– the 3 M principle (*Muri, Mura, Muda*) – elimination of the three primary sources of waste in industry,
– the Heijunka technique (*Sequencer*) – production sequencing,
– the Jidoka technique (*Autonomation*) – capability of stopping a line or process,
– the Kaizen process – an evolutionary process of continuous improvement,
– the Kaikaku process – innovation, sudden change for the better.

3.1. ESSENCE OF THE TPM METHOD

One lean process management tool for companies is the *Total Productive Maintenance* method. The goal of TPM is the pursuit of maintaining operational continuity of equipment and machines that perform specific tasks, which is also related to the improvement of their operational efficiency [11]. The method is based on the utilization of human resources for analysis of the causes of waste (*muda*) occurring in processes; additionally it requires systemic solving of the problems causing standstills of machines and equipment. The primary goals of implementation of the TPM method are:

– reduction of the number of equipment malfunctions,
– speeding up of the time of equipment (line) repair,
– elimination of micro-standstills,
– limitation of losses and waste.

The TPM method is based on eight pillars:

1. Focused improvement.
2. Autonomous maintenance.
3. Planned maintenance.
4. Training and education.
5. Early-phase management.
6. Quality maintenance.
7. Office TPM. 8. Safety, health, and environment.

TPM identifies 6 primary production losses – Six Big Losses (in three subgroups):

Time losses (availability):
– losses caused by malfunction,
– losses due to reconfiguration and adjustments.

Efficiency losses (efficiency):
– losses due to downtime and micro-standstills,
– losses caused by reduction of process speed.

Losses resulting from damage (quality):
– losses resulting from deficiencies,
– losses due to start-up.

The following three indices are most often used in the TPM method: MTTR, MTBF, and the most characteristic, OEE. The first two are exclusively related to technical problems of the studied production line.

MRRT (*Mean Time to Repair*), or average repair time, is an index designating the average time necessary for repairing a piece of line equipment [12]:

$$MTTR = \frac{\sum repair\ time}{repair\ quantity}$$

MTBF (*Mean Time Between Failures*) or the average time between failures, is an index designating the average time between the occurrence of two failures or micro-standstills:

$$MTBF = \frac{\sum faultless\ operation\ time}{proper\ operation\ event\ quantity}$$

However, the primary measure of the effects of TPM implementation is the OEE index (*Overall Equipment Effectiveness*). This index shows the percentage of the efficiency that is theoretically possible to achieve and that characterizes the studied equipment or line. The OEE index is most often calculated by means of the simple formula:

$$\text{OEE index} = \text{availability} \times \text{efficiency} \times \text{quality} \times 100\ [\%]$$

where:
A – availability: practical availability, availability factor;
P – performance: performance efficiency, performance factor;
Q – quality: factor, measure of quality.
Availability:

$$A = \frac{A2}{A1} = \frac{operation\ \ time\ (net\ operation\ \ time\ \quad planned\ \ downtimes\ )}{net\ operating\ \ time\ (available\ time\ )}$$

Performance:

$$P = \frac{P2}{P1} = \frac{real\ \ production}{target\ \ production}$$

Quality:

$$Q = \frac{Q2}{Q1} = \frac{good\ \ production\ (\ faultless\ \ pieces\ )}{real\ \ production}$$

The global standard requires an OEE index higher than 85%. Figure 3 presents the components that enable the practical determination of the Overall Equipment Effectiveness index for a machine or line used to perform a specific process.

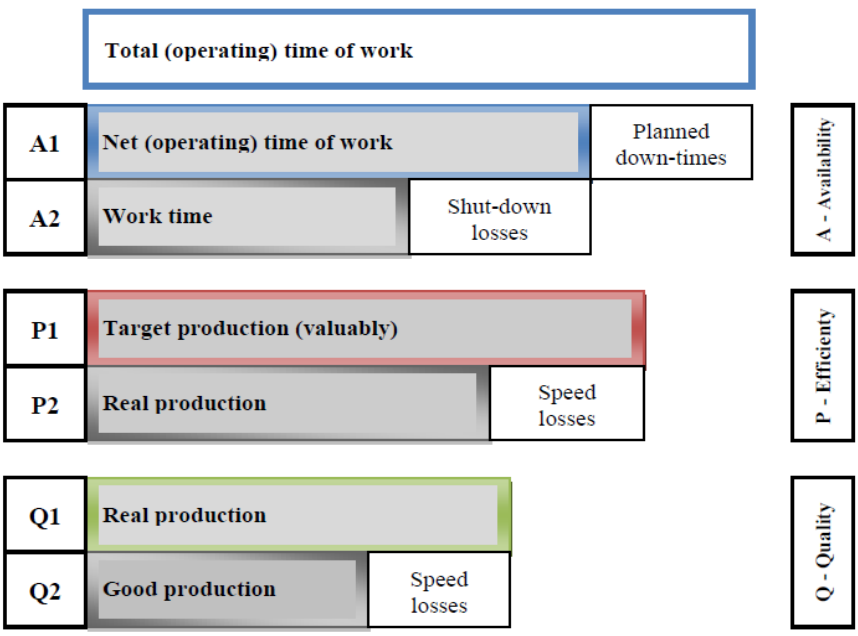

Fig. 3. Components of the OEE index (according to [13])

Loss analysis is the beginning of the entire process of implementation of modifications. The problem is identified and the influence of individual factors (A, P, Q) on the functioning of the subject of study (equipment, line) is evaluated based on this analysis. Based on data concerning losses, priorities of action are established and a remedial action plan is developed.

3.2. VALUE STREAM MAPPING – VSM METHOD

According to Womack [9], value can be defined only by the end recipient and has meaning only when expressed in relation to a specific product that satisfies the needs of a customer at a specific price and a specific time. As a rule, manufacturers have major problems with providing a precise definition of value. When evaluating value, it may be helpful to answer three basic questions:

1. What path do projects take from preliminary concepts to implementation?
2. What path do orders take from a declaration of demand to the time of delivering the required products to the customer?
3. What path do products take during the transformation of purchased raw materials into the goods expected by customers?

In turn, every activity that causes consumption of resources without contributing to the creation of value is waste (*muda*). These include:

– errors that require correction,
– production of superfluous products resulting in the creation of reserves,
– implementation of unnecessary production processes,
– pointless relocation of employees and goods,
– waiting for semi-finished products that have not been delivered punctually for further processes,
– delivery of products and services that do not fulfill the customer's expectations.

Therefore, processes of implementation are accompanied by a value stream, i.e. the set of all activities required for the production of a specific product in a process consisting of three critical tasks:

1. Product design task (from the concept through detailed design to implementation in production).
2. Information flow management task (from the acceptance of orders through production planning to the delivery of finished products).
3. Physical product production task (processing of raw materials into the finished product that is delivered to the customer).

Thus, there is also a need to identify the entire value stream for every produced product (or group of products).

Value stream analysis most often leads to the following conclusions:

– many performed activities contribute to the creation of value,
– many other activities do not lead to the creation of value; however, they cannot be avoided, given the technologies and production facilities used in the company (type 1 *muda;* e.g. quality control),

– additional activities exist whose performance does not contribute to the creation of value; their elimination can be carried out immediately (type 2 *muda*; e.g. unnecessary transport).

Value stream mapping is a method used for the analysis of a production system. The visualization of a value stream makes it possible to notice all types of waste in it and to initiate additional ‘lean’ activities in the company that serve to eliminate waste from the area of activities that add value. One quality that distinguishes mapping from other methods of production system analysis is its grasp of both material and informational flows.

The VSM method (Value Stream Mapping) is a process consisting of three steps [14]:

Step 1. Diagnosis of the existing state – Value Stream Analysis (VSA) – analysis of the current state of the value stream.

Step 2. Creation of a vision of the future state – Value Stream Designing (VSD) – construction of a target value stream state.

Step 3. Improvement plan – Value Stream Work Plan (VSP) – a plan for improvement and implementation of solutions [15].

The following compilation of quantities is to be prepared when creating the first maps:

- cycle time (C/T),
- changeover (reconfiguration) time (C/O),
- availability (availability of a station to undertake work),
- EPE index (elasticity of the lot production process expressed in units of time),
- number of operators,
- number of product types,
- available work time,
- deficiency factor.

The data that should be identified and then placed on the map pertains to:

- the monthly level of orders from customers,
- the form of deliveries,
- the technological processes performed,
- the characteristics of these processes with regard to cycle times,
- changeover times, machine availability times, numbers of operators, etc.
- raw material reserves, work-in-process reserves, and finished product reserves which are physically identified in the production system for individual streams,
- the information system of the sequence of ordered production,
- the system for exchange of information with the customer and supplier,
- forms of material flow (e.g. ‘push’ type), etc.

In order to draw a transparent and communicative map, the established graphic symbols [14] should be used.

The timeline is an important element of the map. Based on observed data, the state of the current value stream can be determined. The timeline (in the form of a meandering line) serves to calculate the total time of passage of a product through the value stream, that is, the time required for a single product to pass through the entire production process, starting from the moment raw materials are supplied to the time the product is shipped to the customer. The time of transit (expressed e.g. in days) is calculated as the quotient of the amount of reserves (expressed in pieces) and the daily demand for products specified by the customer.

Mapping the future state (the second step of the process) has the purpose of developing an implementation plan that will specify the desired target state of the production system over the horizon of the next several months and that will indicate the group of activities necessary for achieving the established vision. The primary goal of these actions is to adapt the rate of production to the rate of orders filed by the customer as well as reduction of stocks in all links of the company's production system.

4. TASK FORMULATION AND PROBLEM SOLVING

Implementation of individual *Lean* elements (e.g. JiT, 5S, Kanban, TPM, VSM) is the beginning of the road to implementation of the complete concept. Perception of the entire process is a real challenge. The field of logistics attempts to deal with this problem by implementing increasingly refined computer software. According to J. P. Womack, this is not the way to success. A real solution is not based on the proliferation of tools but on the creation of a more result-oriented management system that limits waste. This is what lean management offers.

In the case of many companies, particularly small and medium enterprises (SME), complete perception of a process may prove too difficult a task. Thus, implementation of individual elements is the only available avenue. However, for this path to result in synergy, it is worth building a system of goals over a long period of time and setting individual stages over this period. In the beginning, activities related to the internal stream, that is, pertaining only to flows within the company, are sufficient. Rapid effects are achieved e.g. through waste elimination (7 M, 3 M) and introduction of organization according to the 5 S principles.

For example, R. M. Williamson [16] proposes eight steps for problem solving:

1. Determine the primary problem.
2. Collect information that is sufficient for determining the depth and scope of the problem (data).
3. Make an informed decision about what to do to solve the problem (hypothesis).
4. Select the appropriate tools and techniques, i.e. only those tools and techniques that will most probably be necessary for solving the problem.
5. Try to solve the problem using these tools (experiment).
6. Test whether the 'repair' actually works (measure it).
7. If not, re-evaluate the problem and partial solution.
8. If so, this means that something has changed, so that the problem will not repeat itself (standardization).

However, the author recommends the following algorithm that he has tried and tested [12]:

1. Select a process for analysis.
2. Make a precise schema of the technological process.
3. Collect data about the process, including orders, deliveries, stocks, etc.

4. Determine the basic parameters and quantities that describe the process and perform the necessary measurements of the duration of operations.
5. Prepare and describe icons used to carry out mapping.
6. Describe losses and waste in the process.
7. Make a map of the current state (properly legible, in the appropriate format, e.g. A2).
8. Determine and collect information on possible proposals for changes in the existing system.
9. Apply proposals for changes onto the value stream map.
10. Develop arrangements and set deadlines concerning possible changes.
11. Implement changes.
12. Analyze the effects after the implementation of changes.
13. Consistently comply with kaizen!

5. CONCLUSION

Broadly perceived, production management currently offers many different methods and techniques for improving the functioning of production systems.

Some of these methods have been developed within the framework of Lean Management (Production). Systems related to the organization and control of material flows are commonly known, including 5S, 7 Muda, SMED, 5W+1H, JiT, and Kanban as well as MRP- and ERP-class integrated IT systems.

The development of strategies related to supply chains and lean thinking forces one to reach beyond one's own company. This leads to systemic grasping of problems related to goods production. Here, it is necessary to apply knowledge from the field of systems theory. It becomes important to account for the influence and partnership of participants in the supply chain in processes of production system optimization.

Production logistics also responds to these challenges. Improvement of the value stream by using VSM mapping methods is being applied more and more frequently in companies with an assortment of products and a large number of changeovers. TPM, Total Productive Maintenance, is a very helpful tool in many areas of maintaining equipment serviceability.

In contemporary companies, the competencies of the production logistician and production engineer overlap more and more often. Although the question of setting the boundaries of the fields of production logistics and production engineering is not settled here, it is worth taking note of a statement made by J. Weber [1] over twenty years ago: 'it doesn't matter who does it, just that it gets done'.

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