LOGISTICS ENGINEERING AND INDUSTRY 4.0 AND DIGITAL FACTORY

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Abstract:

The number of IT systems and technologies supporting various processes, including the manufacturing, has been growing in recent years. Various versions of integrated ERP-class systems are known. At the same time, we are in the fourth industrial revolution. The future is Industry 4.0 and Digital Factory. Industry 4.0 is an overall term for technical innovations and value change organization concepts which revolutionize the industrial production. Currently, the digital technologies change the way production is carried out by generating, transferring and processing of data, and also by analysing large amounts of datasets. There is a problem of the place and significance of logistics, transport and supply chains in the fourth industrial revolution. What is logistics engineering, what methods are suggested to solve the contemporary problems of logistic support of production processes? To whom are the virtual systems dedicated? What rules should be applied by small and medium enterprises (SME)? Is the pressure of virtual world a threat to such companies? Is it possible to design and make real products without virtual manufacturing? Hence, does Logistics 4.0 exist and where is it used? The practice of logistics engineering is applied during the entire system lifecycle by means of interactive processes supporting the analyses and research (compromise) for optimization of costs, logistics and efficiency. Surely, it can be said that without the correctly designed and effective logistic processes the contemporary production system could not achieve the required productivity and effectiveness. The article describes the basic tasks of logistics engineering in relation to production companies, as well as relations with Industry 4.0. and digital factory. Moreover, a proposal of the author's own algorithms for use in the quest to improve the continuity of flow and of enterprise effectiveness for SME class companies was presented.

Keywords: logistics engineering, supply chain, production logistics, Industry 4.0

To cite this article:

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1. Introduction

The development of supply chain concepts in recent years gave a wider view of the logistics. First of all, it transformed the companies from functionally oriented organizations to process-oriented organizations (Dolgui and Proth, 2010). An important thing is that the shift towards the processes applies not only to single companies, but to all supply chain links. The common element linking various approaches to logistics is material flows which should be competently managed (Taylor, 2009). Currently, due to the fourth industrial revolution Industry 4.0, the importance of logistics has increased and the requirements for logistic systems have grown (Biffl et al., 2017).

There are two main areas in which logistics is necessary for effective operation of production systems:

− supply of components necessary for production of goods (supply chains);
− material flows in complex production and assembly systems (production logistics).

Meanwhile, the terms appearing in publications on the fourth industrial revolution bewilder with modern technologies, inter alia Internet of Things, Artificial Intelligence (AI), Smart Factory, cloud computing, additive manufacturing (3D printing), smart supply chains, and cyber-physical systems. Each of these areas already has methods and tools for execution of specific processes (Pinto et al., 2018). The fourth industrial revolution (Industry 4.0) is largely based on mutual use of automated collection, processing and exchange of data from the entire supply chain. However, a company intending to be transformed into an Industry 4.0 company first needs to put its processes in order and then start collecting data about the deviations in these processes. Automation offers PLCs, multiaxial motions sensors, HMI operator panels (Bauernhansel et al., 2014). It is necessary to implement new IT solutions (e.g. Manufacturing Execution System MES or Warehouse Management System WMS). The result of implementation of Industry 4.0 ideas is an intelligent factory based on the integration of cyber-physical systems using industrial internet of things (IoT). The digital factory changes not only the production range of companies, but requires a holistic view of the business ecosystem, e.g. value chains or supply chains (Kuehn, 2018).

Contemporary production systems, driving for high productivity, require a very good logistic support.

According to Bukowski (Bukowski, 2016), one of the most important objectives of strategic and operational supply chain managements should be the Supply Chain Risk and Continuity Management, with a particular emphasis on safety, dependability and maintaining the supply continuity in crises (resilience).

In case of large companies, where production requires many components, the supply chains are very complex. The requirements for contemporary supply chains are very high and related to many aspects. A systems approach to the logistic process design is suggested by Jacyna and Lewczuk (Jacyna and Lewczuk, 2016). The transport is an important element in supply chains and transport planning requires the use various models, often simulation models (Jacyna et al., 2019). Another very important task is evaluation of supply chain effectiveness. Jacyna-Gołda suggests (Jacyna – Gołda, 2016) single- and multicriterial decision models allowing the effectiveness evaluation in the technical, economic and quality aspects (Jacyna – Gołda et al., 2018).

Kuehn (Kuehn, 2018) believes that the complexity of contemporary production and logistic systems requires multicriterial decision indicators. In relation to contemporary digital enterprises Kuehn suggests a systemic approach to the value chain optimization. By use of integrated software solutions, a digital image of entire value chains can be created.

2. Industry 4.0 and logistics engineering – literature review

Recent years have brought an increasing amount of information and publications related to the fourth industrial revolution. As usual, when something new appears, we get a lot of incomplete and not fully true information, in this case mainly related to the understanding of process virtualization (virtual factory, virtual production). The problem is important as the fourth revolution encompasses a broad area of new technologies affecting not only the industry, but also many other areas of life.

A succinct description of the fourth revolution is given by company Astor in its publication (Gracel et al., 2017):

'Industry 4.0 is an overall term for technical innovations and value change organization concepts which revolutionize the industrial production. Currently, the digital technologies change the way production is carried out by

generating, transferring and processing of data, and also by analysing large amounts of datasets. The use of these opportunities requires digitalization, i.e. the change of the data collection and processing from analogue to digital. The other revolutionary aspect is the possibility of uniting and interaction of two worlds, the virtual and the physical.'

Schwab (Schwab, 2016) gave a very good description of the fourth industrial revolution. It is worthwhile to quote his words from the preface to The fourth industrial revolution:

'…Of the many diverse and fascinating challenges we face today, the most intense and important is how to understand and shape the new technology revolution, which entails nothing less than a transformation of humankind. Consider the unlimited possibilities of having billions of people connected by mobile devices, giving rise to unprecedented processing power, storage capabilities and knowledge access. Or think about the staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few. We are witnessing profound shifts across all industries, marked by the emergence of new business models, the disruption of incumbents and the reshaping of production, consumption, transportation and delivery systems.'

In relation to production processes, the cyber-physical production systems(CPPS) are rather well diagnosed. Kuehn wrote about digital factories and production planning simulation already in 2006 (Kuehn, 2006 a, 2006 b). The general foundations of new technologies used in Industry 4.0 are described inter alia by Bauernhansel (Bauernhansel et al., 2014) dealing mainly with the processes of production, au-

tomation and logistics. The table presenting the development stages of production and logistics taken from this publication shows very well the challenges related to the Industry 4.0 technologies (Tab. 1).

A broader, multidisciplinary approach to cyberphysical systems is presented by Biffl, Lüder and Gerhard, paying special attention to the complexity of design processes (Biffl et al., 2017). The book is a practical manual of production system modelling based on the Product Lifecycle Management (PLM), Production System Engineering (PSE) and on modelling of the IT systems integrated with physical systems.

In a more market-oriented approach proposed by Nyhuis and Wiendhal (Nyhuis and Wiendhal, 2009), the production as a basic function used to fulfil orders for specific products is increasingly used to improve the company's effectiveness on the market. In addition to high standards in terms of product quality and process, the logistic factors: delivery dates and capability of fulfilling and reliability of deliveries can gradually become the possibilities for market differentiation.

…'The goal therefore, is to organize the entire material flow in the supply chain, from procuring raw materials and preliminary products, through the entire production process including all of the interim storage stages, up to supplying distributors or as the case may be, external customers in such a way that the firm can react to the market in the shortest time span'.

In relation to supply chains, Nyhuis and Wiendhal write directly that:

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

Therefore, the long-term market success is decided by production costs, reliability and possibility of deliveries.

Table 1. Stages of production and logistics development on the way to Industry 4.0 (acc. [1])

	Yesterday, previously (Industry 1.0/2.0)	Today, now (Industry 3.0)	Tomorrow, future (Industry 4.0)
Supersystem	Analog communication	Internet and Intranet	Internet of Things (IoT)
System	Neo – Taylorism TRS (TUL) - Processes	Lean Produktion Lean Logistics	Smart Factory Cognitive Logistics
Subsystem	Mechanization	Automation	Virtualization

Very interesting and effective solutions for systemic approach to processes within Industry 4.0 is proposed by Siemens. The fourth industrial revolution is a concept of using automation and data processing and exchange, and also implementation of various new technologies allowing the creation of the so-called cyber-physical systems and change of production methods. It is also related to the production digitalization, where technological equipment and systems communicate with each other, also via the Internet, and where large amounts of production data are analysed. Industry 4.0 is here an aggregate term encompassing a number of new technologies, i.a. Internet of Things, cloud computing, Big Data analysis, artificial intelligence, 3D printing, enhanced reality or collaborative robots. The basic processes related to the transformation of companies operating in accordance with Industry 4.0 to digital companies are described by Mychlewicz and Piątek (Mychlewicz and Piątek, 2017). Twin interconnections of virtual and real processes proposed by Siemens is presented in Figure 1.

The approach proposed by Siemens is known as the Digital Enterprise Suite (DES). The Digital Enterprise Suite offers integrated software and hardware solutions for discrete industries to seamlessly integrate and digitalize the entire value chain, including suppliers. With the Digital Enterprise Suite Siemens integrates Product Lifecycle Management (PLM), Manufacturing Operations Management (MOM),

Totally Integrated Automation (TIA) – all based on collaboration platform Teamcenter and being connected to MindSphere: cloud – based and open IoT operating system.

2.1. Logistics engineering in production systems

Many papers on logistics in companies focus on the processes related to orders, supply of materials, purchases, storage and distribution of products. However in a production company, the most capital-intensive process is the manufacture of goods. The manufacture makes the material stream flow through individual production cells (stations) in a company. This flow depends on many factors, of which the production system structure is absolutely the most important. A skilful use of quantitative methods proposed by contemporary science and technology is necessary in order to determine the company key performance indicators. In Logistics engineering handbook (Taylor, 2008) Taylor wrote:

'It is a fact that there are a few, if any, significant differences between the business logistics and logistics engineering, except the fact that the logistics engineers often use more 'mathematical' or 'scientific' methods in logistic application. In the search for logistics solutions, the future challenge is a broader understanding of the logistics which is reflected by the systemic approach.'
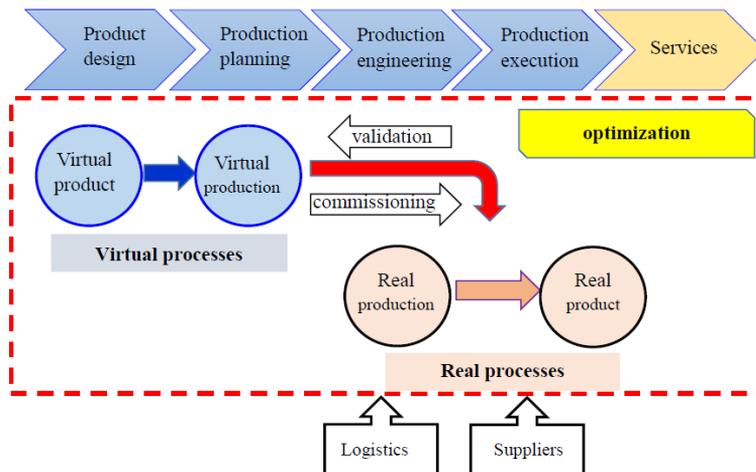

Fig. 1. Twin processes in the Industry 4.0 concept (own study based on Siemens materials)

Hence, new concepts and tasks of production logistics appear. As a method for waste elimination (muda), Womack and Jones (Womack and Jones, 2008) recommend lean approach, lean thinking by creating the value stream in a company. In the simplest words, the lean actions can be described as processes of continual elimination of waste. In such approach, the most important task in production systems is to maintain continuity in material flows (Rother and Harris, 2007), and also permanent improvement (kaizen) of continuity. The term logistics engineering is relatively rarely used in Poland, unlike the USA where the logistics engineering is widely used to solve various problems related to the design and implementation of logistic processes (Michlowicz and Mindur, 2018).

According to the Council of Logistics Engineering Professionals – CLEP: Logistics Engineering: The professional engineering discipline responsible for the integration of support considerations in the design and development; test and evaluation; production and/or construction; operation; maintenance; and the ultimate disposal/recycling of systems and equipment. Additionally, this discipline defines and influences the supporting infrastructure for these systems and equipment (i.e., maintenance, personnel, facilities, support equipment, spares, supply chains, and supporting information/data). The practice of logistics engineering is exercised throughout the system life-cycle by conducting the iterative process of supportability analysis and the accomplishment of trade-off studies to optimize costs and system, logistics, and performance requirements.

Logistics engineering as a discipline is a very important aspect of systems engineering that also includes reliability engineering. It is the science and process whereby reliability, maintainability, and availability are designed into products or systems. It includes the supply and physical distribution considerations above as well as more fundamental engineering considerations. Logistics engineers work with complex mathematical models that consider elements such as mean time between failures (MTBF), mean time to failure (MTTF), mean time to repair (MTTR), failure mode and effects analysis (FMEA), statistical distributions, queueing theory, and a host of other considerations.

The task of the logistics engineering in a company is to develop and prepare a system of acting, which us-

ing the laws and rules of logistics and also other sciences, will allow implementation of the logistic tasks supporting the achievement of effects specified in the company strategy. The actions should focus on 'how'.

– how the product is made;
– how the service is provided.
– The basic strategies may include:
– high customer service quality;
– World Manufacturing Class - WMC;
– desired (specific) productivity;
– obtaining specific business and technical indicators.

The logistic methods and tools useful in company logistics are generally known (Michlowicz, 2013). Their application depends (in addition to the adopted strategy) on potential, knowledge and skills of the technical and managerial team and the area of actions. The choice of the area and the tasks implementation methods are the first, very important stage of actions aiming at the achievement of desired effects. In relation to the new requirements connected with the fourth industrial revolution, the lean methods have become particularly important. Very interesting theoretical foundations necessary to understand the correct use of lean methods in modern manufacturing are presented by Ruttiman (Ruttiman, 2018) in the monograph Lean compendium. Introduction to modern manufacturing theory. Similar changes can be observed in the understanding of the Just in Time systems. The authors of Just in Time Factory. Implementation through lean manufacturing tools (Pinto, Matias, 2018) present new areas of JiT application in manufacturing systems.

The most often used lean methods include:
– VSM Value Stream Mapping;
– TPM Total Productive Maintenance;
– 5 S - 5 Pillars of the Visual Workplace – workplace visualization and standardization;
– SMED Single Minute Exchange of Die;
– JiT Just in Time – just-in-time flows;
– Kanban – organization and control with the use of cards;
– 5W1H - 5 why and 1 how – knowing the problem cause;
– 7 M - 7 Muda, 7 Wastes – waste elimination in processes;
– Heijunka – Sequencer – sequencing of production;

- Jidoka - Autonomation – possibility of stopping the line or process;
- Kaizen – evolutionary continuous improvement;
- Kaikaku – innovation, rapid change for the better.

In addition to methods known as lean tool box (recently more often - lean tool system), the logistics engineering proposes an analysis of manufacturing processes using the production logistics laws – PLL which describe relationships between individual production process parameters (Table 2).

Table 2. Production Logistics Laws PLL (acc. [18])

1_PLL	In a long timeframe the material input level and output level to/from the station must be balanced.
2_PLL	Time of material passage through the station depends on the proportion of work in process (WIP) and the rate of leaving the process.
3_PLL	Reducing the station use levels allows a disproportional reduction of WIP and shortening the time of material passage through the station.
4_PLL	Variance and average value of the labour intensity define the logistic potential of the station.
5_PLL	The size of WIP buffer required to ensure the appropriate station use level depends mainly on the load flexibility and station capacity.
6_PLL	If the orders are performed according to the FIFO principle, the time between operations does not depend on the labour intensity of individual operations.
7_PLL	Application of sequencing rules can significantly affect the average passage time only at a high WIP level and a wide distribution of labour intensity of individual tasks
8_PLL	Passage time variance depends on the applied sequencing rules, WIP level and the distribution of labour intensity of individual tasks.
9_PLL	The logistic process reliability is defined by the average value and the distribution of material flow time through the system.

The contemporary concepts focus on methods to minimize the WIP (Work in Process) level (e.g. Ruttiman, 2018), and also on reducing and unifying the passage times and making the Work Content structure more uniform. Particularly important are relationships between the WIP level, minimization of processing times and material passage times through equipment and the level and reliability of deliveries.

LOC (Logistic Operating Curves) can be used to solve possible conflicts. The curves are measured for all correlations between a selected parameter (goal or variable) and the independent variable (e.g. curve: passage time – WIP) or storage costs – resources). Additional curves accounting for logistic processes in the system include:

- POC – Production Operating Curves;
- TOC – Transport Operating Curves;
- SOC – Storage Operating Curves.

In relation to complex systems in which many different products are made and production is not mass, reliability theories, queue theories or other stochastic theories are often used (e.g. Zwolińska, 2019). Other quantitative solutions are proposed by various disciplines more loosely related to the logistics, inter alia:

- operational research (OR);
- artificial intelligence (AI);
- information technologies (IT).

Figure 2 presents logistics engineering methods which can be used in production companies.

2.2. Solving supply problems in distribution systems

The goal of the distribution is to deliver to the final customers the product they need (type, quantity), to the places where they want to buy such products, at the time they want to buy them, at agreed terms and at the lowest price possible. Therefore, the logistic operator faces the task to develop such transport plan that would give optimum results due to the optimizing criterion used. In addition, there are often other problems to be solved, inter alia:

- minimization of transport lead times;
- shaping the transport network;
- distribution of transport stream in the network;
- selection of technical equipment and determination of potential of transport and logistics systems.

The real logistic systems have many limitations not accounted for by typical algorithms, such as imposed delivery time, capacity of vehicles, sizes of load units. As a result, new algorithms are continuously being searched for to support the achievement of complex tasks of logistic operators (Michlowicz, 2017).
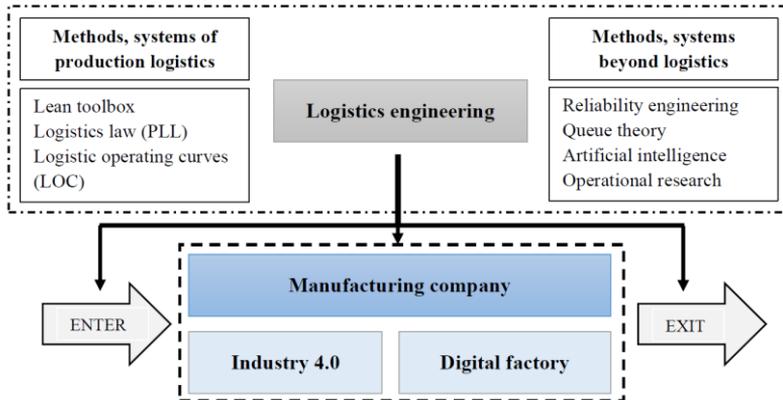
Fig. 2. Logistics engineering in a company (own study)

The best known, typical VRP (Vehicle Routing Problem) involves minimization of transport costs from one warehouse to any number of recipients (customers). Currently, there are a lot of delivery problems. The best known include:

– CVRP (Capacity Vehicle Routing Problem) – all vehicles have identical capacity;
– VRPTW (Vehicle Routing Problem with Time Windows), extension of CVRP to include time windows for each customer (time interval during which the customer can be served);
– SDVRP (Site-Dependent Vehicle Routing Problem), extension of CVRP; vehicles have different capacities; hence limitations in providing service for some customers;
– MDVRP (Multi Depot Vehicle Routing Problem), there are many central depots;
– MDVRPTW (Multi Depot Vehicle Routing Problem with Time Windows);
– VRPSD (Vehicle Routing Problem with Stochastic Demands);
– RDPTW (Rich Delivery Problem with Time Windows), there are defined time windows for customers, the load unit weight is defined, and vehicles have different capacities.

Various hybrid algorithms are used to solve such complex problems. These are most often genetic, evolutionary, adaptive algorithms of searching large ALNS (Adaptive Large Neighbourhood Search), simulated annealing heuristics, and ant algorithms (Ant Colony Systems). The task costs are a very large limitation in the distribution systems. At least 3 cost groups should be considered:

– distribution network maintenance costs;
– transport costs;
– storage costs.

In solving such problems, the methods based on probability theory and stochastic laws are increasingly used, as suggested by the logistics engineering (Zwolińska, Michlowicz, 2016). It is obvious that to solve such problems one must have sufficiently large databases and use ICT (Information Communication Technology) resources.

3. Problem of Polish SMEs. Is Industry 4.0 a threat?

The structure of Polish economy by the basic type of operations is as follows (Zakrzewski, 2019):

– services 52.3 % (including transport and storage – 7.5 %);
– commerce 24.0 %;
– construction 13.6 %;
– industry 10.1 %.

Fundamental questions arise:

'to what group of companies does the Industry 4.0 idea apply?'
'will CPPS (Cyber-Physical Production Systems) be used at small and medium enterprises?'
'which elements of Industry 4.0 should be used at SMEs?'

An extensive report in a PARP (Polish Agency for Entrepreneurship Promotion) (Zakrzewski and Skowrońska, 2019) indicates that in Poland large companies which absolutely should transform towards Industry 4.0 are only 0.2 % (3600 units) of all companies (more than 2 070 000 units). At the same

time, these companies generate 23.8 % of GDP and employ 3.1 million people which is 31.6 % of total employment at Polish companies.

On the other hand, micro and small companies employ 52.1 % of all employees, and their share in GDP is 38.7 %. It seems that the problems with implementation of the fourth industrial revolution technologies in this group are related only to selected technologies (Internet, cloud).

The biggest problem with the Industry 4.0 implementation is at the medium-sized companies. They are 0.7 % of all Polish companies (15 000 units) and generate 11.1 % of Poland's GDP. An average company employs 105 people. Thus, these are companies for which the Industry 4.0 technologies should be thoroughly analysed and implemented (strategic and cost-effective).

Selected characteristics of Polish companies are presented in Table 3.

Figure 3 illustrates the selected characteristics in the context of supplies necessary for achievement of tasks in such companies.

Please note that among all Polish companies (2 073 600 units) transport and logistic companies are 7.5% and industrial companies 10.1%.

4. Efficiency improvement algorithm – solution for SMEs

Currently, the key to understanding the operations of a company is the awareness, that it functions as a part of a larger system. The development of the SCM concept forces the companies to transform from functionally-oriented to process-oriented organisations. The common element, shared by different approaches to logistics are material flows and their skillful management.

Figure 4 presents a simplified diagram of a system comprising processes implemented in production companies, with particular emphasis on the logistic and storage processes.

Implementation of individual tasks (acc. to Fig. 4) requires a specific strategy. The basic tasks necessary for implementation in order to improve the production system performance in such a system are presented in Table 4.

Table 3. Selected characteristics of Polish companies (own study acc. to [25])

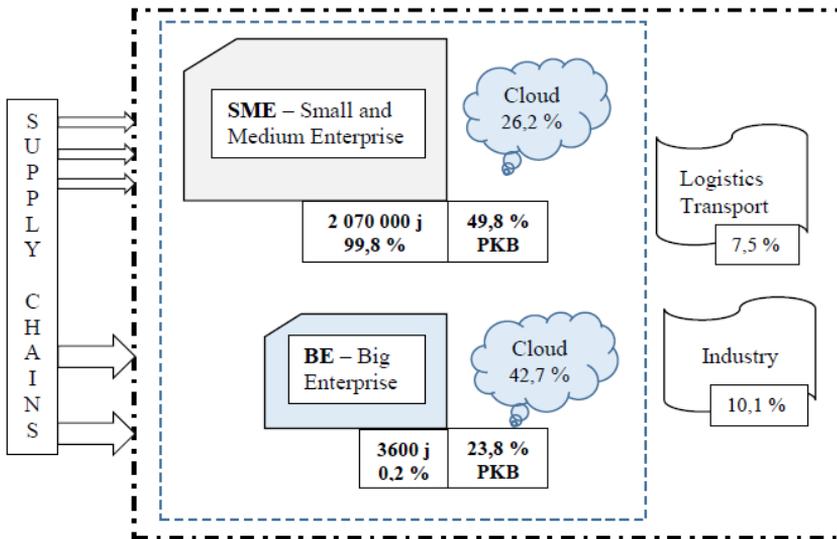| Type	Sector share – quantitative [%]	Employment [M people]	Own website [%]	Cloud computing [%]
Micro and small	99.1	5.1	62.5	7.2
Medium	0.7	1.6	84.5	19.0
Large	0.2	3.1	91.1	42.7

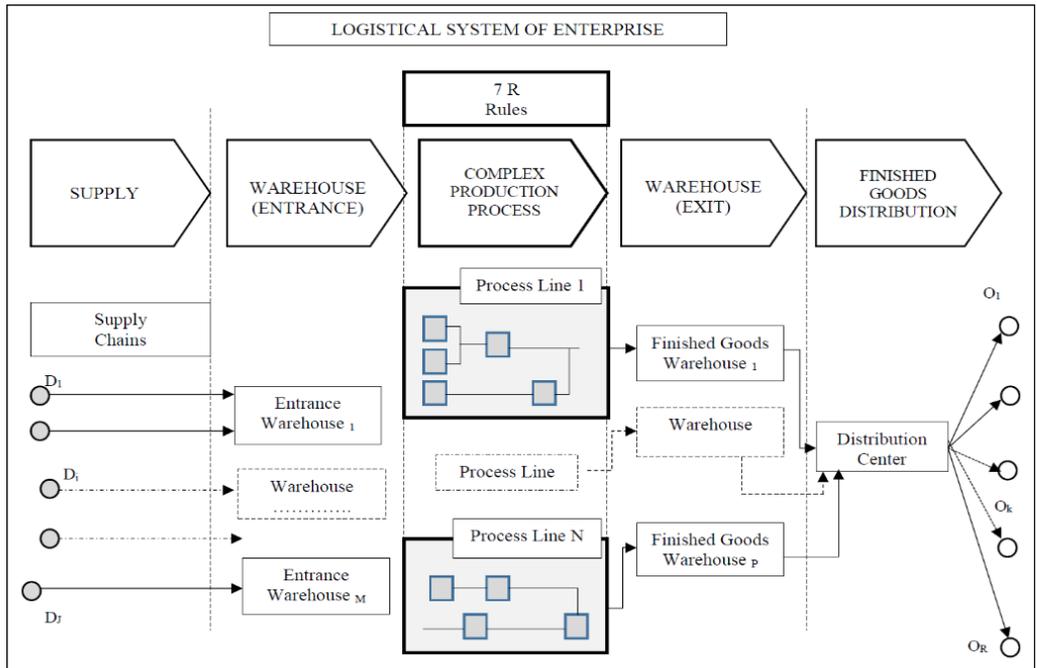Fig. 3 Selected characteristics of Polish companies in context of supplies (own study)

Fig. 4. Diagram of logistic and production processes in a company (own study)

Table 4. Tasks for implementation in a production system (acc. to Fig. 4)

Basic tasks for implementation				
Supply strategy - selection of suppliers	EN storage strategy - input warehouses, - storage area	Manufacturing strategy - material flow continuity	EX storage strategy - finished goods warehouse, - storage area	Distribution strategy - distribution channels, - distribution strategy
Classification of components - ABC, XYZ, Pareto	Reception technology, - identification	Production logistics laws - 9 PLL	Inventory analysis	Order picking
Forecasting	Inventory model	work in process -WIP	Storage strategy	Shipment and customer service model
	Placement - ABC	lean toolbox - JiT, VSM, TPM...	Means of transport	Reverse logistics
	Means of transport	ZSI - ERP, MES,…		Optimization - VRP,…
IT support – common hardware and software platform / Effectiveness evaluation indicators				

The analysis of Figure 4 and strategy from Table 4 indicates that one of the most important tasks in a company is to maintain the continuity of material flow (including information). The discontinuity of material flow can be caused by two main reasons:

−   Absence of components in the areas of processing or assembly – logistics most be improved.

−   Low availability of machinery and equipment – maintenance must be improved.

Implementation of single lean components (e.g. 5S, JiT, Kanban, SMED, TPM, VSM) is just a beginning of the road to the full concept. The true challenge is to see the whole process. In case of companies, particularly SMEs (Small and Medium Enterprises), it could be very difficult to see the whole process, so

the only option left is to implement single elements. For that road to lead to synergy, it is worthwhile to build a system of goals for a longer timeframe and set individual stages for this period. Quick effects are obtained e.g. by eliminating waste (7 Muda) and organization according to the 5 S rules.

The implementation processes are always accompanied by the value stream. The value stream is a set of all actions required to make a product. The value stream visualization allows seeing all waste in it and aiming further 'leaning' actions at eliminating waste from the areas that add value – the VSM (Value Stream Mapping) method.

TPM - Total Productive Maintenance – is one of the most important tools of lean management of manufacturing processes. The TPM goal is to maintain the continuous operation of equipment and machines that perform specific tasks, which at the same time improves their operational effectiveness.

The experience of the author enables the conclusion that the task of introducing the improvement of continuity can be described in several stages.

At the first stage, a very precise identification of all processes associated with production and logistics is required. After identifying and determining the actual purpose of improving production efficiency, the proper choice of methods and tools to achieve these goals should be initiated.

Thus, the initial activities include two stages:

Stage I – identification of the process – activity: 1, 2, 3, 4.

1. Selection of the process for analysis.
2. Drawing up an accurate diagram of the technological process.
3. Collection of data on the process, including orders, deliveries, inventories, etc.
4. Determination of basic parameters and values describing the process, execution of the necessary timekeeping for the timing of operations.

Stage II – The choice of methods and improvement tools (e.g. VSM, TPM) – actions: 5, 6.

5. Description of losses and waste in the process (e.g. 7 muda, 6 big losses).
6. Tool selection.

Figure 5 shows the first two stages of an algorithm for improving efficiency in the production system.

The consecutive steps necessary to achieve the desired improvement of the functionality (effective-ness) of the operation, as well as to ensure the continuity of the flow of materials, depend on the choice of method (tool).

If the VSM (Value Stream Mapping) mapping method is chosen, the algorithm is described by the successive stages III, IV and V.

Stage III – elaboration of the map of the existing state – actions: 7, 8, 9, 10.

7. Development of icons for the process.
8. Preparation of a map of the existing state (readable and in an appropriate format, such as A2).
9. Determination and collection of information about possible proposals for changes to the existing system.
10. Plotting the proposed changes on the value stream map.

Stage IV – introduction of changes – actions: 11, 12.

11. Preparation of arrangements and deadlines for possible changes.
12. Introduction of changes.

Stage V – analysis of results and improvement – actions: 13, 14.

13. Analysis of the effects after introducing the changes.
14. Insistent implementation of the principles of kaizen!

Figure 6 illustrates the stages of an algorithm utilising the VSM mapping method.

As was true of the TPM method, the algorithm takes stages III to VI into consideration.

Stage III – identification of the functioning of machinery – actions: 7, 8, 9.

7. Identification of failures and downtime.
8. Plotting of Pareto diagram – causes of failure. Selection of the reasons for improvement.
9. Determination of objectives – limit values of MTTR and MTBF.

Stage IV – determining the OEE efficiency ratio – actions: 10, 11, 12

10. Determination of the availability indicator for the lines (available time net, working time).
11. Determination of the process efficiency ratio (achieved efficiency, nominal efficiency).
12. Determination of the quality indicator (achieved quality, desired quality).

Stage V – introduction of changes – actions: 13, 14

13. Development of time schedule for implementing changes in the area of reducing the number of machine failures.

14. Introduction of changes aimed at improving the indicators of availability, efficiency and quality (of machines involved in the process).

Stage VI – analysis of results and improvement – actions: 15, 16.

15. Analysis of the effects after introducing the changes.
16. Insistent implementation of the principles of kaizen!

Figure 7 illustrates the stages of an algorithm utilising the TPM method.

These two exemplary methods are very often used in manufacturing companies. The experiences of companies that strive for continuous improvement of productivity show that the onset of improvement should be the implementation of the principles of '5S' (5 Pillars of Workplace Visualisation).
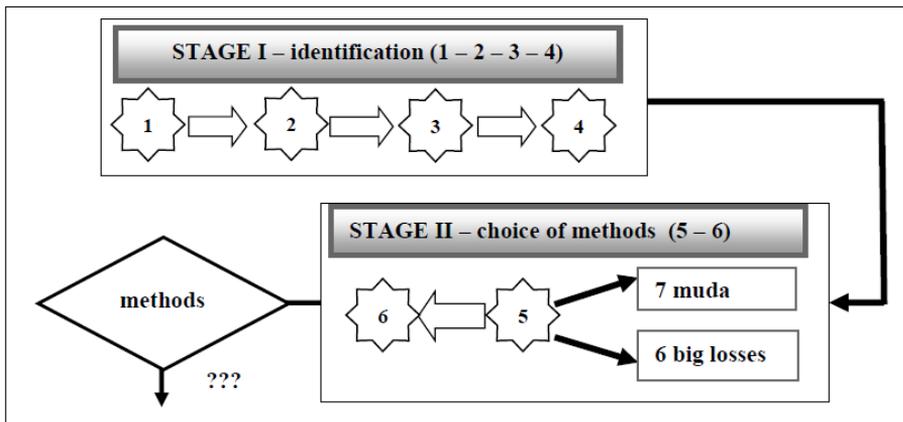

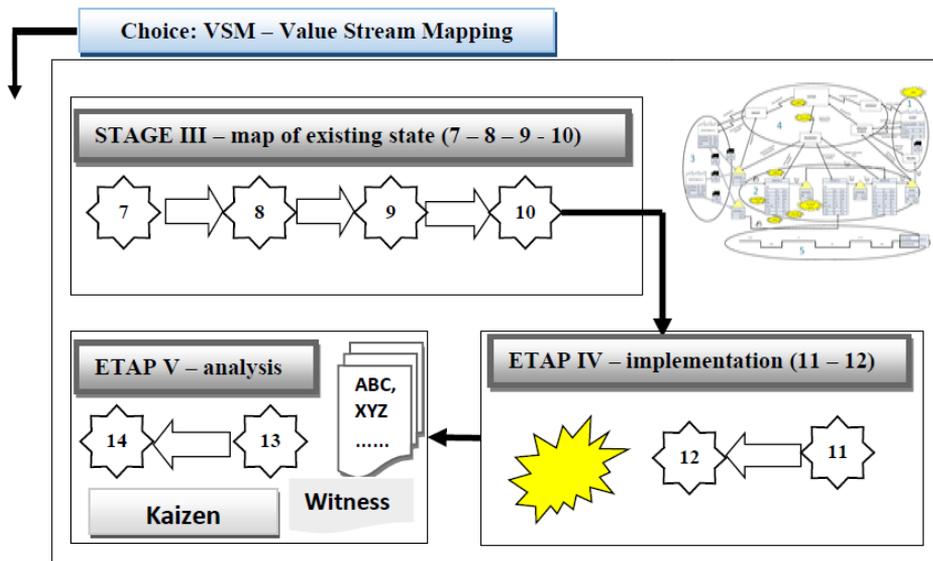Fig. 5. Algorithm - choice of methods for improvement
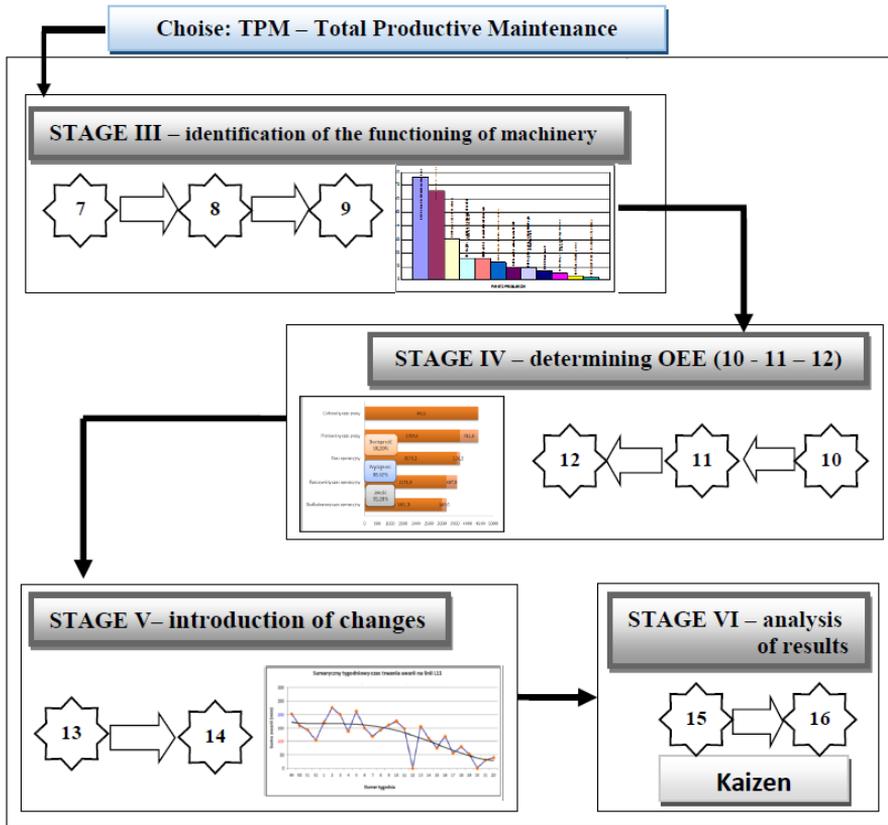

Fig. 6. Algorithm - improvement via the VSM method

Fig. 7. Algorithm - improvement of performance using the TPM method

5. Conclusion

The fourth industrial revolution – Industry 4.0 – requires the use of many information technologies and also cyber-physical production systems (CPPS). It is frequently noted now that the Industry 4.0 is being transformed into Digital Factory and Smart Factory. The key question is to which companies such transformations apply. It is beyond doubt that the changes mainly apply to large companies (in Poland they are 0.2 %, that is 3600 companies) and some medium ones (in Poland medium companies are 0.7%, that is 15 000 units). However, in all modern enterprises, the logistics competence covers an increasing large area. Broadly understood supply chain and production management now suggests many various methods and techniques for improved operation of logistic systems. Some such methods have been developed within Lean Management. Systems for material flow organization and control and ERP integrated IT systems are widely known. Production logistics also faces these challenges. Value steam improvement by VSM and ensuring high availability of machines by means of TPM are oftener and oftener used at production companies. In many areas very helpful are production logistics laws (PLL) and original flow analysis algorithms. The development of theories related to supply chains and lean thinking forces the companies to go beyond their boundaries. This leads to a systemic approach to the problems related to the designing of logistic processes. Logistics engineering is a discipline which, by integrating many processes, using mathematical methods and achievements in the studies on broadly understood logistic processes, allows practical solutions to be found.

For many companies, especially Small and Medium Enterprises (SME), the complete capture of the process may prove to be too difficult. Therefore, the way to implement individual elements of lean methods remains. In order for this path to result in synergy, it is worth building a system of goals for a longer period of time and for this period to set individual stages. VSM (Value Stream Mapping) and TPM (Total Productive Maintenance) are very useful methods for SME class enterprises. The algorithms presented in the article can be directly used to improve efficiency in SME class enterprises.

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