ORIGINAL RESEARCH ARTICLE

Martin Krajcovic - Patrik Grznar - Miroslav Fusko - Radovan Skokan*

INTELLIGENT LOGISTICS FOR INTELLIGENT PRODUCTION SYSTEMS

The main topic of the submitted paper is intelligent logistics and its integration into production systems. In the beginning, the problem that lies in the inadequate knowledge of the internal state has been defined. The new society-wide trends that will originate in a few years are also outlined. Those trends will affect factories and their logistics systems on a large scale. Therefore, it is necessary to have a strategy that takes these new trends into consideration. In this manuscript, is described a strategy for intelligent production systems, as well as technologies for different types of production-logistic strategies. Many of these technologies can be applied together with the Digital Twin. The Digital Twin is a new concept in the field of designing production and logistics systems in the factory. Finally, we provide a description of the implementation of the Digital Twin into the production and logistics system.

Keywords: logistics, strategy, new trends, digital twin, intelligent logistics, production systems

1. Introduction

Logistics is becoming a very powerful engine for the success of industrial organizations in the global markets. Globalization has brought a potential of the global market, an abolition of market barriers and a free capital movement on one hand, but at the same time, on the other hand, the global competition and a so-far unknown rate at which the market turbulence appears. The present effort of designers of modern production and logistics systems is to implement an ability of quick adaptability to constantly changing market requirements as a solid part of their features. Those systems are now called the adaptive logistics systems. They implement new types of technologies to provide adaptability based on computer simulation and emulation. One of those methods, that can be defined as a part of those systems is the Digital Twin. The Digital Twin is a digital image of the production or logistics process, by means of which one can optimize production or logistics process in the factory. With the assistance of the CAx systems and simulation software, one can create the Digital Twin and then apply the Digital Twin into the real world of the factory. That results in an increase in the production and logistics process efficiency. The submitted paper is based on a case study for a medium-sized factory operating in the automotive industry. To maintain competitiveness, the factory cannot be named and detailed results cannot be published. Stated chapters reflect the research that was carried out for the factory and it is possible to implement the selected technologies in the following years.

the use of the most advanced information and communication technologies (ICTs), automation, and robotization of all areas of the industry [1]. Modern factories, utilizing the most advanced technologies, are termed as Smart Factories. This paper responds to the growing need to design intelligent factories with reconfigurable logistics systems and logistics systems testing in real conditions in the case of extending production before the installation of a new production equipment. As the production, delivery and installation of complex production and assembly equipment can take several months, the opportunity to test logistics processes before and during installation can provide, in a dynamic global market, the necessary competitive advantage to the factories [2]. The problem with such implementations of innovative solutions is that factories do not prepare audits of logistics systems, logistics strategy, production systems and technical service in advance and do not know the real technical state of machines and equipment. In most cases, factory authorities do not provide ideas about new tendencies and development in a selected area. Thus, a lack of knowledge of the current state can cause a problem with the level of implementation of the new strategies or solutions. Furthermore, this may result in a sharp increase of financing the implementation of such solutions. In the end, it will affect negatively the schedule of the whole implementation. Therefore, it is necessary to deal with a complex logistics strategy including new trends in this area first, e.g. digitization, robotization, reconfigurable manufacturing systems, a lack of skilled workers, sustainability of production systems, green energy, and others [3], [4].

2. Formulation of the problem

The success in business is nowadays determined more by the brain than by hands. The latest massive wave of innovations is referred to as the fourth industrial revolution, and it is built upon

3. New trends and logistics strategy

There are several megatrends that are fundamentally reshaping the entire industry for the next 10 years. These include increased oil price volatility that creates investment challenges,

* **Martin Krajcovic, Patrik Grznar, Miroslav Fusko, Radovan Skokan**
  Department of Industrial Engineering, Faculty of Mechanical Engineering, University of Zilina, Slovakia
  E-mail: martin.krajcovic@fstroj.uniza.sk

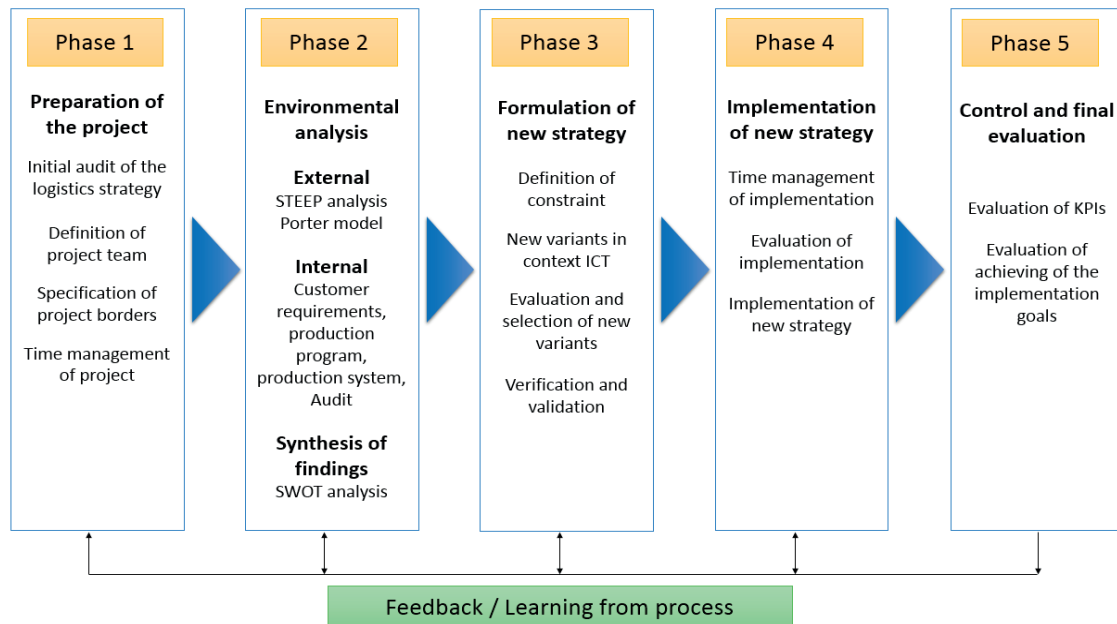| Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Preparation of the project	**Environmental analysis**	**Formulation of new strategy**	**Implementation of new strategy**	**Control and final evaluation**
Initial audit of the logistics strategy	**External** STEEP analysis Porter model	Definition of constraint	Time management of implementation	Evaluation of KPIs
Definition of project team	**Internal** Customer requirements, production program, production system, Audit	New variants in context ICT	Evaluation of implementation	Evaluation of achieving of the implementation goals
Specification of project borders		Evaluation and selection of new variants	Implementation of new strategy	
Time management of project	**Synthesis of findings** SWOT analysis	Verification and validation		

Feedback / Learning from process

Figure 1 The proposed procedure for making the logistics strategy

energy consumers that are driving the transition to a low carbon and efficient energy world, supply constraints that are triggered and controlled by the government and geopolitical events, while also stimulating demands for green energy. The most important area will be the Internet of Things. Internet of Things is a novel paradigm that is based on the pervasive presence of numerous things or objects. [5].

3.1 Industry 4.0

The achievement of a stable economic development of an economic entity and growth of its competitiveness make it necessary to increase the level of its business activity based on improvement of the strategic management process [6]. Currently, everyone talks about Industry 4.0, but it is a topic where directions are indicated, solutions are prepared, but one still cannot imagine all the impacts. The phrase "Internet of Things" is the most widely used in this context, from which only a few of us can put together a clear idea. For this reason, we will use the word SMART. Intelligent and flexible processes and things will define production factories of the future. When the building components of one product communicate independently with the production equipment and if it is necessary, they become self-repair. Furthermore, when people, equipment and industrial processes will be intelligently networked, only then we can talk about complete Industry 4.0. A factory of the future enables mass production of products according to individual requirements and customer wishes - not too costly but of a high quality. Therefore, it cannot be denied that especially for small and medium-sized factories the smart and digital production brings great competitiveness.

3.2 Logistics strategy

Logistics is increasingly becoming a motor of success of industrial organisations on global markets. Resources play a decisive role in the functioning of economy [7]. Globalisation brought not only the potential of global market, disturbance of market barriers and free movement of capital, but also the global competition and so far, unknown speed by which the market turbulences appear [8]. Nowadays, internal logistics is the key to most businesses. Different products from many imported components are often finalized on one production line. Efficient and operation technologies together with auxiliary and service procedures secure whether they reach the line in time in the right version, in quantity and order. In this research, the focus was set on the development of a methodology for the formation of a logistics strategy for a selected medium-sized factory. No similar sequence (methodology) was found in literature by this authors. Relevance of a research subject is caused by the need for economic growth of the enterprise due to increase of its business activity based on improvement of strategic management by the managing subject [6]. The proposed methodology (shown in Figure 1) will provide instructions to develop its own logistics strategy considering an application of progressive tools and the inclusion of new trends in ICT (information and communication technologies) to a factory. The new trends for the factory are developed in the following sections. The first phase provides recommendations for the project preparation of a creation of logistics strategy, such as creating a project team, defining the limits of the strategy, creating a timeline for strategy creation. The second phase demonstrates the analyses that are suitable to be performed before the formulation of the logistics strategy and by the strategic synthesis of the acquired knowledge from the analyses. The third phase focuses on the process of formulating variants of a strategy based on information about the current
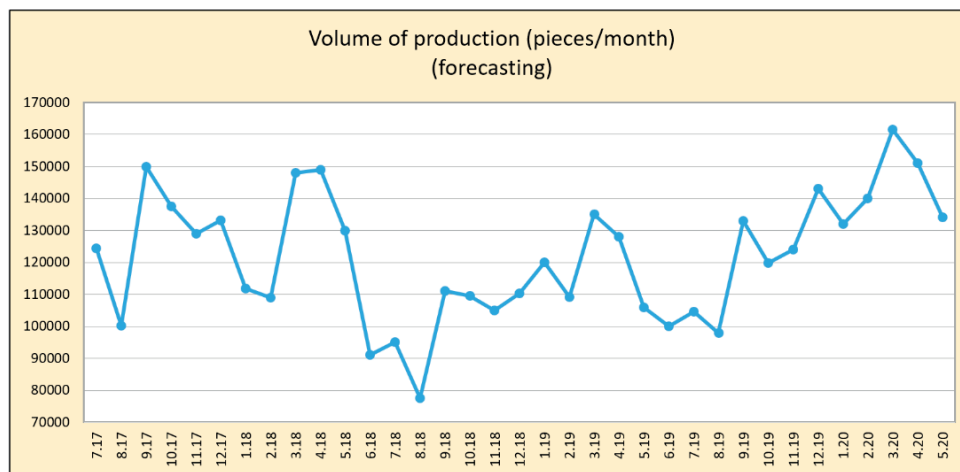
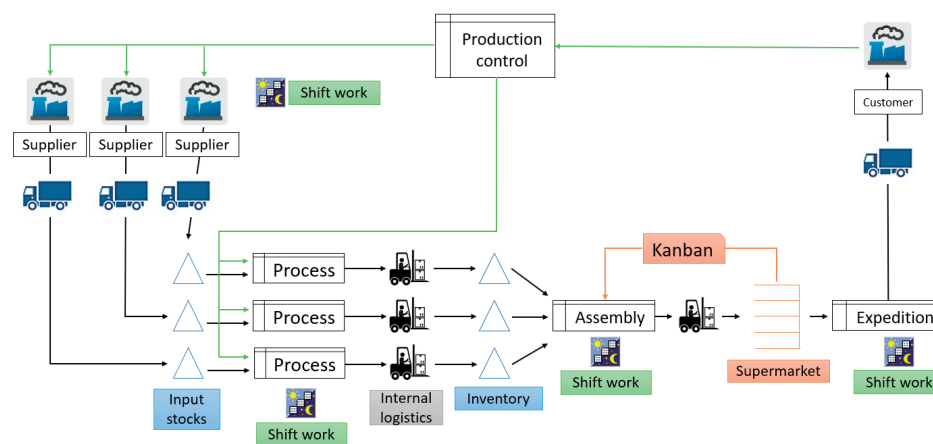*Figure 2* *The forecasting of the produced quantities*

Figure 3 *The simulation of the value flow for the selected representative item*

state, objectives set and possible constraints. The fourth phase shortly demonstrates how the strategy is implemented since it represents the common project management activities. The final - fifth phase demonstrates the proposal evaluation during and after the implementation of the strategy.

The proposed methodology cannot be verified in a short time. The new strategy is usually implemented within 3 - 5 years. Therefore, only a selected part of the methodology, which describes interesting results, was verified. The methodology was experimentally verified in the automotive industry. Only some of the outputs are selected for this manuscript because several factory data are top secret (factory competitiveness information).

3.2.1 Verification results

This part of the section 3.2 contains some results from an analysis of the factory's internal environment.

Production program: The factory provided historical data based on which d the forecast of production quantities for the planned period implementation of the logistics strategy was prepared. The estimated production quantities are shown in Figure 2.

From the forecasting, it is possible to see that the trend of the quantity produced is increasing. Therefore, logistics must expect a growth of manipulated quantities. It is about a 10% increase over three years.

Analysis of the production system: The analysis of the production system was performed by the Value Stream Mapping (VSM). The output of the simulation of the value flow for the selected representative item is illustrated in Figure 3.

By use of mapping, it has been found out that in the production area, in front of assembly, there are disproportionately high inventories of work in process. The simulation also shows that the value of inventories demonstrates an increasing tendency in recent years.

Evaluation of logistics areas: From the point of view of the competitive advantage of the factory, one cannot describe the exact values of the logistics area. It consists of distribution logistics, shopping logistics, warehouse logistics, green and reverse logistics, organization of logistics processes, documentation - layouts, safety and ergonomic, KPI, production logistics, lean logistics, information flows and data, Industry 4.0 and engineering and technology. The overall result of evaluation of various logistics areas, before the implementation of the new strategy in the factory, is shown in Figure 4. There is presented that after the implementation of the new strategy in the selected factory the results is that the factory reached the area of the efficient logistics system.
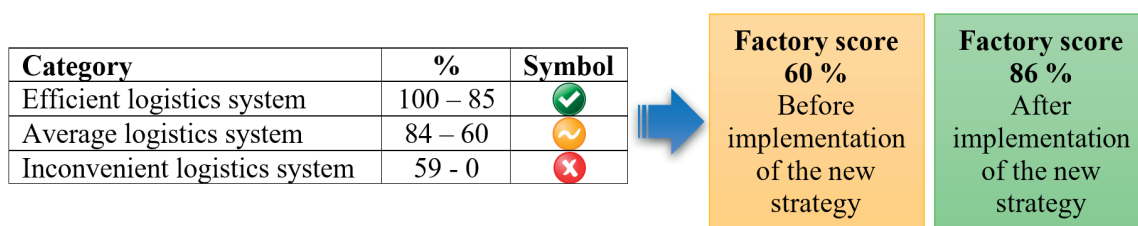
Category	%	Symbol
Efficient logistics system	100 – 85	✓
Average logistics system	84 – 60	~
Inconvenient logistics system	59 - 0	✗

Factory score 60 %
Before implementation of the new strategy

Factory score 86 %
After implementation of the new strategy

Figure 4 The initial and the new valuation of the logistics system

Logistics 4.0

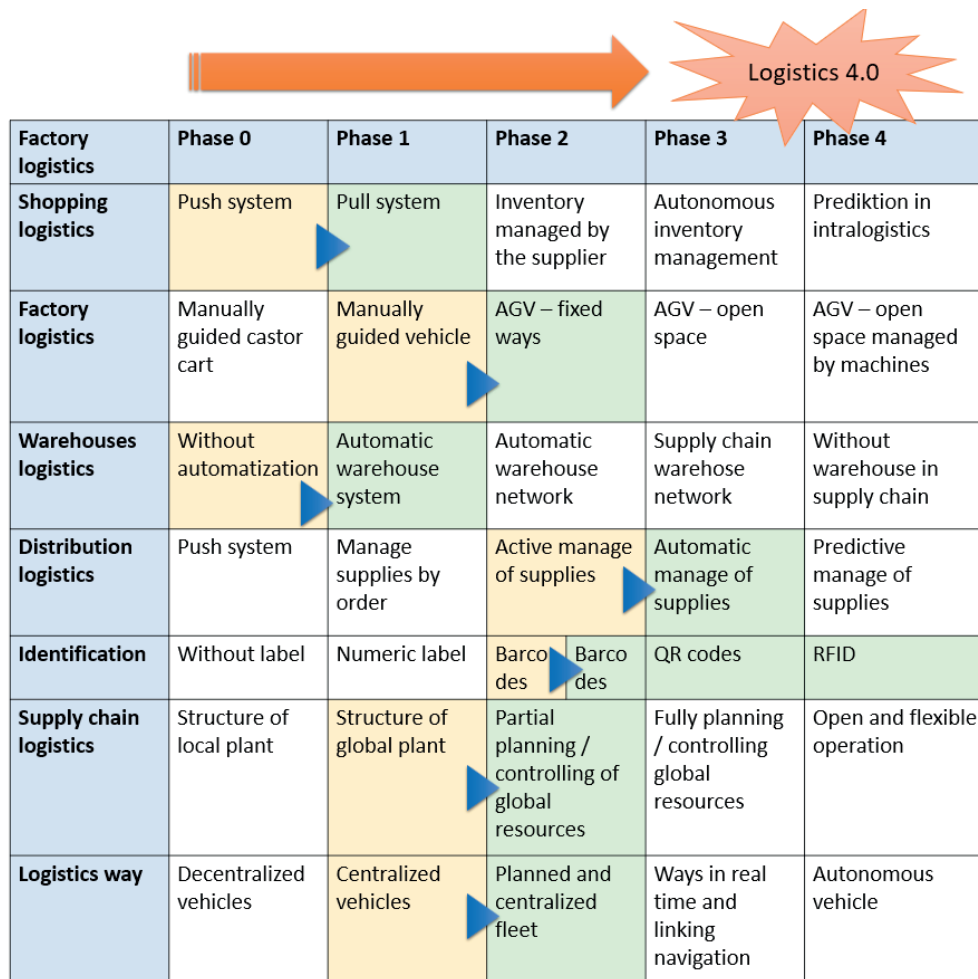| Factory logistics	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4
Shopping logistics	Push system	Pull system	Inventory managed by the supplier	Autonomous inventory management	Prediktion in intralogistics
Factory logistics	Manually guided castor cart	Manually guided vehicle	AGV – fixed ways	AGV – open space	AGV – open space managed by machines
Warehouses logistics	Without automatization	Automatic warehouse system	Automatic warehouse network	Supply chain warehose network	Without warehouse in supply chain
Distribution logistics	Push system	Manage supplies by order	Active manage of supplies	Automatic manage of supplies	Predictive manage of supplies
Identification	Without label	Numeric label	Barcodes Barcodes	QR codes	RFID
Supply chain logistics	Structure of local plant	Structure of global plant	Partial planning / controlling of global resources	Fully planning / controlling global resources	Open and flexible operation
Logistics way	Decentralized vehicles	Centralized vehicles	Planned and centralized fleet	Ways in real time and linking navigation	Autonomous vehicle

Figure 5 Moving of the logistics development in the selected production factory

By means of single phases of the methodology, it was possible to exactly specify areas of logistics, which were needed to be focused on in the creation of a logistics strategy. Based on the SWOT analysis, the individual aspects of the factory logistics system that operates in the automotive industry were identified. Based on the analyses, the goals that factory planned to achieve in the next 3 - 5 years were set. Finally, y the necessary indicators that the company should monitor and evaluate had to be identified.

The industrial environment is characterized by a permanent change. As a result, the production requirements and their processes are constantly changing [9]. From Figure 5, one may observe how the factory will develop in the coming years - green coloured cells. The further set phases were defined and established for the factory. The phases should motivate the factory to reach Phase 4 which means Logistics 4.0. The factory was set

out on the journey already and it has realistic preconditions from an average factory to become a Factory of the Future.

4. Logistics 4.0 (Smart logistics)

Logistic systems have to become more adaptive as well. One can see the growing trend of employing the concept of Factories of the Future (FoF) and Intelligent Manufacturing Systems (IMS), which In Slovakia are being supported by the Smart Industry, a movement that is gaining momentum under the auspices of the Ministry of Economy of the Slovak Republic and the German industry program Industry 4.0. The topic of the smart logistics systems (Smart Logistics) is becoming very popular [10]. The fourth industrial revolution has far-reaching

Table 1 The relations between production, logistics strategy and technologies

Technology/ Strategy	Intelligent systems in pre-production phases	Design to order	Shopping service to order	Production to order	Assembly to order	Make to stock
CAX - Computer-Aided Technologies	4	2	2	2	1	1
Simulation	4	3	2	2	2	2
Virtual Commissioning	4	2	2	2	1	1
Virtual prototyping, Virtual and Augmented Reality	4	1	1	1	1	1
3D Printing	3	4	3	1	1	1
Reconfigurable Production System	0	1	1	4	4	1
Adaptive logistics systems	0	2	4	4	4	4
Advanced Planning and Scheduling Systems	0	4	4	4	4	4
Internet of Things	0	4	4	4	4	4
Real-Time Location System (RTLS)	0	4	4	4	4	4

Usability of the individual technologies for the specific strategies

4 - Full usability 3 - Partially limited usability 2 - Limited usability 1 - Currently difficult to use technology for a strategy 0 - Unusable technology

consequences for logistics and its self-image. Last, but not the least, the consumption behaviour of society leads to the new logistical requirements, for which the concept of an "Internet of Things and Services" is emerging as a probable solution [11]. Logistics 4.0 (Smart Logistics) is the key to the future. Digitization provides new ways of creating networks together with automation of their supply chains to factories. Nowadays, a whole range of advanced technologies is available for the new logistics strategies to optimize the logistics processes. The degree of impact of selected technologies is described in Table 1, where those technologies totally change business models, not only in industry but in services, as well.

At present, in the area of design of production and logistics systems beginning, authorities and professionals start to talk about the Digital Twin. The above-mentioned methods for formation of the physical twin of the real logistic system, as presented in Table 1, were used. These are the specific methods of CAx, simulation, Internet of Things and RTLS systems. Those systems make up a basic structure to create a physical object or system.

5. The Digital Twin

The Digital Twin can be defined as an evolving profile of the history of current behaviour of a physical object or a process. That helps to optimize the performance of a production factory [12]. The Digital Twin creates an environment in which one can optimize a factory operation directly within the production chain. One can modify the relevant production parameters and production processes and tailor a product or a process to meet the market requirements. All the generated data in this production process create a complete picture of a product or production.

The Digital Twin gathers necessary information and permanently evaluates it. This has the effect of shortening and making the production cycle more efficient, shortening of the start-up time of new products and one can easily detect ineffective settings of production processes [13].

5.1 The factory management development

The production factory strategies can be classified as four types of strategies. In the past, the production factory operated on a reactive strategy. That strategy solved different types of problems only after something had happened. Then the second type of strategy followed, a real-time strategy, and it managed to solve production problems in real-time. The future of production factories is a predictive strategy that involves the Digital Twins and the Big Data. Finally, in a proactive strategy, Artificial Intelligence operates hand-in-hand with the Digital Twin. In Figure 6, one can see the production management scheme of the selected production factory.

5.2 Implementation of the Digital Twin in manufacturing factory

The concept of the Digital Twin calls for virtual replicas of the real world products. Achieving this requires a sophisticated network of models that have a level of interconnectivity, [14]. In the first step of implementation of the Digital Twin, one needs to obtain the required data, the so-called Big Data, about a product or a system for which one intends to create the Digital Twin. These data are collected from a production process and
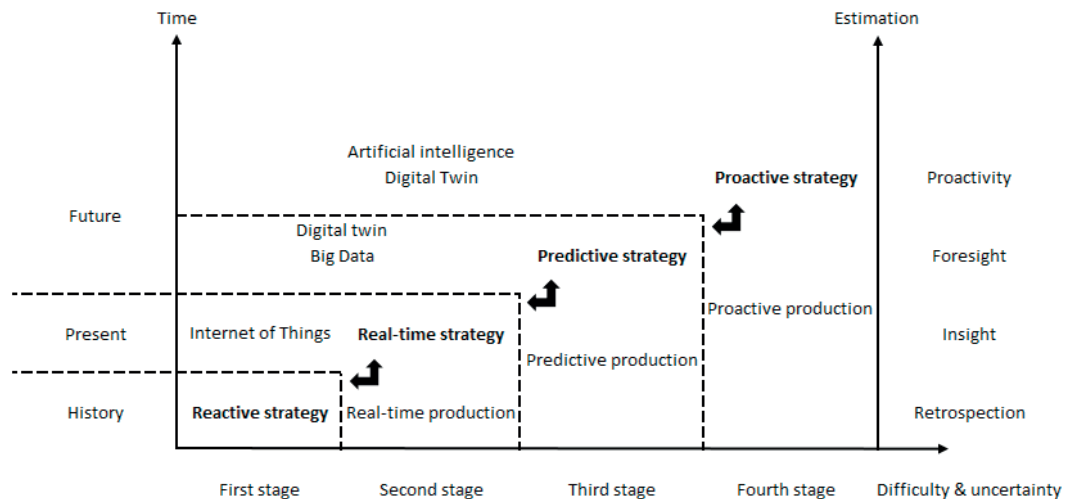
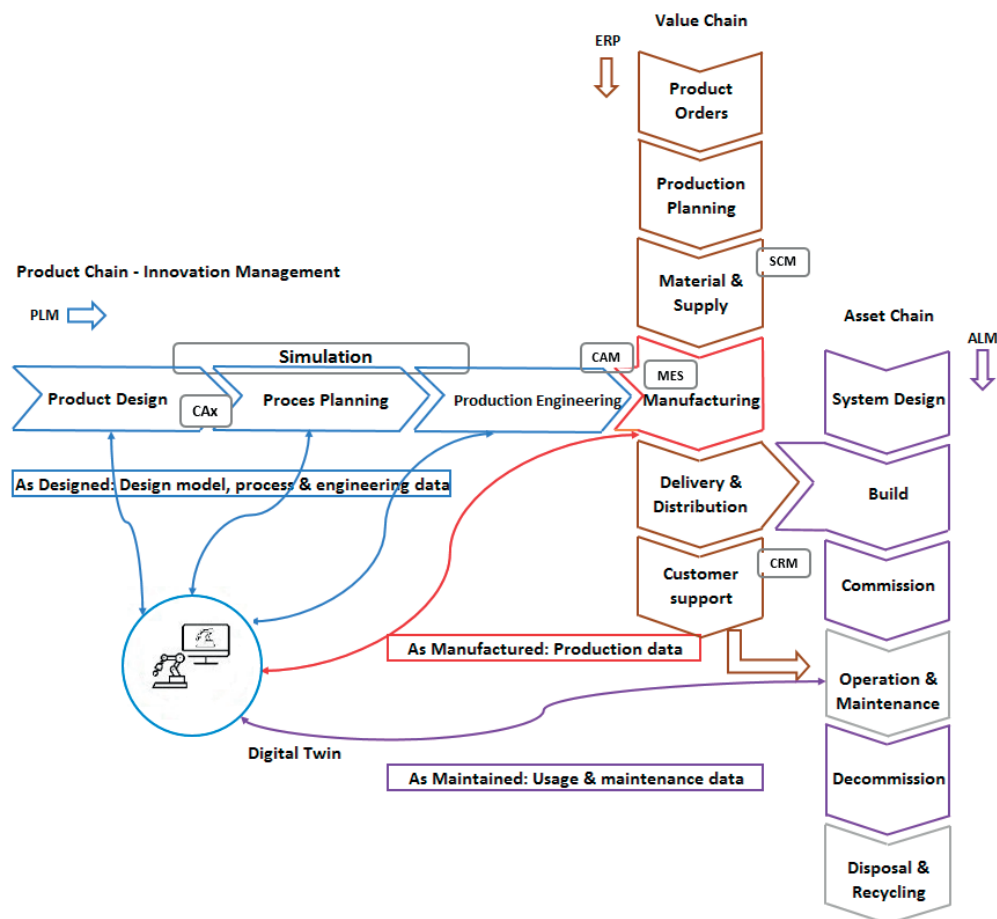*Figure 6 The factory management development*

Figure 7 The proposal of the Digital Twin in the selected production factory

transformed by different methods. One can use several types of monitoring units to gather and process data from the production process to monitor the movement of objects. All the data are stored in Cloud. Consequently, collected data are implemented into the simulation software, where the process is simulated. After obtaining the results from the simulation software, optimization results follow and, finally, improvements are implemented to the real product or process. To collect data within Industry 4.0

concept allows to transfer and apply them in a variety of ways. One needs to consider the distance at which he intends to collect data and the speed of data processing. One can use technology such as Bluetooth, Wi-Fi and UWB (Ultra-Wide Band) for a specific intended operation as these methods can collect data up to a distance of 100 m. However, if one needs to acquire data from a larger production factory or from a whole production factory, then one must apply technology such as Lora, Sigfox, etc.

5.3 The Digital Twin and life cycle of the product

Many of product lifecycle processes, from design, to process planning and engineering, manufacturing is siloed because different software tools, models, and data representations are used and often by many different teams across different organizations and geographic locations. To achieve the goals of smart manufacturing, these product lifecycle processes and manufacturing functions need to be connected and integrated to increase process automation, responsiveness and efficiency and to reduce human errors. In Figure 7, one can see the flowchart about the Digital Twin, where its capabilities and performance can be more readily assessed and deficiencies discovered through analytics and simulation.

One can optimize the manufacturing and operations processes including the better fault detection and diagnostics and predictive maintenance, and thus can improve product design and process engineering and can even precisely determine the product recall scope to reduce the recall cost since the quality factors for each product can be traced back. Within the value, the product and asset chains described previously, the manufacturing, the operation and maintenance and the supply chain management functions deal with physical objects directly and are natural areas that IIoT will bring the most impact. By applying the IIoT technologies to the manufacturing environment, one can collect large amount of data in near-the-real-time covering machine operational states, performance indicators, process parameters, environmental data, quality measurements, all of which reflect the real-time state and performance of the machines and the quality of the products that are being made. Through analytics, one can optimize the manufacturing processes through the real-time monitoring, fault detection and diagnostics, predictive maintenance, precise OEE, online quality assurance, energy efficiency management and worker safety monitoring.

6. Conclusions

The submitted paper includes a survey focused on a medium-sized factory from the automotive industry. The survey focuses on the possibility for implementation of new technologies for the selected factory. Authors in the paper describe the intelligent logistics for the intelligent manufacturing systems. Global developments provide indicators that the main goal is to build intelligent factories that are characterized by capabilities of rapid changes, resource efficiency and ergonomics, as well as the integration of customers and the factory partners into business and value-making processes. Technological bases are Cyber-Physical Systems (CPS) and the Internet of Things (IoT) [15]. Manufacturing factories are economic units that are built for profit. If factory owners want their factories to succeed in a strong competitive environment, it is necessary that they solve their strategy from the perspective of the new trends and the geopolitical and social situation, as well. Factories should consider areas such as digitization, robotization, reconfigurable manufacturing systems and a lack of skilled workers, sustainability of production systems, green energy and others. Technologies that interfere into single strategies in the factory strongly affect the competitiveness of the factory. Therefore, those methods play an important role in different types of strategies for the factory. To improve the efficiency of logistics and production systems in the factory, the Digital Twin starts to be utilized to optimize production systems in the factory. With help of the Digital Twin implementation the factory can increase the efficiency of its production system, minimize costs and times that originate in these production systems.

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