Impact of Industry 4.0 on production logistics

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Abstract. The Fourth Industrial Revolution enables technological processes and digitalization to ensure the transparency of corporate processes; integrates the corporate value chain and the supply network. The aim of the study was to present the technologies of the fourth industrial revolution and to examine the importance of vertical and horizontal integration. The paper reviews the role of production logistics in the corporate logistics system. In a growing market competition, companies are only able to retain their market position by exploiting the integration opportunities between production management and logistics. Based on this, we analyze the positive impacts achieved through logistically integrated production management, providing the possible design of the information system required for implementation and the management tasks. In the context of a specific production logistic example, we present the benefits of real-time scheduling.

1. Introduction
At some stages of industrial revolutions, the evolution of communication coincided with the development of energy utilization and mobility, leading to a higher level of quality of life and changing business models [1]. Today, we are on the verge of the fourth industrial revolution, based on digitization and data. The development of technology creates a permanent network of people, machines and companies, and through continuous sharing of value-creating processes, a competitive, fully customized product is available. The source of competitive advantage, therefore, will not only be the production of coordinated or totally new funds (e.g. additive production), but the supply of products with digital services.

2. Technology background and features of Industry 4.0
Industry 4.0 utilizes the opportunities offered by digitization to maximize the transparency of processes and integrate the corporate value chain and the supply chain, bringing new value to customer value creation. Industry 4.0 technologies can be divided into three major areas: The security problems of information technology (IT) are greatly aggravated by the reuse of previously completed projects.

• Cloud Computing,
• cyber-physical systems,
• smart factory.

Cloud-based services encompass the entire computing space, including computing capacity, storage, platforms, and software. Cloud based systems enable on-demand and decentralized availability of IT resources, data, services and digital business models over the Internet.

Under the Cyber-Physical System (CPS), we mean the integration of IT, software technology, and mechanical and electronics elements where the elements communicate with each other. One of the main features of a cyber-physical system is the very high complexity. Cyber-physical systems are
created by networking embedded systems through wired and increasingly wireless communication networks.

The Industry 4.0 paradigm will be widely spread in many fields of engineering and engineering related systems and processes, including manufacturing [2], assembly [3], logistics [4,5], services [6] but the most intensive development can be recognised in automotive domain [7,8] with focus on the IT and telecommunication [9].

The intelligent factory sees a production environment in which the manufacturing and control equipment largely coordinates and organizes themselves - without human intervention. Its technological basis is formed by cyber-physical systems, the elements of which are communicated with each other through “the Internet of Things” (IoT). In the smart factory, the product (e.g. the workpiece) and the production equipment communicate with each other: the product itself provides production information in the readable, readable form of the production equipment. This data is based on the product on the production line, and the production phases are based on these data.

Figure 1 illustrates the characteristics of Industry 4.0, which demonstrate the enormous capacity that exists in industry and traditional production [10]:

- vertical networking of smart production systems,
- horizontal integration via a new generation of global value chain networks,
- through-engineering across the entire value chain,
- acceleration through exponential technologies.

![Figure 1](image-url)

**Figure 1.** The four characteristics of industry 4.0 [10].

The vertical network of intelligent manufacturing systems uses cyber-physical production systems (CPPS), which integrates production units to make production more customer-oriented and unique. The design of the system requires complete information integration. Integrating data generated during production requires the further development of smart sensor technologies. It is necessary to develop methods to monitor autonomous production systems and track product life. CPPSs should focus not only on the production process, but on the management of the entire supply system. All this requires that all elements of a complex network must record, archive and make available the data generated during their operation. This data should cover all components of the manufacturing process, i.e. production, product, operators, quality change, downtime and, last but not least, resource management [11]. The latter is particularly important because the primary aspect of development is the efficient management of resources, that is, the efficient, full management of material, energy and human resources.

The second key feature of Industry 4.0 is horizontal integration through new generation global value chain networks. These new value creation networks are real-time optimized networks that allow integrated transparency and high levels of flexibility in order to respond faster to problems and failures and thus facilitate global optimization. Like the networked production systems, CPPS provides the network, from procurement logistics to warehousing, production, marketing and distribution logistics to post-tracking services. All data on any part or product is recorded and available at any time,
ensuring constant traceability. This creates transparency and flexibility through the entire chain of processes - e.g. from procurement to production through to sales or from supplier to company through to the buyer. The adaptation of the buyer-specific approach is possible not only in production, but also in development, ordering, production planning, product composition and distribution, allowing to dynamically manage factors such as quality, time, risk, price and environmental sustainability, in real-time, and at all stages of the value chain.

The third key feature of Industry 4.0 is not only the engineering activity across the entire value chain, but also the engineering support and management of product and customer life cycles. This engineering approach is present in the design and development of new products and services, as well as in manufacturing. This feature of engineering is characterized by the fact that data and information are available at all stages of the product life cycle, enabling more flexible data to be formulated by modeling prototypes and product states.

The fourth major feature of Industry 4.0 is the impact of exponential technologies such as an accelerator or catalyst that allows personalized solutions, flexibility and cost reduction in manufacturing processes. Industry 4.0 already requires automation solutions to be highly cognitive and highly autonomous. The potential in artificial intelligence, advanced robotics, and sensor technology is to increase self-reliance and accelerate individualization and flexibility. Artificial Intelligence not only helps to design more driver-driven vehicle paths in factories and warehouses, but also to save time and cost in Supply Chain Management (SCM), increase reliability in production, or analyze large data volumes to find new design and design solutions or to enhance cooperation between man and machine [12].

3D Printing (Additive Production) is an exponential technology that accelerates Industry 4.0 to make it more flexible. 3D printing enables new production solutions (such as functionality, greater complexity at no extra cost), or new supply chain solutions (e.g. reduced inventory, faster delivery times), or a combination of both, leading to completely new business models (e.g. eliminating supply chain members, customer integration).

As far as Industry 4.0 is concerned, the most important requirement is that the elemental manufacturing cells must be "smart" (Figure 2).

![Figure 2. Properties of Smart Cells](image)

| Aware | Connected |
|-------|-----------|
| Smart Products are equipped with sensor technology giving access to condition information regarding the product and its environment | Smart Products are equipped with a M2M communication device that enables interaction and data exchange with other cyber-physical systems |

| Intelligent | Responsive |
|-------------|-----------|
| Smart Products are equipped with computing power that enables autonomous decision-making and self-learning processes based on defined algorithms | Smart Products are equipped with control technology that enables autonomous product adaptation based on internal or external commands |
In the smart cell manufacturer, by using the appropriate sensors, the devices must have information on the qualitative and quantitative properties of the raw materials, the environmental conditions and the expected properties of the product [11]. This implies that the manufacturing unit must be integrated, that is, the cyber-physical system must be connected in the most flexible way via the appropriate communication protocol, in order to ensure the continuous exchange of information for the corresponding data. The smart unit must be intelligent, that is, the unit autonomously organizes its own work by relying on its previous experiences of decisions, that is, the unit learns. Thanks to this learning capability, the unit determines the necessary tasks and order of the production of the product, and provides for the requisite resources [12], based on the signals embedded in products and raw materials.

Through Industry 4.0, the value created for the buyer is transformed. The product should now be understood in an expanded sense, which is equipped with digital elements, e.g. a sensor or communication device (RFID), which sends a signal of its current state. However, development is in the direction of complementing the smart product with data analysis services and providing a complete solution to the customer [13].

The technology elements that are incorporated into the product make it possible for them to offer increasingly complex services to the customer. Four levels of product-based services can be distinguished: monitoring, control, optimization and autonomy, depending on the extent to which they allow autonomy to send the product or machine signal and intervene in the production process [14].

The first level of the clever product is that the product is capable of delivering data on its own, monitoring its status, working process, and external environmental impacts. In this case, in case of deviation from normal, it sends a signal to the operator who can decide on the intervention. This also includes the buyer's ability to track the product's delivery and delivery. Data is excellently utilized in product design, market segmentation, after-sale services.

The second level is for clever products, when monitoring results in an intervention (control). Based on the observed data, the system detects the deviation and either the algorithm or command installed in the device or the cloud is executed.

The third stage is optimization. At this point, not only current monitoring data and built-in control devices are available, but additional software can be used to incorporate historical data into the analysis, which greatly improves production volume, efficiency, and utilization.

The fourth grade is an autonomous product. Autonomous products use algorithms to analyze and communicate with and control themselves and their environment. The human operator now only supervises the operation. Smarter products can learn and be able to memorize their environment, diagnose their own service needs, and adapt to the needs of their users. They can work in places where it’s difficult or dangerous for humans.

In addition to the products, the processes also change. The uniqueness of the product grows, while the flexibility of production processes increases, with the customer and other business partners increasingly intensifying, so the company will not only offer a high-quality product but will also be connected to a high level of service. Innovations in the product and in the production-process make it possible to optimize production, increase efficiency, and reduce downtime, errors and scraps dramatically. All of these circumstances lead us to the clever factory where products communicate with their environment and influence the production system's settings [13].

3. Logistics integrated production management
Production logistics is the most definitive system of corporate logistics; the materials and production tools required for production processes, the harmony of the production process and its sub processes, and the flow of material and related information flow processes are necessary to ensure the production of products in the production to consumers / users. In the process of value creation, its function can only be efficiently fulfilled if connections to purchasing, distribution and waste logistics logistical connections are based on key strategic issues and function optimally, as far as possible. The connections of the production logistic system are illustrated in Figure 3.
Figure 3. Production Logistics Connections [15].

In a growing market competition, companies are only able to retain their market position by exploiting the integration opportunities between production management and logistics. The efficient operation of logistics-integrated production management implies an integrated information system (Figure 4).

Figure 4. Integrated information management system for production management and logistics [15].

Logistics integrated production management takes the inventory level of finished products into account, it manages data from product design (product family tree, component inventory, component drawing) and production technology and process design (order of operation, order of technology data, technology equipment for operation), determines material demand and production capacity needs. Based on the demand for material and the level of readiness of the materials procured - processing of information obtained from the procurement market - is done by sending orders and asking for quotes. Following the evaluation of the quotations and the finalization of the orders, the dispensing of the purchases, the control of the storage of the purchased materials (storage location, assignment order, etc.) and the stock level of the purchased materials will be carried out. A further step in production planning is production scheduling, taking inventory levels and logistics capacities into account. That is, integrated production scheduling also reveals that, besides production resources, logistics resources are also taken into account and optimized.
The scheduling can be based on the computerized management (dispensing) of material flow and storage within the manufacturing process, the control of material flow techniques and production equipment, the monitoring of the interim inventory and follow-up of the products, and the control of the storage of finished products, the finished product level indicator. Production management is closely linked to quality assurance, which can be used to control stock frames, flow management and production control. Finally, the delivery of finished goods takes place in accordance with the order confirmation date and the finished warehousing [15].

Logistic-oriented manufacturing processes aim to create a production organization structure that will solve the logistical principles as fully as possible and thereby increase the company's competitiveness significantly.

The management of the production logistics system is hierarchically structured, that is, strategic, tactical and operational. On the strategic level, processing the order of production and service tasks, taking into account the overall strategy of logistic management, logistics-integrated production-service scheduling, delivery scheduling, stock inventory registration, procurement preparation and administrative work required for these. Logistics control data on the utilization of the device and equipment and capacities are entered to this level. After the processing of such incoming data, the dynamic information base is constantly updated at the tactical level.

The dynamic information base includes a selection of available materials handling equipment, tools and aids, as well as a collection of managed management strategies. At the tactical level, the order of service comes from the strategic level on one hand and on the other hand as a feedback on the operational level as a collection of data. An order management strategy is selected for the order, preparation for dispatching and control is carried out, that is, the delivery of the data to the control body or their manager. At operational level happens the operation of material handling machines, equipment control, acknowledgment of performed tasks and delivery of information to tactical and strategic level. Finally, the logistics system is checked at a tactical level, from which feedback is necessary.

For the cost-efficient operation of companies, the proper management of production logistics processes is of great importance as it is able to influence the company's business performance and customer satisfaction. In logistics and supply chain processes there may be losses in a number of places. The use of sensors in processes creates transparency and flexibility when data is transmitted to the cloud through the Internet and shared with the partners, in order to ensure systemic optimization. By doing so, value-creating processes can be fully tracked in real-time [16].

One of the basic requirements of Industry 4.0 is that it can connect to an electronic network through the Internet. Throughout the entire production chain, data from product data, customer order, capacity data, production logistics data, and quality control are accessed in a network - the cyber-physical system (CPS). Smart innovation is aimed at integrating digital technology into products, machines and processes.

4. Solution for Production Logistics by Industry 4.0 Principles

The Industry 4.0 paradigm should have a great impact on the performance of production logistics. One reason for this is that, in order to meet dynamically changing customer needs, we have to meet manufacturing processes that are flexible and dynamic in responding to customer needs while reducing the finished product inventory. One of the new approaches to manufacturing and installation processes in the automotive industry and the mechatronics assembly industry is the milkrun concept, which essentially means that milkruns are not only supplying material, that is, physical processes, but also providing flow of information.

Numerous well-proven methods are available in the literature for designing the milkrun but have not yet considered how it is possible to schedule new service tasks in real-time while optimizing scheduling of static servicing tasks. During the real-time scheduling of the problem is that for each milkrun scheduled maintenance tasks are assigned to time windows and the milkrun’s capacity limitations not be exceeded. In this spirit, the design of dynamic candidate maintenance tasks can be defined as an NP-hard problem, where assignment and scheduling solutions integrated into the goal.
The starting point of the milkrun is usually warehouse or supermarket, so the optimum target function can be formulated as a complex cost function where each cost component is given by the following activities:

- the cost of pre-scheduled deliveries without assigning dynamic demands;
- the costs of transporting and loading the milkrun to the supermarket and the first and last service places;
- loading and transport costs of dynamic demands.

Limitations to the optimization task affect two areas:

- Limitations on the capacity constraints of milkruns, and
- specifications for time windows for scheduled services.

A number of heuristic algorithms can provide acceptable results for solving this problem, and as a result of this optimization, a reliable, flexible, high availability system can be run that takes into account efforts to reduce the cost of material handling tasks.

As a result of scheduling, it can be stated in general that, due to time constraints and milkrun capacity constraints, dynamically occurring tasks may not be scheduled for the nearest service point but must be pushed in some direction. However, this shift ensures that both time window and capacity limitations can be respected.

Figure 5 shows an example of the practical implementation of the theoretical problem presented above.

Figure 5. Scheduling Dynamic Service Tasks for Milkrun Based Serving.

Three milkrun flights are available and two dynamic requests have to be scheduled. The scheduling of Dynamic Demand #1 could be solved by not having to shift the service from the nearest service point. For Dynamic Action #2, you had to push the drop-out point for the service task that was added to maintain the capacity for milkrun and the service time windows limit. This means that the release of the Dynamic Requirement #2 was only possible at a point of delivery, with all the other delivery points behind, there are enough reserves in the time of delivery, sufficient to perform the material handling operations required to deliver a dynamic demand.
5. Summary
The factory of the future is flexible and transparent. This means that the time of workflows, preparations and switching times can be accurately calculated, so you can determine where there are free capacities. This way, when you receive a customer order, you can accurately calculate when the order is being made and what capacities, machines, tools will be assigned, and what purchases will have to take place until the start of production.

In this paper, we reviewed the technological background and main features of the fourth industrial revolution. We analyzed the competitive advantages achieved through the vertical network of intelligent manufacturing systems and horizontal integration, demonstrated the properties of the smart cell, and determined the levels of services built into the smart product.

The paper deals with the relationship system of the company’s production logistic system, with logistics-integrated production management tasks and with the competitive advantages it can achieve. In solving a specific production logistic problem, we have demonstrated the competitive advantages of real-time scheduling.

The above-mentioned research has many possible directions for further development, as Industry 4.0 is characterized by multidisciplinary that allows further research not only in technical but also in economic and social fields. In relation to production logistics, our future objectives include further examination of the service processes of complex manufacturing systems, in which we intend to set up in-house supply chains that ensure the efficient management of large complex production processes through integrated management of cooperative tools and sub-processes.

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