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INNOVATIVE INDUSTRY 4.0 APPLICATION POSSIBILITIES FOR ROLLER CONVEYOR DESIGN

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Abstract: As a result of constantly changing customer demands, it becomes necessary to review the material flow systems operated by companies from time to time. The purpose of this is usually to minimize material flow losses and/or to ensure the necessary transport capacities. Revisions can affect intermittent and continuous operating material flow systems, and the combination of these. The thesis examines the areas where roller conveyor systems are used. Such systems are typically found in the food industry and the vehicle industry. The development of the 4th industrial revolution, its most important tools, and their applicability in the design and operation of roller conveyor systems will be presented. The article outlines a number of new research areas that may be of corporate interest.

Keywords: roller conveyor system, planning, Industry 4.0

1. INTRODUCTION

Due to the challenges of globalization and sustainability, the management of material flow has become a critical issue for companies engaged in manufacturing activities, as new environmental protection and quality requirements cause a number of challenges involving the transformation of existing material flow serving devices. These challenges can only be successfully overcome with the tools of Industry 4.0. The performance of the material flow can be evaluated with indicators and other factors [1]. Evaluating these factors becomes almost impossible in the absence of Industry 4.0 tools. The tools of Industry 4.0 offer many possibilities to professionals today. The majority of large automotive companies use an extensive roller conveyor system in their production units when performing production tasks. Several types of motor vehicles pass through these roller conveyor systems, whose receiving pallets move in the designated direction towards a specific output/drop-off point with the help of an RFID system. In the roller conveyor system, the company needs to equip the levels with elevators, the branches with a conveyor belt integrated with lifting equipment, and with numerous control units and sensor networks. Nowadays, due to the development of technology, the car factories also have to manufacture many new vehicles with internal combustion and electric motors, which poses a great challenge to the logistics system, because the existing material handling system contains the components of the previous, but still large-volume manufactured vehicles and the manufactured parts of the newly introduced vehicles must also be served. For this reason, the roller conveyor systems often used in the automotive industry have to deal with the level difference, crowded junctions, and conveyor transfers of the roller conveyors in addition to the increased production volume. This dynamic change was not typical in recent decades. The tools of

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Industry 4.0 can be of great help to logistics professionals to solve these types of tasks. For our literature research, we studied the indexed journals found in the Scopus database using the systematic literature review method (SLR).

Table I.

Number of hits of keywords in Scopus [Source: Own editing]

Searched keywords	material flow AND industry 4.0	roller conveyor AND system	roller conveyor	roller conveyor AND material flow	roller conveyor AND system AND (planning OR design)
search within	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords	title, abstract, keywords
2000-2022 in total	278	392	787	29	158
2000	0	3	10	0	1
2001	1	4	14	0	0
2002	2	5	19	1	1
2003	0	11	30	1	4
2004	0	18	36	0	5
2005	0	13	27	1	1
2006	2	17	27	0	2
2007	1	19	24	1	5
2008	2	11	19	0	2
2009	1	16	25	1	5
2010	2	18	33	2	8
2011	2	9	22	0	4
2012	1	21	37	5	14
2013	5	23	38	2	12
2014	1	14	36	3	7
2015	7	15	32	2	6
2016	7	21	42	1	8
2017	14	25	50	1	13
2018	19	18	48	1	9
2019	40	26	52	3	14
2020	52	38	66	0	9
2021	65	28	58	1	14
2022	54	19	42	3	14

Table I shows that we narrowed down the search for the original keywords to the area of "title, abstract, keywords" in order to obtain a search result that better matches the researched topic. After that, the search results for each keyword already yielded sufficiently relevant results. The search results of the repositories in Table 1 were combined, so as a final result, 465 works were analyzed in detail according to the search results of the first, second, fourth and fifth columns. In this regard, it can be concluded that the articles in the publication database overlap, but this does not affect the growth trend in the number of published articles.

Based on Kusiak's 2019 publication, the resilience and sustainability of manufacturing and related logistics activities received limited attention in research. In research, he looks for the solution to make businesses more resilient and sustainable, and with the help of today's innovative technologies, companies can more easily stay on the market [2].

In 2019, Goodall and his co-authors argue that simulations are a vital component in the development of intelligent manufacturing systems because they predict the behavior of shop floor operations and support production planning, scheduling, and maintenance decisions in the manufacturing environment. They note that simulations are often limited in their ability to support real-time business decisions in complex, rapidly changing environments due to the cost and time required to build, update, and maintain simulation models. Their research develops a data-driven simulation approach to predict material flow behavior within remanufacturing operations by using data from digital manufacturing systems (i.e. databases, tracking systems, flow charts) to update and automatically modify simulation constructs to reflect real-world or design [3].

In 2010, Matusiak and Saarinen present methods to evaluate combinations of batches of sequential tasks for assignment to multi-machine system. Two algorithms are used to optimally solve the scenario of an intra-manufacturing transportation application, both based on the principle of best first search, taking into account the total distance traveled within the system [4].

In 2019, Oleśków and Stachowiak spoke about Industry 4.0 and Logistics 4.0. The publication presents the framework of the Logistics 4.0 Maturity Model, which was developed to enable companies to assess the current state of Logistics 4.0 and develop a roadmap for the development process. The model was developed based on Logistics 4.0 literature research and maturity models and planning to offer measures that can be transformed into guidelines or proposed solutions towards Logistics 4.0 [5].

In 2021, Woschank and his co-authors deal with the logistics network of manufacturing companies. They state that industrial logistics primarily deals with the analysis, planning and continuous optimization of the material and information flow of industrial enterprises. In their study, they describe how, in recent years, the digitization movement has created many new opportunities to secure long-term competitive advantages by systematically improving logistics performance and/or gradually reducing logistics costs. In the article, the authors analyze the current literature on digitalization in the field of industrial logistics, with particular attention to action-oriented research results. In this way, the authors systematically examine the latest studies on the technologies and technological concepts of digitalization in industrial logistics, the enablers of digitalization in industrial logistics, the risks of digitalization in industrial logistics and the possibilities of digitalization in industrial logistics [6].

Ruiz, Syberfeldt and Urenda write in 2017 that globalization, product customization and automation play a decisive role in the development of the manufacturing industry in the currently rapidly changing industrialized world. Today, the innovative concepts of The Internet of Things, Factory of Things and Industry 4.0 aim to revolutionize the way technology can help improve production worldwide. While some international companies are studying these concepts in depth and starting to introduce them, it is also clear that they can contribute many advantages to medium and large manufacturers; however, skepticism and uncertainty remain among leaders and stakeholders. This article presents the current and future state-of-the-art technology and implementation of the Factory of Things paradigm, and analyzes examples of current implementation in global manufacturing companies. In addition, this paper discusses the possible implementation of Industry 4.0 in a large manufacturer and how it can facilitate the control and efficiency of production, material flow, internal logistics and production planning [7].

The goal of Dallaora and his co-authors' 2022 publication is to support digital transformation in a manufacturing environment. They discuss that the concept of Industry 4.0 stems from the will to implement the advantages of digital computing in new and existing industrial plants, saving time, materials and energy. Digital transformation requires all machines on the production line to be connected to enterprise applications to capture and analyze data at every stage of production. The collected data can then be used to make and monitor strategic decisions about production, responding to unexpected behaviors, thus reducing downtime and maintenance costs [8].

In 2019, Cortez and his co-authors focus on digitization in their publication. They find that digital manufacturing is an enabler of process planning and decision-making in industry, and the adoption of this technique has improved the bottom line. Taking advantage of the connectivity offered by Industry 4.0 technologies, it is possible to analyze the entire process as the characteristics of individual entities. In addition, simulation creates a digital environment that relies on information that reflects the reality of manufacturing plants, the primary motivation of simulation investments is the creation of different scenarios aimed at the business mission. The model presented in this paper collects information from different entities using Sensory, Intelligent and Sustainable (S3) features to digitize the manufacturing plant and improve the decision-making process. It targets the entire manufacturing process as an opportunity to improve the company's business model practices, taking into account operations infrastructure, workers, and information and material flows [9].

Bondoc and his colleagues write in 2022 that Industry 4.0 requires the development of intelligent systems in order to maximize the uptime of machines and components. They define Digital Twins as a real-time exchange of information between a physical device and a virtual representation in a two-way manner. This connection can best be established with a sensor network. LIVE Digital Twin presents a methodology for designing model-based Digital Twins for asset management through sensors. This method is increasingly useful when the fault history of a device is not immediately available. The LIVE Digital Twin methodology consists of four main stages: Learning, identification, verification, extension [10].

The elements of Industry 4.0 are widely used in many industries. It is important to examine how these innovative tools in manufacturing companies influence the decisions of the new material flow system to be implemented. In relation to roller conveyor systems, the literature deals little with the use of Industry 4.0 devices. In general, a simulation test carried out within the framework of roller conveyor design results in simulation data with industry-standard accuracy.

2. The development of the 4th industrial revolution and its innovative technologies

Without the tools of Industry 4.0, manufacturing companies would not be able to cope effectively and cost-effectively with today's rapidly changing requirements and ad hoc problems. This chapter deals with these innovative technologies. There are two prominent moments in the life of companies when innovation initiatives are more common. The first such moment is when the company is still growing, its performance has not yet reached its peak, but it is already close to it. The desire for innovation is then driven by inner will and passion, and is motivated by maintaining a competitive position and gaining an advantage. The second moment occurs when the company's performance declines. In this case, innovation is affected by the compulsion due to survival [11], which is illustrated in Figure 1.

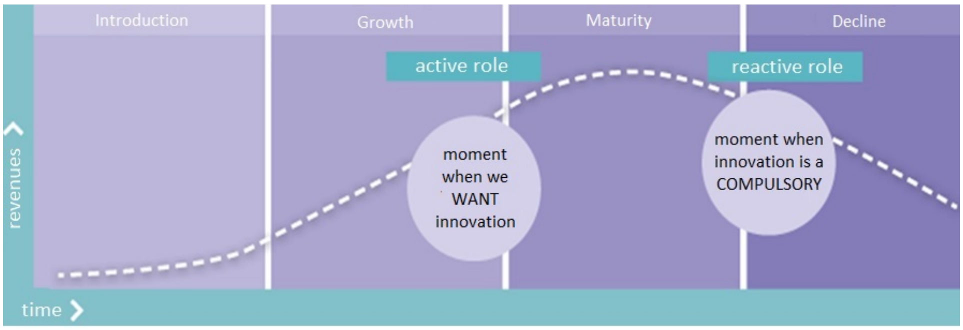

Figure 1. Best moments for the innovation [12]

2.1. Development stages of Industry 4.0

The consistent application of Industry 4.0 not only sets requirements for the company from a technological point of view, but also with regard to the company's organization and work methods. Becoming a company suitable for Industry 4.0 does not happen overnight, but requires continuous development. Examining the economic effects of Industry 4.0, especially at the company level, is a cutting-edge research topic [13]. The definition of strategy and goals must be developed and continuously developed together with corporate development, individual departments and the IT organization in order to achieve a high success factor during the transformation. Figure 2 shows the development stages of Industry 4.0.

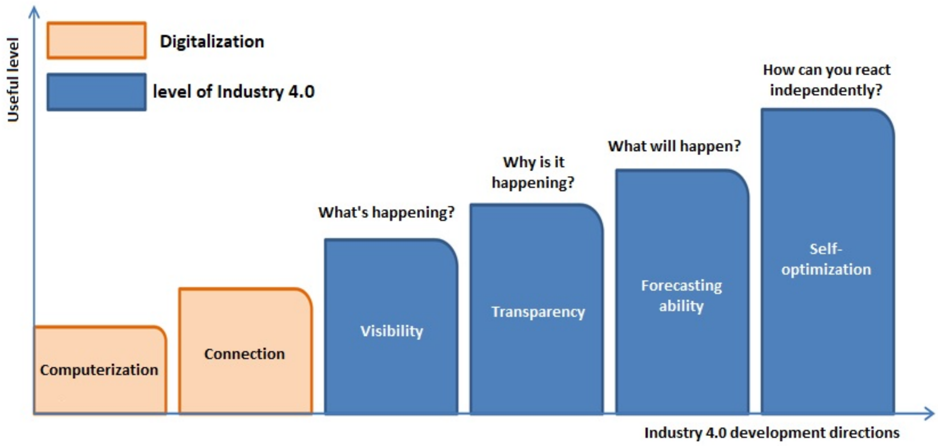

Figure 2. Development stages of Industry 4.0 [14]

The ultimate goal for the company is to achieve optimal operation, which means that the company can make its decisions in the shortest possible time with the greatest positive impact [14].

2.2. The most important tools of Industry 4.0

- *Application of BigData*

There are many representative applications of Big Data, including enterprise management, Internet of Things, online social networks, media applications, collective intelligence, and smart grid [15]. Big Data basically means large amounts of real data generated in the physical and cyber world and their processing. This large amount of data is generated on devices and/or sensors integrated into the IoT, and it is a significant task to ensure the storage and processing of this large amount of data at a level that meets user needs [16].

- *Application of the Digital Twin*

A digital twin system is equivalent to a functional virtual copy of a functioning physical system, which is made up of digital twins. This technology has been used in the space sector for more than 50 years [17]. The development of digitalization has created an opportunity to extract data, gain insight and better situational awareness of the performance of the physical system. Growing interest in the concept has led to the proliferation of digital twin definitions. Consequently, comparing the capabilities of individual digital twins is difficult because they are analyzed using different definitions. In the optimal case, all conclusions and information can be extracted from the system built from digital twins (digital totality), which can be obtained by observing the system built from real elements. The widespread use of the digital twin is illustrated in Figure 3.

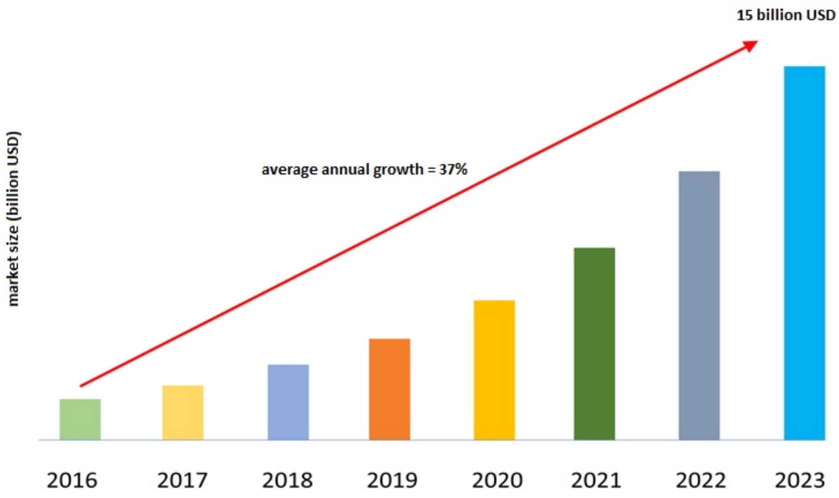

Figure 3. The spread of the use of the digital twin [18]

The application of the digital twin is essential for creating a simulation model from which we can manage the future planned volume with the help of the digital total.

- Simulation test

If we want to define simulation as a concept, then we interpret it as a method that is suitable for realistic modeling of the operation of processes and systems, so that their state changes can be evaluated [19]. When designing a roller conveyor, there are many challenges in creating the simulation model, as we need to accurately recognize the material flow system of the company operating the system and the operation of the roller conveyor.

- Internet of Things

There is no clearly established position regarding the exact formulation of the Internet of Things. According to one wording, "The essence of the Internet of Things is that household appliances, cars, and production equipment will be accessible via the Internet and will be able to communicate with each other - without human intervention." The flow of data takes place between the machines participating in the system and those connected to the Internet - the engine of this data exchange is the "machine-to-machine" (M2M) technology, which is also much talked about these days" [20]

- Additive manufacturing

Additive manufacturing refers to manufacturing processes where objects are made by laying down thin layers, as opposed to traditional machining, during which excess material is separated from a larger raw piece, and the remaining part becomes the finished product. One of its best-known devices is the 3D printer. Its biggest advantages emerge in the area of rapid prototyping and the procurement of smaller parts and auxiliary equipment, through the radical reduction of the turnaround time and the extension of customization.

- Digital factory

There are different applications of the digital factory concept in different industries, all of which are essentially based on digital mapping and continuous matching. There are several definitions for the concept of a digital factory. According to VDI 4499 of the Association of German Engineers (Verein Deutscher Ingenieure), the digital factory is a "comprehensive network of digital models, methods and tools - such as simulation and 3D visualization - integrated by an interoperable data management. Its purpose is the comprehensive planning, realization, management and continuous improvement of all significant production processes and resources related to the product" [21].

The focus of the digital factory is basically production planning. Production planning means the planning of production processes and production systems. Today, the digital factory supports factory planning, product planning and order processing in the same way [14].

3. Application possibilities of Industry 4.0 technologies in the design of roller conveyor systems

During roller conveyor goods transport, piece goods are moved through a row of rollers built into a conveyor with a given conveyor. We speak of gravity roller conveyor transport if the goods move on free-running rollers and the driving force of the movement is the force of gravity. The gravity roller row must be placed at a given slope angle, which determines the transport speed [22].

Roller conveyors enable continuous transport, which has three different versions [22]:

- gravitational movement,
- driven roller movement,
- external movement on free-running rollers.

With driven roller conveyors, the goods move on driven rollers, usually on a horizontal conveyor. Different ways can be used to individually drive the rollers [22]:

- drive belt,
- drive chain, chain system,
- drive belts (straight or spherical belts), etc.

In case of multi-level roller conveyor material handling, we have to solve the bridging of the complex material flow system with the help of other material handling equipment. Since elevators can be easily integrated into such systems, it can generally be said that companies use elevators to solve the bridging of the material flow between roller conveyors in the case of palletized transport of larger loads. In this case, the capacity of the elevator must be designed in such a way as to avoid these material handling equipment becoming a bottleneck.

Nowadays, the integration of Industry 4.0 elements can also be allowed in roller conveyor systems. Their planning, operation and development can only be carried out in an economical and efficient manner by using innovative Industry 4.0 tools.

Table I.
Application possibilities of technologies and their advantages [Source: Own editing]

Name of technology	Possibility of application	Predictable advantage
Big Data	failure prediction, data collection, data processing, machine learning, etc.	preventive maintenance, periodic operation of track sections, control optimization, etc.
Digital twin	virtual commissioning, digital total, etc.	optimization of operations, system configuration, system testing, etc.
Simulation modeling	virtual planning and operation, etc.	data-driven digital maintenance, bottleneck testing, capacity testing, etc.
Additive manufacturing	creation of optimized constructions, rapid prototype production, etc.	easier customization, quick palette prototyping, etc.
Internet of Things	data flow between machines without human intervention, etc.	transparent production system, roller track path optimization - control, etc.
Digital factory	Automated factory planning, connected - networked integration, etc.	reduction of error possibilities, prediction of expected failure, reduction of quality defects, etc.

It can be seen that the tools of Industry 4.0 offer many modern concepts and technologies today in the design of roller conveyor systems, assuming a seamless integration with innovative tools such as the Internet of Things (IoT), BigData, Digital Other or simulation modeling to record and contextualize data to improve manufacturing processes. From this point of view, Industry 4.0 is about information and connectivity.

Mixed reality (MR) takes the data collected by IoT systems and helps workers by displaying the data embedded in the context in real time. Human-computer interaction research has shown that MR can be beneficial in a variety of application scenarios. However, there is a gap between research and practice in real-world scenarios. The question therefore arises as to whether the MR is already suitable to effectively support the daily work of employees in an industrial environment [23].

The continuous operation of production tools and processes is an increasingly important aspect of today's highly efficient production processes. Unexpected operational errors can impact tight production schedules and customers, waste unnecessary materials, and severely damage a manufacturer's reputation. The technology helps plant maintenance teams with an ever-expanding array of sophisticated, condition-based monitoring techniques, allowing engineers to align repairs and replacements with planned downtime. For example, edge network node sensors mounted on motors monitor for vibration signals, and machine learning algorithms "watch" for abnormalities that signal potential early failure. Digital maintenance management solutions provide maintenance teams with an easy-to-use, mobile and efficient tool. Smartenance's web browser-based application adds intelligence to maintenance workflows, and maintenance teams can continuously monitor the maintenance status of the entire field asset on their mobile device. Essential asset drawings, maintenance plans, work orders and task allocation are available through Smartenance's platform, which greatly simplifies maintenance. Machine learning algorithms create maintenance predictions based on real-time data streams from sensors installed on production equipment. The controller creates normal patterns of behavior from the collected data patterns without being specifically programmed to do so. This solution detects anomalies, so you can immediately inform maintenance teams and schedule work orders. Maintenance engineers base their maintenance decisions on data rather than reacting to events.

Understanding device behavior and maintenance requirements is key for digital twins. Modeling and simulating the operation of devices during their entire lifetime takes into account all aspects of their performance, including maintenance. With the implementation of technological innovations, the industrial production environment is also constantly developing. The transformational effects of Industry 4.0 and IoT have already resulted in significant improvements in operational efficiency for asset owners and service providers. The introduction of digital twins seems to increase operational efficiency even further [24]. As production processes become more and more complex, more efficient engineering workflows will be needed so that the production equipment can be put into operation in the production facilities on time or even the system can be optimized in virtual space according to the new challenges. To meet this demand, multiple Industry 4.0 tools must work together to enable customers to more efficiently design, organize and virtually commission their plant systems for better optimization and lower risk.

4. SUMMARY

In the thesis, the many tools of Industry 4.0, as well as the application possibilities of several Industry 4.0 methods in the design of roller conveyor systems, which provide innovative solutions for the industry, and thus can answer important questions mainly with the data and solutions in the virtual space even in the stage of roller conveyor design, have been presented. Innovative industry 4.0 methods do not only mean the application of the most modern technology in the industry, or the continuous catching up with the latest production trends. These are all about applying new innovative strategies that focus more on reality, thereby improving the accuracy of test results. These innovations encourage manufacturing companies to proactively connect and interact with Logistics 4.0 tools.

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