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DEVELOPING THE CONCEPT OF ROLLER CONVEYOR SYSTEMS USING INDUSTRY 4.0 TOOLS

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Abstract: *In the increasingly globalized world, markets are no longer competed for by individual companies, but by groups of companies and networks. Due to the challenges of globalization and sustainability, the management of the material flow has become a critical issue for organizations engaged in manufacturing activities, as the implementation of changed products due to new regulations into the existing material flow service network is a major challenge. Today, Industry 4.0 tools help solve challenges. The tools of Industry 4.0 and Logistics 4.0 offer many opportunities to professionals today, which are driven by several key basic technologies, such as simulation technologies, digital copies, Big Data technology. These technologies have a positive impact on the sustainability performance of material flow activities. Simulation models play an important role in the evaluation and planning of material flow strategies. The purpose of this study is to apply the methods used in Industry 4.0 and Logistics 4.0 in the design of material flow on a roller conveyor.*

Keywords: *roller conveyor, Industry 4.0, logistics*

1. INTRODUCTION

Due to the challenges of globalization and sustainability, the management of material flow has become a critical issue for organizations engaged in manufacturing activities, as new environmental protection and quality requirements pose many challenges to existing material flow servicing 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 difficult in the absence of Industry 4.0 tools. The tools of Industry 4.0 and Logistics 4.0 offer many opportunities to professionals today, which are driven by several key basic technologies, such as simulation technologies, digital copies, Big Data technology. These technologies have a positive impact on the sustainability performance of material flow activities. Simulation models play an important role in the evaluation and planning of material flow strategies. The purpose of this study is to apply the methods used in Industry 4.0 and Logistics 4.0 in the design of material flow on a roller conveyor. Simulation models are multi-criteria decision-making models that simulate reality in virtual space with the help of the digital copy. The simulation model and analysis is done with the Plant Simulation software using a digital copy of a roller conveyor system. The main research areas and future research directions are reported at the end of the study. This study is expected to be useful for specialists working in the field of open innovative methods and material flow systems.

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2. APPLICATION OF INNOVATIVE TECHNOLOGIES IN THE FLOW OF MATERIALS

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 it 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 influenced by the compulsion due to survival [2]. This is illustrated in Fig. 1.

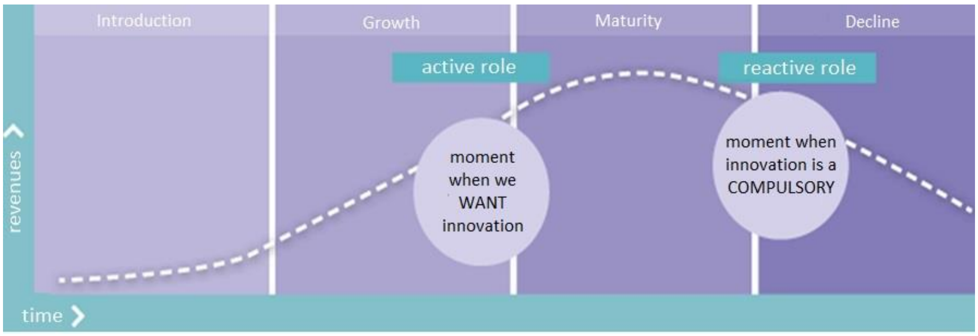

Figure 1. The best moments for innovation [3]

2.1. The stages of the development 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 leading research topic [4]. 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. Fig. 2 shows the development stages of Industry 4.0.

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 [5].

2.2. Application of Big Data

There are many representative applications of Big Data, including enterprise management, Internet of Things, online social networks, media applications, collective intelligence, and smart grid [6]. 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 [7].

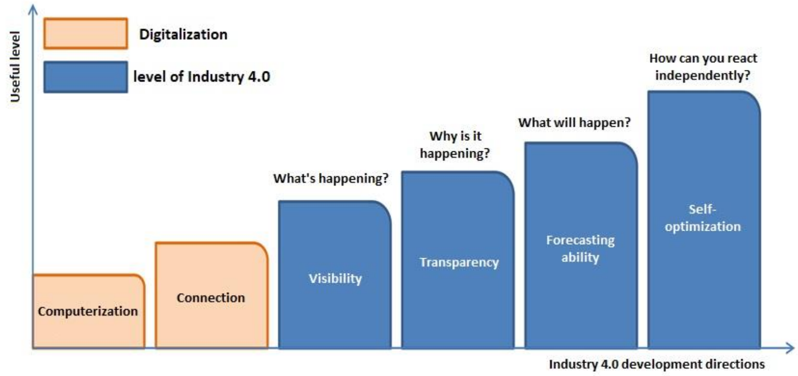

Figure 2. The stages of development of Industry 4.0 [5]

2.3. Application of 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 [8]. 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 analysed 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 Fig. 3.

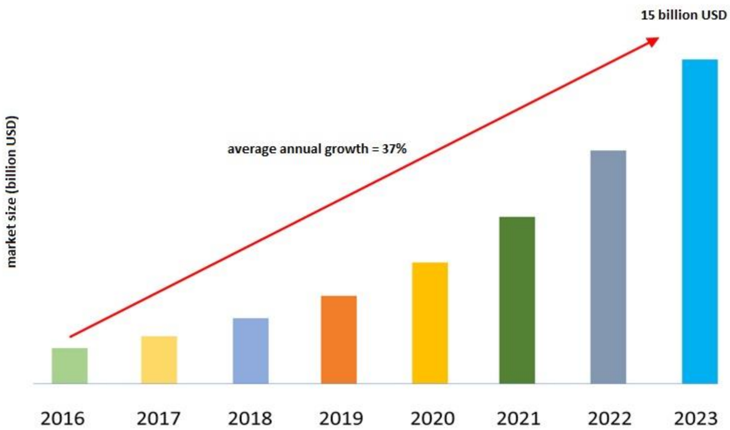

Figure 3. The spread of the use of the digital twin [9]

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.

2.4. Simulation modelling of logistics

If we want to define simulation as a concept, then we interpret it as a method that is suitable for realistic modelling of the operation of processes and systems, so that their state changes can be evaluated [10]. 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.

The most important steps in preparing the simulation study [10]:

- Determination of the purpose of the simulation, delimitation of the logistics system under investigation: Before preparing the simulation program, the objectives under investigation must be clearly defined, since knowledge of them is essential for the delimitation of the logistics system to be investigated. The most important objectives of the simulation study are the following:
    - Discovery of design errors: If, due to the complexity of a system, it may arise that errors may occur in the design (e.g.: selection of inappropriate material handling device, technological equipment, storage between operations), then the future state can be modelled with the help of simulation modelling, so that possible errors can be investigated, become eliminable.
    - Determining the operating characteristics of the examined system variant(s): Before making a decision to revive it, it is often necessary to expand the range of available data (e. g. what effect does changing one or more parameters have on the evolution of the KPI indicator(s)). This data requirement can be satisfied by simulation testing of the current and/or future system version(s).
    - Determination of limit capacities and limit states: When planning developing a logistics system, various limit capacities (e.g.: maximum production capacity, storage and retrieval capacity) and limit states (e.g.: in addition to maximum capacity, the necessary storage capacities, number of employees, number of material handling equipment) with high precision.
    - Optimizing the operation of system version(s): In relation to a predefined system version, simulation modelling can help optimize system parameters (e.g.: ideal number of workers, material handling machines, stocking mechanisms, production plan, arrangement of objects, flight planning), thus increasing the efficiency of system operation.
    - Investigation of malfunctions and their elimination: Many problems can occur during the operation of a system (e.g.: lack of materials, machine downtime, large amount of scrap), the way in which they are solved has a significant impact on the productivity of the system. With the help of simulation modelling, protocols that can be applied when problems arise can be developed, so we can achieve an increase in efficiency.
- Getting to know the operation of the tested system: The persons conducting the simulation test must learn about the material flow and operational characteristics of the elements of the demarcated logistics system, so that all factors important for the test become known in connection with the creation of the model.

- Determination of the set of logistical indicators necessary to achieve research goals (e. g. utilization of technological equipment, lead time).
- Determination of input and output data: After the preceding work phases, the input and output data of the simulation model to be created can be determined, thus the data request made to the examined company can be finalized. The required data is not available in all cases, in which case it is necessary to consider whether to determine the required missing data by on-site measurement or estimation based on statistical data.
- Creation of a simulation model: Based on the available information, the test model is defined, with the help of which the changes in the operation of the system can be evaluated based on the given input data.
- Verification and improvement of the developed model: The operation of the test model must be verified together with company experts (e. g. by comparing the actual and simulation results of the current state and/or by checking the material flow processes in the simulation model). In many cases, the test model may require minor adjustments to function properly.
- Evaluation of test results, formulation of proposals: By changing the parameters selected from the point of view of the test in the certified/validated test model, the changed operational characteristics of the logistics system can be evaluated, based on which proposals can be formulated regarding the appropriate design.

During the development of the examined system, the individual lean methods result in a different degree of transformation in the material and information flow process, so the losses resulting from possible wrong decisions also have different volumes.

3. THE ROLE OF THE ROLLER CONVEYOR IN THE FLOW OF MATERIALS

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 [11].

Roller conveyors enable continuous transport, which has three different versions [11]:

- gravitational movement,
- driven roller movement,
- external goods 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 [11]:

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

Factors determining the movement speed of the goods:

- the design of the conveyor (slope, curve, connection points, etc.),

- the resistance of the rollers (rolling resistance, pin friction, sliding resistance of the goods, etc.),
- the properties of the goods (weight, material, shape, etc.),
- the frequency of arrival of the goods,
- the invested driving power,
- efficiency of the drive system, etc.

Figure 4. Driven roller conveyor types [11]

In the case of a manufactured product with a large mass, the manufactured product and the pallet containing it are transported in the horizontal direction. For this reason, the rollers must be driven, which requires a high degree of automation and sensor positioning. Due to the extension of the service life (e. g. in case of very long transport), the companies divide the roller conveyor system into sections, which sections only work when the pallets pass through them. This also reduces energy consumption.

The driving force requirement for horizontal transport [12]:

$$F_k = F_t + F_{ü} \tag{1}$$

where:

- F_k: the driving force is the need,
- F_t: the load of the loaded conveyor section,
- $F_{ü}$: load on the empty conveyor section.

The load of the loaded conveyor section, if the size of the goods is much smaller than the length of the conveyor:

$$F_t = \left[G \cdot \frac{f}{R} \cdot n_t + \left(G + n_t \cdot G_g\right) \frac{r_c \cdot \mu}{R}\right] \cdot \frac{L}{l_k} \tag{2}$$

where:

- n_t: the number of rollers under the body,
- r_c: spline radius[m],
- μ: friction coefficient of the spline,
- f: half the indentation width [m],
- L: the length of the roller conveyor [m],
- l_k: tracking distance of the goods [m].

Load on the empty conveyor section:

$$F_{ü} = \left[G_g \cdot \frac{r_c \cdot \mu}{R}\right] \cdot n_{ü} \tag{3}$$

$$n_{ü} = n - \frac{L}{l_k} n_t \tag{4}$$

The required engine power:

$$P = \frac{F_k \cdot v}{102 \cdot \eta_{ö}} \tag{5}$$

where:

- $n_{ü}$: the number of unloaded rollers,
- v: speed of delivery of goods [m/s],
- $\eta_{ö}$: the overall efficiency of the drive,
- n: all roller numbers on the conveyor.

In case of material handling on several levels, we must 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 to avoid these material handling equipment becoming a bottleneck.

4. ROLLER CONVEYOR OPERATION AND DESIGN WITH INNOVATIVE METHODS

Nowadays, it is essential for companies to use methods that implement innovative elements. There are many areas in the entire supply chain where it is impossible to achieve the quick and efficient results expected by the management without these technologies.

One of these innovative options for roller design is simulation modelling using digital twins. In the simulation model created in this way, the digital aggregate created from the interconnection of the digital copies can provide the experts who want to improve or develop the roller conveyor with results based on which the current or future bottlenecks and possible problem nodes become visible. Since the problems can even surface during the planning stage, unnecessary investments can be avoided, and the simulation test can provide a basis for a complete rethinking of the system or for the elimination of capacity problems.

4.1. Roller conveyor simulation modelling

The roller conveyor elements in the simulation model must be created in such a way that they have the properties of the real conveyor in terms of size, operation, failure rate, etc. Fig. 5 illustrates the roller conveyor created in virtual space. In general, it can be said that the system is programmed, tested, and statements made in 2D space. The 3D model can also be used to check the location in space and the material flow of the operating process. In the 3D model, it is possible to check the location of the current and/or future conveyors, their right to exist, and their fit into the spaces in the factory, taking into account the width and height limits.

Several sensors are placed on the roller conveyor elements, which helps control the operation of the system. These sensors (light and radio frequency) must also be integrated into the virtual twin, as these sensors will facilitate the control program and the operation of the system cannot be realized without them even in the digital space. The 3D location of the sensors is illustrated in Fig. 6.

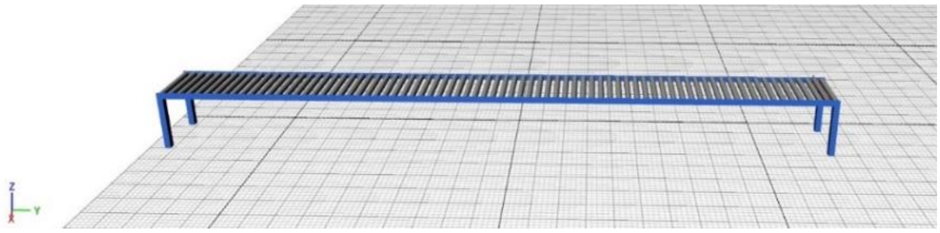

Figure 5. A digital copy of a roller conveyor element [Siemens Plant Simulation]

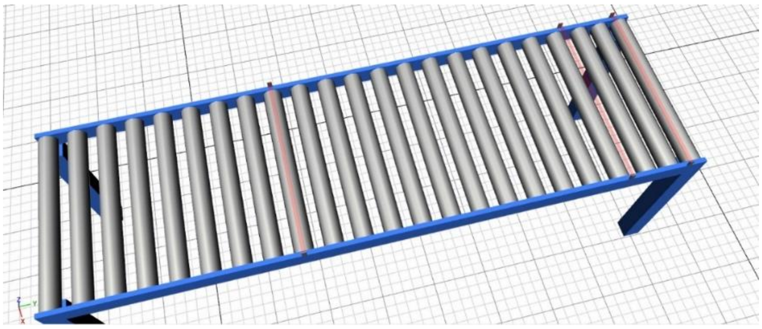

Figure 6. Sensors placed on the roller conveyor in virtual space [Siemens Plant Simulation]

4.2. Simulation modelling of roller conveyor system

The innovative solutions of Industry 4.0 make it possible to create a system built from a set of digital twins in a simulation space, the system of which is the digital whole. Fig. 7 illustrates a system built from such digital twins. With the help of this simulation, tests can be carried out that can provide answers to the uncertain questions of the planned new system or existing system expansion. These can be:

- sizing questions,
- question of sensorization,
- operational strategies,
- search for bottlenecks,
- construction of nodes,
- places and quantity of pulling,
- determining the length of the conveyor section, etc.

Since the innovative feature of the digital environment is that it essentially copies the real system in its entirety, the behaviour of the digital copies during operation and the data and results extracted from the system will be authentic. By applying these methods, manufacturing companies can gain many competitive advantages.

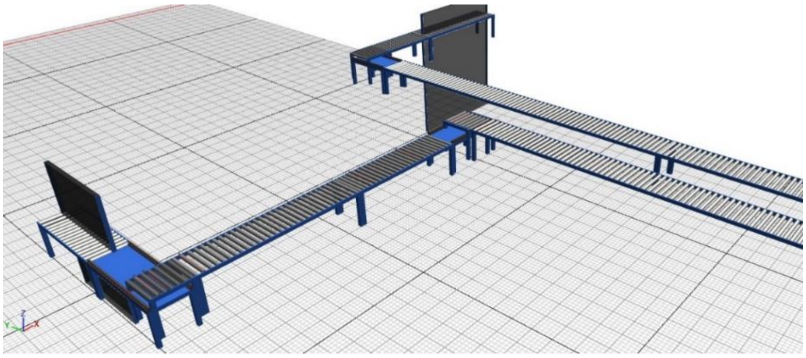

Figure 7 A digital set of a roller conveyor in virtual space [Siemens Plant Simulation]

5. SUMMARY

The thesis presented the many tools of Industry 4.0, as well as the application of a method for the design of roller conveyor systems that simulates reality with innovative digital twin copies, thus the digital totality in the simulation space can answer important questions. The Siemens Plant Simulation software was used for illustration. The principle of operation of the driven roller conveyor systems was presented, as well as their location and role in the material flow. The individual drive modes of the rollers were defined, as well as the factors determining the speed of the goods. The calculation of the driving force requirement of the roller conveyor, the load of the loaded and empty conveyor sections, as well as the engine power of the necessary roller conveyor sections were determined.

The 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 for a new project.

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