Keys Parameters of Digital Transformation of Continuous Transport Systems

Gabriel Fedorko[1*], Vieroslav Molnár[2], Peter Michalik[2]

[1] Technical University of Kosice, Letna 9, 042 00 Kosice, Slovak Republic
[2] Faculty of Manufacturing Technologies, Technical University of Košice with a seat in Prešov, Bayerova 1, 080 01 Prešov, Slovak Republic
* Corresponding author's e-mail: gabriel.fedorko@tuke.sk

ABSTRACT

Digital transformation is nowadays one of key areas of industrial practice, which needs to be addressed in connection with further development of Industry 4.0. Its implementation creates prerequisites for increasing efficiency of process operations at various corporate levels, including logistics. Business logistics processes represent an important element in the value chain of final products manufacturing and services provision. One of main tasks they ensure is transport and handling processes implementation, which can currently be ensured through many technologies, among which continuous transport systems have a significant place. In the paper, a process of digital transformation focused on conveyor transport will be presented in more detail, while individual parameters and key indicators will be specified. Experimental measurement method is considered as a starting point for digital transformation implementation.

Keywords: transport system, pipe conveyor, digital transformation, parameters.

INTRODUCTION

Digital transformation is one of key areas currently requiring intensive attention in the field of science and research [1]. It is because its implementation should, among other things, benefit businesses and the environment. "Digital transformation should bring benefits for all, put emphasis on people and create new opportunities for businesses and their effective functioning [2]. At the same time, digital solutions are a key in fighting the climate change and support ecological transformation of industrial production [3]. Digital transformation affects many areas, including logistics. The implementation of digital transformation in logistics enables to effectively solve current problems and eliminate possible future problems, improve logistics services quality [4], maximize logistics flows' capacity, rationalize material flows, increase transport safety, optimize costs for resources and products supply, eliminate

interlinks by ensuring information transformation into consumer's convenient forms, increase information exchange efficiency, its security, implement new services and innovative customer support tools [5]. Transport processes are an important part of logistics, thus their issues cannot be left out of the digital transformation process [6, 7]. Technologies of digital transformation provide perspectives for ensuring sustainability in logistics and supply chain management [8].

The importance of digital transformation in logistics was also underlined by the worldwide pandemic [9]. "Corona crisis and its consequences have highlighted a necessity of manufacturing companies and logistics' transition to flexible and digital operational, management and business models [10]. In relation to Industry 4.0, digital transformation is becoming a must for businesses by making them more flexible, agile and responsive [11]. Digital transformation at corporate level needs to take place through a complex spectrum

of corporate logistics processes. It needs to cover all areas of corporate logistics, of which one is the area of intralogistics [12].

Intralogistics plays an important role in the functioning of industrial production in various areas. As one of the key tools in it, the digital twin method is nowadays used [13]. It is a highly perspective method that can be used not only in the field of mechanical and electrical engineering production. This method also represents a great potential for the mining and manufacturing industries [14, 15]. However, within each industrial area, digital transformation must be approached based on detailed analyses and analyses of the processes involved in the digital transformation [16].

DIGITAL TRANSFORMATION IN INTRALOGISTICS

Intralogistics, as part of corporate logistics, plays an important role in ensuring production processes in many industrial areas, such as automotive industry, mining industry, processing industry, etc. Intralogistics covers a wide range of business processes, among which the area of intra-company transport dominates. The importance of intra-company transport lies in the fact that it connects individual phases within each production process. It is at the entry of entities needed to implement a production process, ensures their flow and ends by a final distribution of finished products or provision of services. There are currently a large number of technologies for securing internal company processes, among which continuous transport systems play an important role. They also include pipe conveyers (Figure 1). Ecological continuous transport systems (pipe conveyers), as

already indicated, represent an important element in individual intralogistics processes. They ensure their proper operation, impact the level of production's carbon footprint and affect the economic aspect in terms of logistics costs. Therefore, digital transformation implementation makes sense and its research in the area needs to be given adequate attention. Pipe conveyers are an underexplored area for digital transformation. When implementing it, specifics of a particular transport system need to be accounted. For digital transformation, a "digital mapping" needs to be implemented during operation and functioning of this transport system. Digital mapping is understood as a recording of parameters of operational conditions of ecological continuous transport systems. Specifically, these are conditions such as a normal operation, identification of criteria signaling emergence of undesirable operating states [17], etc. In digital mapping, specific indicators and parameters need to be focused on.

Digital mapping of continuous transport systems

"Digital mapping" of ecological continuous transport systems is a process in which key operating parameters are recorded using suitable sensors. Recorded data must then be transformed suitably and imported for further processing, e.g. into monitoring, evaluation or optimization system. The aim of the procedure is, based on collected digital data, to obtain an overview of the pipe conveyer's operation process. At the same time, data can be used to optimize transport equipment's operation, e.g. through the digital twin method or for the needs of planning maintenance, service, ordering and delivery of spare components.

Figure 1. Example of a continuous transport system

DIGITAL TRANSFORMATION OF CONTINUOUS TRANSPORT SYSTEMS

The following parameters were selected for the needs of pipe conveyors' digital transformation (Table 1). The choice was based on providing sufficient information about a relevant continuous transport system. At the same time, the parameters must correspond with the relevant type of continuous transport system (pipe conveyor). The listed key parameters are not final. Other parameters can be defined, depending on other types of damage and operational characteristics.

Operating tension force in the conveyor belt

Tension force belongs to the operating parameters' category. The parameter directly affects

continuous transport equipment's operation. Its size is determined based on the conveyor belt's construction and size. During transport device's operation, the tensioning force is maintained at a required level by means of a tensioning device (Figure 2). A change in the tensioning force's value signals an undesirable operating condition that must be correctly identified and adequate measures taken.

Contact forces on guide rollers

The contact force on guide rollers (Figure 3) is triggered by a mutual interaction of the conveyor belt and the roller's surface. It is a force the magnitude of which depends on the conveyor belt's mechanical properties. The mechanical properties of a conveyor belt are understood as its strength
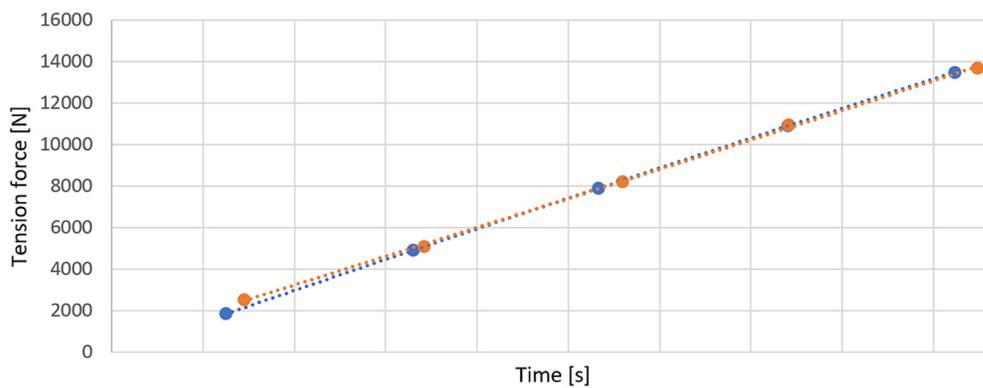

Figure 2. Record of tension force's increase

Table 1. Key parameters of continuous transport systems for the needs of digital transformation

| No.	Measurement	Unit	Category	Failure identification
1.	Operating tension force in a conveyor belt	N	Operating	yes
2.	Contact forces on rollers	N	Operating	yes
3.	Contact forces on forming rollers	N	Operating	yes
4.	Conveyor vibrations	Hz	Consequential	yes
5.	DP speed	$m.s^{-1}$	Operating	yes
6.	Number of DP cycles	-	Operating	no
7.	Ambient temperature	°C	Supplementary	no
8.	Conveyor belt deflection	°	Consequential	yes
9.	Roller and conveyor belt surface temperature	°C	Consequential	yes
10.	Conveyor belt thickness	mm	Consequential	no
11.	Speed of rollers' rotation	$m.s^{-1}$	Operating	yes
12.	Twisting of the conveyor belt	°	Consequential	yes
13.	Resistance force in rolling resistance	N	Consequential	yes
16.	Roller bearings' noises	dB	Consequential	yes
17.	Weight of transported material	$kg.m^{-1}$	Supplementary	no
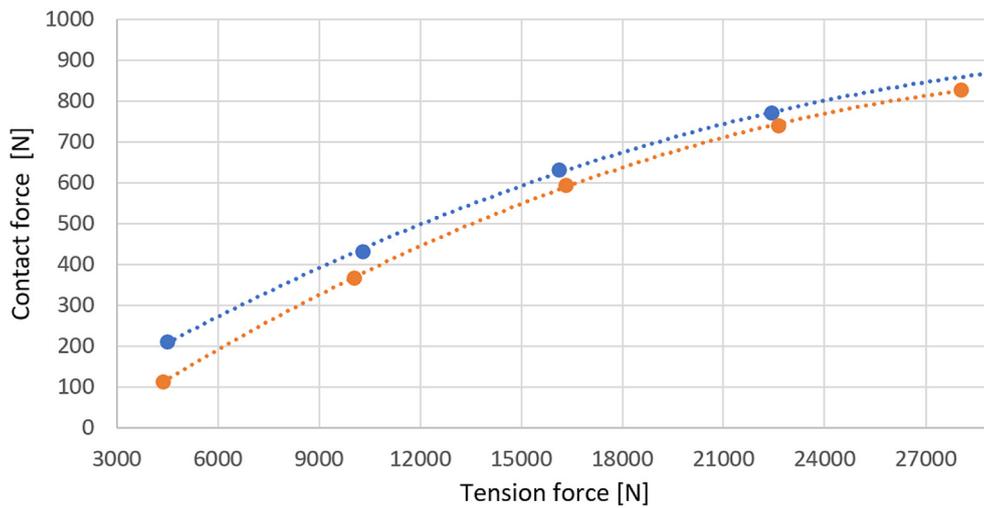
Figure 3. Record of a contact force

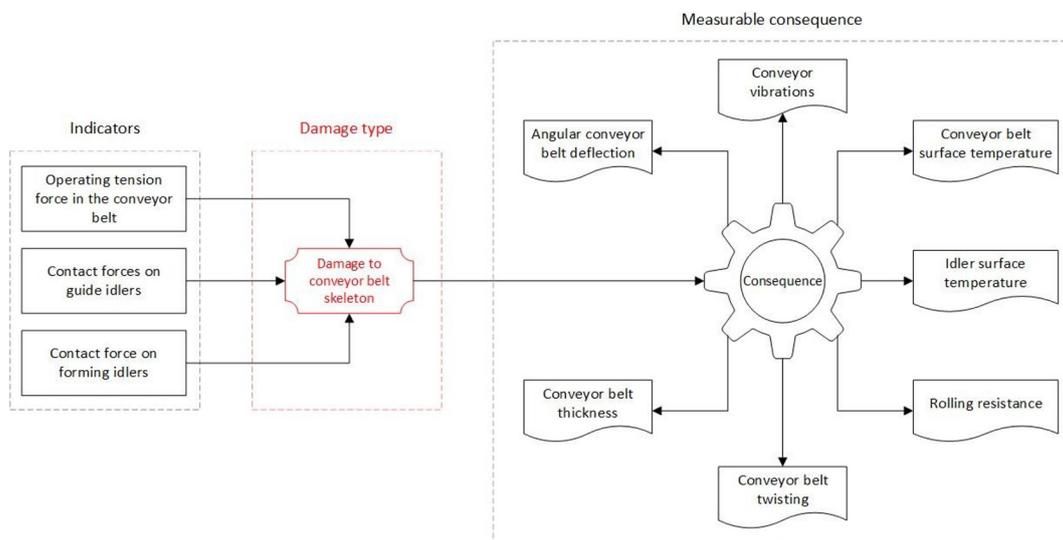**Figure 4.** Example of an insufficient contact force on forming rollers

Figure 5. Digital mapping's result – a digital map for digital transformation

in the longitudinal and transverse direction, and its modulus of elasticity in the longitudinal and transverse direction. These are the parameters which influence its ability to be formed into the shape of a pipe.

The contact force directly effects the extent of the conveyor belt's abrasion (reduction of covering layer's thickness). At the same time, it has a key impact on pipe-like closing of conveyor's belt, thus preventing outflow of material being

transported, its degradation and transport system's surroundings contamination.

Contact force on forming rollers

Forming rollers secure the conveyor belt's pipe-like shaping and closing of transported material in the packed belt. A change in a contact force's magnitude on forming roller signals that the packaging process is insufficient, it can signal outflow of transported material, incorrect packaging, etc. (Figure 4). As a result, the transport equipment's operational safety is jeopardized and there is a risk of possible damage to the conveyor belt.

Use of digital transformation

Digital process maps of various extent can be created, based on digital mapping (Figure 5), to serve for digital transformation of processes in the operation of ecological continuous transport systems and their subsequent identification.

The result of such a digital transformation is a possibility of ecological transport systems' monitoring, based on measured digital indicators. Digital transformation enables full online monitoring with a subsequent diagnostics of undesirable operating conditions' occurrence.

Digital transformation represents a new level in continuous transport systems' management. It brings a new perspective of the wide range of corporate transport processes using ecological continuous systems, enables new approaches' implementation during normal operation, thus increasing efficiency and reducing operating costs.

CONCLUSION

Digital transformation is nowadays one of the most important attention requiring areas. Its scope affects the functioning of various types of industrial plants and the processes taking place within. Digital transformation implementation, for the needs of industrial plants, comes out of the Industry 4.0 philosophy. It has to be implemented in the way so as to include individual corporate processes and enable their integration into the overall corporate digital complex. However, digital technologies trigger a significant change in the way corporate processes take place, including intralogistics. Digital transformation of continuous transport systems represents a challenge in the intralogistics filed, bringing an enormous potential. Its consequence is possible timely failure diagnostics, damage prevention and damage to structural elements of continuous transport equipment. Other possibility to use the data obtained is for creating a digital twin of a continuous transport system. Afterwards, the digital twin can be used to optimize the operation of a part or a complex transport system within intralogistics in various types of industry.

17 key parameters are presented within this research paper that represent a starting point for the realization of the digital transformation of continuous transport systems. The individual parameters have been classified into three categories - operational, consequential, and complementary. These categories declare the impact of each parameter on the operation of continuous systems. The obtained results will be further investigated and evaluated by means of experimental measurements and simulation models. The aim of the research will be in the future to design a system that will implement the collection of operational data of a continuous transport system based on which it will be possible to evaluate its operational states and to perform online diagnostics, or to use the data in the field of the digital twin.

The next research will focus on other parameters that are associated with conveyor belt wear, such as conveyor belt thickness, temperature of bearing of drive and return drum. These are all parameters that will indicate an undesirable operating condition of pipe conveyor. At the same time, there will be an effort to identify other deficiencies, such as dynamic wear, cracks formation and thermal ageing. Their identification will be more challenging and the use of metamodels is assumed.

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