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Using a discrete event simulation as an effective method applied in the production of recycled material

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ABSTRACT

Technological processes play an essential task in the enterprise's production system. The behaviour and functioning of these systems cannot be predicted with certainty as they belong to a group of probable determinate structures. Generally, if we wanted to know precisely the behaviour of this condition in advance, we would have to be able to describe them mathematically or observe the action of the system on a real object. By applying discrete event simulation software, we realize the development of environmentally friendly products and using the simulation, we gain the certainty that the planned tasks can be implemented in a given time frame, while the simulation of the production process can help to clearly clarify and better understand the processes. To choose the optimal manufacturing ways of cleaning the fabrics component from waste tyres, we used the Witness discrete event simulation software to determine the usability and time occupancy of individual machines in the production of new fabric-based material. We simulated the ultrasonic method of cleaning the fabrics component from waste tyres and the subsequent creation of the test specimen. After the simulation, the obtained data can be used by a selection of type and number of machines and auxiliary equipment, by numbers of tools and fixtures, and by numbers of transport equipment. Obtained results bring the best layout of the workplace, the optimal dose of input materials and resources used in production. We have identified bottlenecks in the machines with long waiting times. The research priority was to reduce bottlenecks and increase the effectiveness of the entire of production line.

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1. Introduction

As a result of crucial cost following within each manufacturing process and logistics management, it is required to validate the feasible solutions of scheduled and innovation systems. Important is to look for successful and economical solutions during whole production monitoring [1]. It should be emphasized that the demands for changes in the enterprise still involve some risks. Many problems and dangers arise in the design and operation of complex logistics and production systems. A large number of variants and the complexity of their evaluation do not allow the manager to choose the optimal solution with classic tools [2].

It is through simulation software that it is possible to limit, reduce and limit these risks, by the fact that the simulation software can design the work environment and simulate the results of various conclusions within manufacturing processes [3, 4]. The advantages founded from using of application of the simulation have to be higher than the costs necessary to implement the simulation and improve the system; this is the priority of each simulation used in the manufacturing processes. Industry 4.0 focuses on the complete digitization of all physical assets and their integration into digital ecosystems [5] that communicate with each other, including partners throughout the value chain [6] as can be seen on Fig. 1. Nowadays, the priority is to transform the enterprise with the traditional point of view to a new type, which uses all the knowledge in the field of Industry 4.0, comprehensively in terms of enterprise's digitization, IoT, robotics and connecting the manufacturing enterprise with educational institutions into the one [7].

The certain standard for the simulation to be used in practice introduces a high impact of its use. When deciding whether or not to use simulation support, a simple rule applies – simulation is applicable if the direct benefits of simulation outweigh the simulation costs themselves [8]. It is known that in most cases, the aim of the simulation is not an immediate economic effect. Currently, the use of simulation is focused on increasing a specific market position [2, 8]. This applies to various areas, such as business logistics and supply chain management. This demonstrates functionality, performance or reliability [9]. The effect of simulation is greatly influenced by the time when simulation performed [10]. It is known that optimization by simulation is used at the beginning of the problem. Only in this way will we achieve positive results for the entire company, which will be reflected in the costs themselves, which are the lowest at this stage [11]. In the next step, specifically the introduction of the simulation itself, we have at our disposal the variability of the decision-making process that the simulation brings with it [4]. Quick and correct decisions at the beginning of the decision-making process have a significant impact on the overall result of the examined object [8]. Businesses also use green production strategies that apply, for example, to the principles of lean production, the development of new products that are more environmentally friendly or the use of recyclable, degradable or renewable materials [9, 12]. If green activities are introduced, savings or returns will be proven often in another area and over a more extended period of time [13-15]. If an enterprise invests in these activities, it will achieve efficient use of available resources, a rapid return on investment, increase sales, improve the corporate image and, last but not least, make it easier for new businesses to find new potential customers.

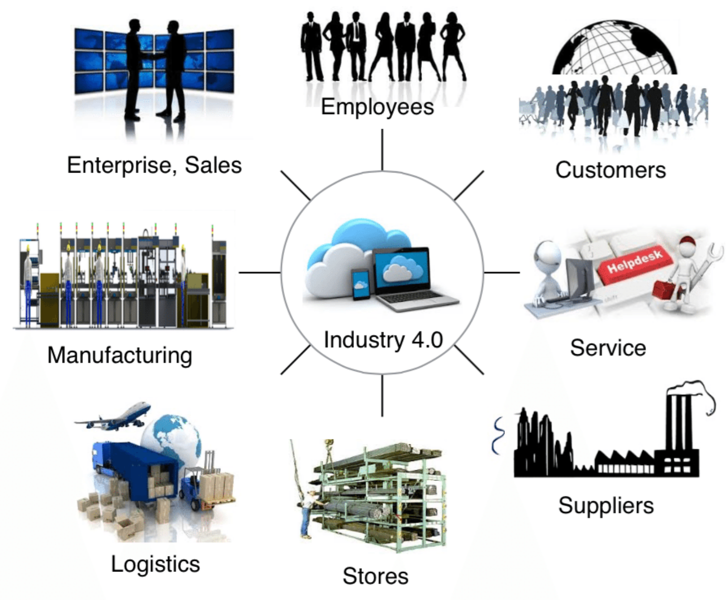

Fig. 1 Industry 4.0 concept [4]

2. Problem definition

Nowadays, the situation in Europe points to increased activity in the field of waste management of waste tyres. At present, waste treatment plants are motivated by the recycling system to recover in terms of environmental solutions [16, 17]. The research enterprises are trying to develop new, more suitable methods for processing waste tyres, as well as using well-known recovery methods and continually updating them. There is no point in using waste tyres philosophy for recycling only. At the beginning of the recycling process, we have to look for and find application possibilities for waste material in the industry. Recycling of waste tyres introduces several technical and technological challenges for recycling companies in all European Union Member States. In each Member State, enterprises involved in the collection and processing of information on the recovery or disposal of used tyres create a critical database [15]. Equally important is ETRA (European Tyre Recycling Association), which collects and elaborates information, processes it and ultimately evaluates and informs the population and other related companies about new opportunities [18, 19]. Simulation significantly helps in planning, management and continuous improvement of production processes. It is an essential help in increasing their productivity, efficiency and flexibility; especially flexibility as a response to the ever-changing requirements of customers in the conditions of global markets that becomes an advantage for companies using advanced technologies, like simulation software. Using discrete event simulation software [20] which we will use in the initial phase of the research, will focus on finding answers to questions presented in Fig. 2. The decision for using a discrete event simulation as a solving method we can see in the uncertainty of future production requirements, time pressure, limited financial resources and the unavailability of modern design tools [21]. Very often, it is challenging to talk about the overall optimization of system parameters. It often happens that there are already shortcomings in the project of the system, which will not allow the full use of all its possibilities [8, 22]. During the real-time monitoring operation presented in the following sections, it is necessary to solve the problems of additional system modifications, which is usually associated with a further increase in costs [9, 23]. The use of discrete event simulation is very suitable for solving the above-presented problems [12]. According to statistics, the area of transport, storage and handling employs up to 25 % of workers, occupies 55 % of the area and accounts for up to 87 % of the time the material spends in the company [15, 18]. These activities sometimes build up 15 % to 70 % of the total cost of the product and also significantly affect the quality of the products (up 3 % to 5 % of the material is degraded by improper transport, handling and storage) [18].

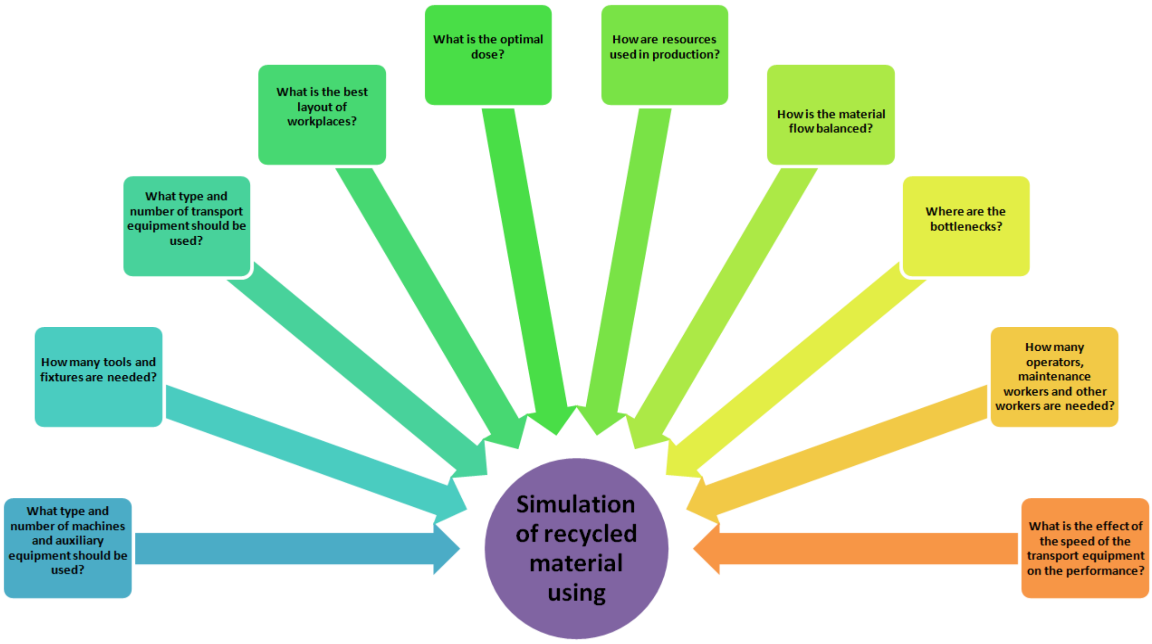

Fig. 2 Main questions about simulation possibilities by the research (Authors own processing)

Waste tyre as a key material

Every vehicle needs a complete replacement of all four tyres every 8 to 10 years. Of course, their wear depends mainly on several kilometre's rides and way of driving. Currently, industrial technologies are dedicated to improving and innovating technologies that deal with the processing of used tyres at the end of their lifetime [19]. In the traditional technological process, separation of three essential components is achieved:

- rubber (Fig. 3),
- steel (Fig. 3),
- fabrics fraction (Fig. 4).

The rubber accounts for about 56 % of the total volume of the separated parts of this commodity. Its other components are steel of about 10 %, fabrics which make up 34 % of the total amount of separated parts of waste tyres [24].

Fig. 3 Waste tyres components: left – rubber; right – steel (Authors own processing)

Fig. 4 Fabrics from waste tyres (Authors own processing)

3. Materials and methods

We used the Witness simulation software, which is the most successful simulation program for the simulation of manufacturing, service and logistics processes offered by the British company Lanner Group Ltd. (UK). The software is suitable for the simulation of discrete systems [25]. The Witness software allows not only the modelling of processes and procedures, it is helpful by visualization of the processes in the 3D view [4]. Still, we used software to select the optimum method for cleaning the fabrics component busyness of individual machines, in the manufacture of moulded test samples, using selected technologies of fabrics component and cleaning analysis of waste tyres (Table 1). Our priority was to use discrete event simulation software [23], in which it is possible to carry out experiments outside the real object and based on the obtained results to propose possible solutions applicable in practice. We can say that simulation is experimenting with a computer model of an entire production system that aims to optimize the production process [19, 26]. The cleaning process [27] of the fabrics component was carried out by the ultrasonic method. The search for optimal solutions by model-based methods is referred to as simulation-based optimization [20].

Table 1 Input parameters of simulation process (Authors own processing)

Name of Process	Fabric from waste tyres	Matrix	Mixtures (fabrics + matrix)	Composites
No. of entered materials	1	1	1	1
No. of assemble	1	1	1	0
Work in process	0	0	0	1
Average work in process	0.98	0.98	0.01	0.00
Average time [s]	1495.00	1495.00	20.00	3.00

Simulation software support used by fabric's cleaning process

The input materials by the investigation are fabrics from waste tyres. Using the ultrasonic separation (Fig. 5), we cleaned the impurities into structures. This separation method is based on the action of the ceramic oscillator. The ceramic oscillator oscillates on the underside of the bath (the bath is filled with liquid) and causing the energy. The result is cavitation effect [27-29]. Material manufactured in this way from the fabrics itself is polyvinyl butyral (PVB) as a thermoplastic matrix to the final product as a composite material [28, 29].

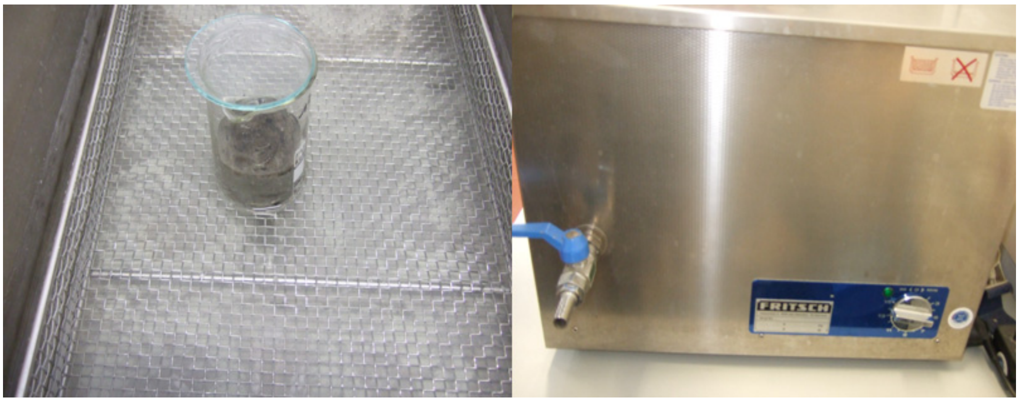

Fig. 5 Ultrasound cleaning process of fabrics from waste tyres: left – sample of fabrics inside equipment; right – ultrasound equipment Fritsch, Germany (Authors own processing)

4. Results and discussion

Using simulation software, which we used in the initial phase of research, we focused on finding answers to questions about material flow and type and number of machines and auxiliary equipment, type and amount of transport equipment (Table 2). The input data from Table 2 is based on a 50:50 material ratio (50 % of fabrics and 50 % PVB matrix). The average work activity for a specific technological process for fabrics and PVB is 98 %. The average technological process times for these commodities are 1495.00 seconds. Table 2 shows the input parameters for operators' work that are transformed into a graphical representation, during their work.

Graphical representation of labour statistics is shown in Fig. 6. From the graph, it can see average job time for each operator. Operator 1 is a crucial employer, deals with the separation process of waste fabrics by 1440.00 seconds. Operators 2 and 3 are excluded from the statistical report because are numbered as a help force (non-full-time employers). Operator 4 works with homogenization equipment. Operator 5 has 0.00 seconds average job time, it is meant only for equipment services. By manipulations with the final product (including all necessary logistics work), our operator spent an average job time of 20.00 seconds.

Table 2 Input parameters of simulation process (Authors own processing)

Name	Operator 1	Operator 4	Operator 5	Operator 6
%Busy	94.86	3.62	0.00	1.32
%Idle	5.14	96.38	100.00	98.80
Quantity	1	1	1	1
Jobs started	1	1	0	1
Jobs ended	1	1	0	1
Average job time (s)	1440.00	55.00	0.00	20.00

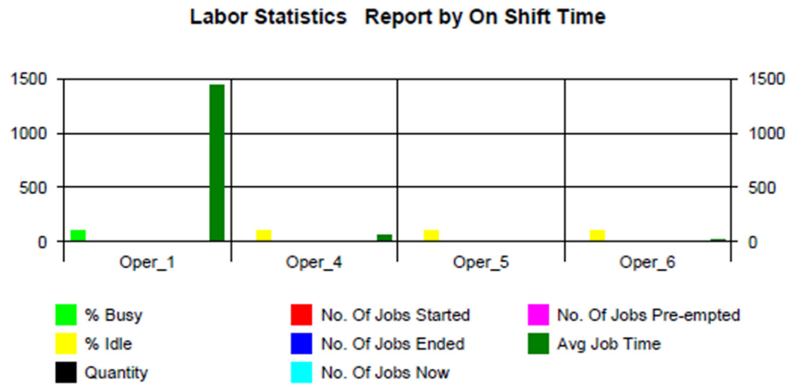

Fig. 6 Statistics evaluation of operators by the ultrasound cleaning method (Authors own processing). Legend: Oper_1 – separation process of waste fabrics; Oper_4 – empty of homogenization's equipment; Oper_5 – moulding process of composites; Oper_6 – manipulation with the final product

Table 3 Part statistics by used conveyors (Authors own processing)

Name	Conveyor 1	Conveyor 2	Warehouse
Total in	1	1	1
Total out	1	1	0
Now in work	0	0	1
Avg. size	0.00	0.95	0.00
Avg. time [s]	2.00	1440.00	20.00

The utilization of conveyors in the simulation of this production process is assumed only at the end of the whole process, it is mean after pressing the board and its transport to the warehouse [26]. However, it is the manual activity of the worker. Table 3 shows the processing of conveyor data used in the individual manufacturing operations, which are preceded by separation by the ultrasonic method.

In the ultrasonic method, the containers were used mainly for material handling for individual operations. The part "Total in" means the total amount of unique components entering the process, also the other items in Table 4 have a value of 1, which represents a value for one particular material, mixture, i.e. for one specific product. The values of 1440.00 seconds belong to fabric's cleaning process. The values 20.00 seconds are by Conveyor 1 and by transporting of product to the warehouse before final control [27]. The cleaning process provided on the one technology equipment located directly on the simulated workplace.

Fig. 7 presents a simulation of material flow in the work environment of Witness software. One of the main advantages of using computer simulation in our research was the ability to simulate the processes mentioned above at the required time [26, 27]. The simulation of the real time necessary in a computer simulation only takes a few minutes [28]. After performing the simulation process, we kept the possibility of reports, based on which it is possible to verify the validity of the required main goal of the simulation, which was defined in Section 2. Through advanced models, it is possible to find the optimal solution under specified limiting conditions in a short time.

Table 4 Part statistics by used buffers (Authors own processing)

Name	Buffer 1	Buffer 2	Warehouse
Total in	1	1	1
Total out	1	1	0
Now in work	0	0	1
Average size	0.00	0.95	0.00
Average time (s)	0.00	1440.00	0.00

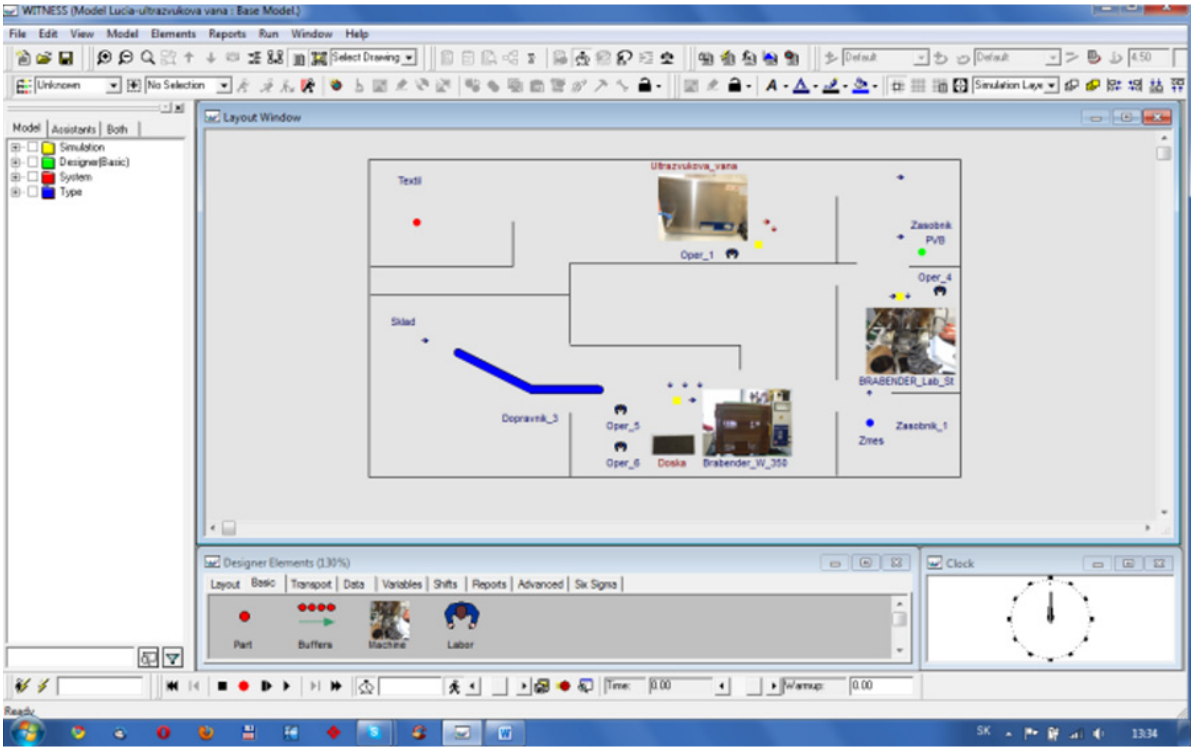

Fig. 7 Ultrasound cleaning process used simulation software Witness – simulated manufacturing process (Authors own processing)

Optimization of the production system requires constant attributes of production requirements, which do not lead to the overall optimization of the system in times of uncertainty of future production requirements, time pressure and lack of financial capital for design tools [30]. Problems arising during operation need to be solved by additional system modifications, which result in increased costs [29]. We can avoid this problem by using Witness discrete event simulation, which will allow a more in-depth examination to occur and significantly reduce the risk [31, 32].

The presented paper used the Witness discrete event software, which can effectively model the critical elements present in the new modern enterprise and industrial systems, as follows:

- manufacturing systems (fabrics separation from waste tyres/cleaning process),
- their internal processes (separation, mixture process of two main components and moulding technology),
- logistics operations (material flow, operators activities, buffers, warehouse logistics),
- available material flow analysis.

After realised investigation, we can answer the question mentioned in the problem definition stage, by the beginning of the research (Table 5). Economic point of view is visible in every step of simulation creation [33]. The modelling itself takes place in a discrete-time. It can be used to design various scenarios of production processes, from which the simulation outputs choose the most suitable in terms of overall optimization of material consumption and operating costs [34].

Intelligent manufacturing systems [31, 33, 35] are at the forefront in which knowledgeable information agents form a network of decentralized and distributed intelligence [36]. Decentralization and distribution of control are equally significant in the case of intra-logistics processes of manufacturing enterprises.

Table 5 Summary results after simulation (Authors own processing)

Summary results	
Problem definition	After the simulation process
What type and number of machines and auxiliary equipment should be used?	• 2 × Conveyor belts • 2 × Buffers • 1 × Ultrasound equipment • 1 × Homogenization equipment • 1 × Moulding equipment
How many tools and fixtures are needed?	• Cleaning • Homogenization • Press moulding
What type and number of transport equipment should be used?	• Band conveyors
What is the best layout of workplaces?	• Best layout of the workplace is presented in Fig. 6, after the simulation process
What is the optimal dose?	• The optimal dose for cleaned material is, according to input data: 1 for fabric-filler, 1 PVB-matrix, 1 mixture, 1 final product-test sample
How are resources used in production?	• Use of recycled material by the production of new material • Waste tyres fabrics • Recycled PVB
How is the material flow balanced?	• Product and by-product (relevant only for organizations that produce a physical product) • Non-product Outputs (Waste and Emissions/Pollutants).
Where are the bottlenecks?	• For production lines, we monitored the percentage utilization of each production unit. The machine that uses the highest percentage of its capacity is an obstacle. • The machine operates at full capacity while working as a bottleneck and limits other production units to a lower capacity utilization rate. • Machine with long waiting times. • We need to increase the capacity of the bottleneck and thus increase the size of the entire production line.
How many operators, maintenance workers and other workers are needed?	• 1x Operator by input materials and manipulation works • 1x Operator by ultrasound cleaning process • 1x Operator by homogenization • 1x Operator by press moulding
What is the effect of the speed of the transport equipment on the performance?	• Conveyor belts provide a speed that can be calculated as the linear distance travelled by a point on the conveyor belt in one minute.

5. Conclusion

Intelligent manufacturing system provides the necessary information infrastructure for the proper functioning of used technologies. In addition to automation and subsequent autonomization of activities, these solutions increase the agility of individual operations [36].

Our proposed production process of cleaning fabrics from waste tyres becomes more flexible and better respond to external stimuli (customers, markets) with the possibility of more significant variability of the resulting product or service. The summary of the most essential inputs and outputs of used simulation software is presented in Table 6.

Advantages of our research we see in minimizing of productions times by homogenization of the mixture and pressing samples and less human intervention in the whole production process in comparison with work without simulation of material flow. Regarding this issue, we can expect less spoilages, optimized distribution ways, better energy and money flow. Last but not least is the environmental impact.

Using Witness discrete event simulation software, we used Icons to create a production system model. The icons formed our "Menu" from which we selected icons that corresponded to the required element of cleaning the fabric from waste tyres. The simulation model created by us can visually precisely communicate to what is required from practice. In the future, we plan to expand our research by adding a third dimension to virtual memory using a simulation model that is created in two-dimensional space. The display of the production line using virtual reality will thus expand the possibility of a visual approach to the simulation model of reality.

Table 6 Evaluation of the use of simulation in the cleaning process of fabrics from waste tyres (Authors own processing)

Strengths of simulation	Weaknesses of simulation
• Fast verification of the simulation process without the need for real time • Detection of restrictions • Enough reports to verify the simulation target • Ease of simulation, with no programming required	• The need to know the researched object and the relationships between entities • Simplification of the model • Failure to anticipate employee behaviour • Higher start-up costs • Methodological complexity
The simulation allows	**The simulation does not allow**
• Solving analytically unsolvable tasks • Examine system dynamics • Temporal and spatial comparison • Disclosure of new facts • Decision support at different levels of decision making • System improvements • Cost savings in various areas of the enterprise	• Replacing a person in the decision-making process • Complete production management • Accuracy of data with incorrect parameters • Automatic system optimization • Result if the goal is not defined

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