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Application of Digital Engineering Methods in Order to Improve Processes in Heterogeneous Companies

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Abstract: In the presented article, the initial phase is focused mainly on familiarization with the production focus of individual enterprises and their financial security, which provides a basis for the proposal of possible solutions to shortcomings. A more detailed study of production through simulation studies using Process Simulate software provides a more comprehensive view of production in the assessed enterprises, where the current course of production at workplaces is evaluated in detail, and suggestions are then offered to improve the revealed shortcomings. In the end, there is an assessment of the companies from the point of view of homogeneity, so that it is then possible to make an inter-industry comparison of the revealed errors and shortcomings, with the result of finding common recommendations for a wide industrial spectrum.

Keywords: process simulate; Tecnomatix; bottleneck; industry; PLM; digitization

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1. Introduction

The main task of corporate strategists is to set the direction of the company and discover how to capture the potential of the company; they should, first of all, take into account Industry 4.0. To a large extent, more and more modern business models are being created and traditional models are being innovated; therefore, nowadays it is more and more difficult to find an opportunity and react to it. Even up to 84% of suppliers expect new competition [1–3].

A PLM solution is not only a technology, but it is also an approach where business processes are very important or even more important than the managed data itself. While information is contained in all media (electronic and print), PLM is primarily about managing the digital representation of that information. That is, it includes the life cycle of a new product from its conceptualization to the end of the life of the device, so we can say that we are talking about the most comprehensive management strategy in the production sphere. In essence, PLM expands the original PDM solution with other areas that are primarily more oriented toward customer needs. PLM includes all the necessary tools, processes, and systems needed to produce a new product or upgrade an older product, as well as to ensure the management of digital content. The PLM solution can adapt very flexibly to customer needs and also support accounting, economic, marketing, and administrative activities [4–6].

More and more companies that already have some kind of data management are realizing that they are far from using the full potential of existing solutions, and are looking for resources to implement a full-fledged solution, for example, with the help of subsidies within innovation programs, etc. Most companies suffer from a long innovative cycle and a slow reaction to the implementation of offers, which is of course of fundamental importance for the economy of the company. Gradually, they begin to understand that without changing the strategy, consolidating tools, and unifying data sources into a unified environment, they have no other option than to implement these two fundamental goals and thereby increase competitiveness [6,7].

The main goal of the work is the use of some elements of PLM solutions in order to reveal possible deficiencies and errors in production, material flow, warehouse management, inter-operational transport, or other aspects of the production process in selected production halls of individual companies [8–10]. Subsequently, after revealing the shortcomings, incorporate proposed solutions gradually for each examined production workplace into simulation studies and evaluate their benefit to the company. The task was to find common features in the production processes of individual companies, whose focus is of a heterogeneous nature, and to point out the same recommendations that, when incorporated into the process, are applicable in every branch of industry [10–14].

The following sub-goals are necessary to achieve the desired results:

- creation of a data analysis of each company, in order to evaluate the current state;
- creation of a library consisting of a wide range of models, applicable when compiling simulation studies;
- developing the necessary number of simulation studies with the aim of creating an optimal material flow for selected production halls;
- evaluation of the achieved results with the compilation of several common recommendations for businesses [15–18].

2. Materials and Methods

Industrial competitiveness is directly linked to the proper integration of physical and information flows [19]. The integration of information and material flows and the improvement of decision-making are highlighted as important benefits of applying the CPS concept in manufacturing and supply chains [20]. Such integration represents a significant challenge due to many stakeholders, processes, tools, and information formats.

A variety of methods can be used in benchmarking decision-making, including optimization, simulation, and hybrid models. The Process Simulate simulation software from Siemens' Tecnomatix portfolio used in the work is a key tool for speeding up time to market, allowing organizations to virtually validate the production process in advance [21]. An important overview of mathematical models is presented in particular by [22] in connection with the integrated planning of production and transport processes. Several optimization problems are considered separately in the operation context [23]. The resulting independent results are then gradually assessed for major planning at the tactical level [24]. Instead of using successive independent areas of planning, a single integrated operational plan represents a relevant opportunity for improvement [19]. The potential for an integrated solution to manufacturing and transportation problems has been documented [25]. However, optimization methods are either too complex or require too much when it comes to computational resources and time to assess the impact of uncertainty. Modeling, on the other hand, can appropriately represent the uncertain behavior of the system, including dynamic conditions and disturbances. To solve production and transportation scheduling problems, [26] proposed an approach to the shop floor (multi-product period) scheduling problem called a hybrid approach that combines linear programming and modeling. The goal of using a hybrid approach is to find a scheduling problem that is not only mathematically optimal but also feasible [19]. In the proposed hybrid algorithm, it is important that the convergence of the method is tested by comparing the optimal production level derived from mathematical programming with the existing time constraints. Subsequently, new properties and scenarios of the method were discussed by [27,28].

3. Studies of the Production Process in Enterprises

This chapter serves to approximate the course of production in individual enterprises in order to reveal possible errors and deficiencies in production by means of a simulation study. Subsequently, the revealed deficiencies are forwarded to correction through proposed solutions, which are then incorporated into the study and bring results.

3.1. Notes jsc

The Company Notes Inc. (Betliar, Slovakia) belongs to the paper and hygiene industry sector. This company produces a wide range of paper products, such as notebooks, record books, sketchbooks, notepads, drawings, folded double sheets, colored paper and cardboard, waiter receipts, and more. As the main representative of production in Notes Inc., from a wide range of products, we chose a school-lined notebook in A5 format with a number of 10 sheets.

3.1.1. Manufacturing Process Processing

The main raw material used in the production of lined notebooks for children in A5 format is wood-free offset paper 60, 70 g/m^2. It is a white paper that must be visually without creases, holes, tears, or other mechanical damage. Another component is the lining paint for lining notebooks in a liquid state, diluted with water. In our case, absorbent paper is also added, which is fed from the side of the line. After cutting the correct number of sheets and adding blotting paper, the paper is placed on the cover of the notebooks. Again, this is wood-free printed offset paper with an area weight of at least 90 g/m^2. Finally, a steel wire with a round section of ∅ 0.55 mm is used in binding, which is wound into a disc weighing approx. 4 kg (Figure 1).

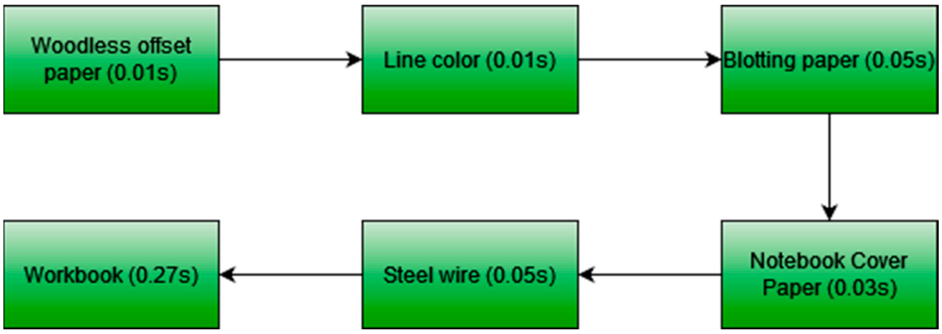

Figure 1. Production scheme of A5 notebook [own processing].

3.1.2. Evaluation of the Current State of the Workplace

The production process of notebooks is ensured on the production line and two additional packaging machines are located continuously behind each other. At the beginning of production, there is a fully automatic line for the production of Bielomatik notebooks, which is complemented by a Hugo Beck packaging machine for packaging products in GP foil and a Hugo Beck packaging machine for group packaging in GP foil. The simulation study will therefore focus exclusively on the given line in a separate hall (Figure 2).

The individual operations that make up the entire process of producing an A5 lined notebook, together with the time values, are shown on the following algorithm (Figure 3).

3.1.3. Proposal for Improvements

The production process of creating 10-sheet lined notebooks in A5 format takes place exclusively on the Bielomatik line with associated packaging machines, therefore the individual operation times are carefully set in advance and offer almost no room for their adjustment. During a deeper investigation of not only the production process itself but also of the associated auxiliary processes necessary for the smooth running of the material flow, and not only on the given line but also on other lines in the production hall, several shortcomings were found.

We would characterize excessive production in advance as the first deficiency. This is manifested in the overproduction of basically every type of product in the company's assortment. We would suggest introducing a suitable production planning system in the company, such as Kanban or SAP, and also applying a method for rapid change of the SMED assortment.

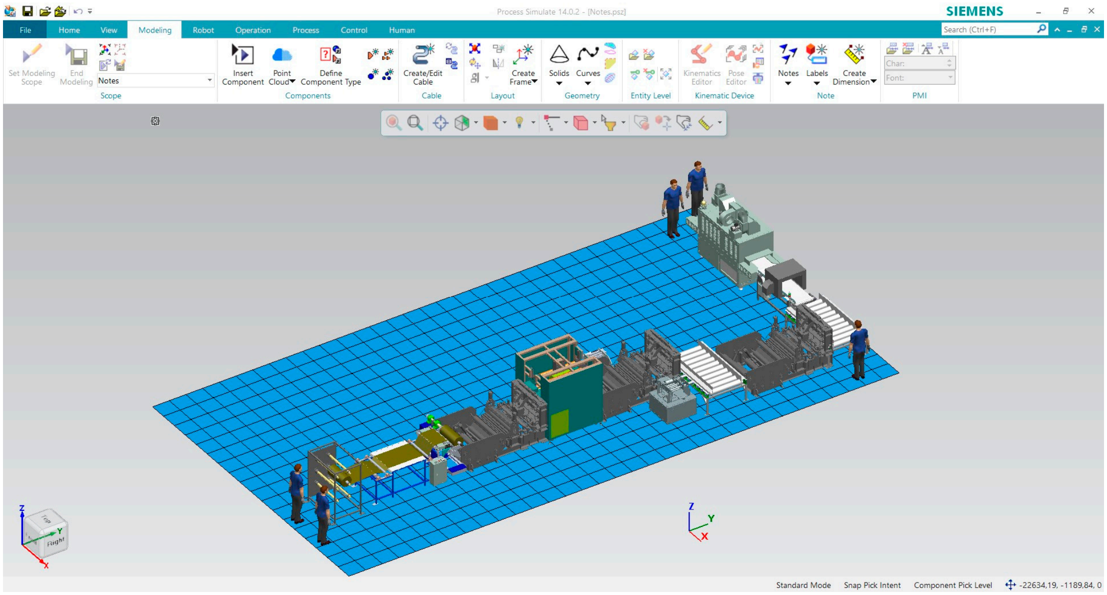

Figure 2. Simulation model of the production line [own processing].

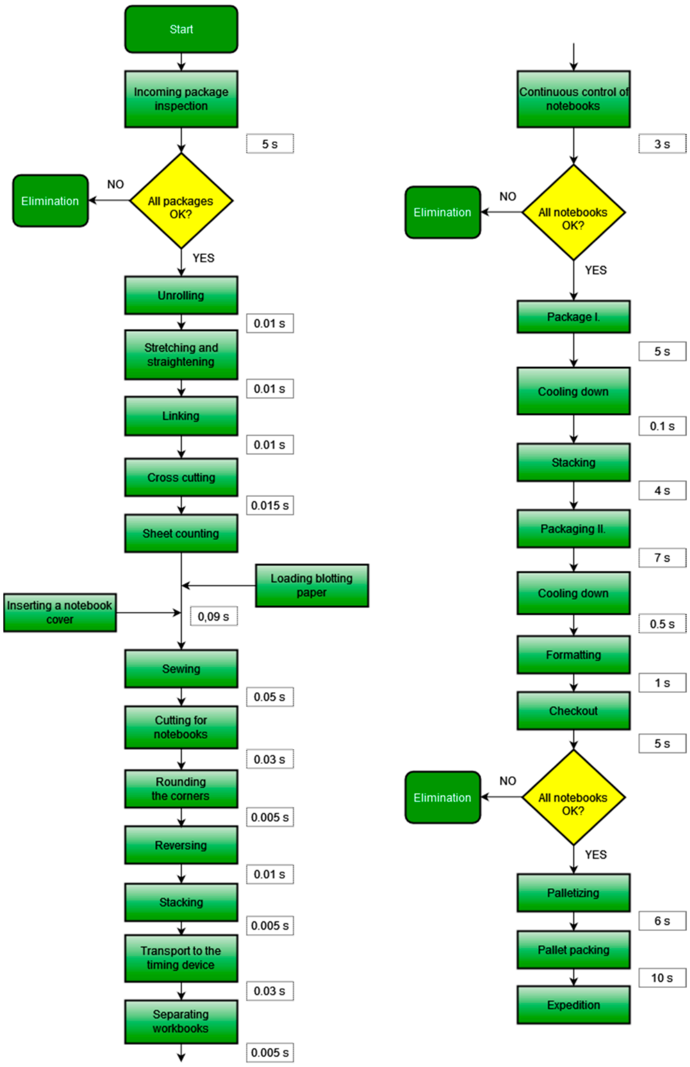

Figure 3. Algorithm for production of A5 format notebooks [own processing].

Another shortcoming we observed in the production hall is the excessive amount of intermediate warehouses. The production hall is oversaturated with them; even though we understand that for a given type of production, it is necessary to have these warehouses in production in larger quantities. Intermediate warehouses in such a volume in the hall cause disproportionate movements of employees when going around them, as well as lengthening the transport of finished products to the warehouse, or the removal of scraps. A possible solution would be the purchase of automatic carts for the transport of semi-finished products needed for production and their programming by employees according to the production plan on individual lines. This would also facilitate inter-operational transport and avoid possible collisions between forklifts and inter-operational warehouses.

3.2. Magna PT Ltd.

The company Magna PT Ltd. (Kechnec, Slovakia) belongs to the automotive industry sector. As the main representative of production at Magna PT Ltd. we chose the DCT300 dual-clutch transmission, which represents the third generation of transmissions in this company. This transmission is used in the BMW X1, MINI, and BMW Series 1 and 2. The third generation of Magna dual-clutch transmissions is the basis for various efficient and scalable hybrid transmissions.

3.2.1. Manufacturing Process Processing

The DCT300 double-clutch transmission under investigation consists of over 300 parts; therefore, for a better overview, we have created a simplified factory-assembly diagram, as you can see in Figure 4. Assembly time data is also assigned to individual parts, and the critical path is highlighted with a thick line. It consists of two manual transmissions, where the gear stages of one are even and the other is odd, and at the same time, each has its own clutch.

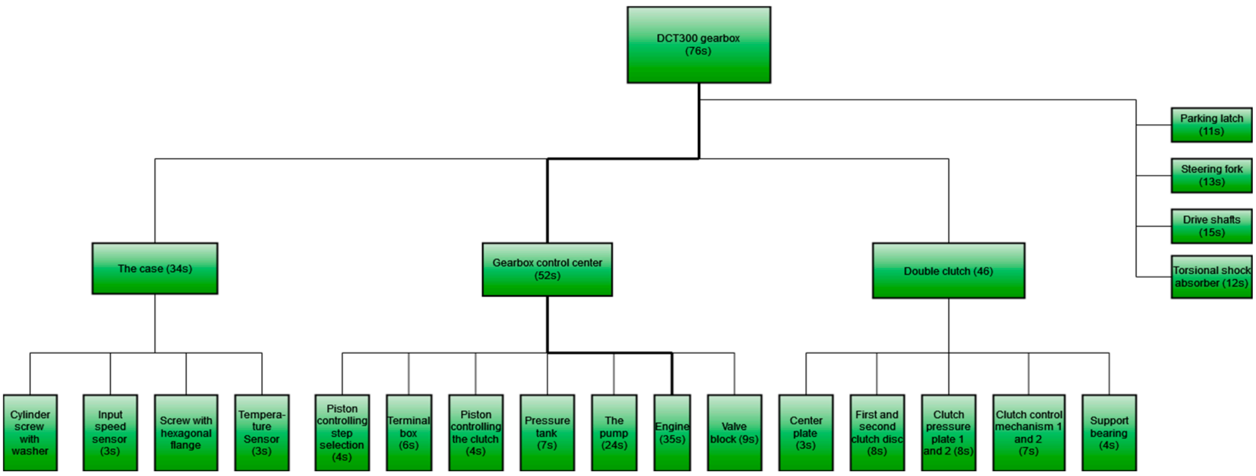

Figure 4. Simplified factory—gearbox assembly diagram [own processing].

3.2.2. Evaluation of the Current State of the Workplace

The production process of the dual-clutch transmission is very complex; therefore, after a thorough analysis of the assembly and test line, the decision was made to transfer the test line to a simulation study for its unused full potential. The assembly line is fully operational without much room for possible variations.

To begin with, a simulation study of the current running of the test line according to the layout was created, which will provide a basis for the detection of bottlenecks and on the basis of which a debugged simulation study will be built (Figure 5).

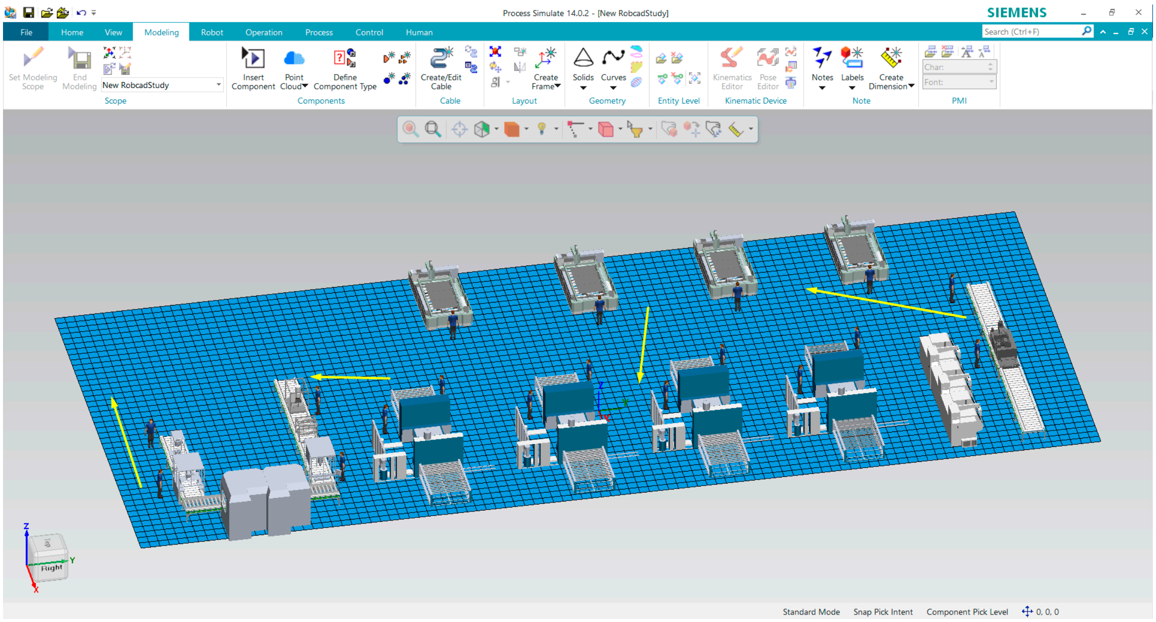

Figure 5. Simulation study of a test hall with marked material flow [own processing].

The on-line testing process begins with weighing the gearbox on the conveyor belt. Next come the operations of filling the gearbox with oil, adjusting the gearbox, the final test associated with uploading the customer software, and oil extraction associated with clutch lubrication. For these operations, the oil supply is provided by a central oil supply station with filtration for fresh test oil. Weighing the gearbox and then pouring residual oil into the gearbox is the next step. After filling in the oil, the test equipment is dismantled, and the transport covers are installed. Next, the filling screw and the breather cap are mounted. The oil adapters are dismantled, and the transport plugs are installed. At the end comes the engraving; manually compliant gearboxes are assembled and moved to the logistics warehouse. Operations with corresponding time values during the test cycle are developed in the material flow algorithm of the test line (Figure 6).

3.2.3. Proposal for Improvements

Manual assembly of gearboxes is unreasonably difficult for workers and also time-consuming, where, due to a faulty gearbox, the rest of the line sometimes has to wait for its assembly. Likewise, the transport of gearboxes to the warehouse is a time-consuming operation for employees who are often needed at the workplace. Therefore, in order to facilitate the work of the workers and reduce the testing time of the gearbox, the operations of manual assembly of gearboxes were replaced by a robotic operation, and programmed automated trucks were used for the operations of transporting gearboxes to the warehouse, which will both collect defective and error-free gearboxes and transfer them to the warehouse, but also ensure interoperation transportation.

Another change lies in the rearrangement of the machines in the core of the test hall, which made it possible to achieve a smoother material flow and save time by using the already mentioned automatic carts. The visual side of the simulation study after incorporating the described changes can be seen in Figure 7.

The average time to assemble a non-compliant gearbox piece was reduced from 62 s to 25 s, and the average time to transport a failed gearbox was reduced to 48 s.

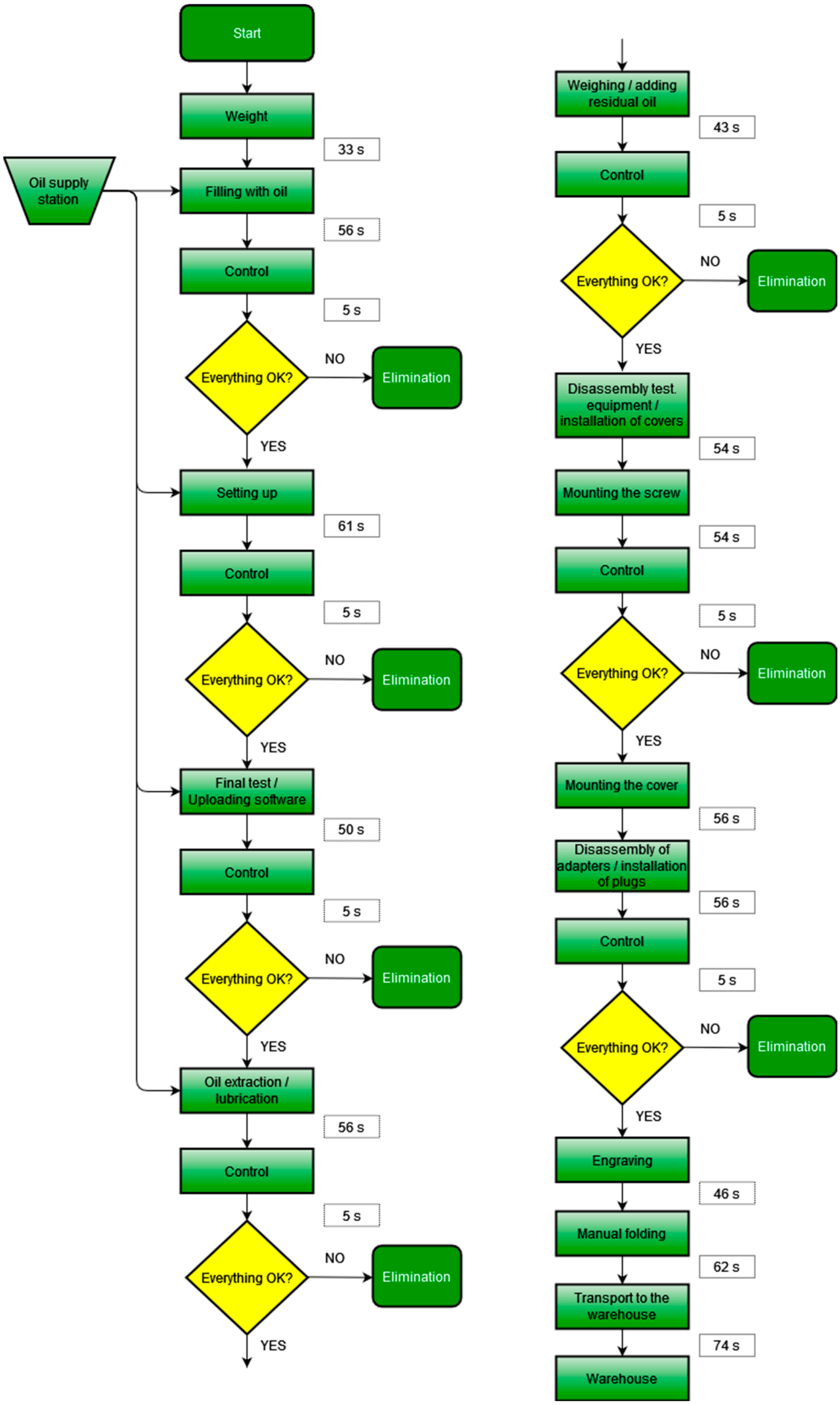

Figure 6. Algorithm of the test process [own processing].

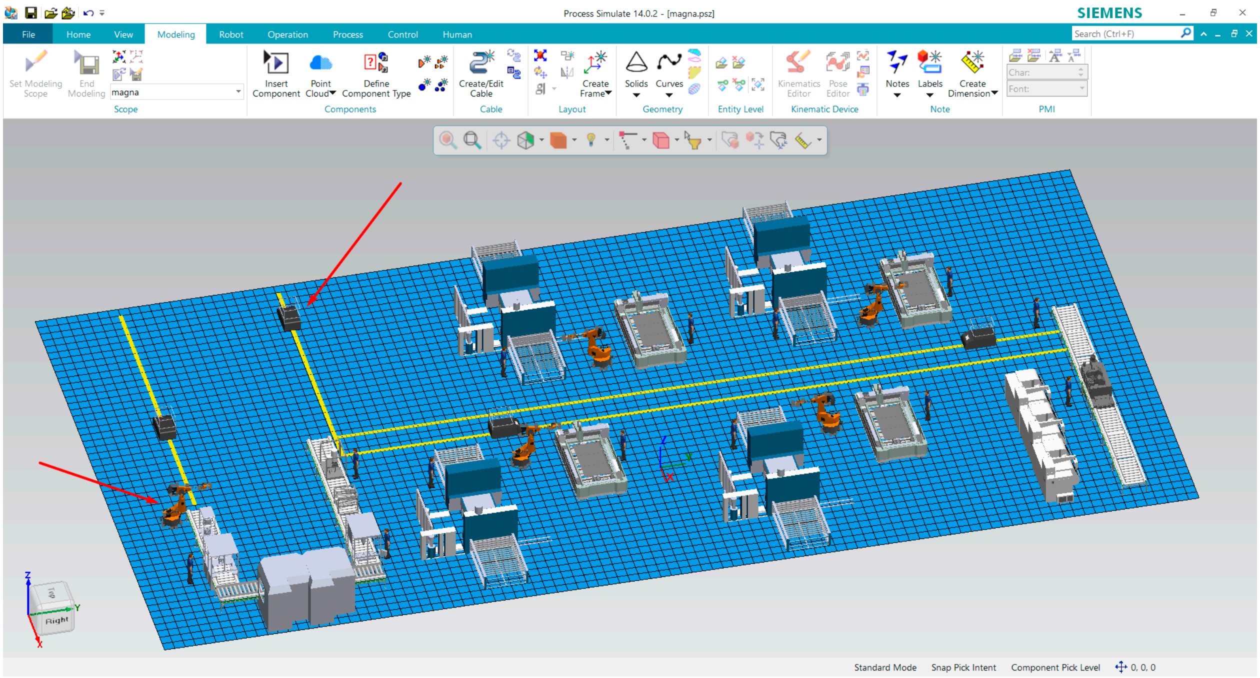

Figure 7. Simulation study of the test hall after incorporating the designs [own processing].

3.3. RYBA Kosice Co., Ltd.

For the company RYBA Kosice Co., Ltd. (Kosice, Slovakia), we selected the main representative of the production with the largest production rate: the codfish in mayonnaise product. This product is produced with a weight of 140 g and is delivered to most retail chains throughout Slovakia. RYBA Kosice Co., Ltd. is included in the food industry sector.

3.3.1. Manufacturing Process Processing

All the raw materials that make up the final cod in mayonnaise product undergo a thorough quality control inspection to avoid the use of low-quality raw materials in the final product. Imported fish meat is marinated in a special cooling box for approximately 15 h before use, and only then is it minced. Sterilized vegetables are added to the minced fish meat, which must be properly rinsed beforehand and left for approximately 5 min to drip. Dried onions and pre-prepared vegetable fiber are then added. Finally, prepared by the FIFO system, mayonnaise is added. The production process of one cod in mayonnaise without preparatory and control operations takes only 3 s (Figure 8).

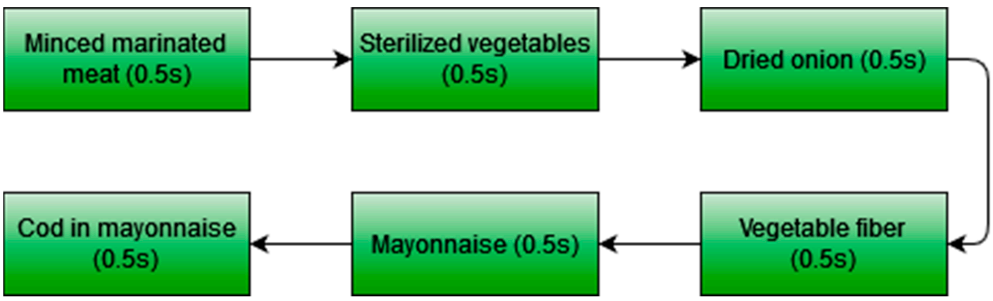

Figure 8. Cod production scheme [own processing].

3.3.2. Evaluation of the Current State of the Workplace

On the ground floor, the frozen raw material is received and unpacked. This is followed by a thawing process in a thawing box for 15–24 h with a box capacity of up to 10 tons. After thawing, the raw materials are unpacked from the foil, and their quality is checked; then, the suitable raw materials are subjected to boiling in the Mauting cooking chamber for 90 min. The cooked raw material is further cooled with air for approximately 40 min in a cooling chamber with a capacity of 1300 kg and cooled with water for 30–45 min.

On the first floor, the marinating process begins in a cooling box for 12–15 h, after which the fish meat is ground in a grinder. Subsequently, the necessary raw materials such as sterilized vegetables, dried onions, vegetable fiber, and previously prepared mayonnaise are added to the minced meat. All additional raw materials are pre-weighed according to the standard. The last production process is machine mixing of the mixture, which, after thorough mixing, is moved to a storage tank for filling into plastic jars. The employee provides the packaging according to the requirements of the individual chains on pallets and moves it to the warehouse for dispatch (Figure 9).

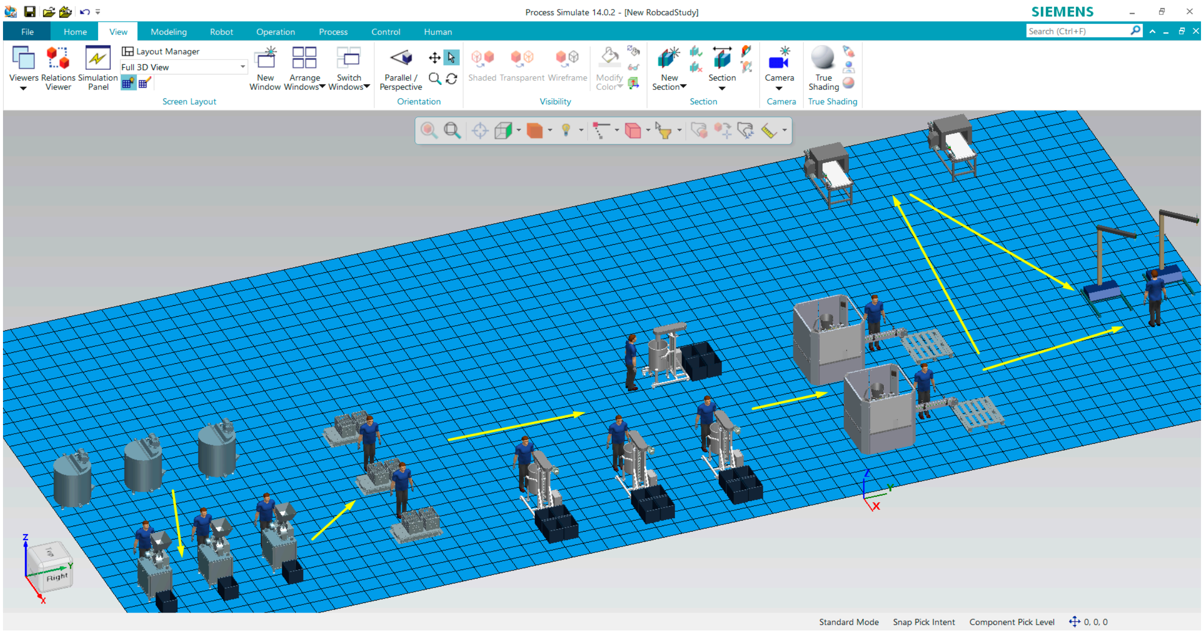

Figure 9. Simulation model of the 1st floor with marked material flow [own processing].

Some food chains also require exit inspection of random pallets to detect the presence of undesirable elements in the product, such as pieces of glass, plastic, etc. This control process takes place outside the established material flow and disrupts its fluidity, which results in an increase in storage time, excess non-delivery (since in case of detection of undesirable elements, even in one crucible, the entire pallet must be discarded), and the associated excess inter-operational transport. A summary of all pre-production, production, and control operations together with the assigned durations can be found in the developed production algorithm in Figure 10.

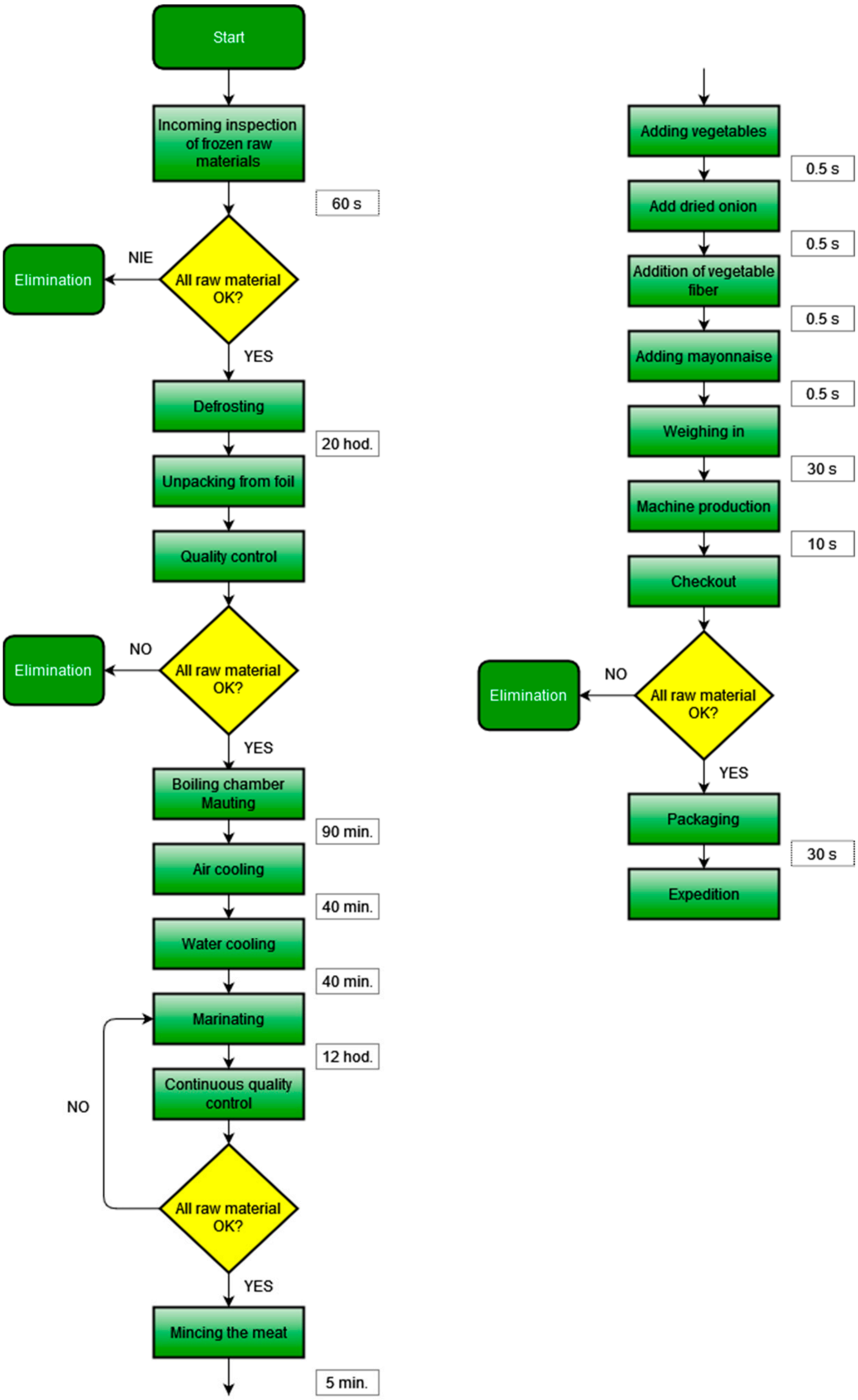

Figure 10. Cod in mayonnaise production algorithm [own processing].

3.3.3. Proposal for Improvements

The main proposal for speeding up deliveries to the warehouse, achieving a smoother material flow, and reducing the non-delivery of manufactured products is to move the output inspection department directly into the production process, whereby installing a special machine for detecting unwanted particles behind the filler, all filled jars with cod will pass inspection individually and only those which may contain unwanted particles will be removed (Figure 11).

In this way, the output inspection time is reduced to a minimum, which makes the material flow through production more efficient and speeds up the transport to the warehouse of finished products. The number of manufactured products will also increase, as only individual non-gift jars will be removed instead of the entire pallet with filled jars. An additional improvement would consist of the automation or semi-automation of inter-operational transport, which would relieve the workers of part of the manual work. This improvement, however, does not affect the time of any operation.

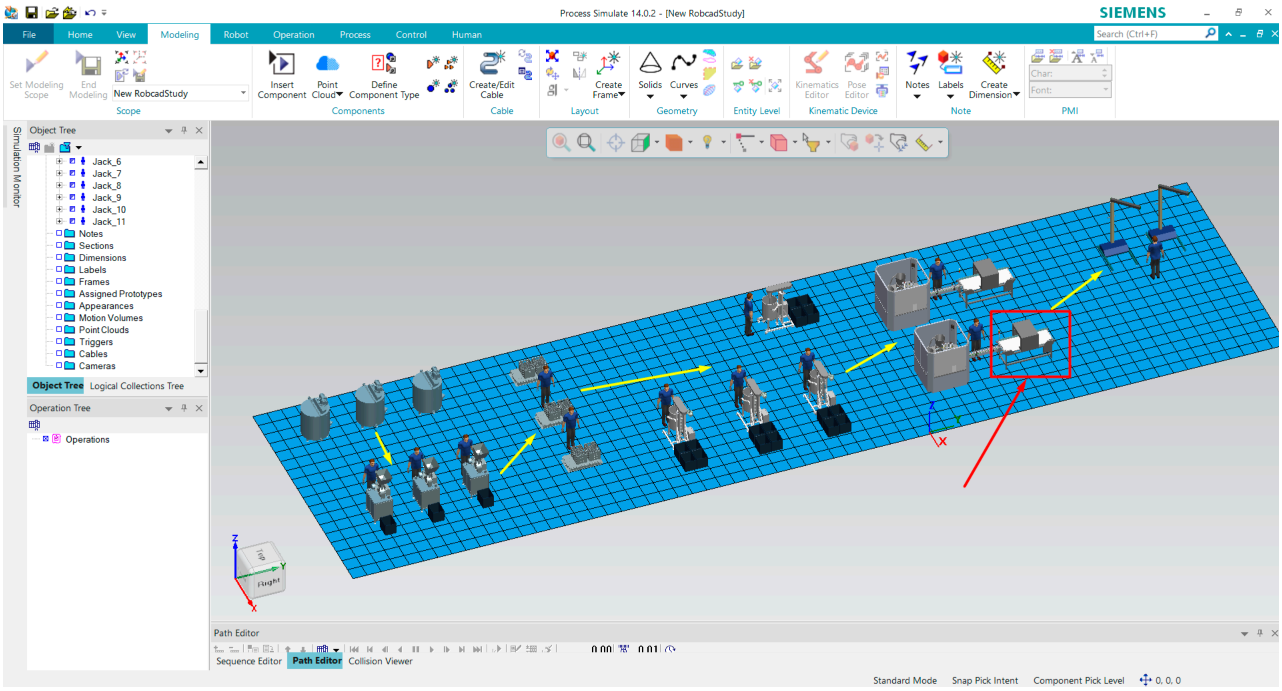

Figure 11. 1st floor after moving the scanner to unwanted particles [own processing].

4. Discussion of Results

In this last chapter, the results obtained from the simulation studies of the individual investigated companies and the findings of similarities in shortcomings and proposed solutions in companies from different industries are summarized. For a better overview, the identified deficiencies in the investigated companies are included in a table where it is possible to compare both individual industries and specific companies. Recurring deficiencies in various companies are marked with the same color (Table 1).

Table 1. Identified deficiencies in individual enterprises [own processing].

Paper industry	**Notes jsc.**	overproduction ahead
		unreasonable downtime
		excessive inter-operational warehouses
		unreasonable movements of employees
		lengthy interoperation transport
Automotive industry	**Magna PT Ltd.**	unreasonable movements of employees
		lengthy interoperation transport
		disturbed fluidity of the material flow
Food industry	**Ryba Košice Co., Ltd.**	disturbed fluidity of the material flow
		redundant lack of supply
		lengthy interoperation transport

The table clearly shows one shortcoming that occurs in all the businesses addressed. Prolonged inter-operational transport, also associated with disproportionate employee movements, can therefore be characterized as the main (main) problem of companies in every industry segment. Another frequent shortcoming is the disturbed fluidity of the material flows through production, which most companies suffer from, except for those where production takes place on a line, where, of course, the smooth material flow is ensured by the precise setting of machines and equipment. Table 2 describes suggestions for improving the situation in companies, through which they can prevent or eliminate the mentioned shortcomings.

Table 2. Suggestions for improvements to eliminate deficiencies [own processing].

Paper industry	**Notes jsc.**	introduce a production planning system
		applying the SMED method
		purchase and programming of automatic carts
Automotive industry	**Magna PT Ltd.**	purchase and programming of automatic carts
		replacing a manual operation with a robotic one
		rearrangement of machines
Food industry	**Ryba Košice Co., Ltd.**	purchase and programming of automatic carts
		reduction of non-sufficiency by transfer of technology and thus also ensure smooth material flow

On the basis of the revealed shortcomings in the production of the companies which were found through elaborated simulation studies, we offer a basic recommendation for companies in each market segment, and that is to automate inter-operational transport, either by using programmable automatic carts or by incorporating a conveyor belt into production, which would avoid lengthy inter-operational transport and relieve employees from monotonous, demanding work.

As an additional recommendation for companies where a violation of the fluidity of the material flow has been detected at a certain stage of production, we see the best solution in a more logical arrangement of technology, which will ensure a fluid flow of materials, reduce non-delivery of products, increase quality, save money, and, above all, reduce the production time of products. As a result, companies can produce a larger number of products in the same amount of time and thus satisfy the needs of more consumers in a timely manner (Figure 12).

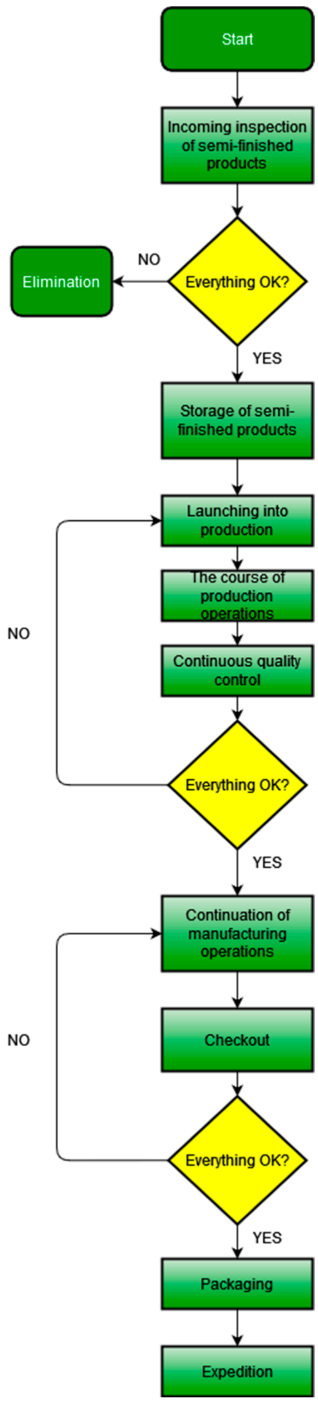

Figure 12. General algorithm of production in the enterprise [own processing].

5. Conclusions

The source of waste in companies, which is certainly of interest to manufacturers, lies in the efficiency of the process. Industry 4.0 offers new tools for the intelligent management of production processes, logistics, and energy consumption management, storing more information in products and pallets (so-called smart places), and providing optimization benefits in real time. Our goal was precisely the detection of waste and shortcomings in companies with the help of developing simulation studies. The simulations were created in the software environment of the Process Simulate product, which belongs to the Tecnomatix portfolio from Siemens. After discovering the shortcomings, we incorporated suggestions for improvement into the simulation studies and then evaluated them. As a result, homogeneous recommendations were offered for heterogeneous companies, which laid the foundations for recommendations for other companies as well.

After achieving the set goals, benefits for the scientific and pedagogical fields are expected, such as the deepening of the data bus from the field of PLM systems, the creation of study literature with an orientation to digital modeling, and the creation of simulations of logistic processes applicable in the field of "Industrial Engineering" and for practice, such as the application and implementation of PLM systems into the space of experimental modeling and their subsequent use in production as well as non-production processes in companies.

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References

1. Lasi, H.; Fettke, P.; Kemper, H.-G.; Feld, T.; Hoffmann, M. Industry 4.0. *Bus. Inf. Syst. Eng.* **2014**, *6*, 239–242. [CrossRef]
2. Chromjakova, F.; Bobak, R.; Hrusecka, D. Production process stability—Core assumption of Industry 4.0 concept. In Proceedings of the 5th International Conference on Manufacturing, Optimization, Industrial and Material Engineering, Taiyuan, China, 24–25 June 2017; pp. 143–154.
3. Bag, S.; Telukdarie, A.; Pretorius, J.H.C.; Gupta, S. Industry 4.0 and supply chain sustainability: Framework and future research directions. *Benchmarking Int. J.* **2021**, *28*, 1410–1450. [CrossRef]
4. Vieira, A.A.C.; Dias, L.M.S.; Santos, M.Y.; Pereira, G.A.B.; Oliveira, J.A. Setting an Industry 4.0 research and development agenda for simulation—A literature review. *Int. J. Simul. Model.* **2018**, *17*, 377–390. [CrossRef] [PubMed]
5. Manlig, F.; Slaichova, E.; Koblasa, F.; Vavruska, J. Innovation of business processes by means of computer-aided simulation: Novel Trends in Production Devices and Systems. *Appl. Mech. Mater.* **2014**, *474*, 67–72. [CrossRef]
6. Glova, J.; Sabol, T.; Vajda, V. Business Models for the Internet of Things Environment: Emerging Markets Queries in Finance and Business (Emq 2013). *Procedia Econ. Financ.* **2014**, *15*, 1122–1129. [CrossRef]
7. Prester, J.; Buchmeister, B.; Palčič, I. Effects of advanced manufacturing technologies on manufacturing company performance, Strojniski vestnik. *J. Mech. Eng.* **2018**, *64*, 763–771. [CrossRef]
8. Zuzek, T.; Gosar, Z.; Kusar, J.; Berlec, T. New product development model for SMEs: Introducing agility to the plan-driven concurrent product development approach. *Sustainability* **2021**, *13*, 12159. [CrossRef]
9. Witkowski, K.; Saniuk, S. Aspekt logistyczny zarzadzania infrastruktura komunalna miasta. *Logistyka* **2011**, *41*, 589–600.
10. Ojstersek, R.; Javernik, A.; Buchmeister, B. The impact of the collaborative workplace on the production system capacity: Simulation modelling vs. real-world application approach. *Adv. Prod. Eng. Manag.* **2021**, *16*, 431–442. [CrossRef]
11. Straka, M.; Lenort, R.; Khouri, S.; Feliks, J. Design of large-scale logistics systems using computer simulation hierarchic structure. *Int. J. Simul. Model.* **2018**, *17*, 105–118. [CrossRef]
12. Wicher, P.; Stas, D.; Karkula, M.; Lenort, R.; Besta, P. A Computer Simulation-Based Analysis of Supply Chains Resilience in Industrial Environment. *Metalurgija* **2015**, *54*, 703–706.
13. Dulina, L.; Edl, M.; Fusko, M.; Rakyta, M.; Sulirova, I. Digitization in the Technical Service Management System. *MM Sci. J.* **2018**, *2018*, 2260–2266.
14. Gregor, M.; Hercko, J.; Grznar, P. The Factory of the Future Production System Research. In Proceedings of the 21st International Conference on Automation and Computing (ICAC), Glasgow, UK, 11–12 September 2015; pp. 254–259.

15. Grznar, P.; Gregor, M.; Krajcovic, M.; Mozol, S.; Schickerle, M.; Vavrik, V.; Durica, L.; Marschall, M.; Bielik, T. Modeling and Simulation of Processes in a Factory of Future. *Appl. Sci.* **2020**, *10*, 4503. [CrossRef]
16. Wiecek, D.; Wiecek, D.; Kuric, I.; Buckova, M.; Krajcovic, M. Evaluation of the effectiveness of implementing production logistics automation systems supported by computer simulation tools. In Proceedings of the 14th International Conference on Modern Technologies in Manufacturing, Cape Town, South Africa, 26–28 May 2019; p. 02007. [CrossRef]
17. Gola, A.; Plinta, D.; Grznar, P. Modelling and simulation of reconfigurable manufacturing system for machining of casing-class parts. In Proceedings of the 21st International Scientific Conference Engineering for Rural Development, Jelgava, Latvia, 25–27 May 2021; pp. 1563–1568. [CrossRef]
18. Ojstersek, R.; Acko, B.; Buchmeister, B. Simulation study of a flexible manufacturing system regarding sustainability. *Int. J. Simul. Model.* **2020**, *19*, 65–76. [CrossRef]
19. Frazzon, E.M.; Albrecht, A.; Hurtado, P.A.; de Souza Silva, L.; Pannek, J. Hybrid modelling approach for the scheduling and control of integrated production and logistic processes along export supply chains. *IFAC-PapersOnLine* **2015**, *48*, 1521–1526. [CrossRef]
20. Wang, L.; Törngren, M.; Onori, M. Current status and advancement of cyber-physical systems in manufacturing. *J. Manuf. Syst.* **2015**, *37*, 517–527. [CrossRef]
21. Szajna, A.; Szajna, J.; Stryjski, R.; Sąsiadek, M.; Woźniak, W.W. The Application of Augmented Reality Technology in the Production Processes. In *Intelligent Systems in Production Engineering and Maintenance: Conference Proceedings ISPEM 2018*; Advances in Intelligent Systems and Computing; Burduk, A., Chlebus, E., Nowakowski, T., Tubis, A., Eds.; Springer: Cham, Switzerland, 2019; pp. 316–324, ISBN 9783319974897.
22. Mula, J.; Peidro, D.; Díaz-Madroñero, M.; Vicens, E. Mathematical programming models for supply chain production and transport planning. *Eur. J. Oper. Res.* **2010**, *204*, 377–390. [CrossRef]
23. Aytug, H.; Bhattacharyya, S.; Koehler, G.J. Genetic learning through simulation: An investigation in shop floor scheduling. *Ann. Oper. Res.* **1998**, *78*, 1–29. [CrossRef]
24. Fleischmann, B.; Meyr, H.; Wagner, M. *Supply Chain Management and Advanced Planning*; Springer: Berlin/Heidelberg, Germany, 2014.
25. Chen, Z.-L.; Vairaktarakis, G.L. Integrated scheduling of production and distribution operations. *Manag. Sci.* **2005**, *51*, 614–628. [CrossRef]
26. Byrne, M.D.; Bakir, M.A. Production planning using a hybrid simulation-analytical approach. *Int. J. Prod. Econ.* **1999**, *59*, 305–331. [CrossRef]
27. Kim, B.; Kim, S. Extended model for a hybrid production planning approach. *Int. J. Prod. Econ.* **2000**, *73*, 165–173. [CrossRef]
28. Byrne, M.D.; Hossain, M.M. Production planning: An improved hybrid approach. *Int. J. Prod. Econ.* **2005**, *93–94*, 225–229. [CrossRef]