Optimization of the Machine and Device Layout Solution in a Specific Company Production

Marian Králik(✉), Vladimír Jerz, and Michael Paštéka

Institute of Manufacturing Systems, Environmental Technology and Quality Management, Slovak University of Technology in Bratislava, Bratislava, Slovak Republic
{marian.kralik, vladimir.jerz, michael.pasteka}@stuba.sk

Abstract. The subject of the paper deals with the plant layout optimization of the existing production halls in a specific company producing components. The aim is to suggest a layout based on analysis of the product portfolio, realization of the capacity calculation and proposition of the optimal machine and device configuration. For this purpose, some optimizing calculations with utilization of simulation were realized. The result is a detailed layout including 3D visualization.

Keywords: Manufacturing systems · Production flow analysis · Optimization · Simulation · Visualization

1 Introduction

Appropriate machinery and equipment layout in manufacturing systems within Industry 4.0 has a direct impact on minimizing material handling costs, thereby contributing to better business management. Another way to make production more efficient is to use lean production as a systematic approach that avoids unnecessary waste by continuously improving production processes. To maximize the company's benefits, a combination of these two ways of cost and production system optimization should be applied. There is an increasing number of the software systems on the market that enable the simulation of production systems with interactive 3D display of the chosen solution. Software tools offering comprehensive solutions that fully adapt to customer requirements are becoming increasingly popular. The advantage of the software products on this basis is the possibility of creating a new and more efficient layout solution, or the entire production system in a virtual environment without the need to suspend production. This design is then directly used after its optimization.

N. M. Durakbasa and M. G. Gençyılmaz (Eds.): ISPR 2019, LNME, pp. 91–103, 2020.
https://doi.org/10.1007/978-3-030-31343-2_8

2 Description of the Solution Procedure

The procedure for creating the optimum layout design for the machines and equipment in manufacturing systems is generally known. We want to point out to some of the solutions used in a company in Slovakia, which produces components ranging from small to medium series. In particular, manufacturing technologies such as turning, milling, material cutting, grinding, honing are used in manufacturing of the components. The company controls the quality of products by the means of the control and measuring technology, coordinate measuring machine, surftest and contour measuring system. The machine base is made up of universal center lathes, automatic saws, NC milling machines, center grinders, honing machines, biaxial and three-axial CNC lathes with driven tools up to four-axial machining centers.

2.1 Preparation of Input Data

The first step in solving the task of optimal layout is to collect accurate data. Accuracy and quality of collected data is a key element of optimization. Any error or inaccuracy in this step will negatively affect every subsequent step. Technological process of the production of components gives information about time consumption for the production of components, the need of production machines and equipment, necessary production tools, cutting conditions, requirements for the quality of components, etc. In the company, the technological procedures for the production of components are in the technological procedures folder in .xls formats and in the given structure according to Fig. 1.

Fig. 1. Technological procedures and their structure

Thus, searching for information about a particular manufactured component requires knowledge about its manufacturer, on the basis of which the designer opens a specific folder with the name of the manufacturer.

2.2 Component Basis Analysis

Components manufactured by the Slovak company include parts for hydraulic systems, parts for bearing reducers, parts of rolling bearings, parts for pneumatic springs clamping, or needle and roller pulleys (Fig. 2).

Fig. 2. Production program of the company

Individual components are used in hydraulic pump or heavy machinery designs such as bulldozers, tractors or harvesters. The P-Q diagram was built on the basis of theoretical knowledge. The “x” axis shows the selected part of the component base and the “y” axis shows the annual production of the individual components. The company produces more than 250 types of components. In the P-Q diagram, 60 components have been selected for clarity to represent a cross-section of the entire manufacturing spectrum, so that all the manufacturing machines available to the company are included (Fig. 3).

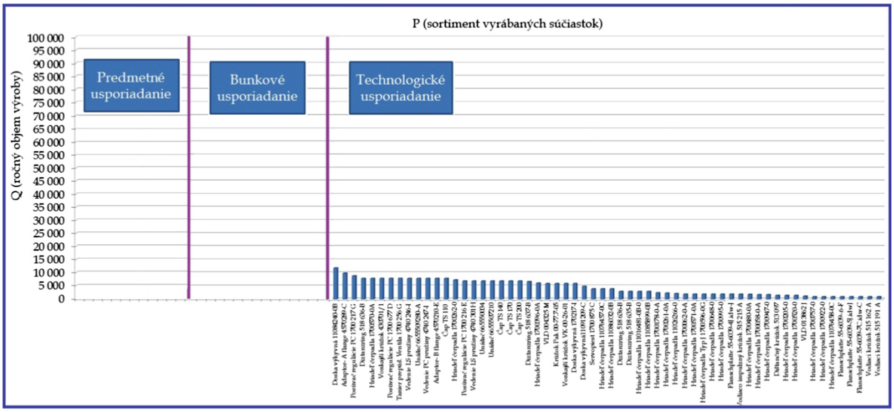

Fig. 3. P-Q diagram of the manufactured components

The P-Q diagram shows that production in the company focuses on a wide range of products, with a maximum annual production of one type of component not exceeding 12,000 pieces. A big problem is updating the data. The company receives “just in time” orders from large customers according to current demand. Production is planned for a maximum of one week in advance, and may additionally modify depending on market requirements. For example, they produce 50 different types of pump shafts and there is no way to determine which type of pump will be the most demanded one in the future.

2.3 Production Segmentation

The segmentation of production is only possible for the components produced in larger quantities. The analysis of the component basis shows that the company does not have products manufactured in large quantities. The company is currently applying for the production of components in larger quantities. The developed procedure will serve as a methodology, if this business plan is successful. For these reasons, the question arose: "Which annual production of the selected component will be economically advantageous for rearranging the machines"? This could happen in practice, provided that the customer would standardize the pumps and at the same time the market demand for them would increase.

A matrix of "machines – components" was constructed upon the company and machine basis data. The individual colors represent the blank from which the components are made (Fig. 4).

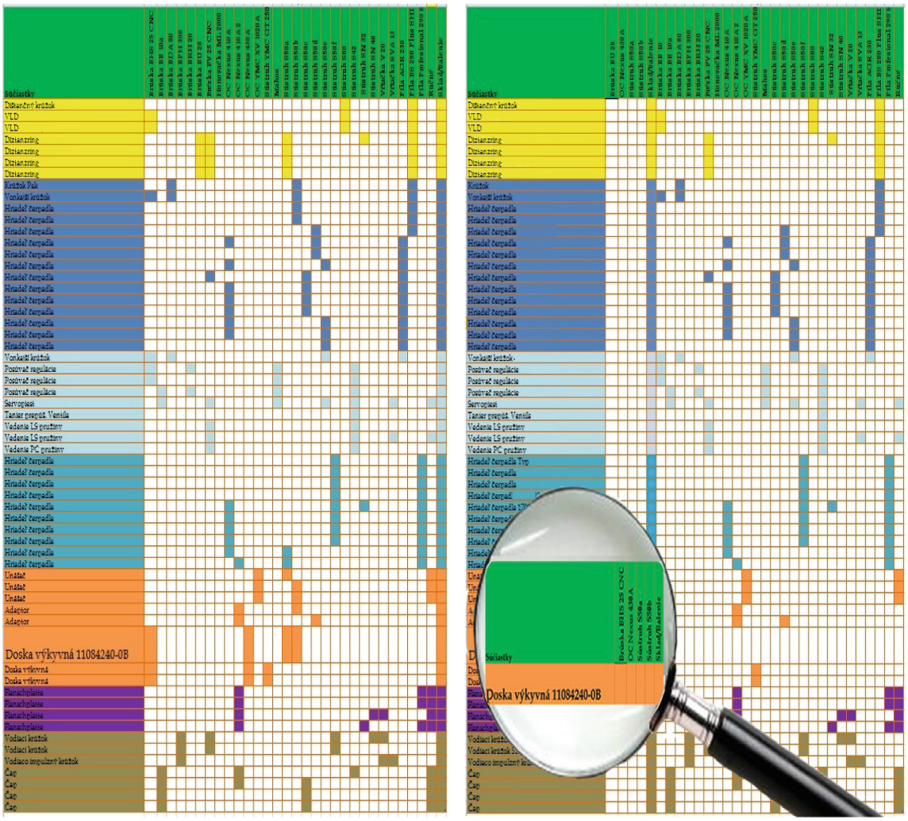

Fig. 4. "Machines – components" matrix – components before and after production segmentation

The need to create a cellular arrangement for the Swinging plate component (“Doska výkyvná”) results from segmentation. This autonomous workstation will need at least 4 machines to operate [1]:

- BHS 25 CNC grinder,
- MazakNexus 430A machining center,
- 2 x S50i lathe.

The exact need for machines, workers, or robots results from the capacity calculations.

2.4 Capacity Calculations

As “Swinging plate” is a really manufactured (part) component, the technological procedure (job description) contains all the necessary data. It provides the information about duration of the technological operation and the number of pieces to be produced per change. The standard was set at 390 min of net time, because it was empirically found, that factors, such as:

- the time needed to exchange tools,
- cleaning the workplace,
- handling time (clamping/unclamping a semiproduct or a part),
- interoperable transport,
- quality control,
- machine maintenance,

take 90 min of a single shift time in case of the technological arrangement. Therefore, production times and standards were recalculated to 480 min. By the subsequent capacity calculations (for a limited range of the contribution, we do not mention it), the number of necessary machines was set to 9 with 100% usability, thus verifying the correctness of the calculation formulas.

2.5 Designing of Production Layout

Based on the calculated data from the previous steps, it is possible to design a new production layout. The company produces a wide range of products, so the technological arrangement of the machines is the most suitable for this type of production. Until now, the company has used all the advantages of the technological arrangement of machines:

- changing the production program does not disturb the production,
- ease of implementation of multi-machine operation,
- better machine utilization,
- easier maintenance.

No changes were made after consulting with the management. But with the further design of the manufacturing disposition solution, an increase in the production of “Swinging plate” is envisaged, and the design of the measures should allow for this alternative. The original layout is shown in Fig. 5.

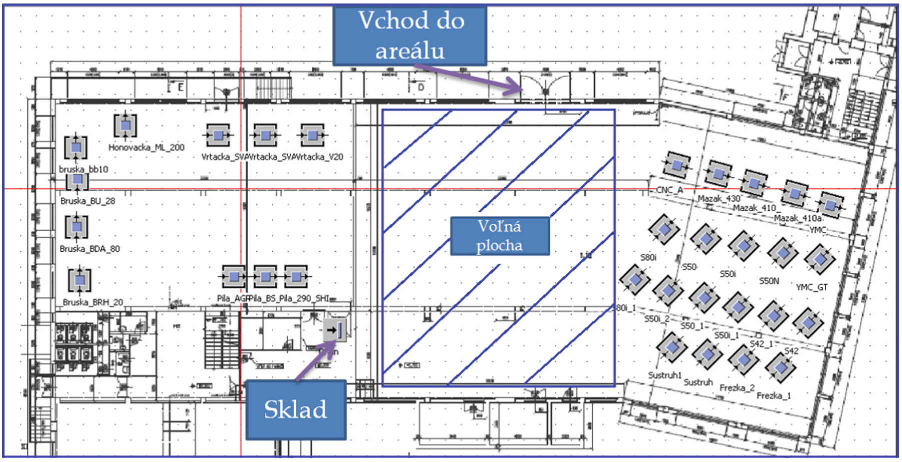

Fig. 5. Current production machinery layout

Capacity calculations have shown that 9 machines are needed to produce a given component. On the basis of capacity calculations and machine times, the exact need of individual machines was determined:

- 6 pcs of S50i lathe,
- 2 pcs of Mazak Nexus 430A machining center,
- 1 pcs of BHS 25 CNC grinder.

The location of the workstation would be best suited to the free area shown in Fig. 5. From among the several variations, the arrangement shown in Fig. 6 was chosen. Creating a new arrangement near the warehouse would minimize the total interoperable transport time. Arranging workplaces with respect to the continuity of operations has created a pyramid arrangement. The advantage of this arrangement is a clearly defined and irreversible material flow.

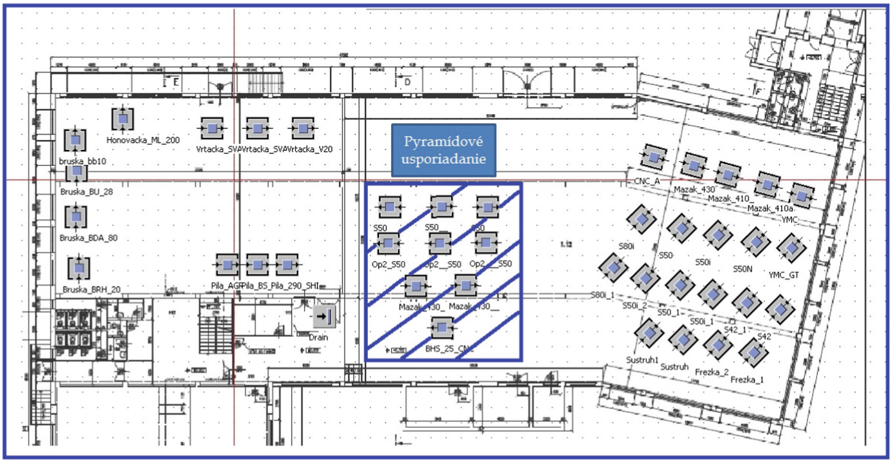

Fig. 6. New production layout design for the component production enhancement

2.6 Simulation

The selected layout had to be verified by simulation. The main task of the simulation was to find out:

- the annual production of the proposed system in three-shift operation,
- percentage use of workplaces,
- verifying the correctness of the current standards (since they have not been calculated but obtained empirically).

Since it was a relatively simple set of nine machines, a manual simulation was performed using calculations. The reason was also the assumption that the designer can design a simpler manufacturing system in this way. Subsequently, the calculations were verified by the Tecnomatix simulation software product, specifically in the Plant Simulation module.

A brief description of creating a simulation model is provided in the text below.

The handling times of the individual workplaces were indicated by the red arrows (Fig. 7). Within this time, removal of the semi-finished product from the pallet, its clamping, unstrapping, and inserting into the pallet were included. Empty palettes were marked in green. The letter "O" represents the casting and the number 117 is the expected production at 100% utilization of the machines. Numbers in other squares express the operation number and the expected production of one change without including handling times, interoperable transport, etc. For example, the designation 2/176 indicates that 176 pieces of "Swinging plate" must be produced on the third machine during one working shift (Fig. 7). Number 2 indicates that the first two technological operations have been carried out on semi-finished products and are ready for the third operation.

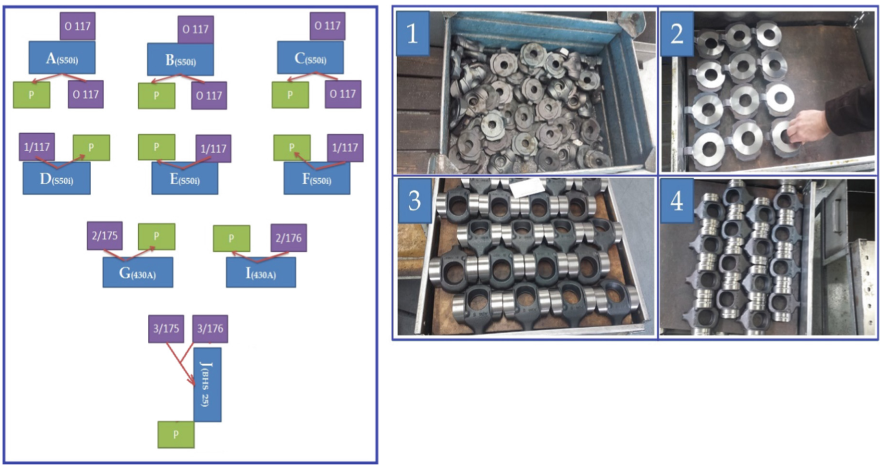

Fig. 7. The contents and location of pallets after the first working shift and the "Swinging plate" component in individual stages of the production process

Subsequently, it was necessary to determine the interoperable transport after each working shift so that the workstation was in the same condition as at the beginning, thus ensuring the repeatability of the cycle (Fig. 8).

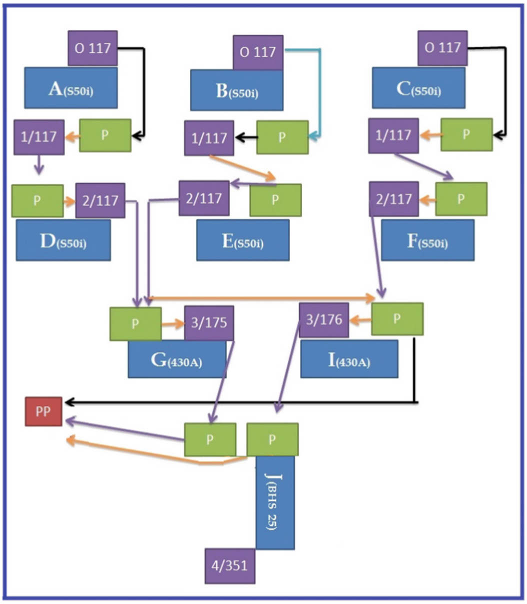

Fig. 8. Contents and location of pallets after the first working shift and the component itself

Figure 8 expresses the proposed interoperable transport. Each worker must perform the exact number of operations in a given order to ensure cycle repeatability. Individual handling operations are performed after meeting the norm of workplace.

Interoperable transport times were estimated by the complexity of the operations and the length of the trajectory. 30 s are added to each worker at the start of the manipulation to find a pallet truck. For example, 170 for worker E originated as follows:

- 30 s to search for a truck,
- 10 s to lift the pallet,
- 10 s to transport to G,
- 120 s to displace 56 pieces to the pallet brought in by a worker D.

Other workers transport the entire daily standard without rehandling.

One-off times had to be deducted from the total working time to set the standard correctly. It included a mandatory break, the time needed to clean the workplace, the interoperable transport, the tool change time, the quality control, the regular machine maintenance regarding the proposed layout. Thus a real number of minutes in norms was obtained when the workplaces can produce, tool change times in machining tools, etc.

It is necessary to include the failure rate of individual workplaces in the calculation of the expected annual production. However, the company does not have statistical data on failures at individual workplaces, nor the times to eliminate failures. A 10% failure rate is considered when planning production of the production systems. This information is relevant when individual machines are connected in series. When creating a new layout, the pyramid arrangement was designed in parallel with the current technological arrangement, so that in the event of failure of any machine, it is possible to move production immediately to another machine. For this reason, the failure rate will only include the time it takes for re-setting of the machine.

In order to verify the results of the manual simulation, in particular the correctness of the calculation formulas, the model created in the Tecnomatix software product was proposed. Modern simulation products allow to insert the building floor plan into the model background, that helps better imagine the layout of the machines (Fig. 9).

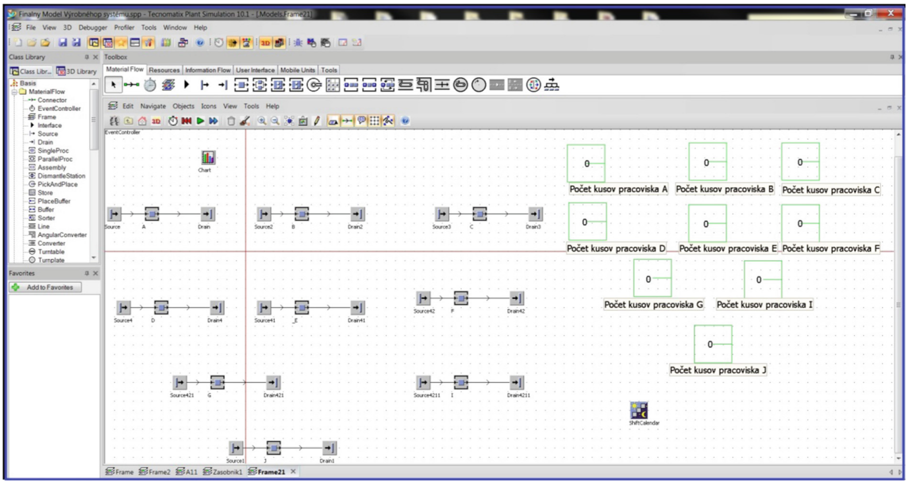

Fig. 9. Basic model of the proposed system

All data was entered into the pyramid model. E.g., to include a mandatory break into the model, the ShiftCalendar (Fig. 10) is used. It enables to insert complete production planning.

In the company, the first shift starts working at 6 a. m. and ends at 2 p. m. with a mandatory break from 10:45 a.m. to 11:15 a.m.

In order to simplify the model and to interpret it using one graph, the times of some operations were joined in the simulation. The term “Elimination of bottlenecks (ÚM)” expresses the time when the machines no longer produce after the standard has been met to avoid overproduction that would impair the cycle repeatability. After all data was entered, the simulation could be started (Fig. 11).

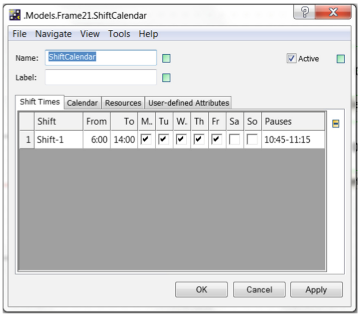

Fig. 10. ShiftCalendar

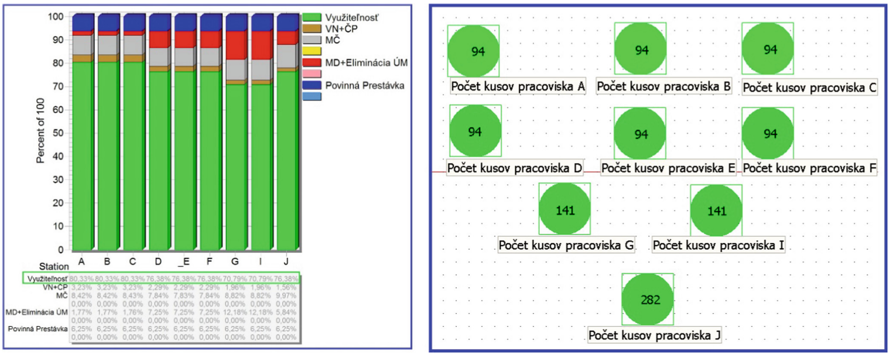

Fig. 11. Graphical representation of simulation study results (workplace utilization and single shift production)

2.7 Visualization

Currently, there is a large number of software products used to simulate manufacturing systems. Apart from standard means of modeled process visualization by 2D images with icons representing the system elements, the latest software products also allow for the use of virtual reality. If we want to bring the simulation model closer to the user with these options, 3D models of individual production machines, handling and transport equipment must be available. This is an illustrative approach to visualization of the static elements layout. For animation of transport, manipulation and technological operations, the models must be composed of several parts, which are then assigned a kinematic structure (e.g. Tecnomatix Process Designer).

Tecnomatix/Plant Simulation software has a basic 3D view that allows a better idea of the manufacturing system (Fig. 12).

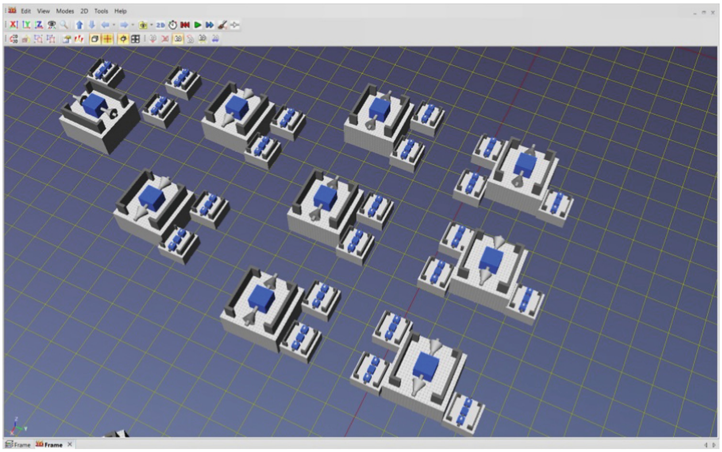

Fig. 12. Basic 3D view of the proposed layout in the Tecnomatix/Plant Simulation software environment

There are many graphic software products on the market to create 3D models. For example, the Solidworks software, uses parametric modelling. Parametric modelling means that first a 2D plan of the desired shape is created and assigned a dimension (parameter). The desired shape is then “drawn” into space. If necessary, adjustments such as removal, chamfering, etc. are made into the “drawn” shape. In this way, the Mazak 430A machining center model was created (Fig. 13).

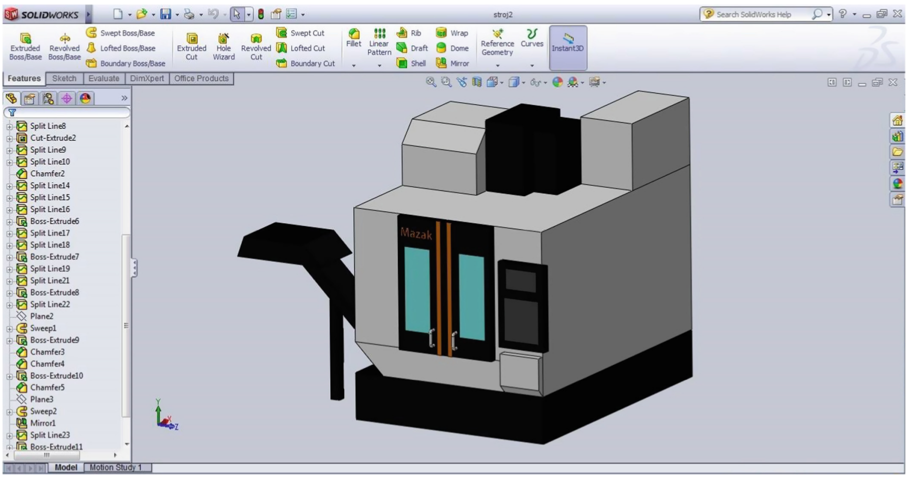

Fig. 13. Lathe model in the Solidworks software environment

Another program for creating spatial models is the Photomodeller which applies so-called digital photogrammetry followed by Photoshop.

Once the 3D models have been created, it is necessary to export them. Each software offers multiple export formats. Tecnomatix software uses its own format with a .jit extension that the used software (Photomodeler, Photoshop) cannot create. For this reason, we have tried to export all types of formats from Solidworks and Photomodeler and then import them into Tecnomatix. Among all formats, WRML (.wrl, Fig. 14) was the most suitable.

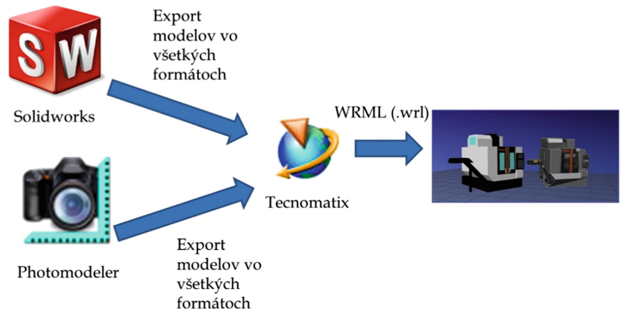

Fig. 14. Importing 3D models into simulation software

After creating the models and importing them successfully, the machines could be arranged according to the simulation model (Fig. 15).

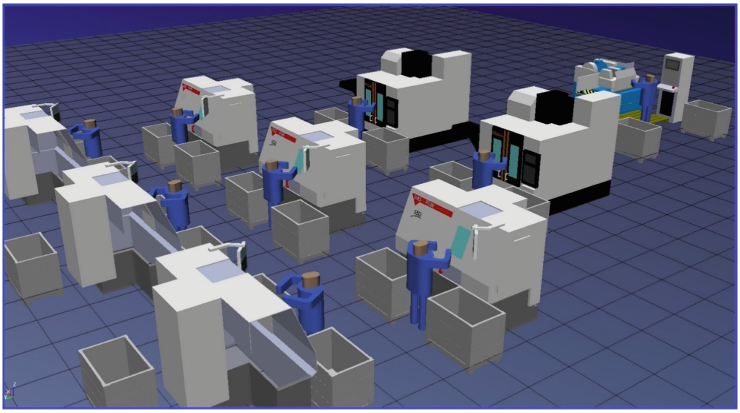

Fig. 15. Visualization of the selected and by means of simulation verified layout

The above mentioned findings, led to the demand for integration of the production design knowledge into one integrated unit. A system for automated production system design containing the data needed for a designer of the production systems has been developed:

- component database,
- technological processes,

- drawing documentation,
- machine database.

A system for automated production system design was created, so called Integrated Design System (ISP). After consideration of the required parameters and consulting with programming experts, the Wampserver 2.4 software package was selected, which includes:

- Apache 2.4.4,
- MySQL 5.6.12,
- PHP 5.4.12.

Due to wide range of issues and the limited scope of the paper, the system will be presented in other professional publications.

3 Conclusions

The paper describes the process of the production project, which can be used in the plants implementing the knowledge and principles of Industry 4.0. The individual described parts of the solutions were subsequently implemented into the system of automated production system design, so-called Integrated Design System (ISP). The created software provides the designer with a better idea of the machine and the component base of the enterprise, thus speeding up the collection process of the necessary data. At the same time, it contributes to more efficient corporate management.

Acknowledgment. The article was written with the help of projects: KEGA 027STU-4/2019.

References

1. Králik, M., Morávek, I.: Programovanie CNC výrobnýchstrojov. Edíciaučebníc. Slovenskátechnickáuniverzita v Bratislave, FX, s.r.o. (2008). ISBN 978-80-89313-36-5
2. Bouyssou, D.: Modelling inaccurate determination uncertainty, imprecision using multiple criteria. In: Locket, A., Islei, G. (eds.) Improving Decision Making in Organizations. Lecture Notes in Economics and Mathematical Systems, vol. 335, pp. 78–87. Springer, Berlin (1989)
3. Azibi, R., Vanderpooten, D.: Construction of rule-based assignment models. Eur. J. Oper. Res. **138**, 274–293 (2002)
4. Slowinsky, R., Greco, S., Matarazzo, B.: Minig decision-rule preference model from rough approximation of preference relation. In: Proceedings of the 26th IEEE Annual International Conference on Computer Softwre & Applications (COMPSAC 2002), Oxford, pp. 1129–1134 (2002)
5. The ISPR2018 website (2018). http://www.ispr2018.org/
6. Kusiak, A.: ISPR2018 homepage (2017). http://www.ispr2018.org/wp-content/uploads/2017/12/Kusiak-Presentation-Smart-Manufacturing-Sept-13-2017_Vienna.pdf
7. Kováčik, R.: Optimization of a layout solution of the machines and devices in production in a specific company. Ph.D. thesis, Slovak University of Technology in Bratislava, Slovak republic (2014)