

Improvement of logistics in manufacturing system by the use of simulation modelling: A real industrial case study

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ABSTRACT

The current practice and the requirements of industrial enterprises in all industrial areas require a detailed display of manufacturing systems course of events. In this paper, we studied the effects and impacts of computer simulation to improve the actual industrial production. We also verified whether the proposed simulation model and its intervention in the logistics of concrete production in a concrete manufacturing enterprise will correspond to reality. The EXTENDSIM simulation software was used. The simulation results utilization in practice has increased the actual production several times. The simulation results indicated that it is necessary to double the intensity of company supply, i.e. a frequency of entry set to 0.15 days for each timber type. This adjustment increased the performance of unutilized devices and the whole manufacturing system several times, up to 54,475 produced building timber elements, which represents an increase of production by about 199.6 % while maintaining company flexibility.

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1. Introduction

The solution of manufacturing logistics problems in specific market area requires the utilization of the means of algorithmization, heuristics, mathematical statistics, modelling and computer simulation. A combination of the defined approaches is possible for the designing, and it solves the problems of any manufacturing system. The objective of the logistics solutions is to influence and manage material flows in the right way. The execution of a concrete manufacturing system from a complex point of view of all types of flows is possible only by taking advantage of computer simulation. The application of mathematical modelling for the designing of material, information and financial flows together is practically impossible (and what about the effect of the human factor, in determination, haphazard and so on). All these facts make computer simulation the perfect facility (in many tasks, the only possible one) for the solution of specific problems of manufacturing systems. The foregoing results clearly show the importance of computer simulation for improving the efficiency of logistics in manufacturing. The problem relates to an effective utilization of the computer simulation with EXTENDSIM simulation system to improve the efficiency of logistics in manufacturing of concrete production company, engaged in the processing of raw timber and the production of building timber in the form of beams, planks, and boards from different types of wood, such as oak, beech, spruce and pine.

Timber production, in general, belongs to the most common types of industrial productions. Timber as a building material is equally popular in all the continents of the world. The methods of processing raw timber are identical, and they work on the same, respectively similar devices under the same, respectively similar conditions. This implies the importance of tackling this issue for the industrial sector in question and the universal character of the usage of this approach to increase the efficiency of logistics in manufacturing by means of computer simulation and the EXTENDSIM simulation system.

The aim of this paper is to clearly define a procedure which must be followed to solve equal or similar types of tasks through the utilization of concrete EXTENDSIM simulation system serving the needs of industrial practice. The tasks that must be executed are related to some given resolution procedures that are generally applicable to streamline the logistics in manufacturing using computer simulation. The quality of the solutions and their impacts on the manufacturing system depend on the quality of the performed analysis, quality and accuracy of data acquired for the purpose of the simulation model, and the knowledge and experience of the creator of the simulation model with the work with a concrete simulation system. The subsequent correct evaluation of the results and the definition of conclusions for the implementation of measures in practice are equally important as well.

2. Literature review

In order to be able to understand the essence of the functioning of the means of simulation, it is necessary to define and understand the basic principles and relations of simulation and modeling and the parts concerned. The goal of a simulation is to obtain information about the system and its elements according to presumed or defined change of characteristics of the elements and their connection.

A simulation of the systems makes it possible to experiment besides real objects, resp. these objects do not have to exist. Simulation as a term means an imitation of some real situation, thing, condition, action, event or process [1, 2]. Simulation is a research method, the essence of which consists of the replacement of an essential dynamic system by its model, simulator, and we perform experiments with the purpose of getting the information about the essential system. Using a simulation, it is possible to obtain answers to some very important questions, such as: "How is the system going to behave when the following (any) changes happen? Which part of the system contains critical points? How long is the distance the conveyor must overcome if two more stations are added in the system? How long will it take to run the production? How many people are needed to meet the deadline of the project?". In a simplified way, it is possible to characterize simulation by three steps:

- design of the simulation model of a real system,
- carrying out the experiments with the simulation model,
- reversed use of the obtained results to improve the system.

In our view, the objects of the simulation will be production processes representing the processes in the group of aggregates, machines and devices, on which the production processes are progressing. The amount of the production operations depends on the type of product and on the used devices, on which the production operations are taking place. Continuous production processes are the processes leading to a smooth, continuous change of the state of the production process (work of the breaker, mills, and conveyor belts). Discrete (discontinuous) production processes are the processes leading to a change of the state of the production process at certain time moments (transport of material by cars, wagons, loading of materials by an excavator). Combined production processes are characterized by combining the discrete and continuous production processes (transport of material by cars from quarry into a ball crusher).

The origins of the creation of simulation models goes back to the 1950's, when universal, general programming systems were used to create simulation models. A gradual development and progress is every area of production, science and practice required increasingly difficult

simulation models and applications. General programming systems proved to be maladroit and not dynamic enough to create fast changes in the simulation models. A special category of programming systems has gradually been invented. These systems are called simulation systems. Simulation systems are adapted for the purposes of simulation. They allow us to create program simulation models in such form to create models representing the simulated systems [3-5]. The simulation models allow us to perform quick changes in the created models, in case they are needed, in such a way that the created models correspond to the changes that can occur in a real system.

The evolutionary phases of the simulation systems change in time and naturally evolve [6]. The recent state is characterized by object and realistically oriented simulation with the support of 3D animations and video on a professional level. According to the functional aspects of the simulation, simulation systems are oriented to activities, events and processes, wherein a change of state can occur continuously, discretely or in a combined form [6-8].

Each area of problem solving relating to logistics combines and uses the required methodology, methods, procedures and tools specific to the given area, but also the methods of other areas. The variability of some solutions within the logistics clearly predetermines the usage of methods based on the principle of multi-criteria decision-making, statistics, modelling, the principles of heuristics and computer simulation [9-11].

To achieve the highest performance with maximum production efficiency, logistics, from the strategic, tactical and operational levels, defines respectively proposes actions that lead to achievement of the required results by using all the available means of science and technology, economics and computer science [12, 13].

The aim of logistics is to create a united, integrated, optimized material flow, which is arisen from different parts of the system in the way to ensure a continuous exchange of goods and services [14]. Logistics has gradually been developing and many definitions have also been developed together with it, while new perspectives on its scope and its level of activity are still being formed. According to Heskett, Glaskowsky and Ivie [15], logistics is the management of all activities that facilitate the movement and coordination of offer and demand in creating of time and place benefits. According to Schulte [16], logistics is an integrated, market-oriented planning, creation, implementation and control of flows of material, goods, information from suppliers to enterprises, in enterprises and from enterprises to clients at optimal costs. According to Malin-dzak [17], logistics is the way, philosophy of flows management (material, information and financial), at which there are applied systematic approach, methods of planning, algorithmic thinking and coordination in order to achieve the global optimization. According to Straka [18], logistics is a system in which there is an affect to elements in order to set coordinated material, information and finance flow, resulting in, respectively, aiming at satisfying customer requirements and respective economic effect. According to Merkuyev, Merjuyeva, Piera and Guasch Petit [19], simulation models have proved to be useful for examining the performance of different system configurations and/or alternative operating procedures for complex logistic and manufacturing systems. It is widely acknowledged that simulation is a powerful computer-based tool enabling decision-makers in business and industry to improve their organisational and operational efficiency. Combining simulation with experimental design or intelligent search has been successfully adopted for simulation optimization [20, 21].

Logistics as a scientific discipline was first defined back in the 50s. Subsequently, there was the development of the MRP I – Material Requirements Planning system. Later in the 60's, the MRP II – Manufacturing Resources Planning system was created, where the original MRP was supplemented by the algorithms for capacity calculations [22]. In the 70s, the method called Just-in-time was discovered for the first time. During the 80's, the advancements in computer technology helped to accelerate the information flows. Later, fully integrated logistics systems gradually started to emerge, which resulted in cost savings and gradual replacement of manual work by mechanisation [23, 24]. The area of logistics covers a variety of technical means, such as the elements of conventional transport, the elements of production facilities, robots [25-27] and, recently, also modern drones [28].

3. Presentation of the problem

The investigated company is focused on timber processing of production of building timber products, such as beams, planks and boards. They are currently very popular for the construction of low cost houses the core of which is formed from beams, planks and boards. That is why there is a high demand for the products of the company for the needs of the building industry. The basic element of the products of the company is timber. The company produces beams, planks and boards of the required dimensions and types by means of timber cutting, edging, planing, milling and trimming. The raw material is supplied from various sources and the main types of woods are oak, beech, spruce and pine. All the types of raw timber for the production companies are represented in the same volume. The supply the production company is carried out by the contracted transport companies supplying one truck of timber of each timber type once a week.

The described production company has its headquarters in the south-east of Slovakia in the vicinity of Košice city. The company provides a complex timber processing, i.e. from the inputs of raw timber through its storage, cutting and drying, to manufacturing of beams, planks and boards. The waste generated during the production is processed in a contracting company to produce pellets and wood chips used for heating.

As there is an increasing demand for the products of the company, which is demonstrated by the increase in the building activities within the region, there are situations during which the company is not able to meet all the requirements of the market in the short term. This is also the reason why the company is interested in identifying the bottlenecks [29] in production and design of the logistics in manufacturing in order to produce and purchase new devices that could increase their production with a minimum investment [30-32]. The entire production process of raw timber processing was developed to its present form only based on the experience of the company operators and workers. Since wood drying is the longest stage in the processing of raw timber in terms of the technological progress, the company bought a drying kiln for the batch drying of wood material. The capacity of the kiln drying device is 40 m³. Drying in this device takes 50 days on average, according to the type and thickness of the wooden elements. Within the technological process, the raw timber material is gradually shifting through the workplaces: receiving raw timber material and its storage – cutting head saw – edging saw – wood drying – crosscut saw – planing, milling, trimming – products despatch (Fig. 1). Cuttings waste is packed into sacks at special workplace for the disposal of waste.

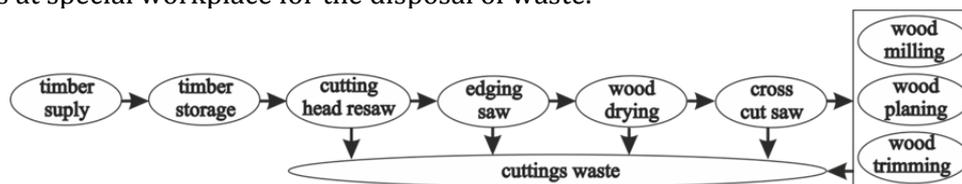


Fig. 1 Schema of the company logistics in the manufacturing system

Capacity utilization of the devices is performed by means of the preparation of raw timber, its drying and the crowdedness of the system in advance. The passage time through the timber manufacturing system depends on the capacity of the individual devices, their cadence and the time necessary for the execution of the manufacturing operation and overloading of the manufacturing system as a whole unit (Table 1). Statistically, most of the time in real operation is required for drying of the raw timber material. The company provides transport of the products to customers by means of outsourcing companies.

Each workstation is equipped with its own buffer necessary for the regulation of different production capacities and to ensure the fluency of production. In each part of the technological process, it is necessary to have an enough semi-finished timber element. That is why a significant amount of semi-finished products and unfinished timber elements is bound in each part of the system and a significant amount of capital is bound in warehousing, resources and in semi-finished products.

Table 1 Parameters of workstations delay, and devices delay in logistics in manufacturing

Timber	Timber entry	Cutting head resaw	Edging saw	Kiln drying	Air seasoning	Cross cut saw	Wood planning	Wood milling	Wood trimming	Packing cuttings waste
Oak	3 pieces / day / type	60 min	3.5 min	75 days	6 months	2 min	5 min	15 min	5 min	5-8 min
Beech		60 min	3.5 min	75 days						
Spruce		40 min	3.0 min	25 days						
Pine		40 min	3.0 min	25 days						

4. Materials and methods

The next step is a prepared comprehensive simulation model of all the activities within the timber material processing, which required a thorough analysis and compliance with the steps formalized scheme: description of production units, block diagram, simulation model, simulation runs, improvement of efficiency of logistics in manufacturing.

4.1 The creation of a formalized scheme

To make the computer simulation model, the first right step is to create a formalized scheme that represents the exact sequence of production operations, interconnecting facilities with the technical resources of the company. This step also involves retrieving the information about the parameters of the material flows in terms of volume distributions. Such a formalized scheme then represents the overall system with its features and links. In this case, the system consists of the individual elements represented by the operations with timber material. Between the operations, there are links formed by the elements of flow management of semi-finished products and of timber waste. A formalized structure (Fig. 2) is a very important basis for the creation of an actual simulation model. The limitations and capacity of the production facilities are important for correct understanding of whole system activity and the elements of logistics in manufacturing. During the subsequent simulation modelling, the individual parts of a formalized scheme will be replaced by a respective block of specific simulation software. Delay parameters (Table 1) are crucial for the setting of the simulation model blocks and for the control and solution of the critical production bottlenecks of the whole manufacturing system.

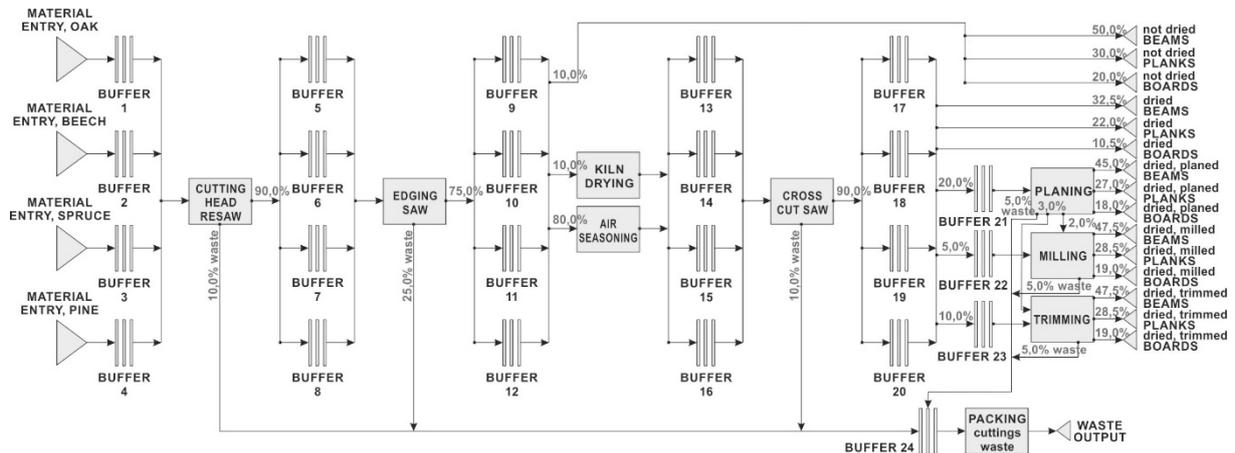


Fig. 2 The formalized scheme of building timber elements production

4.2 The logistics in manufacturing units

The entire manufacturing system and logistics in manufacturing is composed of parts that are arranged in sequence according to the technological procedure. The system is mainly series oriented with the final processing of products according to the required processes. The sequence of production technology is determined by the arrangement of specialized workplaces, which are created by workplace for income and storage of raw timber material, workplace for cutting head resaw, workplace for edging saw, workplace for drying timber, workplace for cross cut saw,

workplaces of products finalization as wood planning, wood milling, wood trimming and with workplace for packing of cuttings waste.

The workplace of income and storage of raw timber material ensures the supply of the company with raw timber material, and its primary storage by the type of timber before processing. The company supply is carried out on a weekly basis with a frequency of one truck for each timber type, which represents about 20-24 units of one timber type per week, i.e. approximately 1 piece of timber material per 0.33 day.

The workplace of cutting head resaw involves raw timber material cutting (depending on the thickness and length of timber) to beams, planks and boards. The output of the cutting is represented by unedged timber elements. The processing time of the elements depends on the type of timber. The cutting process of one timber piece of oak and beech requires about 60 minutes and the cutting process of one timber piece of spruce and pine requires about 40 minutes. The average output after cutting is 20 pieces of various wooden elements in the form of beams, planks and boards. The cutting generates 10 % of cuttings waste and 90 % of wooden elements continuing to the next workplace.

The workplace of edging saw is used for adapting and edging of unedged wooden elements. The time for edging of wooden elements depends on the type of timber, but an average time for oaks and beeches edging is about 3.5 minutes, and for spruce and pine edging, the time is about 3 minutes for one piece of wood element. The edging of wooden elements produces 25 % of cuttings waste. After edging of the wooden elements, 10 % is sold in the raw state and 90 % of the elements will be moved to the workplace of wood drying. 10 % goes to the kiln drying, and 80 % is dried in the open stock in natural conditions.

The kiln drying device has a capacity of 40 m³ for a drying batch. The cut raw timber is dried according to the requirements for the percentage of moisture and for the type of material. In general, the raw timber materials of the oak and beech types are drying for about 75 days and the spruce and pine types are drying form about 25 days. Drying of the raw timber material at the open stock in natural conditions takes about six months for all the types of timber. After drying, the timber elements are cut to the required lengths at the workplace of crosscut saw. The time for timber elements cutting to the required lengths is about 2 minutes per one piece of timber element. The cutting process generates cuttings waste, which represents 10 % of the timber material capacity.

After cutting, 65 % of the timber elements are ready for sale and export, and 35 % of the timber elements are treated according to special requirements of customers at the workplaces of wood planning, wood milling and wood trimming. The workplaces of wood planning, wood milling and wood trimming provide a service for customers and their requirements for the final machining. The processing time of the wood planning and wood trimming is about 5 minutes for a one piece of any type of timber element. The processing time of wood milling is about 15 minutes for a one piece of any type of timber element. All the final activities produce 5 % of cuttings waste.

All the timber waste is situated in the stock of the packing of cuttings waste workplace. The packing of one waste unit requires about 5-8 minutes. Waste taking is carried out by a contracting firm and its own means of transport. Cuttings waste is used for the secondary recovery and for heating.

4.3 The model of logistics in manufacturing represented by a block diagram

To create a block diagram (Fig. 3) as a basis for the actual simulation model, it is important to prepare the data and the information that are essential for the setting of the individual blocks within the simulation model [33]. From the statistical data obtained from observation and measurement in the field as well as from the technical documentation data [34], it appears that the input of the timber material into system occurs each 0.33 day, when another piece of timber material enters the system. In the simulation model, this is modelled by the four entry blocks "create" for each type of timber with a constant distribution setting of 0.33 day. Just before the first production facility, which is the cutting head resaw, there is an unprocessed timber storage which balances the cadence delays within production and the capacity of the control unit. In the

simulation model, this is represented by four blocks "queue" with the setting of "last in first out (LIFO)", material is put on itself. After that, there is a cutting head resaw type of device, where the processing of a single piece of timber ranges from 40 to 60 minutes. In the simulation model, this delay is modelled by a "lookup table" with constant distribution with delay parameters set to 40 minutes or 60 minutes for the processing of one piece and type of timber.

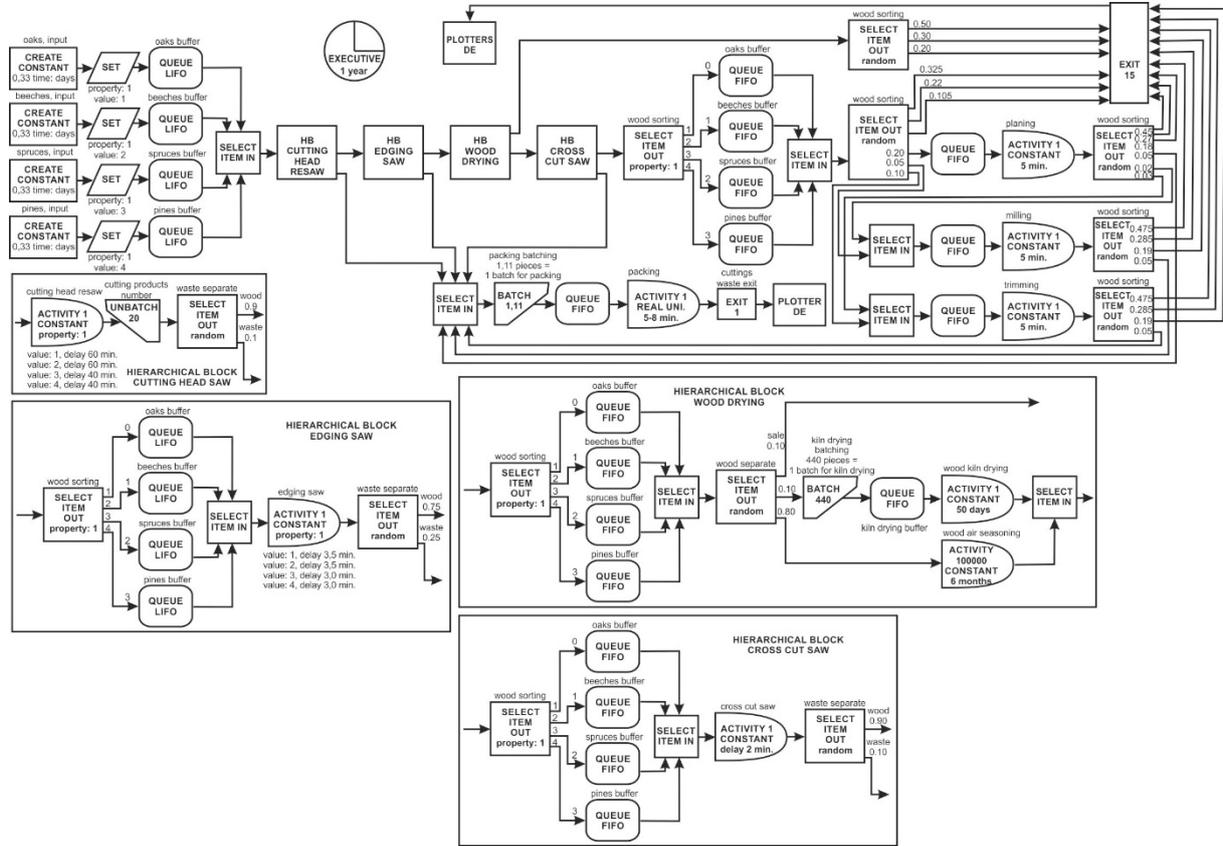


Fig. 3 Block diagram of the building timber elements production

4.4 The logistics in manufacturing of the concrete company designed by the EXTENDSIM

Each real activity, and all the processes and operations of the manufacturing system are necessary to transform and design by the blocks of concrete simulation system EXTENDSIM. Parts of the formal and block diagrams will be translated step by step, block by block to EXTENDSIM simulation model. The entry of timber into the production company, the identification of timber types and the storage of logs are represented by the blocks of "create", "set" and "queue" (Fig. 4). el blocks and for the control and solution of the critical production bottlenecks of the whole manufacturing system.

The place of work of "Cutting head resaw" is modelled in the simulation model using the first "hierarchy block". The hierarchy block for this operation is created using the blocks of "activity" – "batch" – "select item out" (Fig. 5).

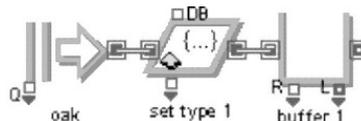


Fig. 4 Blocks "create", "set" and "queue" which represent the entry of timber material into the company, the identification of timber type and the storage of logs

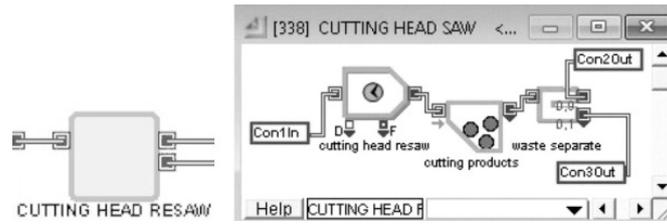


Fig. 5 Blocks of "hierarchy block", "activity", "batch" and "select item out" which represent the cutting of the timber into semi products such as beams, planks and boards

The place of work of "Edging saw" is modelled in the simulation model using the second "hierarchy block". The hierarchy block for this operation is created using the blocks of "select item out" – "queue" – "select item in" – "activity" – "select item out" (Fig. 6).

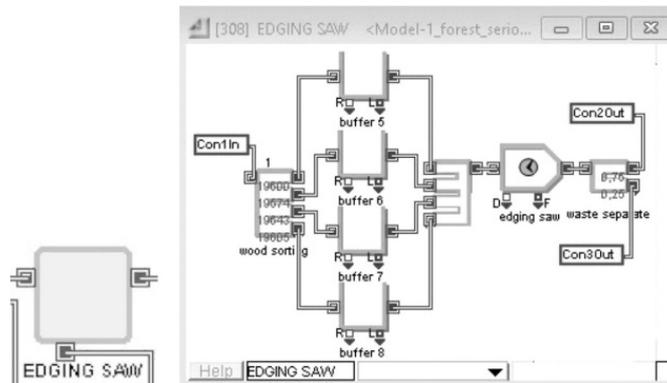


Fig. 6 Blocks of "hierarchy block", "select item out", "queue", "select item in", "activity" and "select item out" which represent the operation edging of the timber

The place of work of "Wood drying" is modelled in the simulation model using the third "hierarchy block". The hierarchy block for this operation is created using the blocks of "select item out" – "queue" – "select item in" – "select item out" – "batch" – "activity" – "select item in" (Fig. 7).

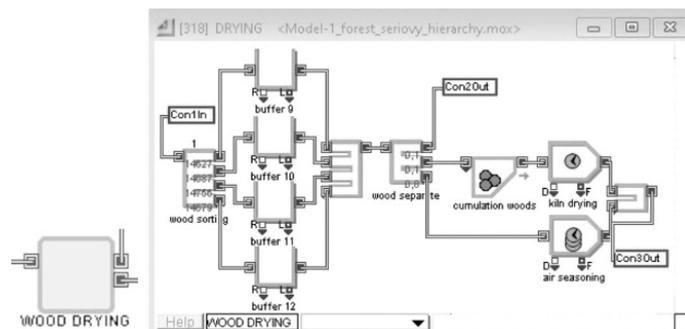


Fig. 7 Blocks of "hierarchy block", "select item out", "queue", "select item in", "select item out", "batch", "activity" and "select item in" which represent the operation drying of the timber

The place of work of "Cross cut saw" is modelled in the simulation model using the fourth "hierarchy block". The hierarchy block for this operation is created using blocks "select item out" – "queue" – "select item in" – "activity" – "select item out" (Fig. 8).

By combining the above described simulation model elements, several selected production processes were modelled, and they represent the actual real-life manufacturing system within the investigated company (Fig. 9).

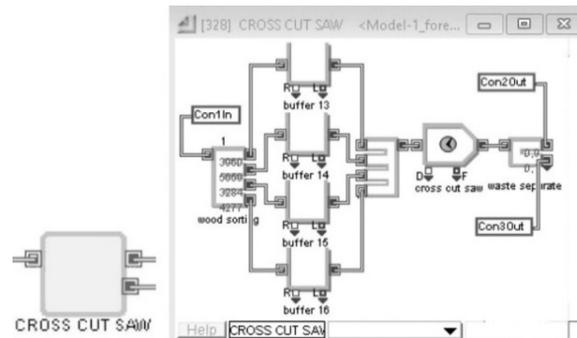


Fig. 8 Blocks of "hierarchy block", "select item out", "queue", "select item in", "activity" and "select item out" which represent the operation cross cutting of the timber

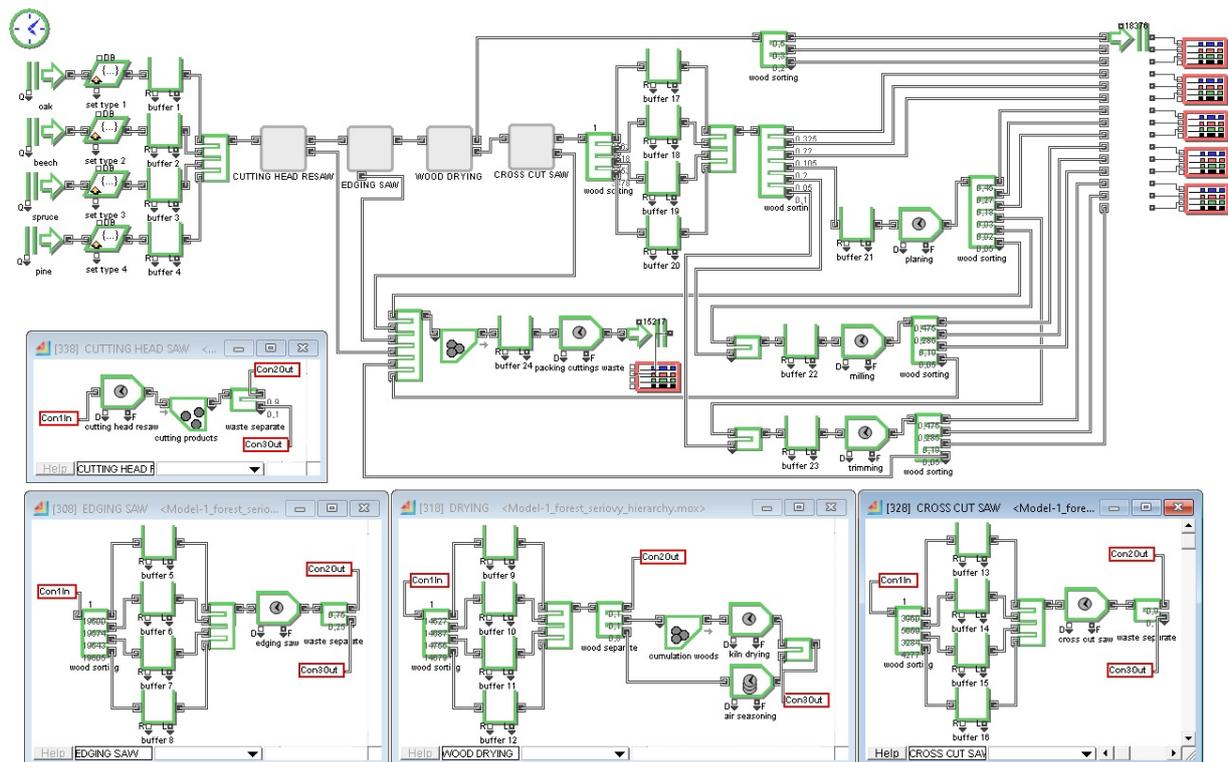


Fig. 9 The simulation model of the researched company building timber production

5. Results

As the simulation results indicate, the drying place of work, namely the facility for drying of timber material is the actual bottleneck. The given state is derived from the simulation analysis and has been verified by the technology management of the company. The findings indicate that this place of work is not sufficiently efficient to process the timber material entering the drying process, which results in an accumulation of unprocessed material (Fig. 10). This stage is solved by means of drying the timber material by air seasoning. This process of drying is extending the time necessary for processing of timber in the manufacturing system and possibly results in gradual degradation of quality timber material and of the company resources.

The simulation results indicate that the company produced a total of approximately 18,000 building timber elements for one year. The most sold building timber materials of the company during the year are the dried and made to measure beams (4,800 pieces), planks (3,309 pieces) and the dried beams of various sizes (1,734 pieces). The utilization of workstations wood planing, wood milling and wood trimming does not exceed 10%, even after the optimization. To increase the utilization of the planing, milling and trimming equipment, the production company must offer these processes used for the finalization of wood elements as a service provided to its customers. This activity can attract new customers for production.

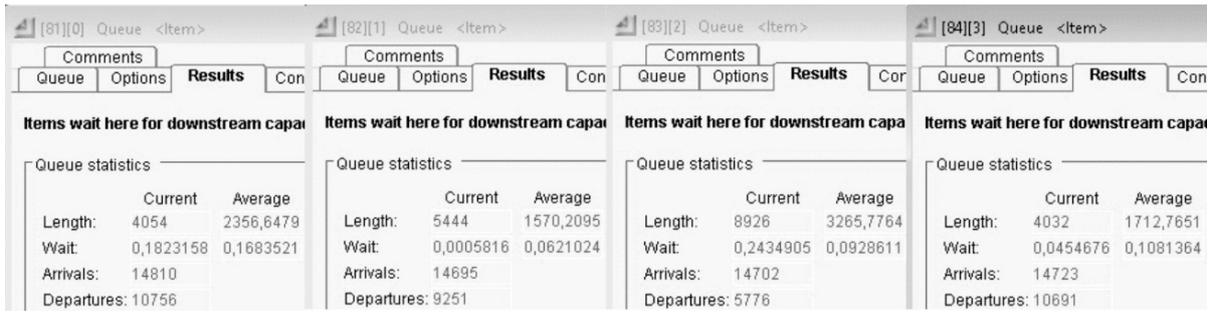


Fig. 10 Length of timber material in blocks of “queue” before processing at kiln drying facility

The researched manufacturing system generates approximately 15,000 pieces of packed cuttings waste units per year. The production of cuttings waste depends on the numbers of processed timber materials and the utilization of production devices. The ratio between the quantity of the incoming material to the manufacturing system and the cuttings waste is approximately 5:1. The ratio between the quantity of the finished products and the cuttings waste is approximately 1.2:1. Other building timber materials are scattered throughout the manufacturing system. This fact makes it possible to state that the store and buffers of the whole manufacturing system contain many unfinished products. The number of elements of unfinished products can be reduced by means of thorough planning of production and by increasing the utilization of the production devices.

The simulation output data show that part of the manufacturing system is overloaded, while other parts of the system have substantial reserves. We have the following possibilities in order to streamline the production:

The streamlining of the manufacturing system activity does not depend on the purchase of new and expensive devices, but only on the change of the logistics in manufacturing and the management of flows. All the workstations of the company have reserves for further development. By changing the management of the company logistics in manufacturing, we will increase the performance of timber drying in the drying device, thereby also increasing the performance of the entire manufacturing system. The company has enough storage capacity and it is therefore possible to increase the intensity of company supply. The simulation results indicate that it is necessary to double the intensity of company supply, i.e. a frequency of entry set to 0.15 days for each timber type. This adjustment increases the performance of unutilized devices and the whole manufacturing system several times, up to 54,475 produced building timber elements, which represents an increase of production by about 199.6 % while maintaining company flexibility (Fig. 11).

This adjustment increases the resources at the input to the system, but the performance of the devices will increase several times and thus the whole manufacturing system. This implies that the intensity of the input material to the system also represents a bottleneck for the produc-

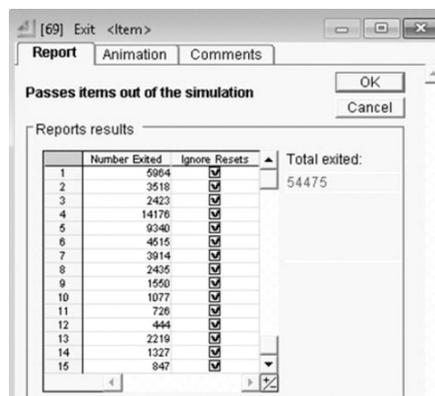


Fig. 11 The increasing utilization of the whole manufacturing system by means of timber supply reorganization

tion. An additional adjustment is related to the preparation of the entry batch for drying in advance, which was described above. The changes in the organization of logistics in manufacturing and the supply of enough input of resources increase the system performance without any necessary investment in new expensive production facilities.

6. Conclusion and questions for discussion

Computer simulation allows users to create simulation models of complex manufacturing systems, detailed orientation in devices, as well as orientation in operations and processes. The utilization of computer simulation, as a scientific method, is very widespread in the area of science, research and practice. The financial, time, material and energy savings and efficiency of the operation in practice are the benefits of the utilization of computer simulation. Simulation software EXTENDSIM, Simul8, Witness, Tecnomatix and other belong to the modern means of simulation, where simulation models are created from blocks, which are kept in libraries, and they are used to build the entire simulation model, similar to building a house from bricks, because their use is easy and intuitive.

In terms of the complexity of technological processes, the creation of their mathematical models is very difficult or even impossible. The conversion itself is protracted and inefficient. The experiments in real operating system are very rare and the main reasons why this experimenting is not used are: experiments with real systems are expensive and lengthy, it is impossible to investigate more variations and more options, important variables are fixed in real operation and it is hard to change them for the purpose of the experiment, experimenting can cause serious system failures, the investigated object does not exist in reality and operation experiments can be dangerous for people or machines, the state changes of the system are too rapid or slow to record the necessary information. Computer simulation of the systems can be executed outside the real objects, without affecting the actual operation, resp. without the existence of the actual investigated system.

The result of a simulation is information about the investigated system and its elements according to the defined parameters. Experimenting with a simulation model sets apart the simulation of systems from other forms of the cognition process. That is why this method is considered as simulation in the narrower sense of the word. The conclusions derived from its usage are applied in all the phases of interactively running simulation process.

The above described case study, where the simulation modelling has been successfully implemented for the needs of a company producing building timber, demonstrates the capabilities of simulation modelling and the advantages of such approach for the advancement of science, as well as for the application in the solution of everyday problems in general practice. The individual parts of the simulated system are described by the sequence of blocks in the model. These blocks are connected by the flow lines with arrows that set the direction of the flows. The recommendations for the above described company, supported by the simulation results, were subsequently applied in practice. The practice has verified the simulation outputs from the EXTENDSIM simulation system and has confirmed the validation of the proposed recommendations. Thanks to the application of EXTENDSIM simulation system, the production capacities have increased in the case study company, which demonstrates the importance of computer simulation use to solve this type of tasks. The assignment goal that was defined in the introduction to this article has been achieved.

In terms of further research, the following questions remain open for consideration:

- How will the increased production performance affect the business position of the company in the market?
- How will the increased production performance affect the whole system and human resources management?

In general, it can be said that computer simulation is an important means for solving problems in the field of logistics in manufacturing, in production and in manufacturing systems [35].

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