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Professional paper

IMPROVED EFFICIENCY OF MANUFACTURING LOGISTICS BY USING COMPUTER SIMULATION

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Abstract
The paper deals with the streamlining of production logistics by using the example of a specific construction production company – through design via ExtendSim computer simulation. The issue concerns researching procedures for the company's long-term sustainable competitiveness in the production of building components in a very competitive market. The research aims to use computer simulation as a means for the regular streamlining of production logistics in a specific manufacturing company, focusing on the production of building parts. The company in question produces building material, which takes place in two types of kilns: the first for drying products, the second for product firing. Yet, these operations represent a bottleneck in terms of production logistics. The final packaging of the daily production of construction products is approximately 280-320 pallets in 12 hours. Yet by adjusting the parameters of production logistics in individual parts of material flow, production can be boosted by 14.96 %. The given solution can be practically applied to modernise production, without additional cost, simply by changing work organisation and the production's bottleneck parameters.
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Key Words: Efficiency, Logistics, Simulation, Design, ExtendSim, System

1. INTRODUCTION

Simulation modelling is an effective tool for analysing scheduling challenges and making parts of various specifications. Simulation is frequently applied to manufacturing facilities to improve production processes where the system has numerous random interacting components [1, 2]. Simulation tools for modelling reality in a virtual environment are becoming a key success factor. Hence their wide use in various industries and areas, such as construction, automotive, healthcare, robotics, information technology, management, economics, trade, logistics and transport [3-13]. In addition to modelling and simulation, a key feature of a simulation tool is the option for automatic or semi-automatic process optimisation [14]. Simulation modelling as a scientific method in research and practise is very widespread. Advantages resulting from simulation modelling include time-, financial-, material- and energy savings, and the practical rationalisation of activities [15]. Process simulation models are an effective tool for identifying obstacles during the production process and improving process parameters since such models incur no costs or negative impacts on the production process. Yet, the development of the correct simulation model requires theoretical knowledge (simulation technique, specific simulation systems), as well as practical experience (description of the system, its components and their mutual interactions and connections) [16-19]. The interest of researchers and the management of companies in the modelling and simulation of supply chains has led to the development of dedicated simulation tools such as EXTEND and ARENA [20-22].

A computer simulation model for streamlining a company's construction production depends on the analysis and quality of available data. The data used to create a computer simulation model is real values obtained from long-term statistical indicators, which a company annually aggregates based on real production in a given year.

According to their current settings, the parameters of production equipment and their representative values in individual parts and blocks of the computer simulation model are real values. Changing the parameters of production equipment is only possible on the scale given by the equipment manufacturer. Additional reserves for streamlining production logistics can be sought only in an available time slot or by modernising production facilities. It is more advantageous to find and use opportunities from available time reserves from the financial perspective since such an approach does not incur any/minimal additional costs. As new production equipment is expensive, it is better to streamline production logistics if such options are available.

2. METHODOLOGY

A building material company's production logistics has a defined system and precise sequence. From the above information and after analysing the logistics of the entire production chain, in terms of the company's micrologistics model, a formalised scheme can be formulated from material input, processing, modification, production of building materials, packaging, and finally dispatch (see Fig. 1). The formalised scheme represents the overall system with elements and links. This includes considering waste generation in individual parts of production and its transfer to another part – both in reality and in a computer simulation model. System elements comprise individual parts, such as operations related to material inputs, crushing, mixing, processing, drying, firing, packaging, and dispatch. Between individual operations, links form through transport, storage, and management elements.

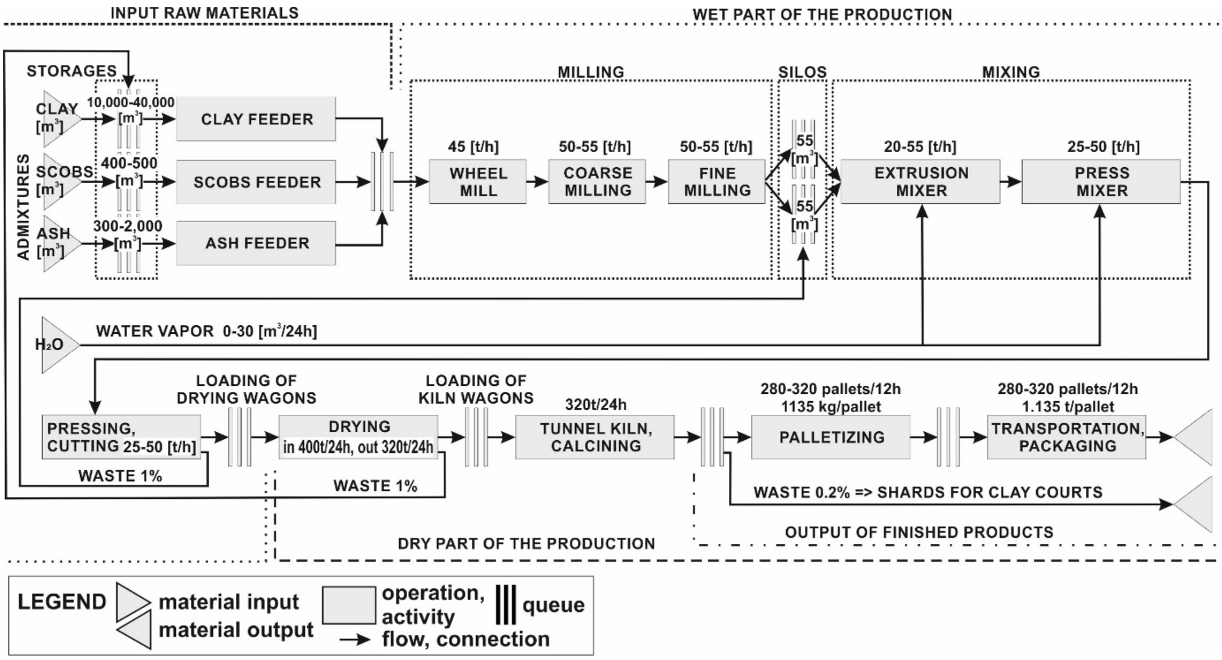

Figure 1: Formalised scheme of the company's building component production.

As part of the researched production system, the main aim is to identify bottlenecks, explore options to streamline the production of a particular operation, design more efficient production by increasing production while reducing/maintaining energy costs and making the most efficient use of available time [16]. From that described, the research problem and problem-solving aim can be defined. The issue concerns researching procedures for the company's long-term sustainable competitiveness in the production of building components in a very competitive market, which brings a whole new perspective on effective construction management. The research aims to use computer simulation as a means for the regular streamlining of production logistics in a specific manufacturing company, focusing on the production of building parts. We intend to highlight the practicality of computer simulation systems and use a specific simulation system (ExtendSim) to streamline a particular company's production logistics/activities [23].

The compiled formalised scheme comprises an important basis for creating a simulation model as part of a specific simulation system. Individual parts of the formalised scheme are gradually replaced by respective blocks of a particular simulation system, which imitate/represent a specific real operation. The creation of a computer simulation model consists of two parts. The first part is represented by a block diagram of the relevant simulation system (see Fig. 2). The second part is the computer simulation model itself with the implementation of data for the researched area of a particular company's production logistics (see Fig. 3).

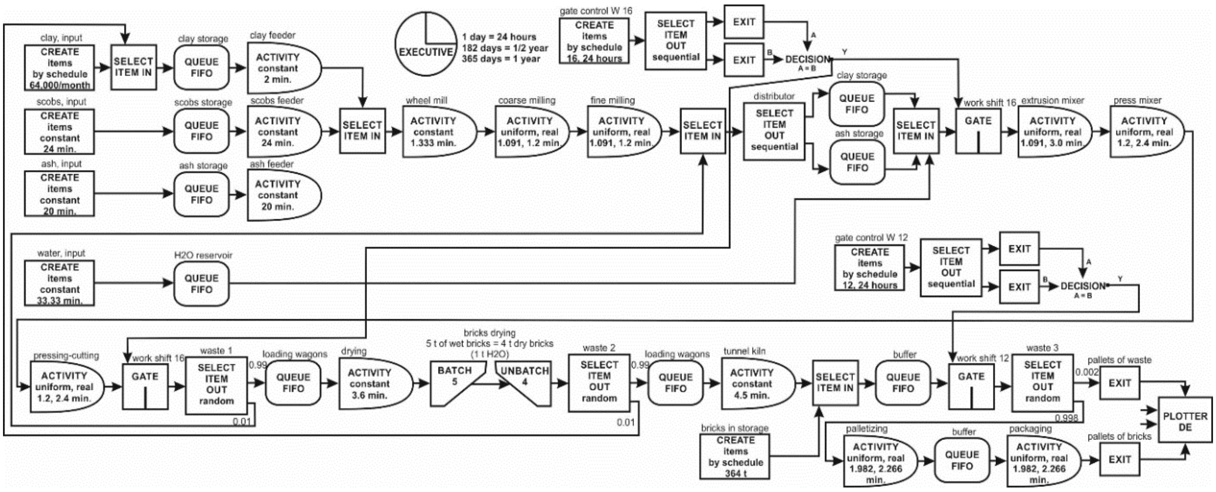

Figure 2: Block diagram of the company's building component production using ExtendSim simulation system.

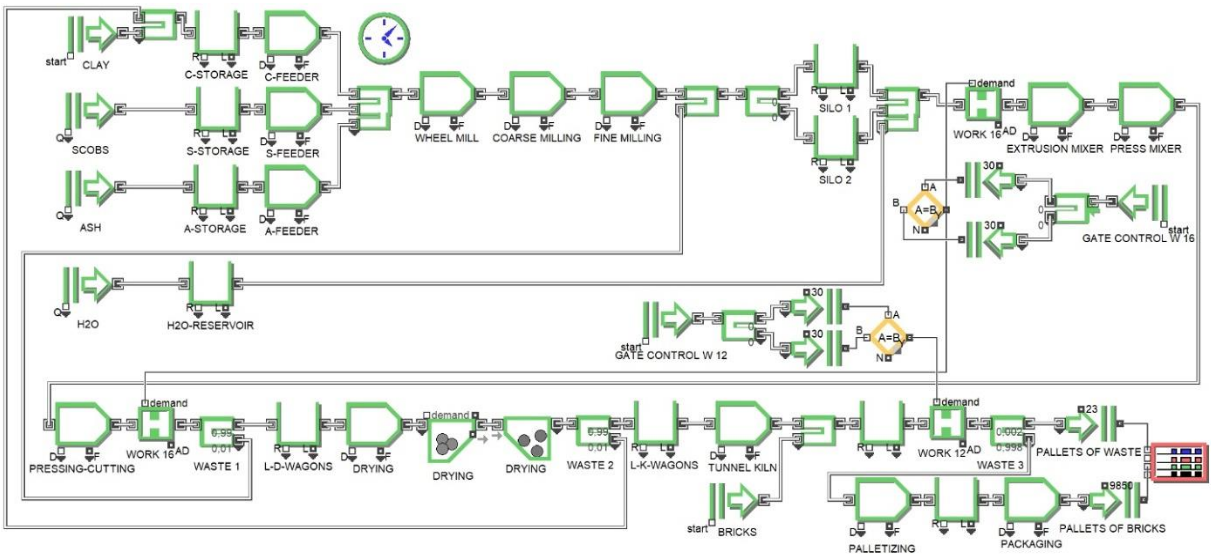

Figure 3: Computer simulation model the company's building component production using the ExtendSim simulation system.

The compilation of the block diagram as a basis for the simulation model is important for preparing data, information, parameters for individual operations, and the branching/merging of flows that are important for the setting of individual blocks of the simulation model. A meaningful computer simulation model can only be created with this prerequisite information and logic of block sequences.

The overall operation of the company's building component production system will be represented by a computer simulation model where the technology is indexed into operational sequences. The most energy-intensive are kilns for the drying and firing of building components, a process that defines the final product status both in terms of shape and quality. The primary raw material to produce building components is quality clay, while other input materials include sawdust and ash. Water is used according to a well-defined recipe to create a standard consistency of mixed input materials. The input material passes through feeders to a wheel mill, followed by coarse crushing and then fine grinding. The resulting material is stored in two 55 m^3 silos. Then is the preparation of the correct consistency of the mixture with water added as needed. This mixture is extruded through an extrusion stirrer into the press mixer. One consistent, continuous product is then extruded through the press, which is cut into precise building components, i.e. "wet bricks". Production of wet bricks takes place over two eight-hour work shifts. The products are then loaded onto drying wagons that pass through a dryer where excess water evaporates: 20 % of the water evaporates from one ton of crude products, i.e. 0.8 tons of dry product results from each ton. Dried building components are loaded onto kiln wagons, which pass smoothly through the kiln, where firing takes about 24 hours. After the drying and firing process, five tons of input raw materials result in four tons of final products. The drying and firing of building components take place in a continual 24-hour work operation, then the finished building components/products arrive at the palletising, packaging and dispatch area. The palletising product workplace has a 12-hour shift operation and dispatches 280-320 pallets of finished products every 12 hours, while one full pallet weighs 1.135 tons.

Parts of the computer simulation model are characterised by a sequence of blocks with connectors that determine the direction of material flow. The position icon defines the basic characteristics of the model's individual blocks, and the name of the block, block connectors, connectors, dialogues with operands, and flows.

Each used block has a defined place/position in the simulation model, representing the actual investigated system. The blocks themselves represent certain parts of the processes/systems from which the model of the real system under study is then created.

Icon and block names are pictorial representations of blocks with an exact unique name that describes their basic function. Each block has its unique icon, name, and function that expresses its basic use in design and modelling.

Block connectors are parts of icons that allow blocks to interconnect. Thereby it is necessary to follow the rule that only input connectors with output connectors can be connected. By connecting two blocks, a logical sequence of blocks corresponds to the investigated real system and forms the basis for the flow of requirements and values.

Blocks' interconnection ensures the creation of flows and triggers their management and control. The connecting of blocks must represent a real sequence of blocks, as per the investigated system. By connecting two blocks through their connectors, a connector is created – a line that clearly defines the sequence of blocks and the flow direction of requests and values.

Dialogues and operands represent specific items/properties of blocks, which are characteristic for individual blocks and necessary for their operation. Opening a dialogue window block displays the specific parameters and properties of the block, which can be/must be set for a specific block.

The following parameters for the investigated production system result from data obtained from the technical parameters of production, long-term measurement, and regular statistical evaluation.

The input/supply of clay for production is from a nearby clay dump which has high reserves for several months. The maximum capacity of the clay dump is 40,000 m^3, which at a weight coefficient of 1.6 tons represents 64,000 tons of clay. In the computer simulation model, material input into production is represented by the "Create" block, with the setting for the input of the required quantity in tons for a given time unit. The basic dynamic unit that moves, changes, and shifts in the model is a ton of material per time unit hour and the converted equivalents thereof. Clay, sawdust, and ash pass through their respective feeders. The clay feeder moves one ton of clay into the system every two minutes; the sawdust feeder moves one ton of sawdust into the system every 24 minutes; and the ash feeder moves one ton of ash into the system every 20 minutes. As an input raw material for the production of a technological building mixture, one ton of water enters the system every approximately 18 to 50 minutes.

The preparation of the technological building mix, wet bricks, drying and firing of bricks, and palletising/packaging of products occur at workplaces and specific facilities. The "Activity" block represents blocks in the ExtendSim simulation system (which represent the given facilities and operations in the computer simulation model). The main parameter for individual operations is the delay for a specific time unit. The wheel mill processes one ton of incoming material every 1.33 minutes. Coarse crushing and fine grinding equipment processes one ton of material every 1 to 1.2 minutes. The extruder mixer processes one ton of material every 1 to 3 minutes, and the press mixer, press, and cutter process one ton of material every 1.2 to 2.4 minutes. From the sequence of the defined chain, many wet bricks form at the outlet. The waste/failure rate represents 1 % of the total amount of wet bricks produced. Such waste is processed and returned to the workplace with an extruder stirrer.

This is followed by 'dry production', which begins with drying in a kiln. Drying takes place as a continuous process, with the device producing one tonne of dry bricks every 3.6 minutes, which then moves on for firing. The failure rate at the end of brick drying represents 1 % of the total amount of production. Rejects are processed and taken to a clay dump, where they gradually degrade and disintegrate under climatic conditions. The kiln also operates as a continuous process, producing one ton of finished product every 4.5 minutes. The failure rate at the end of brick firing represents 0.2 % of the total amount of production. Rejects are processed and repurposed for the production of clay aggregate, which is sold as part of the company's product range.

Finished products are palletised and packaged in the designated workplace. The palletising and packaging department processes one ton of finished products in 2 to 2.3 minutes. Packaged products are dispatched through the expedition warehouse of finished products.

From the perspective of creating a computer simulation model, it is worth mentioning the drying of wet bricks since this part of the weight parameter of products changes: 320 tons of dry bricks are produced from 400 tons of input wet bricks. The question is how to simulate the given status and decrease as water evaporation in the given simulation system/in principle also in other simulation systems. The period in the kiln, i.e. drying in terms of the time required for the quantity, has been described above. From the point of view of the simulation, the change in product weight can be understood as the assembly and disassembly of the products. As the ExtendSim simulation system works with whole units of time, the given status must be converted into integers. As the weight loss represents 20 % of the total weight of the wet product, it follows that four tons of dry products are produced from five tons of wet products. Five tons of wet products represent the 'assembly' of one item, tons of semi-finished product, which is immediately disassembled into four identical items, i.e. four tons of dry products. Hence the drying and change in weight of the finished products has taken place (see Fig. 4). The described status can be simulated in any discrete system simulation, and in ExtendSim is modelled by combining the "Batch" and "Unbatch" blocks. The overall drying operation is modelled by combining the "Activity – Batch – Unbatch" blocks (see Fig. 5).

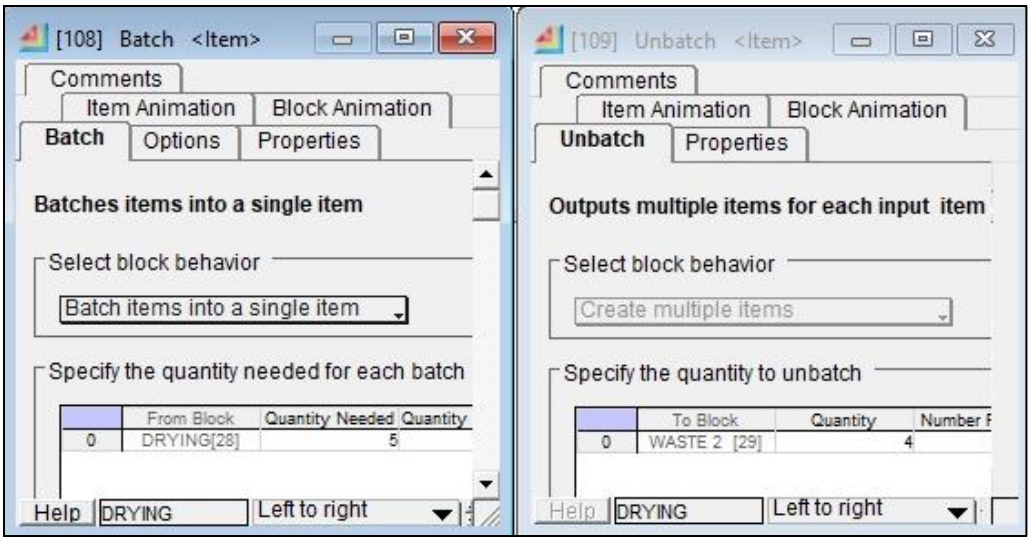

Figure 4: Use of "Batch – Unbatch" blocks for modelling products' weight loss during drying and their setting according to technological parameters in the ExtendSim simulation system.

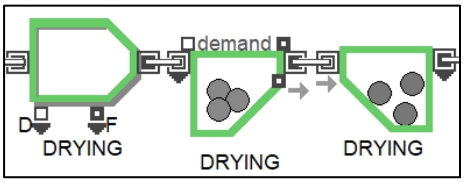

Figure 5: Use of "Activity – Batch – Unbatch" blocks for modelling the whole process of drying bricks in the kiln in the ExtendSim simulation system.

In terms of computer simulation, it is also very interesting that the production line operates across unequal time settings. Part of the production line works 24 hours a day, some 16 hours a day, and another 12 hours a day. How to model a given status in a specific simulation system? The *"Gate"* block model is appropriate to model a given production status. According to the defined parameters, this block closes or opens a certain part of the production line at precisely determined time intervals. The time interval for opening/closing part of the production line via the *"Gate"* block is modelled using the *"Create – Select Item Out – Exit – Decision"* blocks (see Fig. 6). The output from the *"Decision"* block's condition is the value 0 or 1, which enter the *"Gate"* block as impulses to open the gate. If a pulse with value 0 is sent, the gate closes and the line stops working in the given part. In the case of value 1, the gate opens and the line runs again. The given status and activity of the blocks is repeated at 24-hour intervals (see Fig. 7).

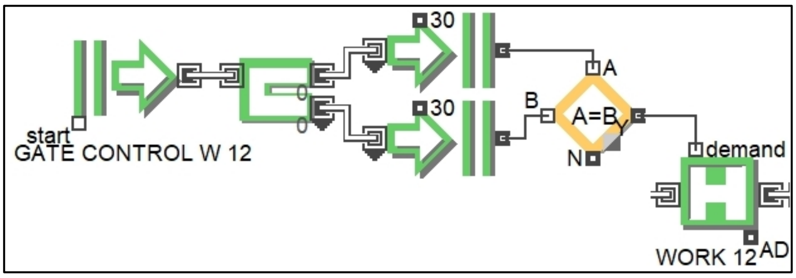

Figure 6: Use of blocks "Create – Select Item Out – Exit – Decision – Gate" for modelling various work changes on one production line in the ExtendSim simulation system.

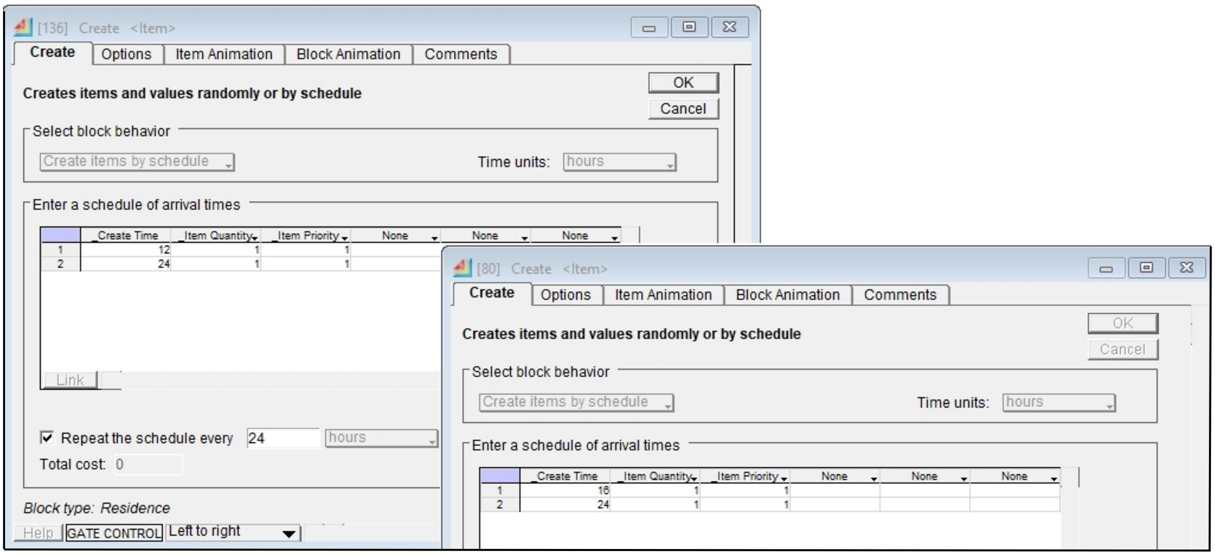

Figure 7: Setting of "Create" blocks for modelling various work changes on one production line in the ExtendSim simulation system.

3. RESULTS AND DISCUSSION

Following set up, the simulation model is used to examine and streamline the production logistics of building components at a selected company. An additional advantage of computer simulation is also that it allows the examination of conditions that would not be real-world possible due to system security and employees. The plan of experiments consists of comparing the results between the current state and two states in which it is assumed to improve the operation of the system and increase its production (see Table I).

Table I: Plan of simulation experiments of the production of bricks.

Plan of experiments		The system, simulation time	Drying and firing time per one ton of production	Working time	Palletizing and packaging time per one ton of production	Working time
1	**Current state**	30 days	3.6-4.5 min	24 h	2.0-2.3 min	12 h
2	**Increased palletising and packaging performance**	30 days	3.6-4.5 min	24 h	2.0-2.3 min	24 h
3	**Increased drying and firing performance**	30 days	3.0-4.0 min	24 h	2.0-2.3 min	24 h
4	**Increased drying and firing performance**	30 days	2.6-3.5 min	24 h	2.0-2.3 min	24 h

Within the defined simulation, the system's operation over 30 days is investigated. The results of the simulation, which captures the current status of the company's activities, show that the bottleneck is the drying and firing of bricks. The given situation also resulted from an analysis of the current status, and was confirmed by the company's respective employees. As the brick drying and firing workplace operates continuously, its output can be increased 1) with a higher volume of semi-finished products for processing, 2) by shortening products' drying and firing time, or 3) by purchasing new, more powerful equipment. The last solution (3) is the least attractive in terms of financial cost.

Total production over 30 days is 9,721 tons/8,565 pallets of finished bricks products and 19 tons/17 pallets of clay aggregate. After conversion, daily production is therefore 285 pallets of finished products and 0.56 pallets of clay aggregate. Workplace utilisation for wet brick production is 53.4 %, for drying/firing of bricks 99.9 %, and palletising/packaging of finished products 44.8 % (see Fig. 8).

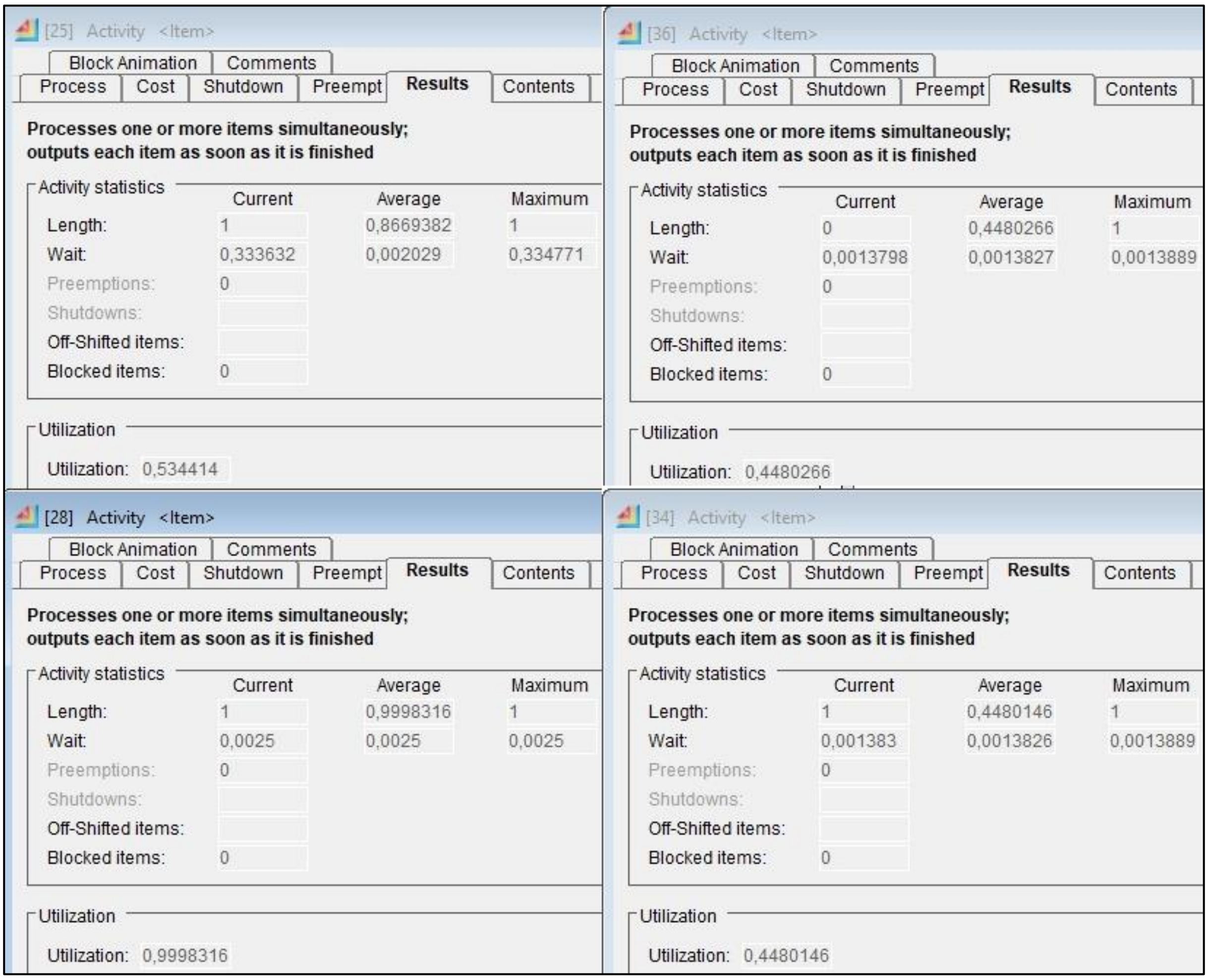

Figure 8: Results of workplace utilisation for the production of wet bricks, drying/firing of bricks, and palletising/packaging of finished products in the ExtendSim simulation system.

Other parts of the production line (such as the mixing of raw materials, moulding, extrusion/cutting of wet bricks, as well as palletising/packaging, also have free reserves in terms of unutilised available working time – either eight or 12 hours. In such a case, the purchase of new, more powerful equipment is not necessary. After using unutilised available time – in terms of wet brick production as well as palletising/packaging of finished products – for a continuous 24-hour period while maintaining the current parameters of drying/firing bricks, there was found to be no significant increase in the production of finished products.

Total production over 30 days with increased available workplace time for the production of wet bricks, as well as palletising/packaging finished products, is 9,881 tons/8,706 pallets of finished products and 22 tons/19 pallets of clay aggregate. After conversion, daily production is therefore 290 pallets of finished products and 0.65 pallets of clay aggregate. Workplace utilisation for wet brick production is 80 %, drying/firing bricks 99.9 %, and palletising/packaging of finished products 44.8 % (see Fig. 9).

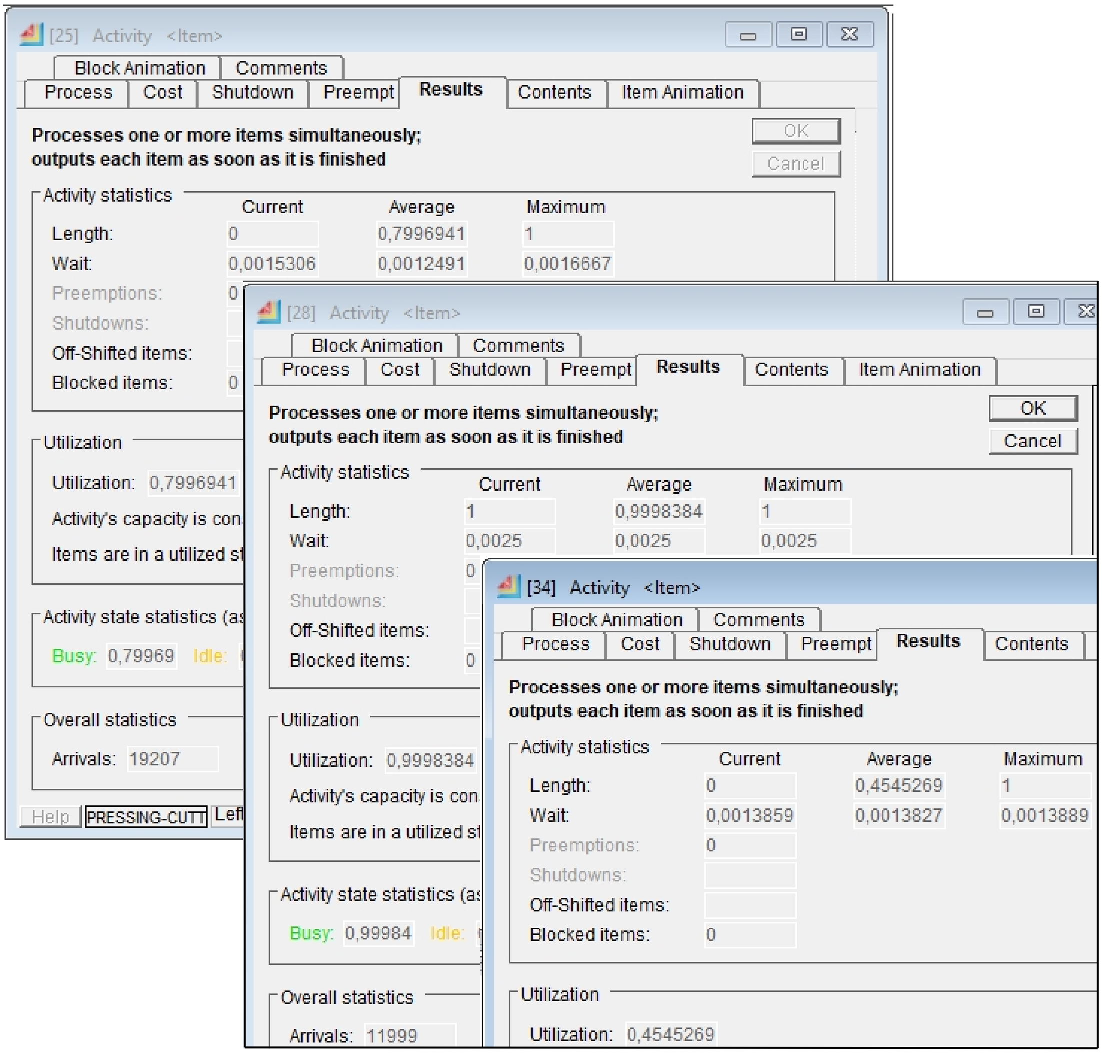

Figure 9: Results of the use of workplaces for the production of wet bricks, drying/firing of bricks, and palletising/packaging of finished products after increasing utilisation of available time in the ExtendSim simulation system.

The given results show that the workplace for drying wet bricks and their firing remains a bottleneck. To really increase the production of finished products, the solution is a technological change in drying and firing by shortening the drying and firing time and adjusting the drying and firing curves of bricks to ensure the quality of finished products is maintained. By reducing the drying time to three minutes per ton and firing to four minutes per ton with the full 24-hour operation of all workplaces over 30 days, the production capacity of finished products can be increased to 11,175 tons/9,846 pallets of finished products, and 26 tons/23 pallets of clay aggregate. In terms of daily production, this represents 328 pallets of finished products and 0.76 pallets of clay aggregate. Workplace utilisation for wet brick production is 80 %, drying and firing bricks 99.9 %, and palletising/packaging of finished products 51.5 %.

With the further technological modification of drying and firing of bricks by shortening the drying time to 2.6 minutes per ton and firing to 3.5 minutes per ton with the full 24-hour operation of all workplaces over 30 days, the production capacity of finished products can be increased to 12,710 tons/11,198 pallets of finished products, and 29 tons/26 pallets of clay aggregate. In terms of daily production, this represents 373 pallets of finished products and 0.85 pallets of clay aggregate. Workplace utilisation for wet brick production is 80 %, drying/firing of bricks 99.9 %, and palletising/packaging of finished products 58.6 % (see Fig. 10 and Table II).

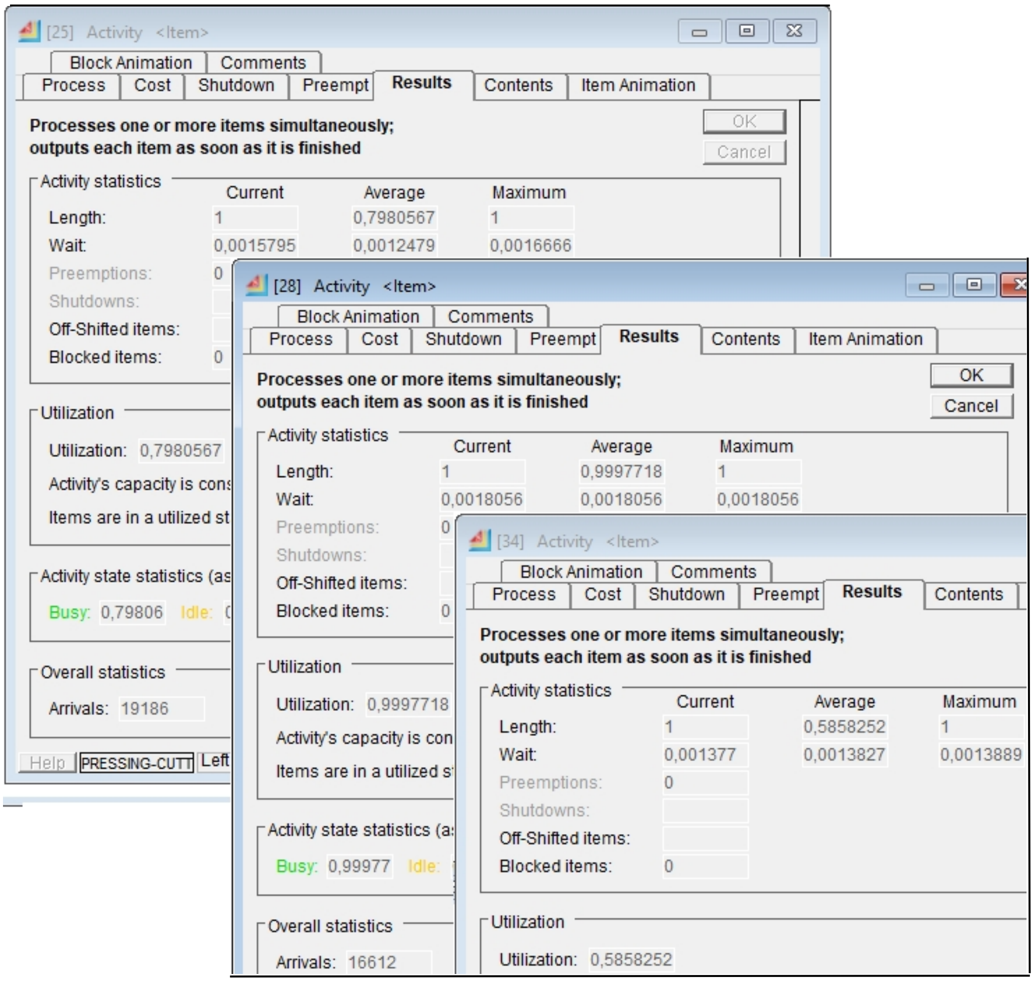

Figure 10: Results of using workplaces for the production of wet bricks, drying/firing of bricks, and palletising/packaging of finished products after increasing the use of available time and shortening the drying/firing time of bricks in the ExtendSim simulation system.

Table II: Results of simulation experiments of the production of bricks.

	Results of experiments	**The system, simulation time**	**Drying and firing time per one ton of production**	**Working time**	**Palletizing and packaging time per one ton of production**	**Working time**	**Production of bricks** (ton)	**Number of pallets of bricks** (pieces)	**Production of clay aggregate (ton)**	**Number of pallets of clay aggregate** (pieces)
1	**Current state**	30 days	3.6-4.5 min	24 h	2.0-2.3 min	12 h	9,721	8,565	19	17
2	**Increased palletising and packaging performance**	30 days	3.6-4.5 min	24 h	2.0-2.3 min	24 h	9,881	8,706	22	19
3	**Increased drying and firing performance**	30 days	3.0-4.0 min	24 h	2.0-2.3 min	24 h	11,175	9,846	26	23
4	**Increased drying and firing performance**	30 days	2.6-3.5 min	24 h	2.0-2.3 min	24 h	12,710	11,198	29	26

In terms of further research plans, certain questions remain open:

- How to introduce a change in production technology related to continuous production? Incremental or dramatic?
- How to implement a change in production technology related to continuous production? Concurrently or sequentially?

4. CONCLUSION

The issue concerns researching procedures for the company's long-term sustainable competitiveness in the production of building components in a very competitive market, which brings a whole new perspective on effective construction management. The research aims to use computer simulation as a means for the regular streamlining of production logistics in a specific manufacturing company, focusing on the production of building parts. We intend to highlight the practicality of computer simulation systems and use a specific simulation system (ExtendSim) to streamline a particular company's production logistics/activities.

From the results, it can be stated that the workplaces of wet brick production and palletising/packaging of finished products have sufficient reserve capacity. Wet brick drying and firing workplaces can increase performance under the given conditions only on the basis of the technical adjustment of drying/firing curves, as well as by shortening bricks' drying/firing time. By reducing drying time to one minute per ton of products and firing time to two minutes per ton of products, 15,381 tonnes/13,552 pallets of finished products and 38 tonnes/33.5 pallets of clay aggregate can be produced over 30 days of continuous production. This represents increased production of 58.22 % compared to the current status. Yet this case represents an already extreme setup of the production equipment. Under actual operating conditions, such equipment would be replaced by more powerful technological equipment for the drying and firing of bricks. In real terms, there is a fine adjustment of the drying/firing time of bricks to produce 11,175 tons/9,846 pallets of finished products and 26 tons/23 pallets of clay in 30 days. Such output would represent increased production of 14.96 % compared to the current status.

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