DISCRETE EVENT SIMULATION USAGE TO MODEL AND OPTIMIZE THE PRODUCTION LINE

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Simulation models are usually used in situations where complex or complicated systems and processes need to be analyzed. The main advantage of the simulation modelling is the fact that it is realized in virtual reality (in simulation software) without the necessity to change the real processes. In this article the process of the model creation, verification and validation is described on the example of the Cisco routers production line in company Foxconn CZ. One part of the production line is modelled in SIMUL8 software. The main aim is to verify options for the line balancing improvement. For the activities' duration times the estimation of the probability distribution was made in R software on the basis of real data or via the experts' estimate. After the process bottleneck findings according to the simulation models' results the changes in the production process were suggested.

KEYWORDS

simulation model, production process, production line, routers, SIMUL8

1 INTRODUCTION

Simulation as a tool for the process analysis has started to be more important and widely used since the times of the computers' development in 1960s' [Pidd 2014]. The main reason for using computer simulation in the analysis of managerial problems is the impossibility of using any other, especially analytical tools due to complexity of real processes. Over the years simulation modelling has become an effective and robust part of the operations research and management science [Braisford 2014], [Rotaru 2014] although nowadays it might also be seen as an IT or statistical tool. Simulation means a technique for imitation (by a computer model) of some real situations, processes or activities that already exist in reality or that are in preparation [Banks 1998]. Models can be created in various software packages depending on the type of the model or on the type of the analysis planned. Sometimes Monte Carlo simulation for iterative evaluation of a deterministic model is sufficient but real simulation is usually made via discrete event simulation or continuous simulation model [Dlouhy 2011]. Simulation could be applied to various kind of processes from manufacturing production lines [O'Kane 2000], [Masood 2006], [Montevechi 2007], [Aguirre 2008], [Ficova 2013], [Fousek 2017] and call centers or help desks [Kuncova 2007] to health care models and hospital processes [Günal 2010], [Ghanes 2014], [Voracek 2014].

Simulation of production processes can be found in various types of industries and at all stages of production - examples in the Czech Republic can be found on the pages of companies that create simulationmodels for other companies – for example Logio [Logio 2018]. and Dynamic Future [Dyn.Future 2018]. Very oftenthe Matlab (Simulink), Witness or Comsol [Humusoft 2018], [Dyn.Future 2017] or Plant Simulation (used in Skoda auto company -[Stocek, 2012]) softwareare used to visualize the necessary processes, usually using 3D graphics.For the basic analysis, however, programs designed for general process simulation, such as SIMPROCESS or SIMUL8 [Dlouhy 2011], can be used although 2D graphics oly is displayed to create a simulation model of the selected process and to analyze its possible extension, modification and alteration.

The selection of the methodology for the simulation modelling can be influenced by the analysis required by managers, software package that is available or by the personal preferences of the modeler [Braisford 2014]. For the production process analysis with a lot of random parameters it is usual to use discrete-event simulation (DES) as one of the operations management techniques that is stochastic in nature. All activities, their sequence, duration and required resources must be defined. In the following text we present the manufacturing problem in company FOXCONN CZ dealing with the production of the Cisco routers. This article describes the simulation analysis of the production process of the routers. The main aim is the finding of the bottlenecks of the process and the analysis of the employees workload followed by the suggestions for the production line improvement.The simulation model is developed in the environment of SIMUL8 software. After debugging the model, results obtained from the simulation runs are analyzed to find the main problems of the process and possibilities of improvements. The experiments are performed with the objective to suggest the management the most responsible decision.

2 DISCRETE EVENT SIMULATION

Discrete event simulation (DES) is focused on modelling entities moving through a set of queues and activities. During the process DES observes only the important events – it means only the time points where there is a change in the system (entity arrival, start/end of an activity). Since these events occur at irregular intervals the simulation time in a DES model moves forward in a jumps bridging the "no important" time between the events – that is why it is called discrete-event [Dlouhy 2011], [Robinson 2014].

DES usually models queuing systems as they progress though time describing entities (people, products, material etc.) moving through a network of queues and activities and using limited resources during activities [Robinson 2014]. In each simulation study a set of several phases should be followed [Wainer 2009], [Dlouhy 2011], [Rotaru 2014]:

- Problem formulation
- Conceptual model
- Collection and analysis of input/output data
- Modelling phase/computer simulation model
- Verification and validation
- Experimentation with the model
- Results comparison and description
- Implementation

Similar phases could be used in system dynamics methodology but it is more static model based on differential equations and it is generally deterministic which might be less suitable for the production process modelling [Braisford 2014]. While in system dynamics the processes are viewed as a series of stock and flows, DES describes the system by a network of queues and activities and the models are simulated in unequal time steps given by the time between an important events. Other possibility is agent based simulation model where the system is described from the point of view of individual objects (product, person) interacting with each other and with the environment. It is only a different point of view on the same problem. As it was mentioned before the simulation model is influenced by the aim of the manager/decision-maker who needs the results from the model and by the software available. DES usually seems to be an easier and more understandable way of modelling the production or business processes.

Simulation model usually helps the companies to see how changes in the process could influence the inputs, other processes, queues etc. O'Kane et al. showed the importance of discrete-event simulation for the decisions to increase in total production output [O'Kane 2000] - their simulation results gave important insights into the behaviour of the real system and provided invaluable knowledge to the company as to the perceived benefits of change within the current production facilities. Masood via DES model investigated how to reduce the cycle times and increase in the machine utilization in an automotive plant – in his study the cycle time cylinder block line was reduced by 32 % and the throughput was increased by 65 % [Masood 2006]. Montevechi et al. showed the meaning of simulation experiments representing different scenarios and company strategies [Montevechi 2007]. Aguirre et al. developed the simulation model focused on the production process of car-parts and they recommended, among other things, to the company to use the simulation tool to try different scenarios to get more experience and knowledge about the inherent dynamic process behavior [Aguirre 2008]. Fousek et al. used the simulation model to find out the total time needed for the production of the new contract and also to show the bottleneck of the production system [Fousek 2017]. Debta et al. Created the model in SIMUL8 to study the throughput, machine utilisation and vehicle utilization in the flexible manufacturing system using various types of the probabilistic distributions to see their impact on results [Debta 2017] These are the examples of DES in production system modelling using DES.

3 DES SOFTWARE SIMUL8

Simulation model structure is dependent not only on the real life situation and process description but also on the software in which the model is created. It is important what kind of simulation model should be created. If only a Monte Carlo simulation (repeated generation of random numbers) is sufficient then MS Excel and its add-ins (like Oracle Crystal Ball) could be used. For DES in case of a process simulation, various software could be used. When deeper technical analysis with 3D visualization is necessary, then the SW like Witness, Simio or Plant Simulation are suitable [Manlig 2017], [Voracek 2014], [Stocek 2012]. If only the processes and queues analysis are needed then 2D type of simulation models can be created in SW like SIMPROCESS or SIMUL8 as it is described in several works such as [Dlouhy 2011], [Concannon 2007], [Aguirre 2008] or[Elder 2014].

SIMUL8 is a software package designed for Discrete Event Simulation or Process simulation. It has been developed by the American company SIMUL8 Corporation. The software has started to be used in 1994 and every year a new release has come into being with new functions and improved functionality. It allows user to create a visual model of the analyzed system by drawing objects directly on the screen of a computer [Concannon 2007], [Elder 2014]. Contrary to similar simulation software like Witness or Plant Simulation that are more suited for the production modelling via 3D animation, SIMUL8 uses 2D animation only to visualize the processes. Each model in SIMUL8 is usually developed via 6 main parts: Work Item, Work Entry Point, Storage Bin, Work Center, Work Exit Pont, Resource [Concannon 2007].

Work Item represents a dynamic object(s), usually called entities (such as customers, products, documents or other entities) that move through the activities and processes, might change their characteristics and use various resources. Their main properties that can be defined are labels (attributes), image of the item (showed during the animation of the simulation on the screen) and advanced properties (multiple Work Item Types).

Work Entry Point is an object that generates entities (Work Items) into the simulation model according to the selected distribution of the inter-arrival times. Other properties that can be used in this object are batching of the Work Items, changing of the Work Items' Label or setting of the following discipline called Routing Out.

Storage Bin is used for queues or buffers where the Work Items wait before next processes. It is possible to define the capacity of the queue or the shelf life as a time units for the expiration.

Work Center represents the main object serving for the activity description with definition of the time length (various probabilistic distributions), resources used during the activity, changing the attributes of entities (Label actions) or setting the rules for the previous or following movement of entities (Routing In / Out).

Work Exit Point describes the end of the modeled system in which all the Work Items finish its movement through the model.

Resource is an object that serve for modelling of limited capacities of the workers, material or means of production that are used during the activities.

4 PROBLEM DESCRIPTION

Foxconn is the registered trademark of the company Hon Hai Precision Industry Co., Ltd. This Taiwan multinational society concerns with the global IT solutions, produces consumer electronics or components for an electronic or communication devices. Foxconn Europe, the Middle East and Africa (EMEA) has factories in strategic places such as the Czech Republic, Slovakia, Hungary or Turkey, and also several distribution centers all over Europe. FOXCONN CZ was set up in the Czech Republic in the year 2000 as a regional central office of the production group Foxconn in Europe. It is oriented at final assembly of PC, production of all-in-one computers (of various brand names), printer cartridges, servers, routers, switches and other electrical and engineering products [Foxconn 2017].

This article is aimed at a simulation of a production line PCBU Systems (Personal Communication Business Unit) producing Cisco routers. The line is a part of the production in the production division CNSBG (Communication Network Solutions Business Group). The aim of the analysis is the improvement of the production process, especially finding out the bottlenecks of the system, analyzing the length of the queues and the workers utilization. Another task is to find out the impact of the decrease of workers at Assembly line on the production. Simulation should cover production of 25 types of routers. These routers can be separated into three groups called Milpitas, Mizuno and Ponderoso with different attributes and different process times.

5 MODEL CREATION

As it was mentioned before several phases were followed to prepare the simulation model and to solve the given problem. The problem formulation was described in previous chapter. The next phase is the preparation of the conceptual model of the problem resp. production line.

5.1 Conceptual model and process description

According to the information of the company [Foxconn 2017] the production process that has to be modeled consist of 10 main parts called Prekit, Assembly, FST & RSSI, HI-POT, Visual Inspection & Packing, Kitting, Packout, OBA, IPQC Fail Station & Repair and Packscan & Occ In.

At Prekit workers prepare material for the production according to the forecasts given by the company Cisco (the client for whom the routers are produced).

Assembly seems to be a critical part of the process that could be separated into more activities but because of the lack of data it is simulated as one activity. At the beginning a worker must scan the assembled product (the main part) to have the information about the product entrance into the system. Afterwards he/she visually control the semi-product and then mounts additional parts such as cards, cooler, modems, cables, antennas etc. At the end of the assembly a worker must again scan the product to see the time when the product left the assembly line. Working times for the 3 product families are completely different – it is given by different number of sub-processes and activities that are necessary to do with each of the product in the given family (Milpitas, Mizuno and Ponderoso).

FST & RSSI is the workplace where tests and SW download take place. According to the time duration the tests belong to the most demanding ones. All products are tested by the function test (FST-Final System Test) using 126 test cells (taken as resources) but only the Mizuno family products must be tested also by RSSI (Received signal strength indication) test – here 64 cells are available. At the end of the testing two results are possible: if the test finds the product to be flawless it continues to the next workplace. If the test detect an error the product must be send to the IPQC (In Process Quality Control System) Fail Station & Repair for repair.

HI-POT workstation stress the routers under test to an AC or DC high voltage and check that there is no breakdown nor perforation happening. A hi-pot tester also checks that insulation distances and distances in the air are respected [Sefelec 2009].

Visual Inspection & Packing is again oriented at testing but now from the visual external quality point of view. It is finally controlled if all the parts are fixed firmly, if all the labels are stuck and if the product is not damaged. Afterwards the router is packed into quick-closing polyethylene bag and put into the box. The same worker who does the inspection of the given product continues with the box to the kitting workplace where other components (adapters, antennas, manuals and instructions) are added into the box on the basis of the client demand.

At following workplace Packout the polystyrene is added into the box so as to fix the product and prevent its movement inside the box. Then the bar code delivery label is stuck. Next at the OBA (Out of Box Audit) station the specialized audit is made to ensure that the material and labels used and the components added are in accordance with the requirements of the client. If not it is send to IPQC Fail Station & Repair.

The last part of the analyzed process is called Pacscan & Occ In Station where each box is closed, sealed up, stuck by labels with the destination location and with the information about the content of the box.

The scheme of the real production line is on the Figure 1, the conceptual model – scheme of the process – is describes by Figure 2.

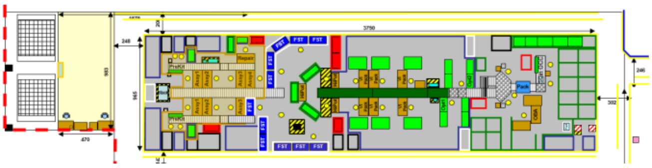

Figure 1. Scheme of the production line

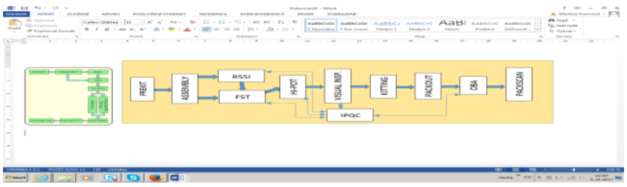

Figure 2. Conceptual model

5.2 Data

To be able to create a simulation model it is necessary not only to know the sequence of the activities but also the duration of activities and number of resources required. Thus the analyst of the model had to spend some time in the company to understand the process and to gain the data. Data collected at the production line are of the two types. Part of them was collected manually by workers as in most of the activities described before they have to scan the semi-product at the beginning and at the end of the activity. It might seems that there is no problem with these data collection. But the main problem is the human factor and human behavior as sometimes workers scan the semi-product before the activity is finished. The second part of data set is represented by data taken from the test software. This information is more accurate but also here the human factor can influence the start of an activity as he/she is responsible for the connection of the unit to the test machine. Data are saved to several servers with different hardware and this also leads to small differences among the times. For the analysis data from the continuous all day production were used although in some situations the production can be separated in two 8-hours shifts only.

As the human behavior causes the randomness of the duration of activities it is necessary to use a probability distribution for the time estimation. A company usually thinks that if it has data taken electronically it is good enough for any analysis – but it is not entirely true. For the simulation model it was necessary to find out the appropriate probability distribution for the time duration of each activity – so data taken from servers were pre-prepared in MS Excel to know for each semi-product the time of the entry to a workplace, ID of the semi-product, type and family of the product being assembled or time spend at a workplace. Some corrections had to be made especially in the manually scanned data (it was consulted with the company). Then the software R was used to find out the probability distributions – details of this statistical analysis were described in [Zajoncova 2017]. Figure 3 shows the example of estimation of duration of the tests at FST station.

To set the production volume for the production line in one hour the minimal unit production per hour for each of the family product was selected. It is 137 products of Milpitas family, 64 products of Mizuno family and 150 products of Ponderoso family.

On the basis of the aim of the simulation analysis workers are taken as the only resources necessary during the production process (it is supposed there is no problem with material or components availability, no machines disorders are included).

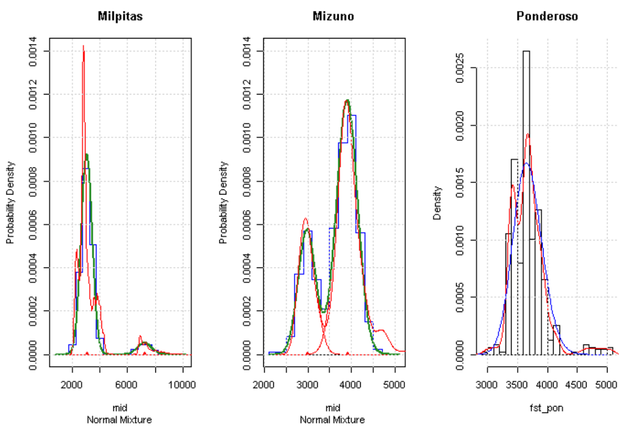

Figure 3. Estimation of probability distributions of the test duration at FST station for 3 different family types of products

Station	Number of workers
PREKIT	4
ASSEMLY	7
FST & RSSI	3
HI-POT	2
VISUAL INSP. PACKING KITTING	5
OBA	2
IPQC	1
PACKOUT	2
PACKSCAN	3.5

Table 1. Number of workers at a station

Table 1 describes the number of workers at each stage of the production. As it was mentioned before the stations Visual Inspection & Packing and Kitting share the same workers. At Packscan workplace 1 worker is there for a half-time.

5.3 *Model in SIMUL8*

After the data analysis and preparation the model could be created in SIMUL8 software. The generation of the entry of the products being assembled and packed is given on the one hand by the percentage of the family products production and on the other hand by the interarrival times. The probabilities of the products Milpitas, Mizuno and Ponderoso were given by the company as 81%, 15% and 4%. The interarrival times are (according to the statistical analysis) estimated by exponential distribution with the mean value 29 seconds. Figure 4 describes the Work Entry Point settings.

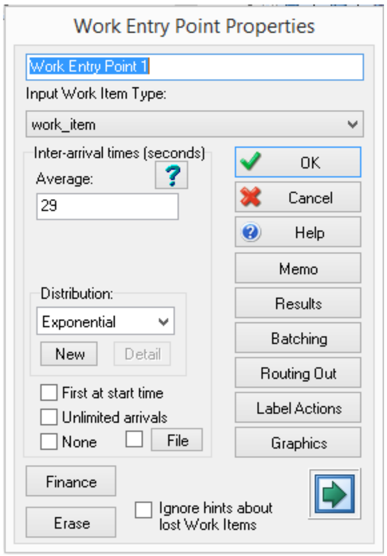

Figure 4. SIMUL8 Work Entry Point settings

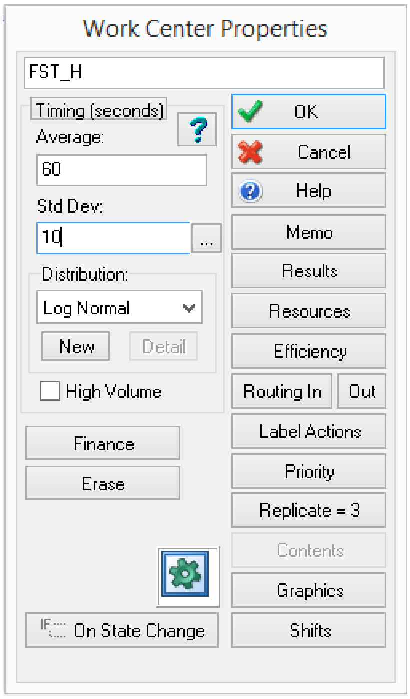

Figure 5. SIMUL8 Work Center properties for FST station

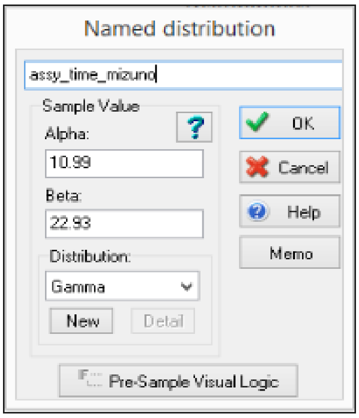

Figure 6. SIMUL8 – Named distribution used at Work Center Assembly for Mizuno family of products

All other activities are modeled in SIMUL8 by Work Centers where the probability distribution of the duration is set (according to previous statistical analysis) for each of the product (like at the FST station – Figure 5) or for each of the family of products (like at the Assembly station for Mizuno – Figure 6).

According to the information of a company that only less than 1 percent of the products were sent to IPQC because of some error it was decided not to include this station and OBA station in the model. The whole model in SIMUL8 is shown at Figure 7.

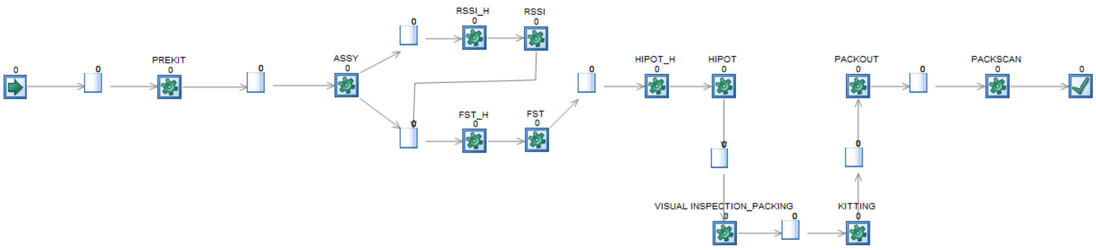

Figure 7. Model of the production process in SIMUL8

5.4 *Verification and validation*

When the model is prepared the first step of the verification is the visual control of the conceptual and simulation model conformity. Then it should be tested if the results of the model are in accordance with the company data. Again R software was used to prove the conformity. Figure 8 shows the comparison of real and simulated values from PREKIT station. Both controls showed that the model describes the production process well enough and can be used for further analysis and experiments.

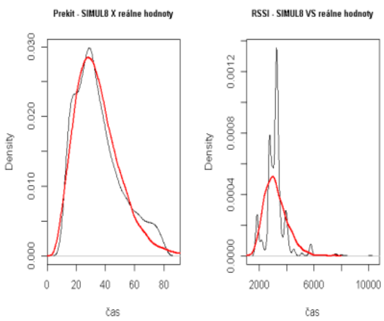

Figure 8. Comparison of the simulated (red line) and real (black line) data at PREKIT station (R software)

5.5 *Results and experiments with model*

In every simulation model the simulation time for one trial must be set and also more trials should be run to have more credible results. For the production process analysis the time for one trial was set to 5 days period, every day from 0:00 till 23:59:59, it is 1,728,000 seconds. Afterwards 50 trials were set for the result collection period (it represents 1 year production). The average production is about 59,500 routers. The analysis was aimed at the queues in front of the stations, especially waiting for ASSEMBLY, FST and HI-POT stations. Table 2 shows the results of the sizes of queues (max.queue size is calculated as the average of maximums of 50 trials).

Results	Avg. Number of units	Max. Queue size
Queue to ASSEMBLY	1.18	23.54
Queue to FST	2.32	39.28
Queue to HI-POT	0.24	12.44

Table 2. Results – queues at selected stations

From this point of view there is a lot of units waiting for the FST station. The queue in front of the ASSEMBLY station (example of one day trial and number of units in a queue is at Figure 9) might also be a problem but it is necessary to analyze the waiting times. Table 3 shows the average and maximum waiting time (taken as the average from 50 max. waiting times). Again the highest value is at FST (at average more than 1 minute, in maximum it might be more than 20 minutes) and ASSEMBLY (average is half a minute but maximum might be about 10 minutes). Similar information is seen in the percentage of busy/idle resources where the percentage of resource (workers) usage is nearly 80% in ASSEMBLY and RSSI & FST while only 34% at HI-POT (Table 4).

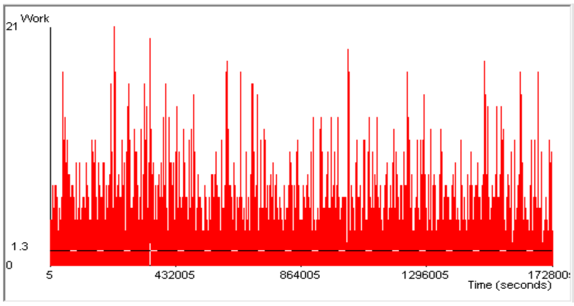

Figure 9. Example of the queue size to ASSEMBLY in one trial

Results Waiting times	Avg. Waiting time (seconds)	Max. Waiting time (seconds)
ASSEMBLY	34.22	544.75
FST	67.17	1041.78
HI-POT	6.86	259.86

Table 3. Results – waiting times

Results	No. of workers	Avg. No. of workers used	Utilisation (%)
ASSEMBLY	7	5.58	79.76
RSSI & FST	3	2.38	79.22
HI-POT	2	1.08	34.43

Table 4. Results – resource usage

These results show us that there is a space for changes to improve the process. As for the managers requirement the first change that was tested was aimed at the decrees of number of workers at ASSEMBLY station from 7 to 6. From the results in Tables 2, 3 and 4 it is clear that the decrease of workers is possible but we can expect the increase of the queue and the increase of the capacity utilization.

The impact of the change (6 workers in ASSEMBLY) on the results is both positive and negative. The positive effect is that the average number of products produced is nearly the same (only 7 pieces less which is 0.01% of the whole production) and the average waiting time for FST (following the assembly process) is about 44 seconds with the average number of units equal to 1.5 second which is about 1/3 lower than before. This might suggest that the company could decrease the cost by decreasing number of workers at ASSEMBLY station from 7 to 6. But there are also some negative effects of this change: the average waiting time to ASSEMBLY is nearly six times higher than before with the queue more than two times longer (which might cause the problems with space for the waiting units) and also the utility of workers raised on more than 93%. It means that there is no time for the workers to have a rest resp. it is necessary to replace each worker in any word break by another person quickly (so to have some workers that might help in any part of the production process). On the other hand the analysis at HI-POT station showed that the average utilization is about 1 person so the second worker could help at previous stations.

Results	Orig.	1.change	2.change	3.change
Avg.time in system (s)	4517	4646	4659	4641
Avg. Queue ASSEMBLY	1.18	6.54	6.54	6.54
Max.queue ASSEMBLY	23.54	53.66	53.66	53.66
Avg.utility ASSEMBLY	79.76	93.04	93.04	93.04
Avg. Queue FST	2.32	1.52	1.52	0.85
Max.queue FST	39.28	30.16	30.16	22.04
Avg.utility FST	79.22	79.21	79.21	79.21
Avg.waiting time FST (s)	67.17	44.08	44.08	24.81
Max.waiting time FST (s)	1042	808.3	808.3	593.2
Avg.cells used at FST	114.6	114.555	114.555	114.558
Avg. Queue HI-POT	0.24	0.23	1.28	1.31
Max.queue HI-POT	12.44	12.7	17.52	17.76
Avg.utility HI-POT	34.39	34.39	68.77	68.77
Avg.waiting time HI-POT (s)	6.89	6.78	37.25	37.97
Max.waiting time HI-POT (s)	259.9	267.8	411.6	427.7

Table 5. Results of all 3 experiments

According to this assumption the second experiment was tried with 6 workers at ASSEMBLY station and 1 worker at HI-POT station. Afterwards the change in the number of FST test cells (from 126 to 130) was tried as the third experiment. Table 5 shows the results of all 3 experiments compared to original settings. The average time that each product spends in the production system increased in all experiments at about 2 minutes. As mentioned before the queue for ASSEMBLY has worst characteristics but improves the situation at FST. The second change in HI-POT doubles nearly all monitored parameters but the change does not make the situation worse and the utilization of the worker is still not extremely high. The last change in FST cells has the main impact on the FST queue especially in decreasing the waiting time.

The last part of the analysis was aimed at the evaluation of efficiency of the production line via the line balance parameter. This parameter describes the percentage of the continuity of the movement of a unit through the system [Zajoncova 2017]. Table 6 shows that the changes in the system improved the line balancing of all families of products.

Using the simulation model, the queues emerged in front of the Assembly and FST stations were analyzed and described (their average and maximum sizes, average and maximum waiting times for queue units, queue length development, and probability of queues before individual stations). In addition, the resource usage for individual stations and the average number of busy employees for the monitored stations were found. On the basis of the results obtained, changes were made in the simulation model to improve the processes in the real system. Afterwards a changes in the stations inside the company were suggested so as to improve the production process. The results showed that the changes could be advantageous both from the point of view of the fluency of production and from the point of view of resources usage. Although all real conditions were not included in the model, and some simplification was necessary, the results nevertheless showed the appropriate direction of the changes the firm should take in the production process to be more succesfull. SIMUL8 in this case was a useful tool to study and analyze the system.

Since only part of the production process has been explored, there is still scope for further analysis, model extension and subsequent experiments to achieve further improvements of the entire manufacturing process.

Model	Family	Line balance
Original model	Milpitas	72.28%
	Mizuno	48.75%
	Ponderoso	58.76%
1.change 6 workers at ASSEMBLY	Milpitas	73.62%
	Mizuno	49.84%
	Ponderoso	59.28%
2.change 1 worker at HI-POT	Milpitas	77.96%
	Mizuno	53.47%
	Ponderoso	60.97%
3.change 130 cells at FST	Milpitas	80.11%
	Mizuno	53.30%
	Ponderoso	62.59%

Table 6. Results – line balancing

6 CONCLUSIONS

Simulation models belong to the analytical tools that can be used in "what if" analysis, for the process description or for the looking of the bottlenecks in the modeled system. SIMUL8 is one of the software for the discrete event simulation. It is suitable for modelling of various kind of processes and it might be used also for the analysis of the production process especially when no deeper technical analysis is needed. The aim of the analysis described in this article was to build a simulation model of the production line for routers production in FOXCONN CZ company and to analyze the impact of several changes on the production. According to the results of the original model it is possible to say that there are two main bottlenecks of the system – the ASSEMBLY and FST stations but the original settings (especially number of workers) are set quite right due to the resource utilization. On the basis of the task of the company to analyze the possible changes in the number of workers in ASSEMBLY station the first experiment was run. The removal of 1 worker can decrease the company cost and improve the situation in following station (FST) but the workers utilization seems to be high enough for the real conditions and with respect to the employees' conditions. Afterwards other two changes were suggested and tested to see the impact of the critical parts of the production. Both could be applied in real process as they improve the line balancing of all families of products with lower costs.

The given example shows how helpful the simulation model can be. The main problem in the process of the model creation is the knowledge of data or the transfer of the real data into probabilistic distributions. But the results of the model balance this problem as they could answer to a lot of different questions and could be important for managers in the decision-making process.

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REFERENCES

[Aguirre 2008] Aguirre, A. et al. Applying a Simulation-based Tool to Productivity Management in an Automotive-parts Industry. In: Proceedings of the 2008 Winter Simulation Conference, Piscataway, 2008, New Jersey: Institute of Electrical and Electronics Engineers, pp 1838-1846. ISBN 978-1-4244-2708-6

[Banks 1998] Banks, J. Handbook of Simulation. USA: John Willey & Sons, 1998. ISBN 978-0-471-13403-9

[Concannon 2007] Concannon, K. et al. Simulation Modeling with SIMUL8. Canada*:* Visual Thinking International, 2007. ISBN 0-9734285-0-3

[Debta 2017] Debta, M., K., Mishra, S., S. And Mishra, D. Simulation ofaReal Life Problem in FlexibleManufacturing System withoutBreakdown andHaving Alternate Machines Using SIMUL8. International Research Journal of Engineering and Technology (IRJET) 2017, Vol. 4, Iss: 5, pp 1267-1274. ISSN 2395-0056

[Dlouhy 2011] Dlouhy, M. et al. Business Process Simulation (in Czech). Brno: Computer Press, 2011. ISBN 978-80-251-3449-8

[Dyn.Future 2018*] Dynamic Future – web pages*[online]. 2018 [cit. 2018-02-08]. Available from http://dynfut.cz/

[Elder 2014] Elder, M. DES view on simulation modelling: SIMUL8. In: S. Brailsford et al., ed. Discrete-event simulation and system dynamics for management decision making, Chichester, 2014, John Wiley & Sons, Ltd., pp 199-214. ISBN 978-1-118-34902-1

[Ficova 2013] Ficova, P. and Kuncova, M. Looking for the equilibrium of the shields production system via simulation model. In: Proceedings of the 12th International Conference on Modeling and Applied Simulation MAS 2013, Athens, September 2013. Genova: DIME Universita di Genova, pp 50–56. ISBN 978-1-629-93490-7

[Fousek 2017] Fousek, J., Kuncova, M. and Fabry, J. Discrete Event Simulation – Production Model in SIMUL8. In: Proceedings of the 31st European Conference on Modelling and Simulation *ECMS* 2017, Budapest, May 2017. Dudweiler: Digitaldruck Pirrot, pp 229–234. ISBN 978-0-9932440-4-9

[Foxconn 2017] FOXCONN CZ – web pages, [online]. 2000-2017 [cit. 2017-05-01]. Available from http://www.foxconn.cz/foxconn-v-cr/

[Ghanes 2014] Ghanes, K. et al. A comprehensive simulation modeling of an emergency department: A case study for simulation optimization of staffing levels. In*:* Proceedings of the 2014 Winter Simulation Conference, December 2014. Savannah: IEEE Press Piscataway, NJ, USA, pp 1421-1432. ISBN 978-1-4799-7487-0

[Günal 2010] Günal, M. M. and Pidd, M. Discrete event simulation for performance modelling in health care: a review of the literature*.* Journal of Simulation, 2010, Vol. 4, No. 1. pp 42-51. ISSN 1747-7786

[Humusoft 2018] Humusoft – web pages. [online]. 2018 [cit. 2018-02-08]. Available from http://www.humusoft.cz/

[Kuncova 2007] Kuncova, M. and Wasserbauer, P. Discrete Event Simulation – Helpdesk Model in SIMPROCESS. In: Proceedings of the 21st European Conference on Modelling and Simulation ECMS 2007, Prague, June 2007. Dudweiler: Digitaldruck Pirrot, pp 105–109. ISBN 978-0-9553018-2-7

[Logio 2018] Logio – web pages[online]. 2018 [cit. 2018-02-08]. Available from https://www.logio.cz/

[Manlig 2017] Manlig, F. Computer simulation usage in teaching (in Czech). 2017, Liberec [online]. 2017 [cit. 2017-09-22]. Available from http://dynfut.cz/vyuziti-pocitacove-simulace-ve-vyuce/

[Masood 2006] Masood, S. Line balancing and simulation of an automated production transfer line*.* Assembly Automation, 2006, Vol. 26, Iss: 1, pp 69-74. ISSN 0144-5154

[Montevechi 2007] Montevechi, J. A. B. et al. Application of design of experiments on the simulation of a process in an automotive industry. In WSC'07 Proceedings of the 39th Conference on Winter Simulation, 2007, Washington, DC: IEEE Press Piscataway, NJ, USA, pp 1601-1609. ISBN 1-4244-1306-0

[O'Kane 2000] O'Kane, J. F. et al. Simulation as an essential tool for advanced manufacturing technology problems. Journal of Materials Processing Technology, 2000, Vol.107, Iss.1-3, pp 412-424. ISSN 0924-0136

[Pidd 2014] Pidd, M. The ways forward: A personal view of systems dynamics and discrete-event simulation. In: S. Brailsford et al., ed. Discrete-event simulation and system dynamics for management decision making, Chichester, 2014, John Wiley & Sons, Ltd., pp 319-336. ISBN 978-1-118-34902-1

[Robinson 2014] Robinson, S. Discrete-event simulation: A prime. In: S. Brailsford et al., ed. Discrete-event simulation and system dynamics for management decision making, Chichester, 2014, John Wiley & Sons, Ltd., pp 10-25. ISBN 978-1-118-34902-1

[Rotaru 2014] Rotaru K., Churchilov, L. and Flitman, A. Philosophical positioning of discrete-event simulation and system dynamics as management science tools for process systems: A critical realist perspective. In: S. Brailsford et al., ed. Discrete-event simulation and system dynamics for management decision making, Chichester, 2014, John Wiley & Sons, Ltd., pp 77-104. ISBN 978-1-118-34902-1

[Sefelec 2009] Sefelec, S. A. Hipot tester. 2009, France [online]. 2009 [cit. 2017-05-06]. Available from http://www.sefelec.com/en/HIPOT-TESTER.php ¨

[Stocek 2012] Stocek, J. Computer simulation in Skoda Auto company as a tool for the inventory optimization of the production lines (in Czech). 2012, Mlada Boleslav [online] 2012 [cit. 2017-09-22]. Available from https://is.savs.cz/dok_server/slozka.pl?id=1678;download=6542;z=1

[Voracek 2014] Voracek, J. et al. Modelling and Improvement of Hospital Processes. In: Proceedings of the 10th European Conference on Management, Leadership & Governance ECMLG, Zagreb, November, 2014. Kidmore End: Kidmore End Academic Conferences International Limited, pp 363-371. ISBN 978-1-910309-75-9

[Wainer 2009] Wainer, G. A. Discrete-event modeling and simulation: A Practitioner's Approach. Boca Raton: CRC Press, Taylor & Francis Group, LLC, 2009. ISBN 978-1-4200-5336-4

[Zajoncova 2017] Zajoncova, M. Simulation models usage for the analysis and improvement of the production line (in Czech). Master thesis 57969. Prague: University of Economics, Department of Econometrics, 2017.

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