PROCESS OPTIMALISATION WITH EFFECTIVE INTERCONNECTION OF PRODUCTION SYSTEM MODELS IN PLANT SIMULATION

David Tuček, Ivo Novák

Abstract: *This paper describes an object-oriented simulation approach for the design of a production system that is primarily focused on data exchange between system models of one manufacturer. Article deals with Plant Simulation software utilization for production systems modelling. The paper emphasizes the option of production process optimization and data exchange between models. Also the model can be utilized to predict the production sequence in a short period of time. There is also emphasized the global point of view to optimization of a system. The simulation issue is solved by fundamental construction of system models, which require data exchange. Furthermore the model functions for data exchange in Plant Simulation are programmed. The contribution that we described in this article is the introduction of the possibilities of simulation programs for production optimization.*

Keywords: *Computer simulation, Plant Simulation, Data exchange, Model, Optimization, Process.*

JEL Classification: M11, M15, M100.

Introduction

Currently it is relatively common that the completion of a final product is the result of the cooperation of several suppliers, who are often far away from each other. Some of the individual components are manufactured, some are purchased and then assembled. It is necessary to efficiently control such a chain, and to predict its efficiency to ensure optimal efficiency. Computer simulations are one of the optimization options. These programs can completely optimize the chain via external data exchange between models, however this article focuses on another option, and specifically efficient data exchange between individual models e.g. of production systems within the plant of a single company. We will describe methods with an emphasis on user friendliness of simulations for the purpose of increasing their efficiency. We will first introduce a short theoretical basis which follows from the results of some research on Faculty of management and economics e.g. of the GAČR 402/08H051 project, R&D project: Ergonomic – Evaluation of Local Muscular Load – Carpal Tunnel and other then we will introduce a case study applying this research into practice. The Plant Simulation software will be used.

1 Statement of a problem - production systems simulations

For the following research results, we would like at first define several significant manufacturing system simulation approaches that address real-time control issues. One of them is the Rapid-CIM project [5] develops a plug-and-play shop floor control design environment based on a simulation model of a target system and a simulation model of its controller. All to often this systems are based on the control system architecture described by e.g. Smith, Hoberecht, and Joshi [12], and an automatic control code generator for message passing between workstation controller and equipment developed by Smith and Joshi [13].

But in Rapid-CIM, the control modules are integrated within the simulation. It is anticipated that, after debugging a control module, it can be plugged into the actual physical environment and serve as the shop floor control system. This is accomplished by using the simulation software package Arena [14]. World known is Plant Simulation too. It is a computer application developed by Siemens PLM Software for modelling, simulating, analysing, visualizing and optimizing production systems and processes, the flow of materials and logistic operations. Using Tecnomatix Plant Simulation, users can optimize material flow, resource utilization and logistics for all levels of plant planning from global production facilities, through local plants, to specific lines. History of this SW application started in 1986 in the Fraunhofer Society for Factory Operation and Automation. This company develops an object-oriented, hierarchical simulation program especially for the Apple Macintosh.

The recent extensive survey by Narayanan et al. [10] summarizes the efforts in the last decade towards the development of object-oriented simulation of manufacturing systems. From the real-time control simulation perspective, OOSIM project [1] addresses deadlock issues within their described framework.

Current state of research

The primary contribution of object-oriented approaches is through their ability to facilitate links.

Between the analysis and specification of a real system and the design and implementation of an action model for that real system where the structure and behaviour of entities are readily modelled as objects. An object, in the object-oriented paradigm, is a collection of data (attributes) together with all the operations (methods) which access or alter that data [4].

Computer simulation stands among relatively new fields of research; not only from time perspective but also from perspective of their utilization. This is implicated by the lack of research papers dealing with the subject thoroughly and particularly through data exchange between models. The availability of simulation software is known. Many authors mention this, but only as a significant feature of the system, e.g. [11], [15].

Other authors point out external data upload possibilities and their integration to a model (e.g. machine cycle times). They also provide description of data route through production system, which is a useful feature for improving accessibility of the model for uninitiated people, e.g. [2].

Moreover different simulation models are described, such as ones with output functionalities that provide statistical data transfer into Excel, after the termination of simulation procedures (e.g. [6], [7]). Thus a considerable significance of linkage between simulation software and Excel is shown by these synergies. The linkage is provided both from the input and output perspective and provides a fairly large amount of data. Particularly Lassalle [7] describes the linkage involving different types of transferred information (number of manufactured products etc.)

But simulations we can also use in so more other areas and the development of simulation models, their program support and increasing computing power brought about attempts at use of simulation techniques for solving for example large Travelling Salesman

Problem. Their merit rests in random PC sampling in large scale that is later evaluated according to a selected objective function. Though the solution does not guarantee the global optimum, a sufficiently large number of simulations will issue in achieving the best possible solution, the value of which will be close to the optimum [3].

Yalcin &Namballa [16] define that the output produced by the simulation model is often captured in data files and includes event trace information, system performance information, and supervisory controller computation complexity information. The trace information includes a trace of the events ordered by time for understanding the behaviour of the system. The system performance information includes measures such as the throughput, resource utilization, etc. Also, included are the state space and response time of the supervisory controller to keep track of computational complexity.

The subject of this paper is to elaborate methodology with the usage of Plant Simulation program. This methodology can be utilized for data exchange between individual and independent models, but is recommended for dependent models. The emphasis is put on elements which considerably decrease demands on servicing staff qualification.

2 Methods - Options for effective data exchange between models

What is necessary to do on the start of the simulation? At the beginning of each simulation, the user has to specify the number of machines in the model, the number of parts and types of conveyors to be processed in the plant during whole the simulation. The user can also simulate resource failures in the plant by specifying failure-rates and repair rates for the resources. These set of details are complete in themselves in describing the structure and behaviour of the plant comprehensively.

The creator of the cell class is used as an initialization procedure to create the buffer, the machine, the material handler and the part objects that form the cell object, and to create certain information arrays from the input files. These arrays capture all the information on the cell behaviour and are henceforth, used by the supervisor to formulate a control strategy [16].

For the following case study, a part of the research focusing on data exchange between models via frame hierarchic organization was selected. Here a main frame is selected, which will represent the model of the plant and which will contain other frames as components representing individual, mutually interdependent processes. This solution is suitable especially for internal customers. The simulation will be performed based on the size of the customer's order – the required number of produced pieces will be an input for the model.

Thus, the basis is the main frame, and individual complete models of production lines are then inserted into it. It is important to properly interconnect these production line models. This is done via so-called connectors. However, the key aspect for utilizing the power of the simulation software is the proper setup of the correct monitoring functions, which show the current numbers of produced parts, the time of production of individual components and how individual production lines interact. For this monitoring, it is necessary to use so-called variables and to prepare a range of so-called methods, which contain programming code to assign the correct values of elements to variables.

This manner of building models is relatively fast and convenient. It is well suited for internal customers, since mutually dependent processes affect each other both in the direction of production and the opposite direction, as is often the case in real life. This also comes with a high level of flexibility – if we have a complete frame with prepared models of processes, these can be changed in seconds/ A disadvantage of this approach can be e.g. higher hardware requirements in case of complex production processes all running simultaneously.

The case study forming the second part of the article provides a closer view of the area.

2.1 Used methodology

The simulation issue is solved by fundamental construction of system models, which require data exchange. Furthermore the model functions for data exchange in Plant Simulation are programmed. The models are submitted to experiments and observed, particularly from the perspective of service. Evaluation of monitoring procedures is conducted. On the basis of evaluation results, the authors seeks arrangements, which enhance efficiency of the model for purposes of service simplification and production time reduction.

3 Problem solving – qualitative research

In this type of research it was necessary of course use qualitative techniques, e.g. case study. In this article we would like to demonstrate the problem solving thanks to one specific case study. There is no other possibility to introduce the problem solving then in the case study.

The case study focuses on the practical application of research within the project GAČR 402/08H051, called *Optimization of multidisciplinary design and modelling of production systems of virtual companies.*

Plants with mutually dependent production processes are introduced and data exchange is performed via simulations. The Plant Simulation software is used.

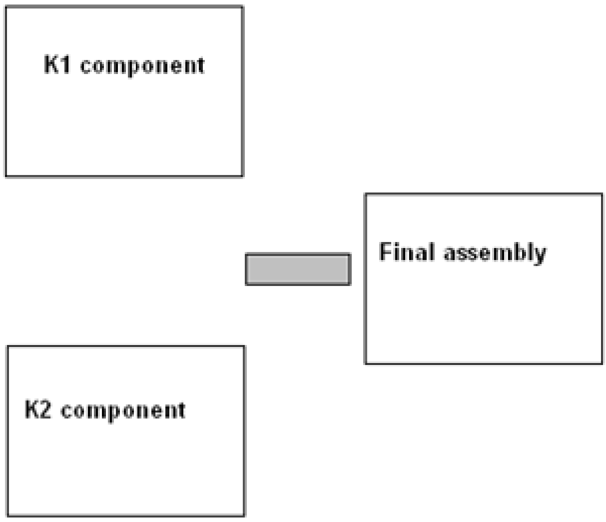
3.1 Workplace introduction

XZ is a foreign-owned company focusing on the production of plastic mouldings. Several workplaces were selected for the purposes of this study. These are located in different rooms in a single building, and so material exchange occurs without problems. The final product is a case for paper towels.

The workplace where the final assembly takes place stores most of the components, these are purchased from external suppliers.

Several intermediate products is however produced by the company in-house and their production and the management of requirements will be the subject of this case study. In line with GAČR research, internal solutions for data exchange will be used and some specific elements will be added for this particular situation.

Fig. 1: Production layout



Source: Custom-made

The cycle times of machines are shown in the following table. Machines K1 and K2 work automatically, including the delivery of material into the machine, however an operator needs to remove the product and place it in a box. The final assembly is manual and the task of the operator is not only to bring components K1 and K2 from the input material holder, but also the pre-final product where the components are to be placed. He also needs to perform the assembly itself, and place the final product into the box. Transportation of components K1 and K2 is performed via manipulation trolleys between workplaces.

Tab. 1: Cycle times in seconds

Machine	**Machine cycle time in seconds**
K1	10
K2	20
Final assembly	120

Source: Custom made

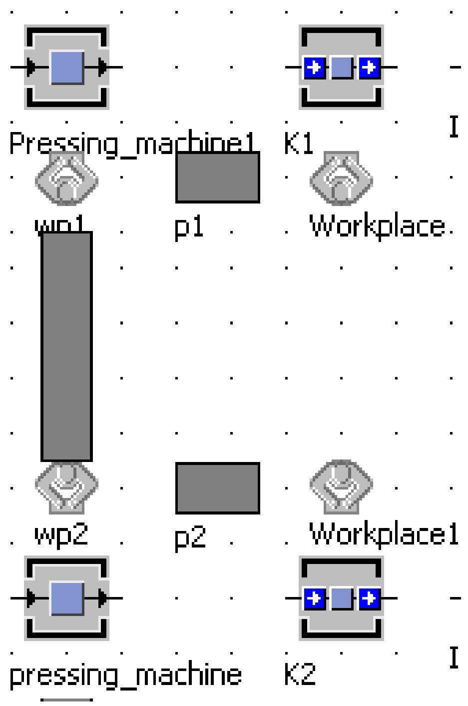
3.2 Task assignment

The task is to model the production systems and model adequate data exchange between individual workplaces. Another task of the simulation is to mark possible optimizations and their effects on production. It is also required to have clearly defined time requirements of individual productions to allow timely entering of components orders and, including an indication of the duration of complete production. These times must be flexible and reflect the current configuration of the model so that real-life scenarios can be applied with different numbers of operators or optimization of the workplace and the impacts of these changes on the time requirements for production must be immediately visible.

4 Discussion – workplace for component production

Currently the operator regularly moves between machines and new products and brings them to the boxes. Two machines are operated at once. The following figure illustrates the layout.

Fig. 2: Component production layout

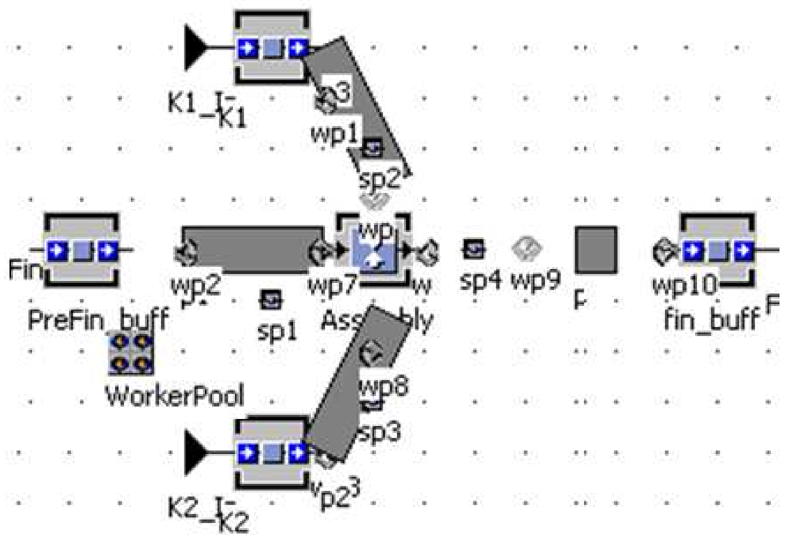


Source: Custom-made

The distance between workplaces is 19.5 meters, which is not optimal, and the distance between the machine and the holder is 1.5 m.

4.1 Current status – workplace of final assembly

Fig. 3: Final assembly workplace layout



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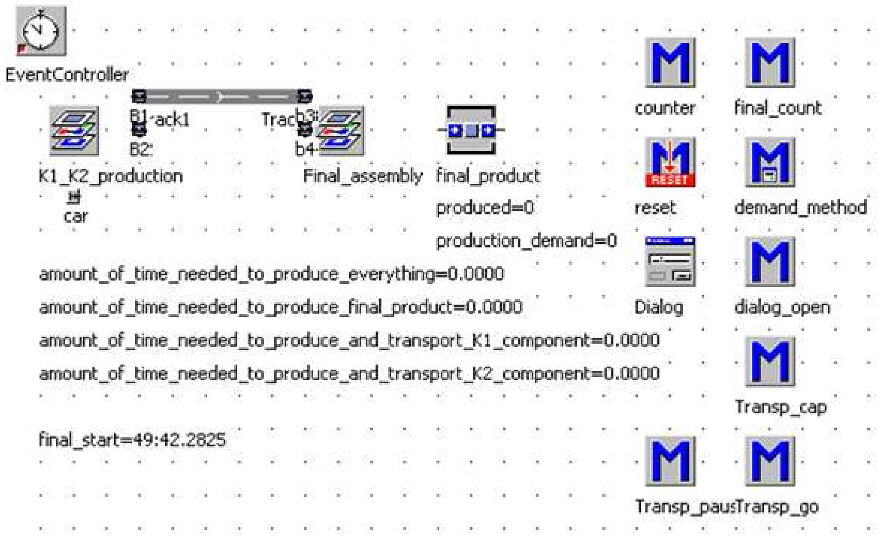
The distance between the input holders and the machine are always 3 meters, and the final product needs to be then brought by the operator to a holder which is 4 meters away.

4.2 Basic model

Fig. 4: System layout



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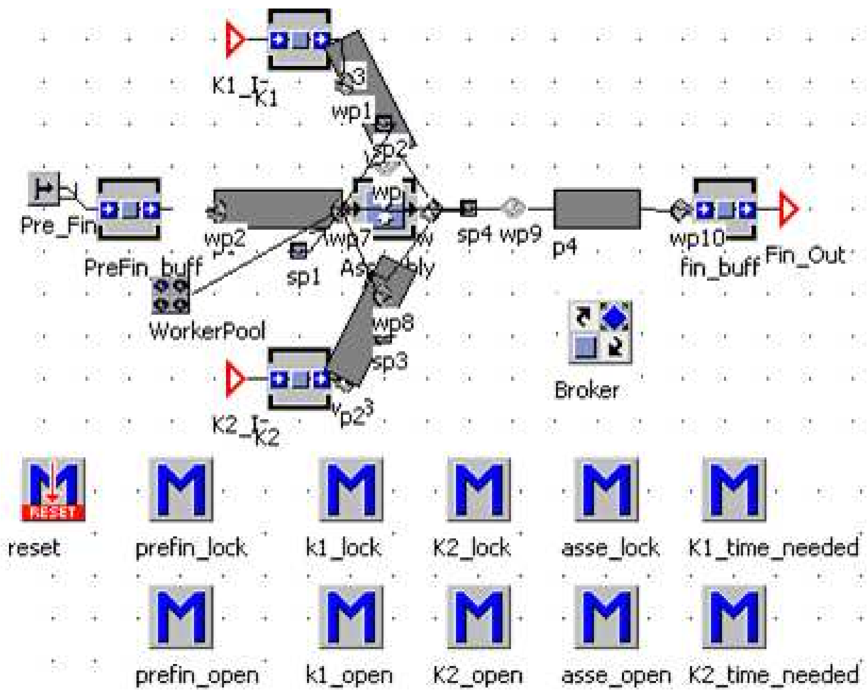
Based on the research realized in the GAČR project, the frame hierarchic organization method was used for this system. This means that the model for component production and the model for final assembly were placed into a parent frame, which represents the whole system. Figure 4already shows the necessary methods for the model and the key items are those displaying the amount of time necessary for individual production phases. The distance between the component production workplace and the final assembly workplace is 35 meters (shown smaller on figures for clarity).

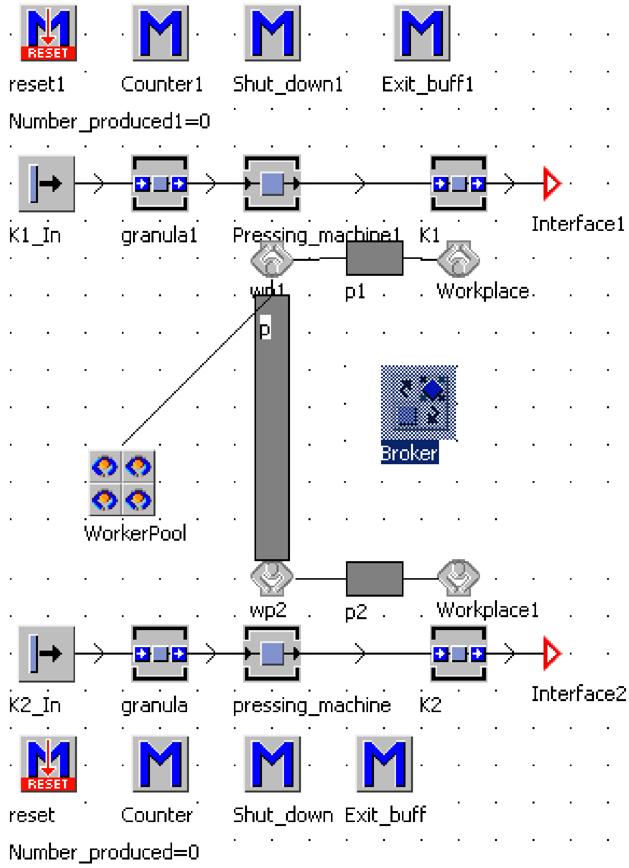
The component production and final assembly subframes including methods are illustrated on the following figures.

Fig. 5: Complete subframe of final assembly



Source: Custom-made

Fig. 6: Complete subframe of component production



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4.3 Basic model of current status run

We will now test the results the model provides in its basic configuration. We have entered 100 pieces of final products as the customer's requirement. The simulation then outputs the results shown in the following figure.

Fig. 7: Basic model results

produced=100
production_demand=100
amount_of_time_needed_to_produce_everything=4:56:16.7076
amount_of_time_needed_to_produce_final_product=3:41:37.7784
amount_of_time_needed_to_produce_and_transport_K1_component=1:14:04.1914
amount_of_time_needed_to_produce_and_transport_K2_component=1:14:23.2932
final_start=1:16:38.9293

Source: Custom-made

It takes almost 5 hours to produce 100 pieces of products. It is also clear that we need to begin the production of components at the latest 1 hour and 14 minutes before final assembly to be able to finish in 5 hours.

4.4 Optimized model run

We will now look at optimizations of the model. The machine times are fixed and cannot be reduced. The greatest potential for improvement lies in changing the workplace layout, where it would be possible to reduce the distance the operator needs to travel. It was possible to slightly reduce all distances. The greatest reduction was possible in the transfer distance between workplaces K1 and K2, where the distance was reduced to 10 m.

However, it was not possible to reduce the travel distance of 35 m, since it is necessary to move from one room to another.

We will also show variants for servicing workplaces by a single operator and 2 operators. The production batch has so far been always delivered all at once. We will also show variants for two and four deliveries.

The following table clearly illustrates the obtained results.

Tab. 2: Cycle times in seconds

Variant	**Obtained time for 100 pieces of products in hours**
Without layout adjustments, with two operators on two workplaces	4:21 h
Layout adjustment with reduced distances	4:34 h
Two operators in final assembly (incl. layout adjustment)	4:23 h
Two operators in component production (incl. layout adjustment)	4:29 h
Two operators in both workplaces (incl. layout adjustment)	4:18 h
Increasing the number of deliveries between workplaces to 2 (every 50 pieces, incl. layout adjustment)	4:01 h
Increasing the number of deliveries between workplaces to 4 (every 25 pieces, incl. layout adjustment)	3:52 h
Increasing the number of deliveries between workplaces to 4 (every 25 pieces) with only a single operator on each workplace (incl. layout adjustment)	**3:59 h**
Original time required for production, without optimizations	**4:56 h**

Source: Custom - made

The results show that using several operators leads to time savings. This advantage is significant especially with the unadjusted layout, since several operators can help reduce the necessary amount of travel. The greatest savings potential however lies in changing delivery policies. The workplace for final assembly so far had to wait for components delivered in bulk after their production. IF deliveries were more frequent, the whole production time would be significantly lower. A mere 7 minute difference between optimized production with 1 operator and with 2 operators indicates that it is probably more profitable to use a single operator. The final time savings are thus 57 minutes, almost 20%.

Conclusion

Several approaches can be used to program data exchanges between models, such as using additional files as information carriers or internal methods. It is also possible to use different simulation programs and ensure their mutual communication. Each method has its own advantages and disadvantages.

The contribution of this case study is the introduction of the possibilities of simulation programs for production optimization. We have managed to obtain a time saving of over 20%. The main benefit is however the application of research within the GAČR project. We have successfully modelled data exchange between models of production systems within a single company. The contribution in this case is a summary of the production time of individual productions - we know how long the production of components and the final assembly take, and can use this to enter orders into production. **The contribution of this specific solution is that it can be very easily replicated.** The methods used for creating the model are universally valid and can be extended to arbitrarily large productions of many components. The direct interaction between systems is also a key contribution here. If one system has an error, production stops or slows down due to the unexpected event or adjustment or work procedures, and the effects on the whole system are immediately available. It is thus possible to search for the global optimum of the whole system instead of only realizing local optima, as is often the case. It needs to be noted that local optimization can in fact lead to a reduction of global efficiency.

Thus, the contribution of simulation lies not only in finding the global optimum, but also in the possibility of quickly testing various scenarios of production system configurations and production predictions.

So many applications of this type of models we can use in logistics chain and logistics supply chain systems. Some of these applications are very sophisticated. For example simulation model by Liao and Chang for the supply chain of the hospital logistic system [8]. This simulation model it is possible to combinate and based on the dynamic Taguchi method too. Of course some study on the quality of decision-making problems under multi-period conditions in the logistics service supply chain (LSSC) are very practical. Logistic service quality is not easy to measure. Hence, paper of Liu et al. proposes a multi-period quality coordination model based on the single-period quality coordination model in a two-echelon LSSC, and establishes a new model in a three-echelon LSSC when the logistics service integrator (LSI) is punished [9]. Simulation results indicate that under multi-period cooperation conditions, the LSI tends to make rapid decisions when punishment intensity is below the critical value.

References

[1] BODNER, D. A., DILLEY-SCHNEIDER, S. J., NARAYANAN, S., SREEKANTH, U., MCGINNIS, L. F., MITCHELL, C. M., & GOVINDARAJ, T. *Object-oriented modeling and simulation of automated control in manufacturing.* Proceedings of the 1993 IEEE international conference on robotics and automation. Washington, DC: IEEE Computer Society Press, 1993, Vol. 3, pp. 83–88.

[2] DANEK, J. *Vyuziti simulace procesu v automobilovem prumyslu*, 2005. Retrieved from WWW: <http://www.humusoft.cz/old/pub/witness/trna0510/trna0510.pdf>

[3] FU, Y., CHEN G. An improved genetic algorithm for solving TSP problem. *Journal of Guilin University of Electronic Technology*, 2007, Vol.27, No.4, pp.287-290.

[4] HILL, D. R. C. *Object-oriented analysis and simulation*. Reading, MA: Addison -Wesley, 1996.

[5] JOSHI, S. B., SMITH, J. S., WYSK, R. A., PETERS, B. A., & PEGDEN, C. D. *Rapid-CIM: An approach to rapid development of control software for FMS control.* 27th CIRP international seminar on manufacturing systems, Ann Arbor, MI, 1995.

[6] KUMAR, S., NOTTESTADT, D, MACKLIN, J. A Profit And Loss Analysis For Make-To-Order Versus Make-To-Stock Policy—A Supply Chain Case Study. *Engineering Economist,* 2007, vol. 52, no. 2, pp. 141-156. ISSN 0013-791X.

[7] LASSALLE, S; WANG, Q; OWEN, GW; MILEHAN, AR. A Study of In-process Waiting Time on a Linear Walking Worker Assembly Line. *Proceedings of the Institution of Mechanical Engineers Part B-journal of Engineering Manufacture*., 2007, vol. 221, No. 12, pp. 1763-1770. ISSN: 0954-4054.

[8] LIAO H. Ch., CHANG H. H. The optimal approach for parameter settings based on adjustable contracting capacity for the hospital supply chain logistics system, *Expert Systems with Applications*, 2011, vol. 38, no. 5, pp. 4790-4797, ISSN 0957-4174, http://dx.doi.org/10.1016/j.eswa.2010.09.168.

[9] LIU W. H., XIE, D., XU, X.C., Quality supervision and coordination of logistic service supply chain under multi-period conditions, *International Journal of Production Economics,* 2013, vol. 142, no. 2, pp. 353-361. ISSN 0925-5273. http://dx.doi.org/10.1016/j.ijpe.2012.12.011.

[10] NARAYANAN, S., BODNER, D. A., SREEKANTH, U., GOVINDARAJ, T., MCGINNIS, L. F., & MITCHELL, C. M. Research in object oriented manufacturing simulations: An assessment of the state of the art. *IIE Transactions,* 1998*,* Vol. 30, pp. 795–810.

[11] PRZYBYLSKI, L. *Industrial simulators – instrument for decision support (modeling in Witness software). 2008.* Retrieved from WWW: <http://is.muni.cz/th/100100/esf_m/Diplomova_prace.pdf>

[12] SMITH, J. S., HOBERECHT, W. C., & JOSHI, S. B. A shop-floor control architecture for computer-integrated manufacturing. *IIE Transactions*, 1996, Vol. 28, pp. 783–794.

[13] SMITH, J. S., & JOSHI, S. B. *Message-based part state graphs (MPSG) for shop floor control.* Proceedings of the second IIE research conference, Los Angeles, CA, 1993.

[14] SYSTEM MODELING CORPORATION. *Arena professional edition reference guide*, Swickley, PA, 1999.

[15] SILHANEK, J. *Simulacni metody jako nastroj rozhodovani modelovani pomoci programu. 2008.* Retrieved from WWW: <http://is.muni.cz/th/137556/esf_m/DP_-_Silhanek_Jiri.pdf>

[16] YALCIN, A., & NAMBALLA, R. An object-oriented simulation framework for real-time control of automated flexible manufacturing systems. *Computers & Industrial Engineering,* 2005, pp. 111-127.

Contact Address

David Tuček, Ivo Novák
Tomas Bata University in Zlín, Faculty of Management and Economics
Mostní 5139, 760 01 Zlín, Czech Republic
Email: tucek@fame.utb.cz, inovak@fame.utb.cz
Phone number: +420 576 032 825

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