The Virtual Reality Concept for the Warehouse Simulation Model Implementation

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Abstract

This paper presents a method of warehouse simulation model implementation using concepts of virtual reality (VR). The basic idea is to compare the "real process" controlled by operator with his/her heuristics to the "virtual process" represented by a simulation model, controlled by the optimization algorithm. The optimization algorithm is based on a SD model of the warehouse and decision support module. The SD warehouse model represents the abstraction of "virtual process" and is considered as a model of a model. The state of the "virtual process" is controlled with the help of a decision support module and is compared with the state of the real process on the basis of actual information regarding the state of warehouse. This concept is useful for predictive model validation where the parallel observation of the actual system and virtual one takes place simultaneously, and for the optimization algorithm migration into practice.

Keywords: simulation, validation, virtual model, warehouse

1. Introduction

In the last two decades, computer simulation has become an indispensable tool for understanding the dynamics of business systems. Many successful businesses intensively use simulation as an instrument for operational and strategic planning. A simulation is the imitation of the operation of a real-world process or system over time. Whether done by hand or on a computer, simulation involves the generation of an artificial history of a system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system (Banks et al., 1996). The modeling methodology and simulation models of the business systems, as well as their validation, are described in (Kljajić et al., 2000). In comparison to the other methods, a dynamic analysis of the considered system behavior is the main advantage of testing the strategy with the aid of simulation scenarios (Larsen et al., 1997).

Clearly, the imaginative and disciplined application of dynamic modeling and simulation provides a potentially useful mechanism through which managers can gain a comprehensive understanding of system behavior, concentrating on core business processes such as order fulfillment, product development as well as customer acquisition, satisfaction, and retention. However, the means by which management in general and senior management in particular make decisions can, in itself, also be regarded as a core value-adding process that impacts fundamentally upon the overall effectiveness of the organization (Fowler, 2003).

Among specialists, it is widely accepted that mathematical or analytical modeling techniques are not sufficient if a detailed analysis is required of complex systems. The major weaknesses in using mathematical or analytical methodologies are (Wang and Chatwin, 2004):

1. When analyzing a complex system, stochastic elements cannot be accurately described by a mathematical model and cannot be evaluated analytically as modern systems consist of many operations that occur randomly and nonlinearly. Therefore, the objective function may not be expressible as an explicit function of the input parameters; hence, mathematical models or other methods are impractical.
2. Dynamic systems involve randomness that changes with time, such as an assembly line, where the components being assembled change with time. The modeling of complex dynamic systems theoretically requires too many simplifications, and the emerging models may not, therefore, be valid.
3. Purely analytical methods are often insufficient for optimization because a mathematical model can only be built based on simplifying assumptions; therefore, accuracy often becomes a major problem for system optimization.

In some cases, one must resort to simulation even though in principle some systems are analytically tractable; that is because some performance measures of the system have values that can be found only by running a simulation model or by observing an actual system. Consequently, the analytical effort required to evaluate the solution may be so formidable that computer simulation is the only realistic option. Instead of using experts to build an extensive mathematical model by using the analytical approach, computer-based simulation is used where the method of analyzing the system is purely theoretical. Computer-based simulation is seen as an integral business tool giving flexibility and convenience in designing, planning and analyzing complex processes and/or systems. This is because computer-based modeling and simulation methods have the capability of representing the complex static structure as well as the dynamic behavior of systems (Wang and Chatwin, 2004).

In previous work (Kljajić et al., 2004) the method of warehouse optimization in uncertain environment was described. Although initial results were promising and replicate, and logical validation was accepted from the research team, it is a demanding task to transfer the method into practice. The potential risk of accepting an obtained solution as reliable is too high to start with ad-hoc implementation. Therefore we decided to introduce the method of virtual reality (VR), a kind of flight simulator, for the stand-by simulation of the ordering policy of a warehouse. This way we provide users a chance to learn about the new algorithm and participate in its final development. Their confidence in the new methodology should rise as users are in a position to actively participate in the process rather than being passive observers.

2. Methodology of VR concept of model validation and transfer into practice

The problem of finding the right ordering policy belongs to a large scale systems with over 1,500 variables classified in nine groups according to ABC-XYZ classification. There is a high probability that such problem could be solved by using simulation and optimization methods.

The key issue is that most people tend to be very skeptical towards new techniques and methodologies. It is hard to persuade them that computer technology can be a tremendous supplement to their knowledge, experience and intuition. These people are used to their "own" algorithms, considering them as the best, and they do not need anyone to tell them "how to do their job", although new algorithms could prove to be more efficient and rational.

Although modeling and analysis of computer models can be used to reduce time and costs of systems in stochastic environments, there is one major disadvantage: only experienced and long trained experts are able to operate with simulation programs. The graphical user interface is very complex and not intuitive to use. This results in an extensive and error-prone modeling of complex simulation models and a time-consuming interpretation of the simulation results. To overcome these weak points, intuitive and understandable man–machine interfaces like augmented VR can be used (Dangelmaier et al., 2005).

Therefore we decided that the concept of VR (Figure 1), or a simulation of simulation, could be useful in model validation and its migration into practice, because skepticism towards new technology and its complexity make the transfer of new methods and techniques into the actual process a very delicate task.

The virtual reality simulation model can also be classified as a Virtual Reality-based Training System (VRTS), which is an advanced computer assisted training systems using VR technology. Compared with traditional training approaches, these systems would allow trainees to properly operate new equipment before it is actually installed. The important perceptual cues and multi-modal feedback (e.g. visual, auditory, and haptic) provided to trainees enable VRTSs to more effectively transfer virtual training to real-world operation skills. More importantly, the systems can provide a higher degree of freedom for operation and the results of improper operation can be simulated without incurring the associated costs or damage (Lin et al., 2002). This opens up another significant aspect worth mentioning - the warehouse operator learns about the behavior of virtual process and has the ability to use its advantages (compared with the real process) in the real process which he controls.

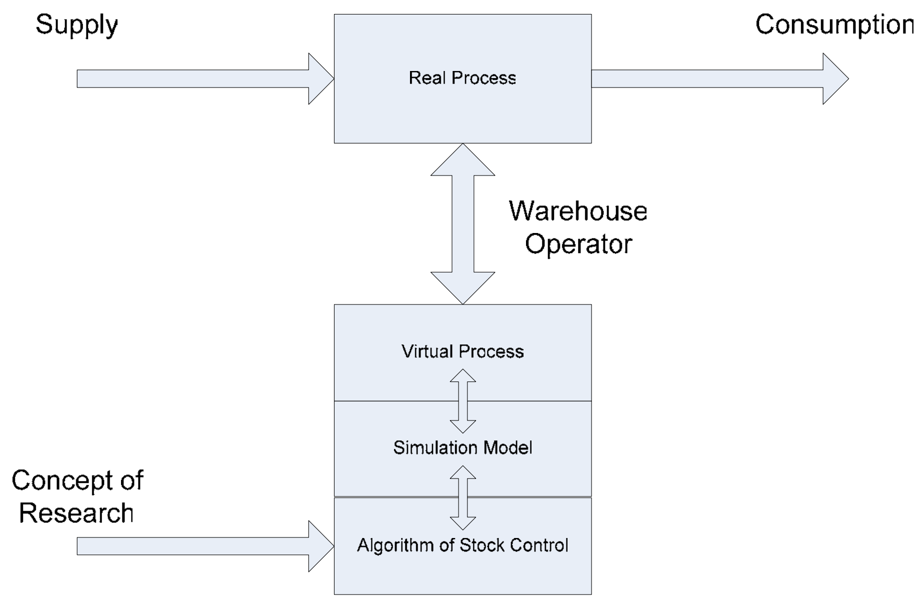

Figure 1: The basic concept of VR simulation model

The main concern of the operator is an ordering strategy that would produce minimal warehousing costs without stock-outs. Barlas and Özevin (2004) have proved that people can be classified into different ordering behavior patterns. The virtual simulator's ability of visual presentation could prove to be one of its main advantages as each subject is prone to its behavior and visualization of the process could provide help in learning new methodologies that subject is not prone to, thus making the learning process faster and more efficient.

The warehouse operator is in a position to actively participate in the process of validation with a VR validation approach rather than being a passive observer. He is able to run simulation scenarios and decide if ordering strategies suggested by VR simulator are of any use to him. The VR simulator can be used extensively and repeatedly for long periods by the operator giving him time to "accept" the simulator as a decision support tool enabling him to improve his ordering strategy.

Validation is one of the steps in a simulation study and is the process of determining that the system fulfills the purpose for which it was intended. It is often used in the context along with verification and evaluation. Verification should answer the question "Did we build the system right?" and evaluation should provide an answer to the question "Is the system useful?" On the other side, validation should provide an answer to the question ”Did we build the right system?” In the negative case, validation should point out which aspects were not captured, or any other mismatch between the system and the actual requirements (Desel, 2002).

Validation of complex computational organizational models is a challenging problem that has received considerable attention as described by Thomsen et al. (1999). Validation of simulation systems should be an iterative, multi-faceted approach in which each successive validation experiments builds confidence in the validity of the simulation model.

The term validation, in its classical form, may be considered in most cases as a "rough" tuning of the model. It helps in revealing significant differences between the reality and the model. Validation with the VR approach could reveal small but still significant differences that may exist between the actual process and the model. Validation of such kind may be considered as a "fine tuning" phase of the modeling process (Figure 2).

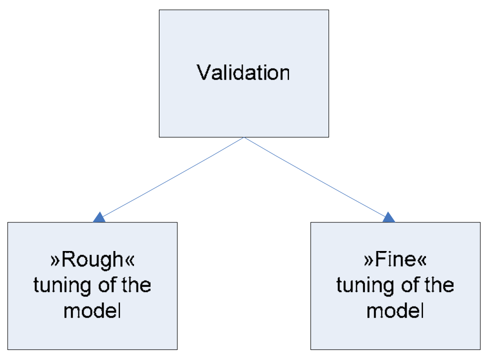

Figure 2: Validation components

Model choice and validation have a central role in data analysis, including predictive modeling. While standard diagnostics can help identify model inadequacies, it is natural to use predictive accuracy as the decisive criterion in the final choice of predictive model. Predictions are often applied under quite different conditions from the data and conditions may be so different that a realistic assessment of predictive accuracy is impossible.

Although there has been a long history of predictive model generation from statistics, more recent developments of predictive modeling include areas from machine learning, including pattern recognition and artificial neural networks, optimization techniques, and theory of learning. Is there also a place for the VR simulator? It simulator could be used to help with realistic assessments of predictive modeling, because in this paper we are dealing with a warehouse model whose main goal is to predict the best ordering strategy based upon a consumption plan.

2.1. SD presentation of VR concept of warehouse model validation

Virtual reality is a computer simulation that models natural environments in which the user can actively participate and influence the virtual environment.

The Real Process (RP) is the process running in the actual warehouse, while the Virtual Process (VP) and SD model are simulation models of a simple warehouse. The Virtual Process is an abstraction of the actual warehouse, thus representing the virtual environment, while the SD model represents the abstraction of the VP and is considered as a model of a model.

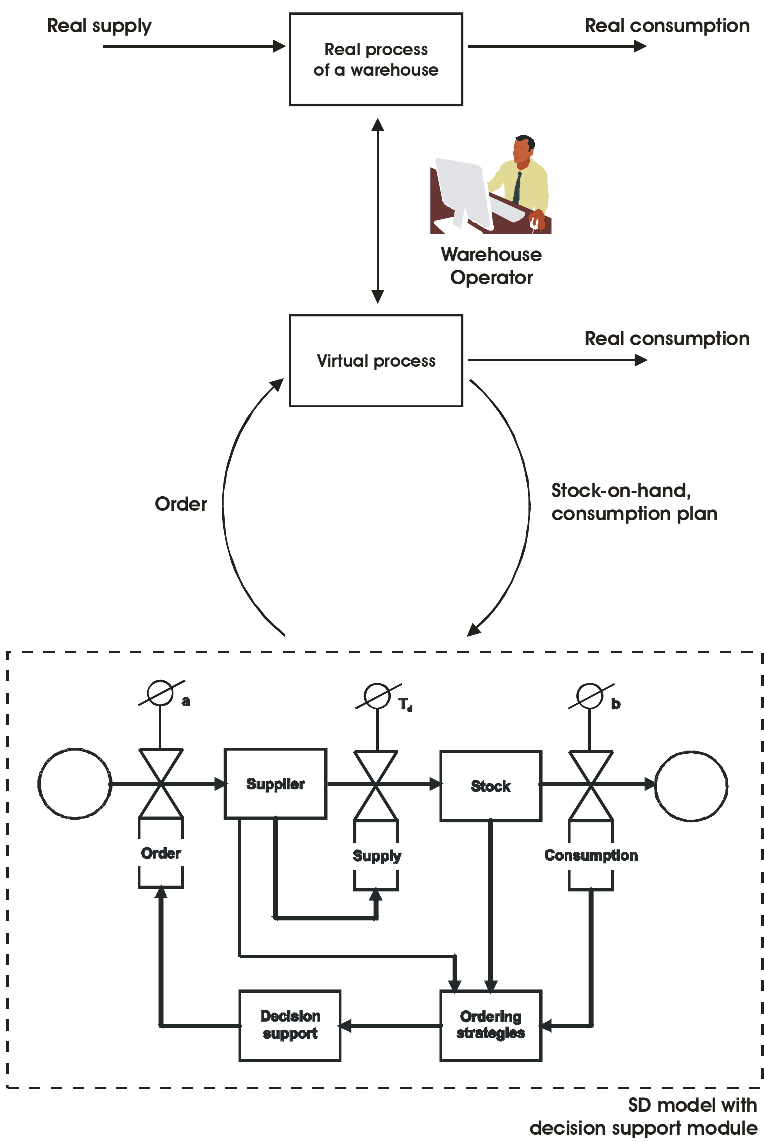

Figure 3: SD Representation of the Real and Virtual Process interconnection

Figure 3 represents the basic concept of the RP and the VP interconnection. The *Real supply* is the actual supply of products which increases stock-on-hand in the warehouse while the *Real consumption* is the actual consumption which decreases stock-on-hand. Both, *Real supply* and *Real consumption*, are stochastic variables and influence warehousing costs. *Real supply* is affected by the warehouse operator whose task is to maintain such an ordering strategy that the needs of *Real consumption* are satisfied. The ordering strategy is usually based on operator's experience and intuition without any or with very limited help of information systems.

The main difference between VP and RP is that the VP does not use the *Real supply*. Supply for VP is replaced by an *Order* from the SD model while consumption remains the same as with the RP. The VP can be run in real-time together with the RP.

The SD model is the abstraction of VP running several times faster. It needs information about stock-on-hand and a consumption plan supplied by the Virtual Process. The SD model runs a simulation on the basis of this information thus providing the order to the VP and closing the loop between the two models. On the other hand, the SD model provides simulation results to the decision support module, which chooses the best ordering strategy at the given moment considering all the limitations and information.

All models are based on the system dynamics methodology (Forrester, 1961) and are a part of a decision support integrated system development. Matlab was used to build models, because it supports simulation with Simulink and offers a powerful computational engine, which provides a quick execution of the simulation runs.

2.2. The warehouse problem formulation

Dealing with problems of warehousing, we encounter several contradictory criteria. An overly large warehouse means a greater amount of stock, greater capital cost and more staff. The space itself is very valuable today. An overly small warehouse can represent possible stock-outs: it demands a reliable supplier etc.

Our goal is to rationalize the warehouse ordering process, this means determining the interval between orders and the quantity to be ordered, so that the warehouse will operate with minimal common costs. Cost function includes:

- fixed ordering costs,
- transportation costs,
- costs of taking over the products,
- costs of physical storage,
- cost of capital.

The following limitations have to be taken into consideration:

- maximal warehouse capacity for a specific product must not be exceeded,
- no stock-outs may occur.

In this case we are dealing with a simple warehouse used for storing components for further build-in. The lead time for products delivered into the warehouse is not variable. The problem occurs in defining ordering quantity, because past orders must be considered as well as the average consumption of a specific product. Long lead times also represent a problem, because they are usually much longer than the time period in which the consumption plan can be predicted with a certainty. Therefore, the variability of a production plan has to be considered. Unlike deterministic models, stochastic models do not necessarily give the same output for the same input. Within a stochastic model there will be at least one variable that is not known with certainty (Oakshott, 1997). In this case this variable is the consumption plan.

A consumption plan is planned for 24 weeks and can be predicted with a certainty e.g. for 6 weeks. After this period, a consumption plan uncertainty factor (e.g. 3%) must be considered every 2 weeks. Therefore, a safety factor, which increases the ordering quantity, must be considered when placing an order (e.g. 10%).

2.3. CLD of the warehouse model

Figure 4 represents the CLD from which the influences of the warehouse model elements can be observed. The arrow represents the direction of the influence and the + or – sign its polarity.

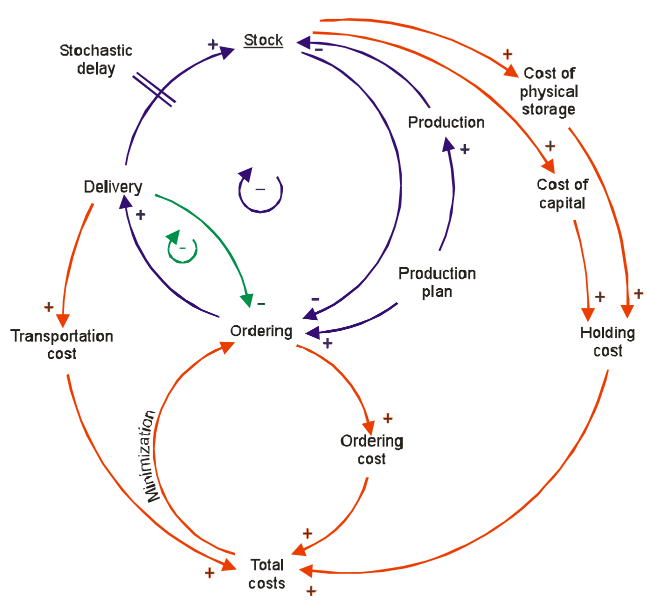

Figure 4: Causal loop diagram of the warehouse model

Delivery impacts *Stock* and *Transportation Costs*. If the amount of *Delivery* increases above what it would have been, the *Stock* and *Transportation Costs* are increased above the initial value. The increased value of *Stock*, increases *Cost of physical storage* and *Cost of* *capital*, but it decreases *Ordering* quantity. If the quantity of *Production plan*, which represents the reference value, is increased, *Consumption* and *Ordering* quantity are both increased. The increased value of *Consumption* decreases *Stock*. If the *Ordering* quantity is increased, the *Delivery* and *Fixed ordering cost* are both increased. The increased values of *Cost of physical storage* and *Cost of capital* increase the value of *Holding cost*, which increases the value of *Total cost* together with *Fixed ordering cost* and *Transportation cost*.

There are two negative feedback loops in the causal loop diagram. The first interconnects *Stock*, *Ordering* and *Delivery* and it represents the fact that we order less if the stock level is high. The second interconnects *Delivery* and *Ordering* and represents the concept that we order less if we have ordered more before. This loop takes into account orders which haven't been delivered yet and will have impact on the stock level later on.

2.4. The model in detail

The warehouse model is described in detail in our previous work (Kljajić et al., 2004). The Virtual Process uses the basic warehouse model, while the SD model uses the model with fixed review period.

The Virtual Process simulates the process in the actual warehouse, while the SD model is used to control the Virtual Process. The tasks of the Virtual Process are:

- to calculate stock level considering actual consumption plan and ordering strategy provided by the SD model,
- to calculate warehousing costs, annotate stock-outs, cumulative consumption, minimal and maximal stock level, and all other information concerning the Virtual Process, and providing this information to the warehouse operator,
- to provide information to the SD model.

The SD model is supplied with the following information from the Virtual Process:

- consumption plan,
- stock-on-hand,
- past orders,
- lead time.

The SD model runs the simulation for 24 weeks (duration of consumption planning period) seeking the ordering strategy which would produce minimal costs of the warehouse. The ordering strategy is sought between several review periods (e.g. 2, 3, 4 and 5 weeks). Considering the information from the Virtual Process and simulation results, the decision support module within SD model decides which review period gives the best results at the given moment thus providing the Virtual Process with ordering quantity and the point in time at which the order should take place. It is not necessary that the same review period will be chosen throughout the simulation. The review period depends mostly on the dynamics of consumption plan and is subject to any changes of it.

A Monte Carlo simulation is used for variation of consumption unreliability. Fifty simulation runs are executed for every review period. On the basis of these simulation runs, average costs and average stock-outs are calculated. With several simulation runs and a calculation of average values, we have tried to minimize the influences of the random generator, which represents the stochastic environment. Out of all simulation runs the maximum stock level is taken into consideration as the warehouse capacity limit.

3. Results

The experiment was performed with the actual historic data for seven years provided by the observed company. In this paper we present results for one case (product).

Figure 5 presents results for the Real Process and Virtual Process. The Real Process is represented by the red line and the Virtual Process is represented with a blue line. The first graph presents stock level dynamics, the second delivery dynamics and the third the consumption dynamics throughout simulation time (time unit is weeks). Numerical simulation results are shown at the bottom and represent:

- stock-outs,
- minimal stock level,
- maximum stock level,
- cumulative stock,
- cumulative consumption,
- fixed ordering costs,
- transportation costs,
- costs of taking over the products,
- costs of physical storage,
- capital costs,
- total costs.

The results shown in Figure 5 can be used to indicate similarities or differences between the two processes. Similarities stress the fact that Virtual Process has captured some aspects of the Real Process well, while differences show that the Virtual Process is missing some aspects. Only the research team can decide whether those aspects are significant or not.

Figure 5 shows a big difference between the Virtual Process and the Real Process stock-on-hand and supply dynamics for the observed case. The supply dynamics graph indicate some similarities in the ordering strategy – some peaks (representing order quantity) are very similar but with some time delay. While looking at the costs, the Virtual Process has produced much lower costs than the Real Process (65%). The biggest difference is in the *Physical storage* and *Capital cost*, due to the high *Cumulative stock* in the Real Process.

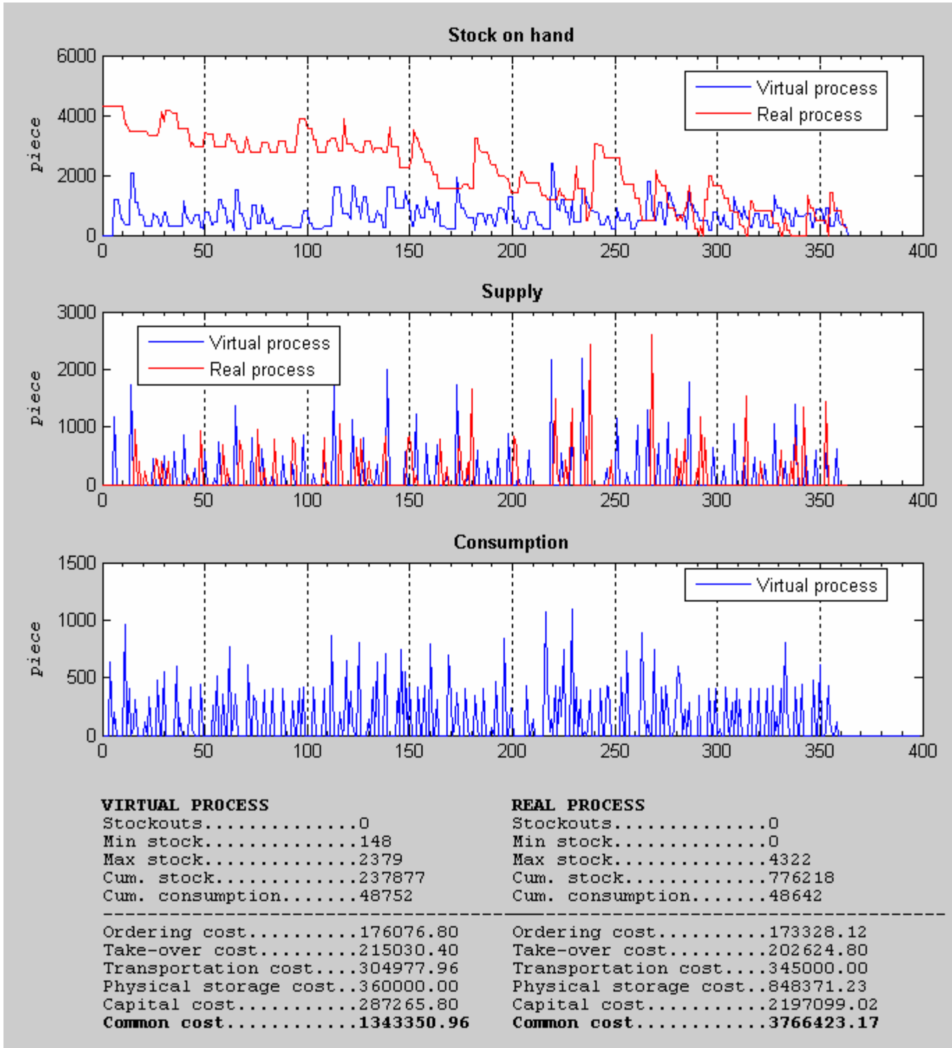

Figure 5: Simulation results for the observed case

The virtual simulator also allows us to compare two methodologies used in the ordering process (Figure 6):

- heuristics of the warehouse operator (based on experience and intuition),
- heuristics used by the Virtual Process (based on simulation, artificial intelligence, fuzzy logic etc.).

Figure 6 consists of 4 four histograms. The histograms on the left represent *Order quantities* (number of pieces ordered), while those on the right represent *Order intervals* (time intervals between two consecutive orders). The upper histograms represent the Real Process, while the lower ones represent the Virtual Process.

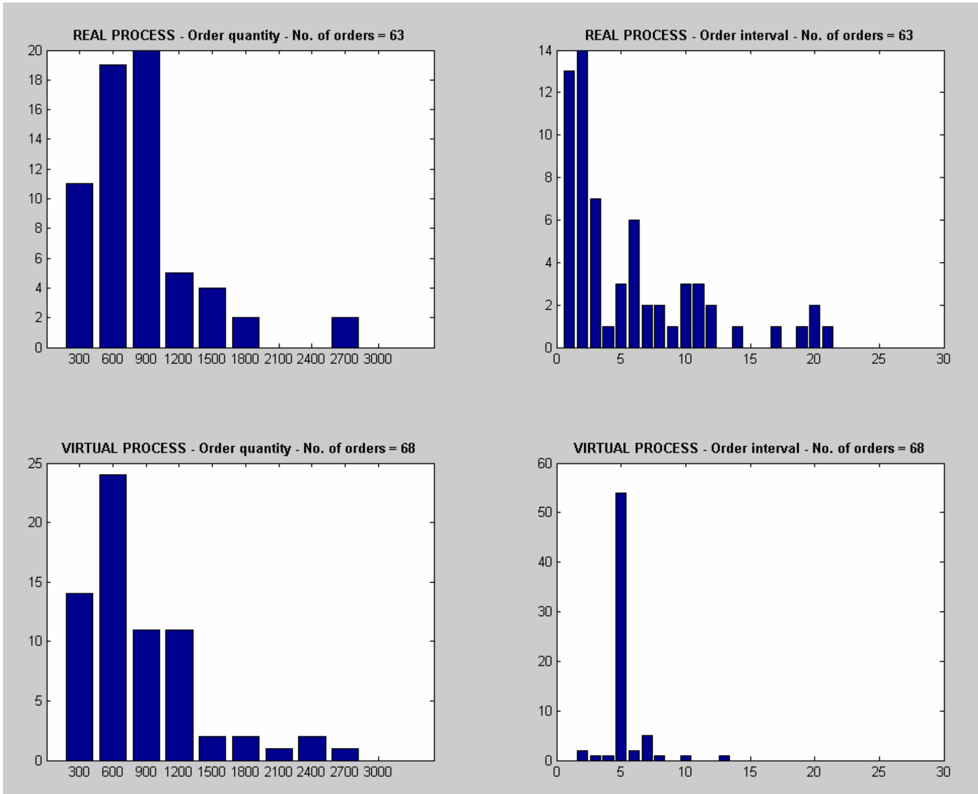

Figure 6: Comparison of ordering strategies for the observed case

Comparisons provide an insight into their advantages and disadvantages. The operator is allowed to improve his heuristics based on intuition and experience with heuristics based on sophisticated data analysis and prediction techniques.

For the observed case, histograms of order quantities of both processes show some similarities, while histograms of order intervals are not at all similar. The majority of order quantities is around 600 pieces in both cases. On the other hand, order intervals in the Real Process are scattered all over the histogram with majority at the interval of 2 weeks. Order intervals in the Virtual Process are close to the value of 5 weeks, thus showing significant difference towards the Real Process.

4. Conclusion and discussion

The main goal in developing the virtual reality simulator was to give the ability to introduce simulation models into real processes while observing the real process at the same time for the purpose of validation. With the virtual simulator's transparency and visual presentation, the simulator can play a significant role in a learning process of using new optimization algorithms as people tend to resist using methodologies that they are not familiar with, especially if they are used to controlling the process using only their experience and intuition. Considering the simulator's characteristics, we can conclude that the warehouse operator could quickly understand and adapt to a new methodology used in the ordering process.

The virtual reality simulator can be used as a useful tool in a faster and more efficient migration of simulation models into real processes. The key point is the ability to compare the states of the real and virtual process at any moment. That allows finding significant differences that may still exist between the real process and virtual model in the process of validation.

Persuading people in management about the profitability of using modern optimization methodologies is another advantage of the virtual reality simulator as modern technology provides a way of efficient analysis of the current state of the process and its behavior in the future. Equipped with visual presentation, the simulator can give a more presentable and understandable insight into sophisticated techniques, which can offer tremendous support in the decision process, thus providing help to company in cutting costs.

This paper has researched a virtual simulator using the model with fixed review period. Future research would include research with the model with variable review periods and products with variable lead times. Ordering strategy decision making process could also be improved by using more sophisticated methodologies, e.g. fuzzy sets.

Another aspect of future research is the development of optimization algorithms concerning products belonging to all classes under XYZ and ABC classification. As products belong to classes with completely different characteristics, it is expected that several optimization algorithms would be used to cover the whole product classification.

5. References

Banks J., Carson J.S. II, Nelson B.L. (1996). *Discrete-Event System Simulation*. Prentice Hall, Upper Saddle River, New Jersey.

Barlas Y., Özevin M.G. (2004). *Analysis of stock management gaming experiments and alternative ordering formulations.* Proceedings of the 22nd International Conference of the System Dynamics Society, Oxford, England, UK, July 25-29, 2004.

Dangelmaier W., Fischer M., Gausemeier J., Grafe M., Matysczok C., Mueck B. (2005). *Virtual and augmented reality support for discrete manufacturing system simulation*. Computers in Industry, Volume 56, Issue 4, May 2005, Pages 371-383.

Desel J. (2002). *Model Validation - A Theoretical Issue?* Applications and Theory of Petri Nets 2002: 23rd International Conference, ICATPN 2002, Adelaide, Australia, June 24-30, 2002, p. 23-43.

Forrester J. W. (1961), *Industrial Dynamics*, MIT Press, Cambridge, MA.

Fowler A. (2003). *Systems modelling, simulation, and the dynamics of strategy*. Journal of Business Research, Volume 56, Issue 2, February 2003, Pages 135-144.

Kljajić M., Bernik I., Škraba A. (2000). *Simulation Approach to Decision Assessment in Enterprises*. Simulation 74:4, Simulation Councils Inc., pp. 199-210.

Kljajić M., Kofjač D., Škraba A., Rejec V. (2004). *Warehouse optimization in uncertain environment*. Proceedings of the 22nd International Conference of the System Dynamics Society, Oxford, England, UK, July 25-29, 2004.

Larsen E.R., Ackere A., Warren K. (1997). *The Growth of Service and the Service of Growth: Using System Dynamics to Understand Service Quality and Capital Allocation*. Decision Support Systems 19, pp. 261-287.

Lin F., Ye L., Duffy V.G., Su C.J. (2002). Developing virtual environments for industrial training. Information Sciences, Volume 140, Issues 1-2, January 2002, Pages 153-170.

Oakshott L. (1997). *Business Modelling and Simulation*, Pitman Publishing.

Thomsen J., Levitt R.E., Kunz J.C., Nass C.I., Fridsma D.B. (1999). *A Trajectory for Validating Computational Emulation Models of Organizations*. Publisher: Springer Science+Business Media B.V., Formerly Kluwer Academic Publishers B.V. Volume 5, Number 4, Pages: 385 – 401.

Wang Q., Chatwin C.R. (2004). *Key issues and developments in modelling and simulation-based methodologies for manufacturing systems analysis, design and performance evaluation*. The International Journal of Advanced Manufacturing Technology, Springer-Verlag London Ltd.