

- creation of system performance indicators for simulation tools and justification of criteria for evaluating the effectiveness of alternatives;
- choice of methods for estimating indicators of simulation tools;
- implementation of the inventory control models in the ExtendSim and AnyLogic environment;
- performing simulation test;
- assessment of criteria for simulation tools.

The contents of the separate steps are described below.

CRITERIA FORMATION

The problem of simulation tools efficiency evaluation and selecting the most appropriate option was considered by many authors. First of all, we can mention the works (Seila et al. 2003; Verma et al. 2010). It should be noted that in these researches the amount of estimated indicators are significantly different. So, the Seila et al. (2003) have investigated the effectiveness of 20 discrete event simulation tools using a small number of indicators. But Verma et al. (2010) have made an assessment of 4 software tools, estimating more than 200 parameters. Some of the parameters have been evaluated by the expert methods; some parameters were obtained as a result of the experiments.

Taking in account the specificity of inventory control model simulation the authors have formed the system of criteria which includes 28 indicators. These indicators were distributed in five groups shown in the Tab. 1.

Table 1: Groups of criteria of the effectiveness of inventory control simulation tools

Group No	Group Name
1.	General
2.	Programming aspects
3.	Visualization
4.	Simulation
5.	User support

Distributing indicators in the groups allows involving in assessment process various experts: programmers, graphic interface creators, support team, etc.

To evaluate each indicator the authors have selected the numeric scale from 0 to 3, with: 0 – unsatisfactory; 1 – satisfactory; 2 – good; 3 – excellent.

The effectiveness of each simulation tools for the selected groups is characterized by following criteria:

- 1) the sum of scores $S_j^{(i)}$, where $j=1$ for package ExtendSim and $j=2$ for package AnyLogic, where numbers of groups are $i=1,2,..,5$;

- 2) the priority vector (local criteria) $p_i = [p_{i,1}, p_{i,2}]$, where the elements of the vector, respectively, define priorities (weights) of ExtendSim 8 and AnyLogic 6.7 calculated for the i -th group of indicators as follows:

$$p_{i,j} = \frac{S_j^{(i)}}{S_1^{(i)} + S_2^{(i)}}, \quad j=1, 2. \quad (1)$$

It is easy to see that always it is $p_{i,1} + p_{i,2} = 1$.

In the final step of the assessment process the vector $P = [p_1, p_2]$ of the global criteria priorities can be calculated:

$$P_j = \sum_{i=1}^5 \beta_i p_{i,j}, \quad j=1,2, \quad (2)$$

where $\beta_i > 0, i=1,2,..,5; \sum_{i=1}^5 \beta_i = 1; \beta_i$ is the weight of criteria of the i -th group.

DESCRIPTION OF THE MODEL

To evaluate the efficiency of the selected simulation packages for inventory control tasks there have been selected various models, among them: single- and multiple-product, with random demand, with random and fixed lead time, with different ordering strategies, without restrictions on storage and financing resources.

In this paper we consider a single-product stochastic inventory control model under following conditions. The demand for goods D has a normal distribution with known parameters mean m and standard deviation σ . In the moment of time, when the stock level $\varphi(t)$ falls till certain level R , a new order is placed (see Fig.1). The quantity R is called as reorder point. The order quantity Q is constant. We suppose that $Q \geq R$. The lead time L (time between placing an order and receiving it) is fixed. There is the possible situation of deficit, when demand D_L during lead time L exceeds the value of reorder point R . We suppose that in case of deficit the last cannot be covered by expected order.

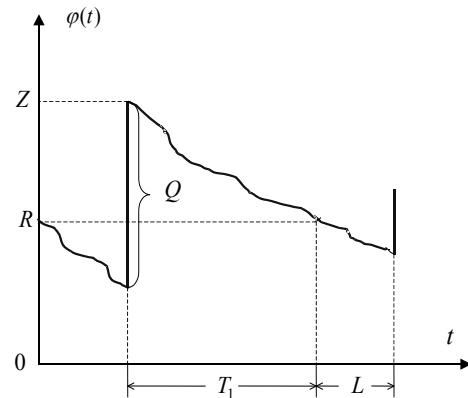


Figure 1: Dynamics of inventory level during one cycle

Denote as Z the quantity of goods in stock in the time moment immediately after order receiving. We can determine this quantity of goods Z as function of demand D_L during lead time L :

$$Z = \begin{cases} R + Q - D_L, & \text{if } D_L < R; \\ Q, & \text{if } D_L \geq R. \end{cases} \quad (3)$$

Expression (3) is basic. It allows expressing different economical indexes of considered process.

Let T be the duration of a cycle. Length of the cycle consists of two parts: time T_1 between receiving the goods and placing a new order and lead time L , i.e. $T = T_1 + L$ (see Fig 1.).

We suppose that next parameters of the model are known:

- the ordering cost C_0 is fixed;
- the holding cost is proportional to quantity of goods in stock and holding time with coefficient of proportionality C_H ;
- the shortage C_{SH} should not exceed 1,5% of demand.

The principal aim of the considered model is to define

where $E(TC_H)$ and $E(TC_{SH})$ are average holding and average shortage costs within cycle accordantly.

Note that $E(TC_H)$ and $E(TC_{SH})$ depend on control parameters R and Q . Analytical formulas for these economic indicators have been presented in the paper (Kopytov and Greenglaz 2004). For problem solving we have to minimize criteria (4) by R and Q .

The realizations of considered model in ExtendSim 8 and AnyLogic 6.7 environments are presented in the next sections. In examples of simulation presented below we have used the following initial data. The demand for goods D has a normal distribution with parameters mean $m = 80$ and standard deviation $\sigma = 18$. The lead time L equals 5 days. Starting values for control parameters are: $Q = 600$ and $R = 500$.

SIMULATION MODEL IN EXTENDSIM 8 ENVIRONMENT

For solving the problems considered above we have used discrete events simulation method realized in the package ExtendSim 8 (Strickland 2011). In discrete-event simulation, the operation of a system is represented as a chronological sequence of events (see Fig.2). Each event occurs at an instant in time and marks a change of state in the system (Krahl 2007).

Let us consider the main parts of the simulation model

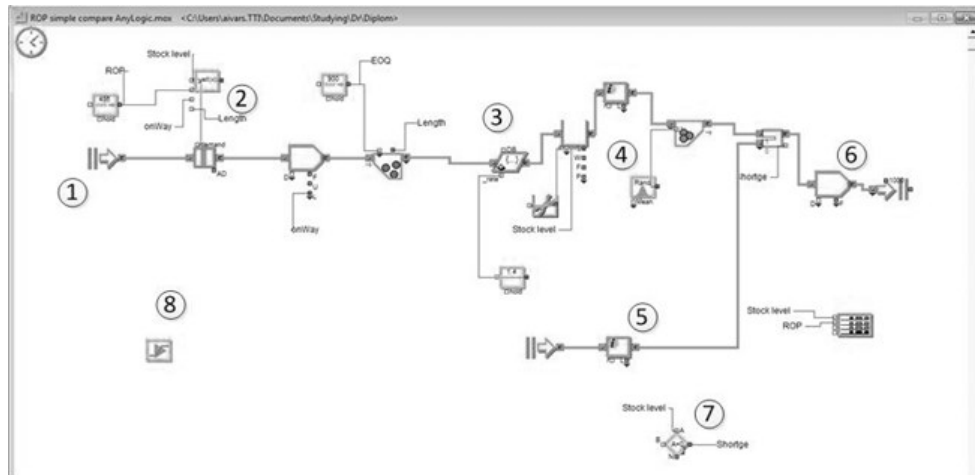


Figure 2: Inventory control model in ExtendSim environment

the optimal values of order quantity Q and reorder point R , which are *control parameters of the model*. A criterion of optimization is the minimum of average total cost in inventory control system per time unit. Denote this average total cost by $E(AC)$ which can be found as average total cost during one cycle divided by average cycle time $E(T)$ (Ross 1992):

$$E(AC) = \frac{E(TC_H) + E(TC_{SH}) + C_0}{E(T)}, \quad (4)$$

shown in Fig.2. In the area #1 there are placed executive and generation blocks that control model time and transaction generation in the model. Area #2 is responsible for order making decision with equation block results in area #7. Next area #3 represents transportation activity. Demand simulation and decreases in stock are simulated in area #4. Shortage occurrences are represented in area #5. Area #6 is the end of the model and is used for transaction termination.

The example of one realization of inventory control simulation is presented in Fig.3. The plot is showing the stock level for 100 days period simulation.

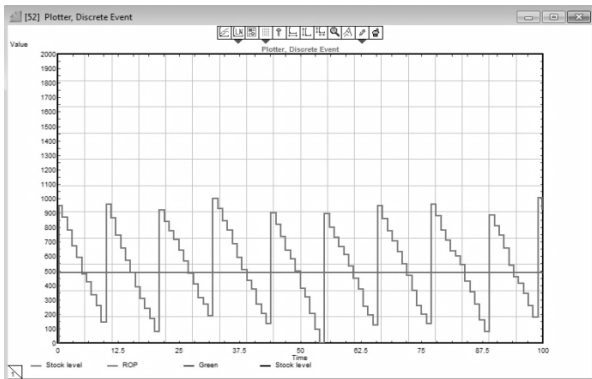


Figure 3: Example of simulation process in ExtendSim

SIMULATION MODEL IN ANYLOGIC 6.7 ENVIRONMENT

The model considered above uses discrete event simulation approach. On the other hand AnyLogic developers promote agent-based modeling (ABM) approach. In ABM the focus is on individual agents, their rules, their behaviors, and their interactions with each other and the environment (Salamon 2011). Collectively agents may exhibit emergent behaviors such as self-organization. Since agents do not follow a pre-scripted flow (as in Discrete Event) and their

From an architectural viewpoint, a typical AnyLogic agent based model would have at least two active object classes. There would be a main class for a top-level object where agents would be contained and a class for an agent or person. The Person class in most cases would be declared as Agent which is a special subclass of the ActiveObject class that extends the latter with services useful for agent based modeling. A number of agents would be embedded into the Main object, as a replicated object of type Person. One or more Environment constructs may be defined at the level of Main to specify properties shared by the agents.

The suggested inventory model realization is presented in Fig.4. In this figure we can see variable and parameter window that also contains agents for distributor, retailer, truck and events for ordering and transportation tasks. These agents can be used in future more complex models with multiple retailers, distribution point and multiproduct ordering.

In AnyLogic 6.2 are introduced special graphical tools Action Charts. The designers of AnyLogic have suggested Action Charts as a simple and commonly accepted language, that makes action/decision logic visual, easy to communicate to other people and easier to develop at the same time. Action Charts consist of nested elements, each corresponding to a Java statement: decision-statement, several kinds of loops, local variable declaration, code section, etc. An action chart is straightforwardly mapped to a Java method and

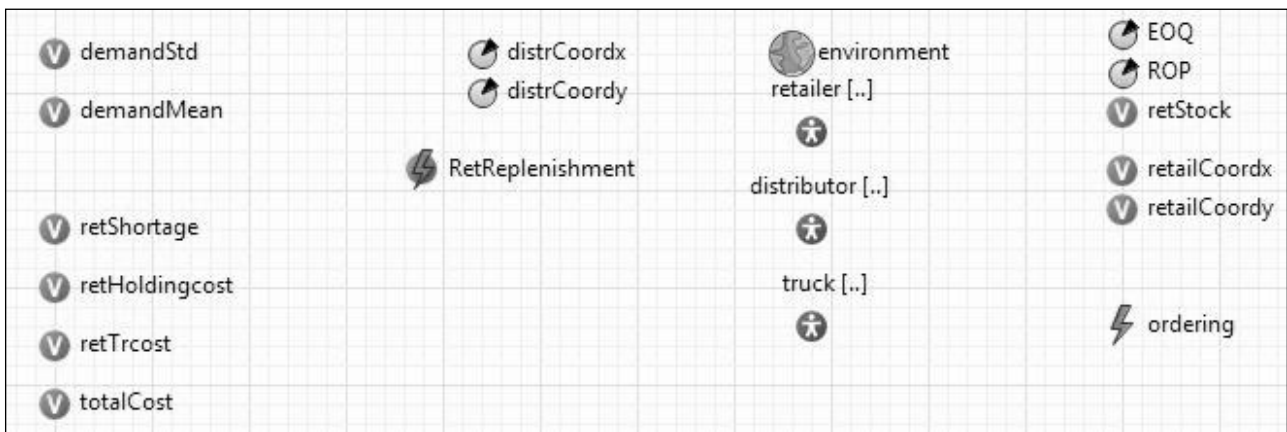


Figure 4: Inventory control model in AnyLogic environment

structure is not pre-specified at the global/aggregate level (as in System Dynamics), they can exhibit novel or surprising behaviors that were not anticipated during design. ABM is a great methodology for exploring non-linear, dynamic environments. ABM is also well suited for situations with no precedent or where past data or experience does not exist. When combined with data and data analytics, ABM forms one of the most powerful predictive analytics / forecasting methodology.

therefore is equally efficient. The developers can choose colors and labels of the action chart boxes to further improve its expressiveness. The example of action chart for inventory control model with reorder point is shown in Fig.5.

The example of simulation process realization in AnyLogic environment is presented on Fig.6. As is easily seen, the plots in Fig.3 and Fig.6 are very similar. And this is natural, because the plots show the simulation results of the same task.

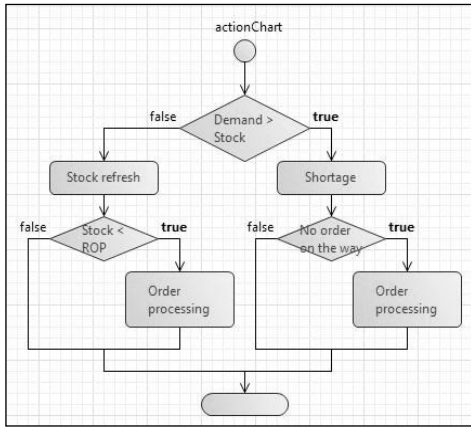


Figure 5: Action chart

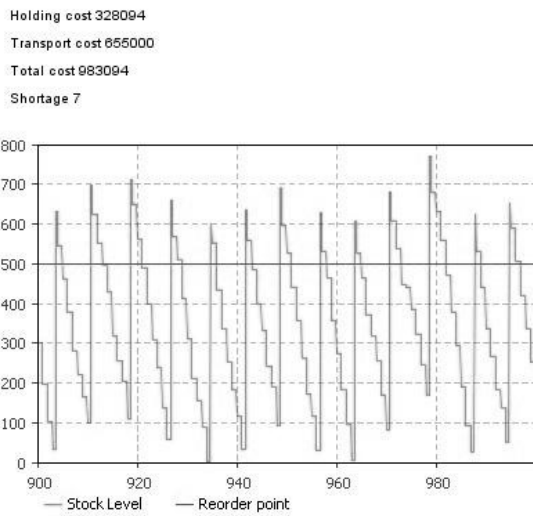


Figure 6: Example of simulation process in AnyLogic

EXAMPLE OF INVENTORY CONTROL SYSTEM OPTIMIZATION

As it was mentioned above the control parameters for presented model are the order quantity Q and reorder point R . In considered example the optimum search of control parameters is carried out in range for $400 \leq Q \leq 1200$ and $200 \leq R \leq 800$. Both presented simulation packages have integrated optimization tools that we had used to find optimal result.

At first let's consider optimization process in AnyLogic. To run optimization we should manually create and tune optimization experiment. In tuning process we need to create user interface, define objective function, optimization parameters and constraints. The example of optimization process in AnyLogic environment is presented In Fig.7.

Next let's look at the same procedure in ExtendSim tool, which is a little easier. We can use the same user interface, just putting into model window optimization block, all other steps are similar to AnyLogic except

that in ExtendSim we can use optimization parameters only in constraints. The example of optimization process in ExtendSim environment is shown in Fig.8.

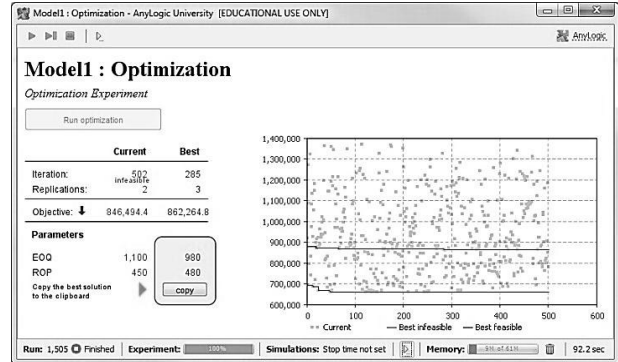


Figure 7: Example of optimization process in AnyLogic

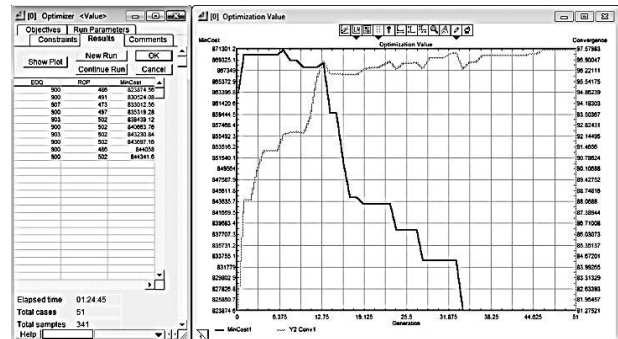


Figure 8: Example of optimization process in ExtendSim

In Tab. 2 final optimization results for both simulation tools are shown. Apparently the obtained results are very similar to each other.

Table 2: Optimization results

Parameter	Simulation tools	
	AnyLogic	ExtendSim
Reorder point	480	486
Order quantity	980	900
Total cost	862 264 EUR	823 874 EUR

The authors also have investigated more complex models of inventory control systems (for example, see (Kopytov and Muravjov 2011)), which due to the article size limitation are not presented in this paper. The simulation results were used by authors in the comparative assessment of ExtendSim 8 and AnyLogic 6.7 presented below.

ASSESSMENT OF EXTENDSIM AND ANYLOGIC EFFICIENCY

The developed system of criteria described above has been used for comparative assessment of efficiency of the packages ExtendSim 8 and AnyLogic 6.7 for inventory control system simulation. Consequently, the

different groups of criteria have been evaluated by different qualified experts. For instance, the programmers have assessed the general and programming aspects criteria; the experts from the supporting service have evaluated the user support criteria, while the decision makers have estimated the visualization and simulation criteria.

A numerical weight or priority has been derived for each group of criteria (see Tab.3-Tab.7). Each group of criteria has been evaluated by three or more experts then average value of each indicator has been calculated.

Table 3: Simulation tools assessment, group “General”

Indicator	Simulation tools	
	AnyLogic	ExtendSim
Programming language	2,66 (Java)	2 (ModL)
Primary domain	2 (General purpose)	2 (General purpose)
Operating system	3 (Win/Mac/Linux)	2,66 (Win/Mac 2)
Data connectivity with other applications	2,66 (MS Excel/ Access / SQL ODBC)	2,33 (MS Excel/ Access COM/OLE)
Model packaging	3 (Standalone Java application or embedded to WEB browser)	2,33 (Need ExtendSim player)
Price for universities	2,66 (2600 EUR)	2,66 (1880 EUR)
Optimization	3	2,33
Sum of score	18,98	16,31
Criteria priorities	0,54	0,46

Table 4: Simulation tools assessment, group “Programming aspects”

Indicator	Simulation tools	
	AnyLogic	ExtendSim
Programming flexibility	3	1,33
Support of programming concepts	3	1,66
Built in functions	2,66	2
Debugging	2,66	2,33
Code editor	2	2,33
External code connection	3	1,66
Built-in random numbers generators	2	3
Sum of score	18,32	14,31
Criteria priorities	0,56	0,44

Table 5: Simulation tools assessment, group “Visualization”

Indicator	Simulation tools	
	AnyLogic	ExtendSim
Animation	2,33	3
Logical animation	2	3
Playback mode	3	1,66
3D Animation	1,66	2,33
Graphic library	1,66	1,66
Sum of score	10,65	11,65
Criteria priorities	0,48	0,52

Table 6: Simulation tools assessment, group “Simulation”

Indicator	Simulation tools	
	AnyLogic	ExtendSim
Model execution speed	3	2,66
Simplification of simulation process	2,33	2,66
Variety of simulation approaches	2,66	2,33
Hardware requirements	2	2,66
Sum of score	9,99	10,31
Criteria priorities	0,49	0,51

Table 7: Assessment of ExtendSim and AnyLogic, group “User support”

Indicator	Simulation tools	
	AnyLogic	ExtendSim
Documentation	2,33	2,66
Training courses	3	2
Users forum	2,33	1,33
Knowledge base	2	1,33
Demo models and libraries	3	3
Sum of score	12,66	10,32
Criteria priorities	0,55	0,45

In the final step of the assessment process criteria priorities are calculated using (1), (2) for each of the simulation tools. The weights of relative importance of the various local (group’s) criteria suggested by experts are presented in Tab.8.

Table 8: The weights of group’s criteria

Group number, i	Group title	Weight, β_i
1	General	0,18
2	Programming aspects	0,30
3	Visualization	0,16
4	Simulation	0,24
5	User support	0,12

The final results of tools assessment are presented in Tab.9. They can be used for choosing simulation package in a particular inventory problem solving. In three groups the criteria weights of AnyLogic are greater (from 8% till 12%) than the weights of ExtendSim. In two groups the AnyLogic yields the ExtendSim by 2-4 %. The global criteria for AnyLogic is greater than global criteria for ExtendSim by 0,06.

Table 9: Evaluations of the vector of the global criteria priorities for ExtendSim and AnyLogic

Group number	Group title	Simulation tools	
		AnyLogic	ExtendSim
1	General	0,54	0,46
2	Programming aspects	0,56	0,44
3	Visualization	0,48	0,52
4	Simulation	0,49	0,51
5	User support	0,55	0,45
Global criteria priorities		0,53	0,47

CONCLUSIONS

This article solves the issue of estimation and choosing the simulating tools for inventory control system modeling. To fulfill the evaluation of the simulating tools, a two-level hierarchy system of criteria has been developed. For investigation two simulation tools ExtendSim 8 and AnyLogic 6.7 were chosen. The assessment was made on the results of the inventory control models implemented in chosen environments. The results indicate the feasibility of the application of ExtendSim 8 and AnyLogic 6.7 in inventory control tasks. Further guidelines of the current research are the following: to apply multiple-criteria decision analysis methods for systems efficiency evaluation; to consider the multi-product inventory control model with certain constraints.

REFERENCES

Chopra, S. and P. Meindl. 2001. *Supply Chain Management*. Prentice Hall, London.

Emrich, Sh.; S. Suslov and J. Florian. 2007. "Fully agent based modellings of epidemic spread using AnyLogic". *EUROSIM 2007*, (Sept. 9-13). Ljubljana, Slovenia, 9-13.

Kopytov, E.; L.Greenglaz; A. Muravjov and E. Puzinkevich. 2007. "Modeling of Two Strategies in Inventory Control System with Random Lead Time and Demand". *Computer Modeling & New Technologies*, Vol. 11(1), Riga: Transport and Telecommunication Institute, 21-30.

Kopytov, E. and L. Greenglaz. 2004. "On a task of optimal inventory control". In *Proceeding of XXIV International Seminar on Stability Problems for Stochastic Models* (Jurmala, Sept. 9-17). Riga, TTI, 247-252.

Kopytov, E. and A. Muravjov. 2011. "Simulation of inventory control system for supply chain "producer – wholesaler – client" in ExtendSim environment". In *Proceedings of the 25th European conference on modeling simulation (ECMS-2011)*. (Krakow, June 3-4). Poland, 580-586.

Krahl, D. 2007. "ExtendSim 7". In *Proceedings of the 39th conference on Winter simulation: 40 years!* (Dec. 09-12), S.G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J.D. Tew and R.R. Barton (Eds.). Washington D.C., 226-232.

Magableh, G. M. and S. J. Mason. 2009. "An integrated supply chain model with dynamic flow and replenishment requirements". *Journal of Simulation*, Vol. 3, 84–94.

Marin, M.; Zhu, Y.; Andrade, L. Al.; Atencio, E.; Boya, C. and C. Mendizabal. 2010. "Supply chain and hybrid modeling: the Panama Canal operations and it's salinity diffusion". In *Proceedings of the 2010 Winter Simulation Conference*. (Dec. 5-8). American Technologica, Orlando, FL, USA, 2023-2033.

Ross, S. 1992. *Applied Probability Models with Optimization Applications*. Dover Publications, INC, New York.

Salamon, T. 2011. *Design of Agent-Based Models: Developing Computer Simulations for a Better Understanding of Social Processes*, Bruckner Publishing.

Seila, A.F.; V. Ceric and P. Tadikamalla. 2003. *Applied Simulation Modeling*, Thomson Learning, Australia: Thomson Learning.

Stewart, R. 2004. *Simulation – The practice of model development and use*. Wiley.

Strickland, J. 2011. *Discrete Event Simulation using ExtendSim 8*. Lulu.

Verma, R.; A.Gupta and K. Singh. 2009. "A critical evaluation and comparison of four manufacturing simulation software". *Kathmandu university journal of science, Engineering and technology*. Vol. 5(1), 104–120.

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