MULTIPLE CRITERIA ANALYSIS AND CHOICE OF SIMULATION TOOLS FOR INVENTORY CONTROL MODELLING USING AHP METHOD

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The given research fulfils evaluation of the efficiency of two universal simulation packages ExtendSim 8 and AnyLogic 6.7 for inventory control system modelling. As an object of simulation the inventory control model with reorder point strategy and stochastic demand has been chosen. In the study twenty eight evaluating criteria have been developed, which are distributed in five groups: general, programming aspects, visualization, simulation and user support. For assessment of the suggested packages the Analytic Hierarchy Process (AHP) method is applied. The study presents the AHP method as the most suitable one for comparative evaluation of different simulation packages.

Keywords: inventory control, simulation package, multiple criteria choice, AHP method

1. Introduction

The existence of a variety of simulation tools makes the issue of choosing the most suitable package for inventory control system modelling rather difficult. The problem of simulation tools efficiency evaluation and selection the most appropriate option was considered by many authors. Usually, this problem is formulated as multiple criteria choice problem (for instance, see [1, 2]). It should be noted that in these researches the amount of estimated indicators are significantly different. So, the authors of the paper [1] have investigated the effectiveness of 20 discrete event simulation tools using a small number of indicators, but the authors of the work [2] 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.

On the other hand, it should be noted that the known studies do not consider the problem of simulation tools efficiency for inventory control modelling, which have a number of specific characteristics. For this reason the presented research has been executed. Taking in account the specificity of inventory control models simulation the authors have formed the system of criteria which includes 28 indicators characterized the efficiency of simulation packages. In the previous work [3] the authors have proposed the simple assessment of simulation tools efficiency based on the peer review. In the present paper one of the most effective methods of multiple criteria choice – the Analytic Hierarchy Process (AHP) method [4] is applied. In our opinion, this method is the most suitable for the examined problem solving. It is necessary to mention important advantages of the AHP method: it gives possibility to distribute the criteria by several groups and to evaluate the significance of every group components independently; the computable consistency of the judgments allows controlling the accuracy of estimation; it does not require the special software; the algorithm of AHP operation and the table form of representation of principal and intermediate results give possibility to demonstrate visually the reason for choosing the certain alternative [5]. To illustrate the offered approach the authors have evaluated two alternatives of simulation tools: packages ExtendSim and AnyLogic. During this research various inventory control models have been created and realized in ExtendSim 8 and AnyLogic 6.7 environment, one of these models is presented in the paper.

The procedure of evaluation the effectiveness and choice of the simulation tools for inventory control system includes the following stages:
1. Selection of the simulation tools (packages) for evaluation;
2. Implementation of various inventory control problems in the selected tools environment;
3. Formation of the system of criteria characterizing the efficiency of the simulation tools;
4. Choice of the method for simulation tools assessment;
5. Performance of the analysis and choice of the simulation tools.

The contents of the separate stages are considered below.

2. Simulation Tools under Investigation

The package ExtendSim [6] is a proven simulation environment capable of modelling a wide range of systems. ExtendSim is used to model continuous, discrete event, discrete rate, and agent based systems. ExtendSim's design facilitates every phase of the simulation project, from creating, validating, and verifying the model, to the construction of a user interface that allows others to analyze the system [7]. Simulation tool developers can use ExtendSim's built-in, compiled language Modl to create reusable modelling components. All of this is done within a single, self-contained software program, which does not require external interfaces, compilers, or code generators.

The package AnyLogic [8] is a tool that supports all the most common simulation methodologies in place today: System Dynamics, Process-centric (AKA Discrete Event), and Agent Based modelling. The unique flexibility of the modelling language enables the users to capture the complexity and heterogeneity of business, economic and social systems to any desired level of detail. AnyLogic's graphical interface, tools, and library objects allow users to model diverse areas such as manufacturing and logistics, business processes, human resources, consumer and patient behaviour. The object-oriented model design paradigm supported by AnyLogic provides for modular, hierarchical, and incremental construction of large models.

3. Inventory Control Model under Investigation

3.1. Description of the model

To evaluate the efficiency of the selected simulation packages for inventory control tasks we have investigated various models, among them: single- and multiple-product, with random demand, with random and fixed lead time, with different ordering strategies, with restrictions on storage and financing resources (for instance, see [7]).

In this paper as example let us 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.
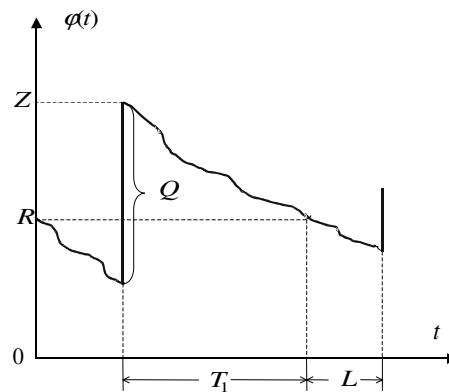

Figure 1. Dynamics of inventory level during one cycle

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:

$$Z = \begin{cases} R + Q - D_L, & \text{if } D_L < R; \\ \\ Q, & \text{if } D_L \geq R. \end{cases} \qquad (1)$$

Expression (1) 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 following 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 the optimal values of order quantity Q and reorder point R, which are *control parameters* of the model. A criterion of optimisation 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 $E(T)$ [9]:

$$E(AC) = \frac{E(TC_H) + E(TC_{SH}) + C_0}{E(T)}, \tag{2}$$

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

Note that costs $E(TC_H)$ and $E(TC_{SH})$ depend on control parameters R and Q. Analytical formulas for these economic indicators have been presented in the paper [10]. For problem solving we have to minimize criteria (2) by R and Q.

The realizations of considered model in ExtendSim 8 and AnyLogic 6.7 environments are presented in the next sections. In the 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: $R = 500$ and $Q = 600$.

3.2. Simulation model in ExtendSim 8 environment

For solving the problem considered above we have used Discrete Events simulation method realized in the package ExtendSim 8 [11]. 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 [6].
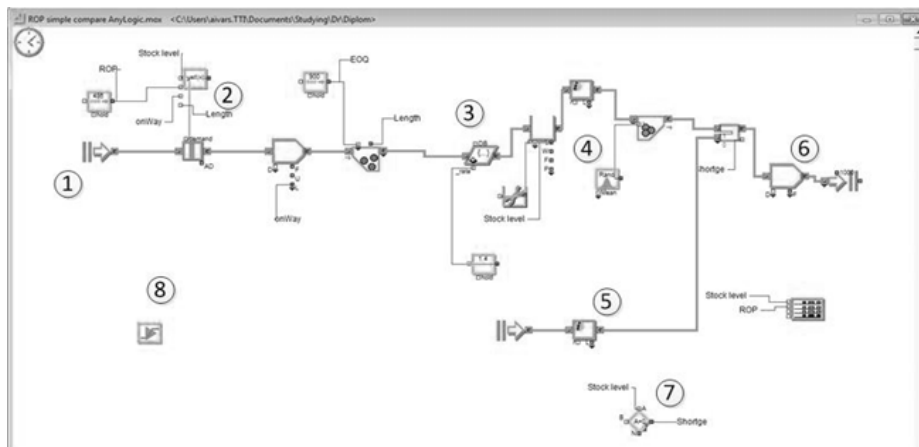

Figure 2. Inventory control model in ExtendSim environment

Let us consider the main parts of the simulation model shown on Figure 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 with equation block results in area #7. Next area #3 represents transportation activity. Demand for goods and reductions 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 on Figure 3. The plot shows the stock level for 100 days period simulation.
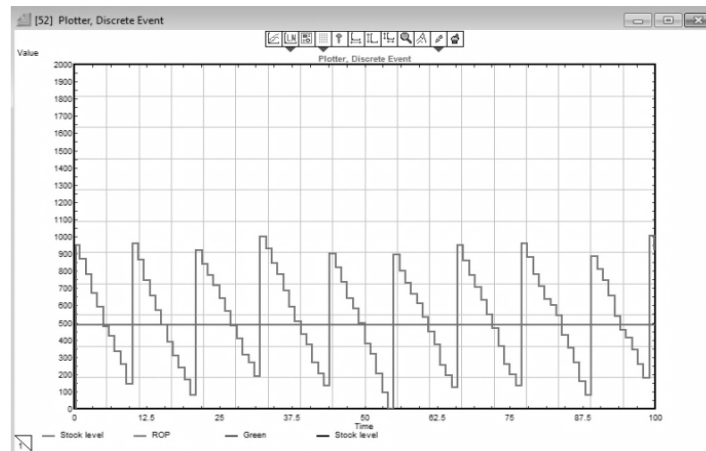

Figure 3. Example of simulation process in ExtendSim

3.3. 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 modelling (ABM) approach. In ABM the focus is on individual agents, their rules, their behaviours, and their interactions with each other and the environment. Collectively agents may exhibit emergent behaviours such as self-organization. Since agents do not follow a pre-scripted flow (as in Discrete Event) and their structure is not pre-specified at the global/aggregate level (as in System Dynamics), they can exhibit novel or surprising behaviours 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. 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 modelling. 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 on Figure 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 more complex models with multiple retailers, distribution point and multiproduct ordering.
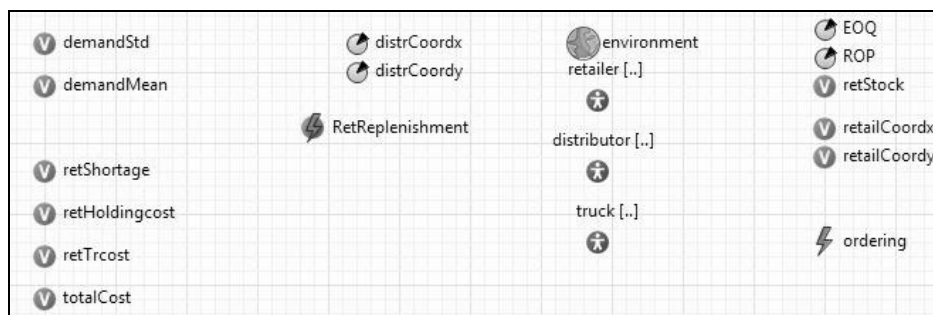

Figure 4. Inventory control model in AnyLogic environment

In AnyLogic 6.2 special graphical tolls Action Charts are introduced. 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 therefore is equally efficient. The developers can choose colours 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 on Figure 5.
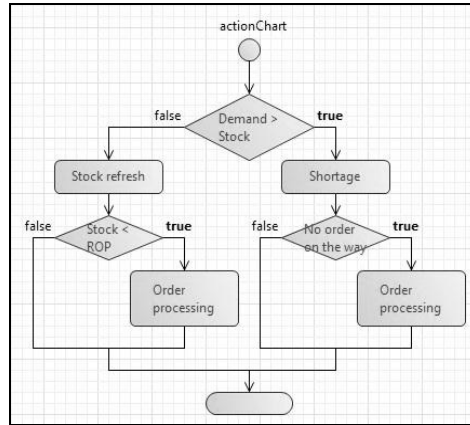

Figure 5. Action chart for inventory control model

The example of simulation process realization in AnyLogic environment is presented on Fig. 6. As it 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.
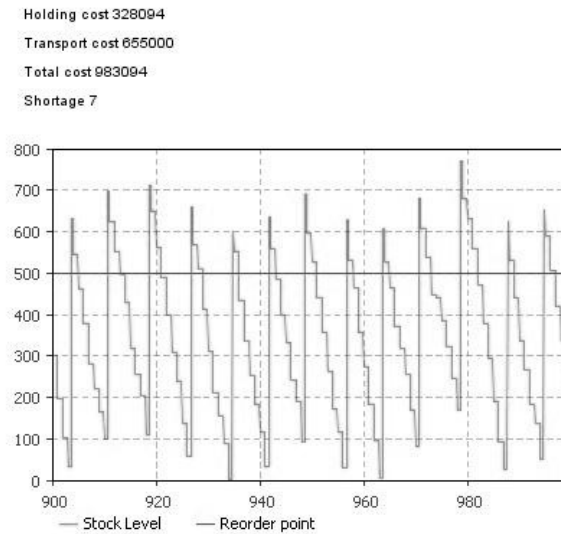

Figure 6. Example of simulation process in AnyLogic

3.4. Example of inventory control system optimisation

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 the range for $400 \le Q \le 1200$ and $200 \le R \le 800$. Both presented simulation packages have integrated optimisation tools which can be used to find the optimal result.

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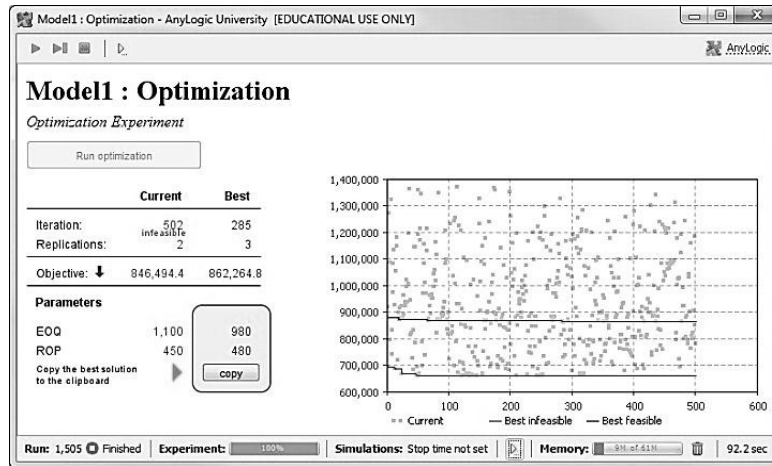
Figure 7. Example of optimisation process in AnyLogic

Next let's look at the same procedure in ExtendSim tool. We can use the same user interface, just putting optimisation block into the model window; all other steps are similar to AnyLogic except that in ExtendSim we can use optimisation parameters only in constraints. The example of optimisation process in ExtendSim environment is shown on Figure 8. In Table 1 the final results of optimisation for both simulation tools are shown. Apparently the obtained results are very similar to each other.
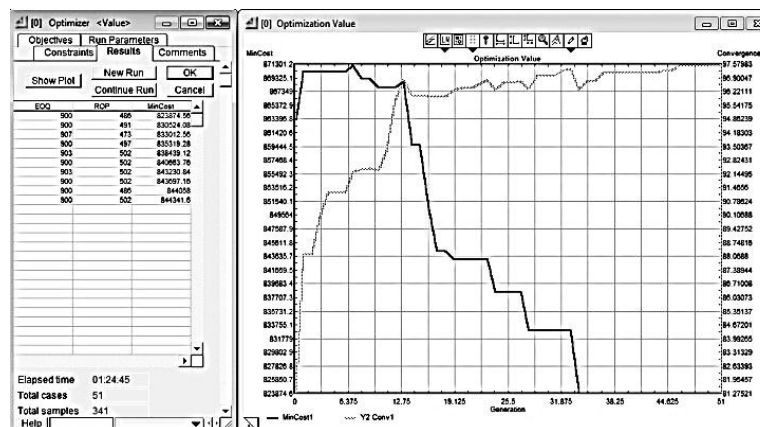

Figure 8. Example of optimisation process in ExtendSim

Table 1. Results of inventory control system optimisation

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 [9]), which due to the article size limitation are not presented in this paper. The simulation processes were analysed by authors in the comparative assessment of simulation tools presented below.

4. Comparative assessment of simulation tools efficiency

4.1. Formation of the system of criteria characterizing the efficiency of the simulation tools

In the process of criteria formation the authors have been focused on the specificity of inventory control models simulation. This research offers a system of criteria which includes twenty eight indicators. The criteria are distributed in five groups shown in the Table 2. Distributing indicators in

the groups allows involving in assessment process various experts: programmers, graphic interface creators, support team, etc. The hierarchical structure of the criteria is shown on Figure 8. This structure has two levels of the hierarchy.

Table 2. Groups of criteria of the effectiveness of inventory control simulation tools

| Group Name	Criteria
General	Programming language, Primary domain, Operating system, Data connectivity with other applications, Model packaging, Price for universities, Optimisation
Programming aspects	Programming flexibility, Support of programming concepts, Built in functions, Debugging, Code editor, External code connection, Built-in random numbers generators
Visualization	Animation, Logical animation, Payback mode, 3D Animation, Graphic library
Simulation	Model execution speed, Simplification of simulation process, Variety of simulation approaches, Hardware requirements
User support	Documentation, Training courses, Users forum, Knowledge base, Demo models and libraries
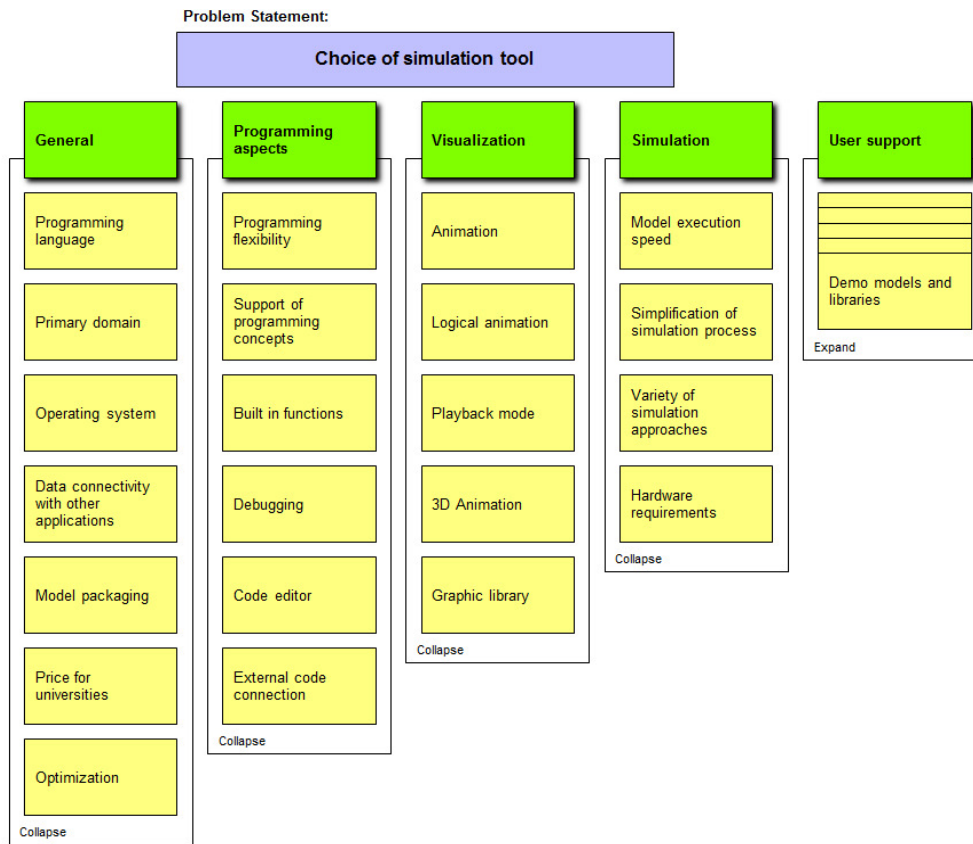
Figure 8. Hierarchy of the criteria for evaluating simulation packages

4.2. Choice of the method for simulation tools assessment

There are currently various methods that have been developed and implemented to analyse and choose from a range of alternatives using multiple-criteria. These methods include multiple criteria decision making (MCDM), multiple criteria decision analysis (MCDA), and multiple attribute decision making (MADM) [12]. The existence of this variety of methods makes the issue of choosing the most suitable one rather difficult [13]. The authors have analysed the possibility of employing various popular MCDM methods (the simple additive weighting (SAW) method [14], the AHP method [4] and collections of ELECTRE methods [15]) to solve the problem of choosing the best simulation tools for inventory control modelling. In our opinion, the AHP method seems to be a more attractive choice since it allows structuring the choice procedure as a hierarchy of several levels. It allows the distribution of the criteria by several groups, and evaluates the significance of each group's components. Consequently, the different groups of criteria can be evaluated by different experts. The opportunity of the pairwise comparison of

a smaller number of criteria in every group allows the experts to determine better weighted values according to these criteria. The estimation of the significance of the criteria groups can be determined by the experts with greater qualification. The AHP method also allows controlling the consistency of the experts' judgments, making it possible to increase the reliability of estimation.

Summary, in the judgment of the authors, AHP method is the most efficient for choice of optimal simulation tool. The method allows arranging the alternatives of simulation tools in the order of their efficiency and showing their difference in the given set of criteria.

4.3. Assessment of ExtendSim and AnyLogic efficiency using the AHP method

The system of criteria shown on Fig.8 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: 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.

To perform the calculations of criteria, the authors have used standard algorithms of the AHP method with the commonly used pairwise comparison scale 1–9, proposed by Saaty [4]. In the case when alternative A1 is compared with alternative A2, this scale has the following values: 1 – if A1 and A2 are equal in importance; 3 – if A1 is weakly more important than A2; 5 – if A1 is strongly more important than A2; 7 – if A1 is very strongly more important than A2; 9 – if A1 is absolutely more important than A2; and 2, 4, 6, and 8 are intermediate values between the two adjacent judgments.

The summary data of the pairwise comparisons for the criteria of the first hierarchy level are presented in Table 3. The importance of the criteria is evident from the evaluation of the criteria priority vector. It is easy to notice, that "Programming aspects" criteria with value 0.434783 (or 43.48%) have the highest importance.

Table 3. Paired comparisons matrix for criteria (first hierarchy level)

Criteria	General	Programming aspects	Visualization	Simulation	User support	Priority vector
General	1	1/10	1	1/5	1	0.053140
Programming aspects	10	1	5	1	10	0.434783
Visualization	1	1/5	1	1/5	5	0.119163
Simulation	5	1	5	1	10	0.354267
User support	1	1/10	1/5	1/10	1	0.038647

We have calculated the matrices of the evaluations of the priority vector for the suggested simulation tools based on the evaluation of the criteria priority vector of two levels of the hierarchy. Table 4 presents an example of calculating the priorities of the second level criteria "Programming aspects". Similar calculations were made for all other the second level criteria – "General", "Visualization", "Simulation" and "User support". To perform the verifying the correctness of judgments in the criteria evaluation, the consistency ratio [4] has been calculated, and for different groups of criteria it is from 3.7% till 9.22%. The values of consistency ratio under 10% indicate that the experts' judgments are sufficiently consistent. The final matrix of the evaluations of the global priority vector for the suggested simulation tools is shown above in Table 5. This can be used for choosing simulation package in a particular inventory problem solving. The value of the global criteria priority for AnyLogic is 0.5966, and it is significantly higher than the final evaluation of ExtendSim, which criteria priority has the value 0.4034. For groups "General", "Programming aspects" and "User support" the criteria values (priorities) of AnyLogic are greater than these criteria values of ExtendSim. The special note for AnyLogic should be given to the criteria "Programming aspects" with value 0.7520; this criterion is three times higher than ExtendSim efficiency, having 0.2480. ExtandSim package evaluation exceeds AnyLogic package

evaluation for group "Visualization" only, where the criterion value of ExtendSim has been estimated at 0.6291, while AnyLogic has been estimated at 0.3709. In the group "Simulation" both packages have practically the same values (0.491 and 0.5086). Consequently, the evaluation results show that the package AnyLogic has the higher value of priority and is recommended as a simulation tool for inventory control tasks. Nevertheless, the package ExtendSim is recommended for an employment in case, when property of visualization is the most important.

Table 4. Matrix of evaluations of the vector of the criteria priorities of the "Programming aspects" group

Alternatives	Criteria						Priorities in group 'Programming aspects'
	Programming flexibility	Support of programming concepts	Built in functions	Debugging	Code editor	External code connection	
	Numerical value of priority vector						
	0.20134	0.26174	0.22148	0.13758	0.05034	0.12752	
AnyLogic	0.80000	0.88889	0.66667	0.66667	0.25000	0.83333	0.75196
ExtendSim	0.20000	0.11111	0.33333	0.33333	0.75000	0.16667	0.24804

Table 5. Final evaluating result for simulation tools

Alternatives	Criteria					Global criteria priorities
	General	Programming aspects	Visualization	Simulation	User support	
	Numerical value of priority vector					
	0.0531	0.4348	0.1192	0.3543	0.0386	
AnyLogic	0.5726	0.7520	0.3709	0.4914	0.5406	0.5966
ExtendSim	0.4274	0.2480	0.6291	0.5086	0.4594	0.4034

Comparison of the results of estimating the packages AnyLogic and ExtendSim presented in the authors' previous paper [3] and in the research under consideration, demonstrates the coordination of the assessment results for the criteria of the first and of the second hierarchy levels. However, the estimations obtained with employment of simplified expert evaluation method are insignificantly different for AnyLogic and ExtendSim packages, while AHP method shows substantial differences in the packages efficiencies for the criteria of the first and of the second hierarchy levels. In the authors' opinion, employment of AHP method allows more objective estimation of the efficiency of implementing the simulation tools in various inventory control tasks. AHP method important merit is also the possibility of controlling the consistency of the experts' evaluations, which facilitates the reliability of estimation.

Conclusions

This article solves the issue of estimation and choosing the simulating tools for inventory control system modelling. To fulfil 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 ExtendSim 8 and AnyLogic 6.7 application in

inventory control tasks and allow choosing the most favourable simulation tools (in considered example it is AnyLogic 6.7) for which the global priority has the maximal value.

The AHP seems to be the most attractive multiple criteria method in this context since it allows structuring the choice procedure as a hierarchy of several levels. It allows for the distribution of criteria into several groups and the evaluation of the significance of every group's component. Consequently, the different group's criteria have been evaluated by different experts with proper qualification. A consistency ratio has been used to verify the judgments in the criteria evaluation, which for different criteria groups have not exceeded 9,22%.

Further guidelines of the current research are the following: to apply multiple criteria decision analysis methods for various simulation systems efficiency evaluation.

Acknowledgements

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