ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 7 Number 1 (September)
http://doi.org/10.9770/jesi.2019.7.1(21)

Publisher
http://jssidoi.org/esc/home

SUSTAINABLE PROJECT MANAGEMENT FOR MULTI-AGENT DEVELOPMENT OF ENTERPRISE INFORMATION SYSTEMS*

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Received 22 March 2019; accepted 2 July 2019; published 30 September 2019

Abstract. The paper includes a review of processes in managerial decision-making based on results of multi-agent simulation in development of enterprise information systems. Authors have proposed the multi-agent model, within which agents' actions depend on a hybrid function of preferences. On this basis, authors have formalized the method, with which it is possible to evaluate agents' judgments. The method combines qualitative, quantitative and fuzzy approaches provide by the decision-making theory and the idea of the criteria space divided into sectors. The synthesis of these approaches has made it possible to lower subjective uncertainty inherent in shared managerial decision making. For the multi-agent model, they have drafted event processing algorithms and identified criteria to evaluate simulation results necessary to support decision making in order to identify the most effective option in development of enterprise information system. Authors have also introduced a methodology-related toolkit in the form of software, including the multi-agent model, decision system and optimization module.

Keywords: multi-agent simulation; enterprise information systems; hybrid function of preferences; web-based decision support services

* *The Russian Foundation for Basic Research supported the research under research project No. 18-00-00012 (18-00-00011) COMFI.*

Reference to this paper should be made as follows: Batkovskiy, A.M.; Kurennykh, A.E.; Semenova, E.G.; Sudakov, V.A.; Fomina, A.V.; Balashov, V.M. 2019. Sustainable project management for multi-agent development of enterprise information systems, *Entrepreneurship and Sustainability Issues* 7(1): 278-290. http://doi.org/10.9770/jesi.2019.7.1(21)

JEL Classifications: C10, C44, C52

1. Introduction

Information and telecommunication technologies have recently become one of the most crucial factors in enterprise development. Information systems for enterprise resource and product life cycle management are facing their active transformation into a global strategy (Hess, Matt, Benlian, & Wiesböck, 2016; Kuzmin, 2017), where integrated automation of all the business processes (Shi & Wang, 2018) is getting more and more in demand.

Application of the potential of information technology in enterprise modernization goes hand in hand with a number of the contradictions that we need to overcome. The main contradiction is that existing function-aimed organizational structures of enterprises do not always suite efficient decision making on introduction of new information technology in the field of design. This is due to a number of closely interrelated factors. This is also an important research objective, solvable, from our point of view, with the shared methodological framework in place that includes decision-making systems based on multi-agent and simulation modelling (Batkovskiy, Konovalova, Semenova, Trofimets, & Fomina, 2015). For this reason, it is of immediate interest to establish management of designing, development and introduction of the systems that use integration mechanisms. Such management has to ensure building of a shared information space.

Therefore, a research purpose is development of methods that support decision-making, as well as development of the multi-agent model and a number of the statistical criteria for simulation, which contribute into such the distribution of tasks between performers that ensures the highest economic efficiency in building of enterprise information systems.

2. Literature Review

Introduction of an information system aims at higher performance of production facilities (Belás, Bartoš, Ključnikov, and Doležal, 2015), as well as supporting of managerial decision-making under conditions of uncertainty and risk (Mohammad, 2015). There are several reasons for this. Note that well-time, accurate and complete managerial data are factors that provide for production efficiency (Batkovskiy, Kalachikhin, Semenova, Telnov, and Fomina, 2016b), while sustainable production scheduling and its monitoring might be achieved with an efficient enterprise information system (Gontarz, Hampl, Weiss, and Wegener, 2015). A current situation brings up to date development of the all-inclusive integrated information systems that provide for necessary managerial functions (Mamary, Shamsuddin, and Aziati, 2014).

For the abovementioned reasons, some methodological aspects in development of information systems and issues of ensured efficient project management in IT system development have not yet been elaborated to a required level and have been intensively discussed (Batkovskiy, Kalachikhin, Semenova, Telnov, and Fomina, 2016a).

Main strategies and approaches to building of large-scale information systems have been developed for a long time (Marcinkowski & Gawin, 2016) to meet ever-changing market needs. For instance, cloud technologies (Nguyen & Luc, 2018), sensors and intelligent control systems (Vlasov, Grigoriev, Krivoshein, Shakhnov, Filin, & Migalin, 2018; Vlasov, Echeistov, Krivoshein, Shakhnov, Filin, & Migalin, 2018) are of particular importance now. Over the past few decades, many product lifecycle models and group development methodologies have been developed to improve a quality of the software being developed (Mihaela Dima & Maassen, 2018; Tavares, 2016). To assess success and quality aspects of the information systems being developed, there are sets of metrics and indicators (Delone & McLean, 2016).

Many researchers pay attention to development management in case of changed functional requirements to a software product. See the model for evaluation of such cases in Shah, Kama, and Bakar, 2018. See a detailed analysis of problems (incorrect prioritization of tasks, errors in a source code, and incompliance with functional requirements) in Sun, Ni, Lam and Ng (2016), as well as in Lehtinen, Mäntylä, Vanhanen, Itkonen, and Lassenius, 2014.

Simulation of decision support and analysis of processes has found its applications in many areas of research and in practiced-based solutions (Zulkosky, White, Price, and Pretz, 2016; Marzouk & Mohamed, 2019; Schubert, Moradi, Asadi, Luotsinen, Sjöberg, Hörling, Linderhed, and Oskarsson, 2015; Güçdemir & Selim, 2018).

Multi-agent simulation, chosen as one of the main tools in this research, has found its applications in various domains. For instance, for development of network topologies (Kamiyama, 2016), consciousness (Arsene & Dumitrache, 2017) and transportation-related tasks (Mastio, Zargayouna, Scemama, and Rana, 2018). The second most important tool applied in this research is the decision support system. For instance, in management of corporations (Chen, Yen, Lin, and Chou, 2018), when people decide on location of production facilities (Kuzmin, 2018) or a reasonable configuration of the product being designed (Buchert, Ko, Graf, Vollmer, Alkhayat, Brandenburg, Stark, Klocke, Leistner, and Schleifenbaum, 2019). Object ranking methods have been also in wide use and have faced their development (Asadabadi, 2018; Safarzadeh, Khansefid, and Rasti-Barzoki, 2018). We are aware of the attempts to describe a development process of enterprise information systems with the help of the multi-agent model. However, specifics of its application does not make it possible to have full and comprehensive review of the problem of large-scale project management, where projects assume development of information systems.

3. Materials and methods

3.1 Simulation formalization of EIS development

In this research, the methodological framework for applications of decision-making support models have found their further development with regard to tasks of planning and management in the development and introduction of enterprise information systems.

There are the following components in the development process model (DM):

a) Tasks for development of the modules that an enterprise information system includes, for which there is a need in a research at a pre-design stage.
b) Alternatives are options of EIS development. They all find their representation in the form of a relevant model with a specific set of parameters (for instance, distribution of powers at stages of design and development) and, possibly, unique structure. The models are ranked to help decision makers to choose a rational scenario for EIS development.
c) Parameters of the simulation model and criteria for evaluation of simulation results are main criteria for ranking of alternatives.

To state the problem in a formal way, let us introduce the following denotations.

$$T = \{T_1, T_2, \ldots, T_i, \ldots, T_n\}, i = \overline{1, n}, \quad (1)$$

where T is an array of assignments (orders for EIS development).

For each assignment, there is a finite sub-array of alternatives shown with models A_i :

$$A_i = \{\alpha_{i1}, \alpha_{i2}, \dots, \alpha_{ij}, \dots, \alpha_{im}\}, i = \overline{1,n}; \; j = \overline{1,m}, \tag{2}$$

where $\alpha_{i,j}$ is the j -th alternative for the i -the assignment;

$$M = \{M_1, M_2, \dots, M_i, \dots, M_n\}, i = \overline{1,n} \tag{3}$$

M is an array of options of the models compared with each sub-array of alternatives in such a way as each set of alternatives A_i has array of models M_i, where:

$$M_i = \{\mu_1(\Lambda_1, \Xi_1), \mu_2(\Lambda_2, \Xi_2), \dots, \mu_j(\Lambda_j, \Xi_j), \dots, \mu_m(\Lambda_m, \Xi_m)\}, i = \overline{1,n}; \; j = \overline{1,m} \; , \tag{4}$$

where μ_j is a specific implementation of a model, while

$$\begin{gathered} \Lambda_j = \{\lambda_1, \lambda_2, \dots, \lambda_l, \dots, \lambda_{k_j}\}, l = \overline{1,k_j}; j = \overline{1,m} \\ \Xi_j = \{\xi_1, \xi_2, \dots, \xi_s, \dots, \xi_{v_j}\}, l = \overline{1,v_j}; j = \overline{1,m} \end{gathered} , \tag{5}$$

where Λ_j is an array of input data – model parameters, while Ξ_j is a vector of criteria for the evaluation of simulation results.

The above-mentioned assumes that there is a need in introduction of the algorithm that establishes correlation between objects T, A, M, L, Ξ:

$$\forall T_i \exists A_i : \forall \alpha_{i,j} (\alpha_{i,j} \in A_i) \exists \mu_j (\Lambda_j, \Xi_j) [\mu_j \in M_i], i = \overline{1,n}; j = \overline{1,m} \tag{6}$$

There is a separated review of model optimization (rationalization). This process refers to a selection of the most favourable vector for model parameters. In this case, there is an aim to achieve the indicators that a user wants for EIS development process. Let us introduce the following denotations:
n is dimensionality of the model parameters' vector;
m is dimensionality of the vector of evaluation criteria for simulation results;
$X = \{x_1, x_2, \dots x_i, \dots x_n\}, i = \overline{1,n}$ is a set of parameters for a model;
$Y = \{y_1, y_2, \dots y_j, \dots y_m\}, j = \overline{1,m}$ is a vector of evaluation criteria for simulation results;
$A = \{a_1, a_2, \dots a_i, \dots a_n\}, i = \overline{1,n}$, where a_i is a down-top constraint by amount of available resources in EIS development;
$B = \{b_1, b_2, \dots b_i, \dots b_n\}, i = \overline{1,n}$, where b_i is a top-down constraint by amount of available resources in EIS development.

With the denotations introduced, the formal record of the task has one of the following forms depending on user's preferences:

$$\begin{gathered} \max_X \{y_j = f(X)\} \\ \min_X \{y_j = f(X)\} \end{gathered} \tag{7}$$

In Equation (7), $f(X)$ refers to a transformation of the vector of parameters into one of criteria y_j to evaluate simulation results and chosen by a user as a target function. Given the resource constraints:

$$\begin{gathered} x_i \le b_i, (i = \overline{1,n}) \\ x_i \ge a_i, (i = \overline{1,n}) \end{gathered} \tag{8}$$

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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Note that almost in each tasks related to CIS development, $m > 1$. That is, the optimization problem belongs to the class of multi-criteria problems. To work with this class of engineering challenges, we applied the hybrid method for preference identification. With this scenario, it is possible to use quantitative ranking methods for the alternatives that fall in the same area (Spina, 2016).

When people build, upgrade and introduce IESs, it is necessary to provide a project manager with probabilistic and temporal performance metrics for the personnel involved in parametric and structural changes in software development. This is necessary for taking necessary measures and making influence performers (Sudhaman & Thangavel, 2015).

To debug and explore a chance of an application of the considered approach, authors built the development model (DM) for an enterprise information system. Taking into account the accepted assumptions, there are the following stages in a flow of applications in development of the enterprise information system (Fig. 1).

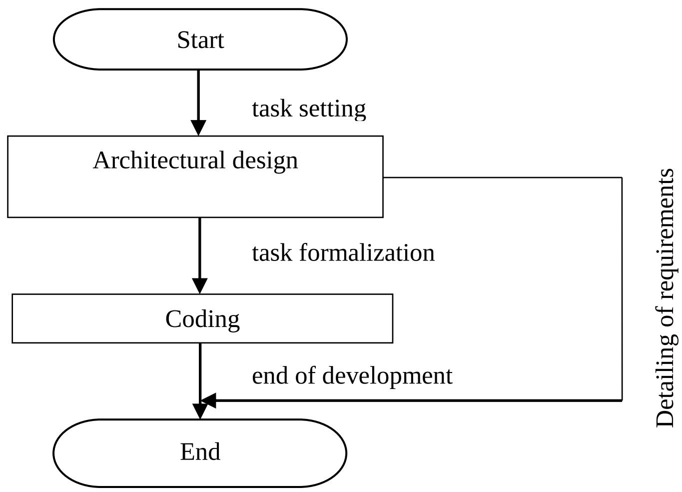

Fig. 1. Diagram of interconnected stages in the software development simplified cycle

DM is based on simplified development of software. There are the following events in the model considered in enterprise information system development: (1) application enters the system, (2) application processing at the *Architecture* stage, (3) application processing at the *Development* stage. See the relationship of the abovementioned model events in Fig. 2.

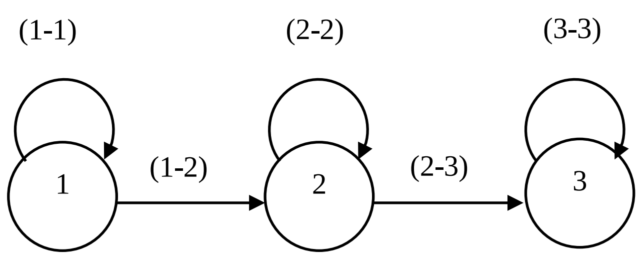

Fig. 2. Model event graph

Each transition on the model event graph triggers scheduling of a model event. It is enough to have such a relatively simple model for development for a further test and debugging of an approach, as well as substantiating of its possible use in more complex tasks of IES development with the multi-agent models applied.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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3.2. Multi-agent model for development of enterprise information system

To achieve high performance of employees when they build, update, apply and maintain the information system (Wanderley, Menezes, Gusmão, & Lima, 2015), (Choudhary, Kumar, Kumar, Mishra, & Catal, 2018), based on the abovementioned approach, the authors developed the multi-agent model of the development process (DM).

It is assumed that in the model under consideration, agents have preference functions and they are guided by such functions. It is assumed that the agent's preference function (that belongs to class *Problem Owner [PO]*) is without changes. For the tasks that allow the optimization of a structure, it is possible to set functions of the agents that belong to class *Object* (O), for the other tasks, *O* function stays unchanged. The preference function for an agent that belongs to class *Subject (C)* has two parts: it includes one's own interests that are assumed unchanged, and the interests affected by *PO*. In its last part, the preference function is adjustable. Virtual agents (*VAs*) are, as a rule, made with such the system of preferences as to provide a search for a global optimum. Agent's preferences are often imprecise and unclear. Besides, estimated judgments of agents by criteria can often be obtained with a certain error, which is reasonable to be taken into account. To use fuzzy judgments in the model, it is necessary to apply the apparatus from the theory of fuzzy sets. See the diagram that describes a subject area and task transitions between agents in Fig. 3

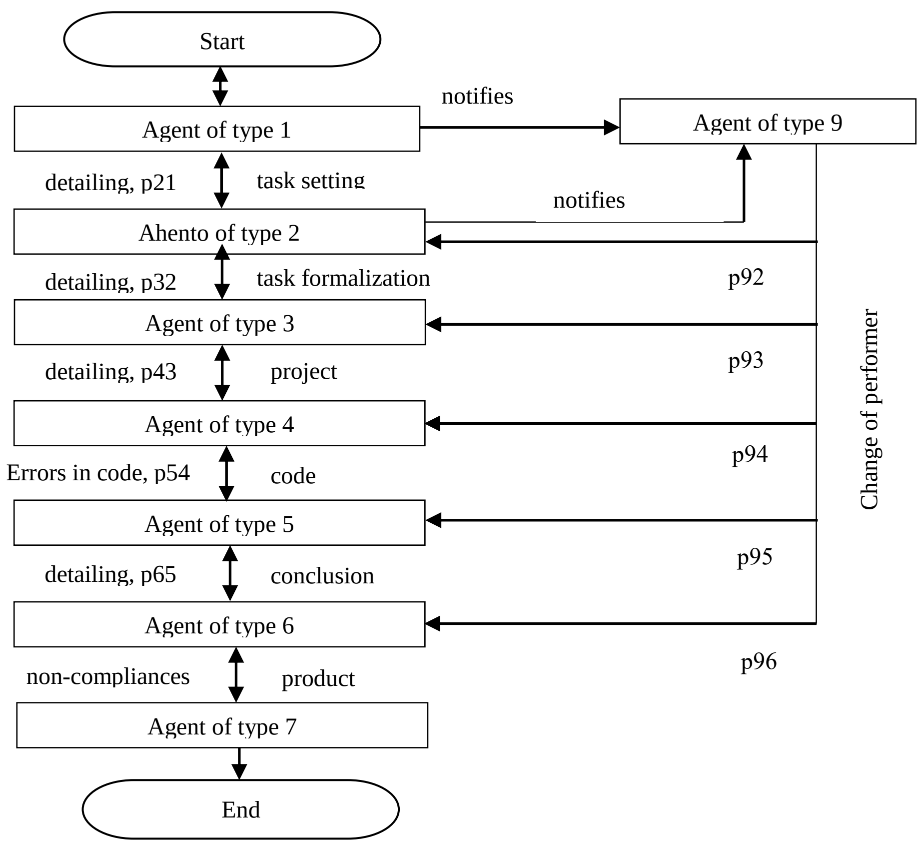

Fig. 3. Application flow chart in the multi-agent model for development of enterprise information system

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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Tasks to change the EIS arise in communication between agents of type 1 and type 2. After this, a task is successively transferred by agents of type 2 to agents of type 3 and so forth. With certain non-zero probability (p21, p32, p43, p54, p65, p76), it can return to agents at any of the previous stages. The information model of inter-agent interaction looks like a backboard.

Agents independently choose tasks, based on their own preference function, while others are forcedly assigned to performers by the agent of type 9 based on his/her preference function. Furthermore, the agent of type 9 may block a possibility of independent allocation of tasks between some other agents of types 2-6. Any of the abovementioned operations might happen with certain probabilities (p92, p93, p94, p95, p96).

It is possible to present a choice of the most suitable ('profit-bearing') employee as a process (to solve a task) in the following formal way:

$$I = \min_i arg\left\{\max_i\left(S_{ijn}KS_{kn} + \left(1 - L_{in}\left(t\right)\right)KL_{kn}\right)\right\}, \tag{9}$$

where i is a unique identifier of a software developer; j is a unique identifier of a type of an application; k is a unique priority identifier; n is a number of a service stage; $S_{i,j,n}$ is experience of a developer with identifier i to perform tasks with identifier j at stage number n; $L_{i,n}(t)$ is a load of a developer with identifier i at moment of time t at stage number n; $KS_{k,n}$ is a weight contributed by experience of an employee for a case of an application with k priority at stage number n; $KL_{k,n}$ is a weight contributed be the load of the employee for the case of an application with k priority at stage number n.

4. Results

4.1. Software for application of the multi-agent model

The most important result from the research is the developed multi-agent model, in which people apply the considered simulation algorithms. See the diagram of classes within the developed model in Fig. 4.

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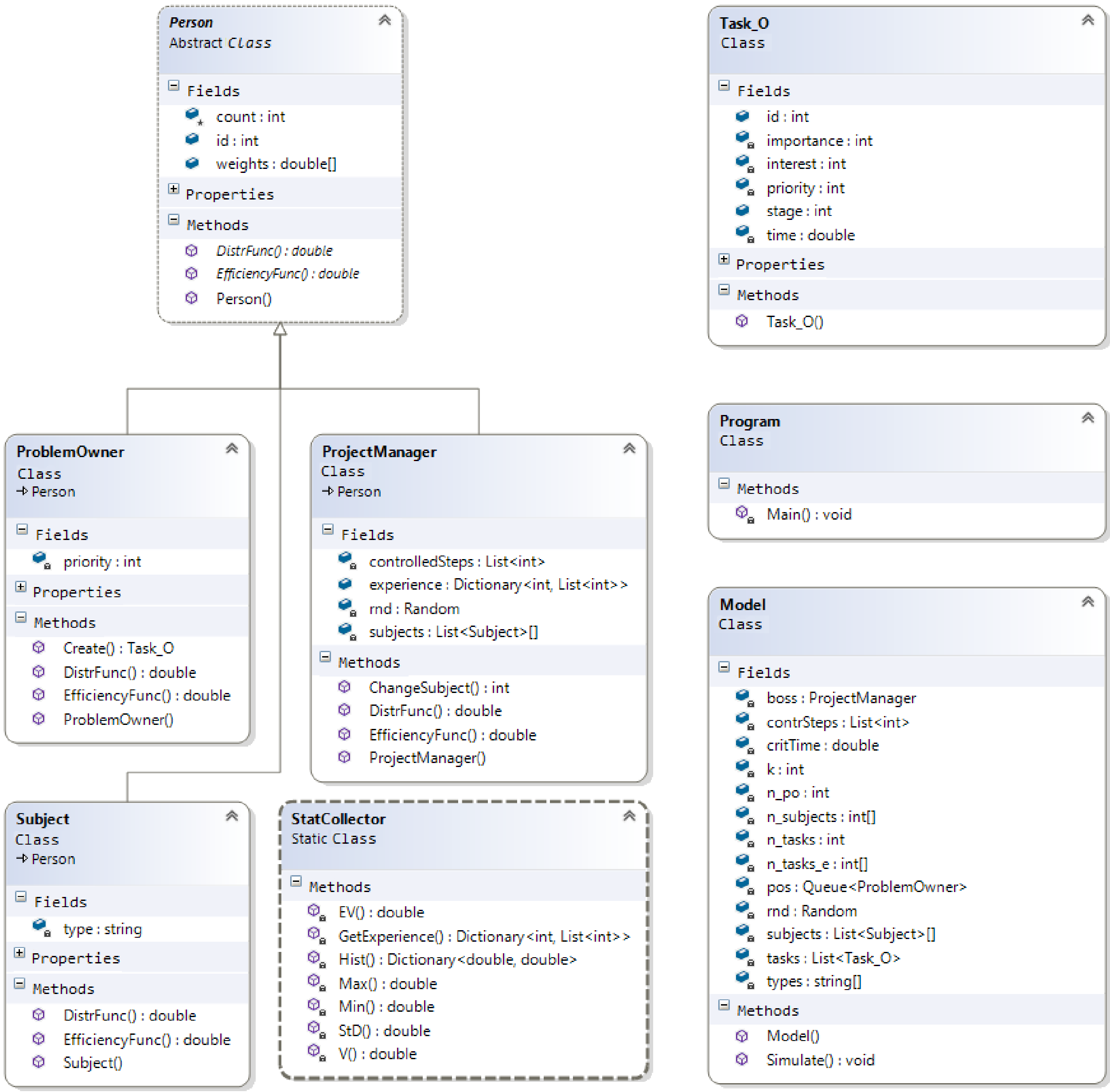

Fig. 4. Diagram of classes in the multi-agent model for enterprise information system development

The *ProblemOwner* class performs functions of the *VP*-type agent. It is possible here to set tasks using the Create method, perform the distribution function with regard to a number of tasks and preference function, *DistrFunc* and *EfficiencyFunc*, respectively. The *ProjectManager* class makes it possible to implement functions of the 9-type agent. It has its own preference function regarding a choice of a performer for a task (Equation 9) - *EfficiencyFunc*, and the method that makes it possible to change performers of tasks - *ChangeSubject*. The *Subject* class describes all the other *C*-type agents considered within the model. The *Task_O* class describes the O object, i.e. the task that is to be solved. The *StatCollector* class is auxiliary used to gather statistics when the model is in operation. The *Model* class provides a description of model parameters, as well as methods, with

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which we apply the simulation algorithm. The described multi-agent model was made using *C#* in *MS Visual Studio*.

4.2. Software to apply the hybrid method of preference identification

There is the open access module at ws-dss.com for cloud computing. It contains the developed function that makes it possible to apply the hybrid method of preference identification (Fig. 5).

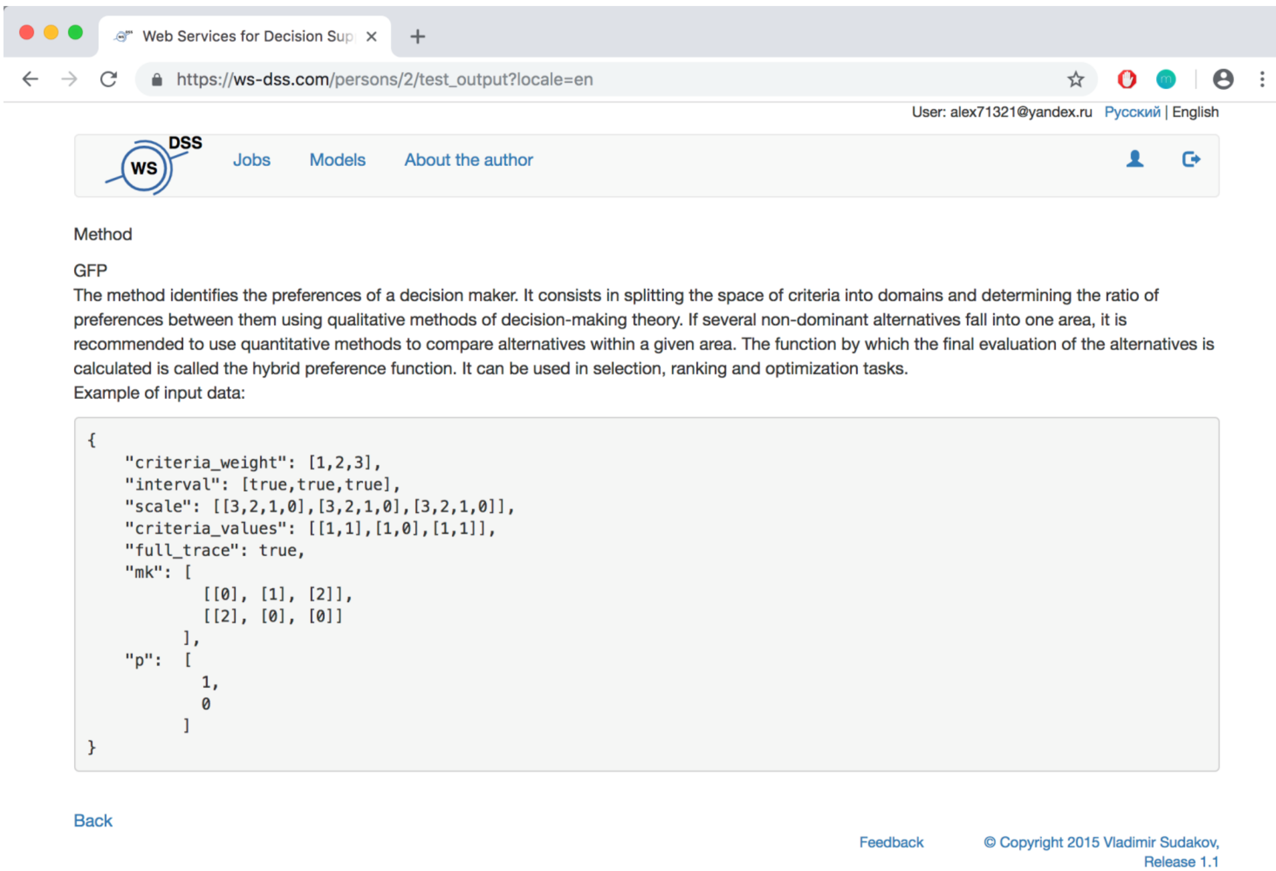

Fig. 5. Hybrid preference function call interface

The authors has developed the system using open source software, which is a positive aspect (Paschali, Ampatzoglou, Bibi, Chatzigeorgiou, & Stamelos, 2017; Olson, Johansson, & De Carvalho, 2018). Modules of WS-DSS decision support system, as well as in the domain model, are independent agents. Thus, there is no single framework in the system. Agents interact using an exchange of messages. The described and introduced approach using agents independent of each other results in almost no communication between modules. This significantly reduces labour costs for changes in the system and significantly improves its performance (Yatsalo, Didenko, Gritsyuk, & Sullivan, 2015; Rodríguez-Padial, Marín, & Domingo, 2015).

In its development, authors considered that the enterprise information system is to cover all the aspects in the enterprise's life (procurement, production, sales, personnel management, etc.). In the overwhelming majority of cases, each relevant aspect has an assigned employee in charge, who assigns tasks based on his/her distribution function and preference. Besides, the model takes into account the factor of interaction in a team shown by chains of transfers and returns of tasks between performers, as well as the ability of agents to choose tasks by their own preference functions. All the above mentioned suggest that the proposed multi-agent model adequately and fully describes actual development and introduction of enterprise information systems.

Conclusion

In the research, authors developed the algorithmic decision-making support based on multi-agent simulation. They also piloted the heuristic method intended for rationalization of the parameters that the model has. An advantage of the developed multi-agent model compared to the models referred to by similar research, lies in high level of details in the process of information system building (task setting, requirement review, development, introduction, etc.) with due regard to personal preferences. Authors offered the hybrid method, with which it is possible to identify preferences for a multi-criteria analysis of options for the multi-agent model of the development process. It covers the expert's overall system of values in terms of high-dimensional criteria, including both qualitative, and quantitative components. Developed software includes independent services that interact with each other using network data transfer protocols, which makes it easy to adjust and enhance the model to meet changing needs. Integration of methods for decision support and multi-agent simulation within a shared system framework provides the synergistic effect in management of building and introduction of enterprise information systems.

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Aknowledgements

The Russian Foundation for Basic Research supported the research under research project No. 18-00-00012 (18-00-00011) COMFI.

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