Roman N. KVYETNYY[1], Natalia F. KUZMINA[1], Olexander A. POPLAVSKYY[2], Vira A. DRABOVSKA[3], Valentyna B. KUZMIK[4], Konrad GROMASZEK[5], Aliya KALIZHANOVA[6], Saule SMAILOVA[7]

Vinnitsa National Technical University, Vinnitsa, Ukraine (1), State University for Transport Economy and Technologies (2), Vinnitsa Cooperation Institute (3), Vinnitsa State Pedagogical University named after M. Kotsyubynsky (4), Lublin University of Technology (5), Kazakhstan Engineering Technological University (6), East Kazakhstan State Technical University named after D. Serikbayev, Ust-Kamenogorsk, Kazakhstan (7)

doi:10.15199/48.2020.09.26

Group decision support system based on Bayesian network

***Abstract**. The article examines the process of building a developed group decision support system, its analytical and informational support. Different modes of the operation of the system are described. Software implementation and practical aspects of using such a system to resolve conflicts in supporting group decision making process are proposed. The experimental results, which allowed to confirm the effectiveness of the developed system and its application for evaluation and teaching of users are presented.*

***Streszczenie.** Artykuł analizuje proces budowy rozwiniętego systemu wspomagania decyzji grupowych, jego wsparcie analityczne i informacyjne. Opisano różne tryby działania systemu. Proponowane jest wdrożenie oprogramowania i praktyczne aspekty korzystania z takiego systemu do rozwiązywania konfliktów we wspieraniu grupowego procesu decyzyjnego. Przedstawiono wyniki eksperymentów, które pozwoliły potwierdzić skuteczność opracowanego systemu i jego zastosowania do oceny i nauczania użytkowników. (**System wspomagania decyzji grupowych oparty na sieci bayesowskiej**).*

Keywords: group decision support system, evaluation, Bayesian network.
Słowa kluczowe: system wspomagania decyzji grupowych, ewaluacja, sieci bayesowskie.

Introduction

The development of modern science and technology is characterized by human activity, which is closely linked to decision making process and consists of determining the most effective action from the set of all possible actions to achieve a specific goal [1, 2]. The outcome depends on the true state of the world, which in many cases is only partially known to the decision maker [3]. Some of the decisions made are aimed to solve the important problems of managing objects and actions and are characterized by a significant impact on course of events [4]. In this case, it is advisable to make decisions by a group of individuals to ensure greater efficiency [5]. Social choice theory still seeks to establish principles for how decisions involving more than one decision maker should be made [3].

It should be noted, that group decisions are usually made under uncertainty [6]. Voting methods, ranking, fuzzy rules algorithms are different approaches to solving this problem, however, they are only effective under the condition of known algorithms for making individual decisions for a group of users [7].In a real-world context, users can make decisions based on their experience and knowledge in the field, so group decision-making methods should allow for all the factors influencing the individual choice of each decision-maker, and therefore the complex group decision in general [8]. Existing methods that take into consideration the experience of decision makers have great computational complexity especially if the users are geographically distributed [9]. Distributed group decision support systems are easily connecting users to computing resources and successfully hiding the fact that resources are deployed in different locations across the network [10]. The process of forming a complex solution by a group of individuals is a hard task that does not yet have an optimal solution, although it is based on the principles of individual decision-making process [11, 12, 13]. Group decision support systems are interactive automated systems that help a group of decision-makers use data and models to identify and solve poorly structured tasks [14, 15].As of now, there is no generally accepted classification of decision support systems for group decision making, but one of the main parameters by which such systems are classified is the degree of certainty of the conditions under which decision making is taking place.

The degree of certainty of group decision making plays a very important role in the decision-making process. Uncertainty in such systems is driven by one or more parameters: participation in the decision-making process of several participants, each with its own psychological characteristics, uncertain or not fully defined goals and knowledge about the decision-making industry, since any decision made can lead to one of many possible outcomes which probabilities are unknown. In general, the decision-making process under uncertainty is reduced to finding the optimal alternative on each stage of decision selection to form a comprehensive solution.

There are three main types of group decision support systems that are used uncertainty: rule-based systems, neural network systems, and Bayesian network systems [16]. Let's review the main types of systems in more detail.

Rules-based systems. Rules-based systems are based on a library of rules and allow to draw logical conclusions about the investigated area and to take action based on the information received. The rules reflect the relationships in the data. The following are the most popular techniques that allow for uncertainty in rules-based systems: fuzzy logic, certainty factors, and Dempster-Shafer expectation functions. The disadvantage of these techniques is that they account for uncertainty locally, which can lead to serious errors.

Systems based on neural network. Neural networks consist of several levels of interconnected vertices. The neural network is capable of operating in two modes: the learning mode, when logic circuits are formed, and the recognition mode when the neural network with high accuracy determines where the object belongs to and what actions should be taken [17].

If the relationship between the vertices is uncertain, the neural network, after appropriate training, will be able to find the most probable solution for a given set of input variables. The disadvantage of using the neural network method is that it does not allow to obtain the next most probable solution and to determine under which assumptions about the data area the proposed solution will be most probable [16].

Bayesian-based systems. Bayesian-based systems use the analytical apparatus of probability theory. The Bayesian network is a probabilistic model that represents variables and their probabilistic dependencies. Formally, the Bayesian network is represented as a directed acyclic graph which vertices symbolize variables of any type (parameters, hypotheses), and edges symbolize conditional dependencies between the variables [18]. Bayes' formula relates the relative probabilities of events [19]:

$$(1) \qquad P(H \mid e) = \frac{P(e \mid H)P(H)}{P(e)}$$

where e is an observation and H is ahypothesis.

Bayesian networks allow for a direct, logical interpretation of the structure of relations between the variables, which greatly simplifies the understanding of the decision-making process [20].

In Bayesian networks, empirical frequencies of occurrence of different values of variables, subjective estimates of expectations, and the theoretical perceptions of the mathematical consequences' probabilities of a priori information can be organically combined [21]. This is an important practical advantage that distinguishes Bayesian networks from other informational modeling techniques [20]. Bayesian networks use probabilistic inference by calculating the posterior distribution of variables through evidence of other variables. This property allows to gain new knowledge about the state of a subset of variables by observing other variables, which in turn is one of the main reasons for the widespread use of Bayesian networks in decision support systems. The disadvantage of using this method is the complexity of its implementation for large and complex cases, although it should be noted that this disadvantage can be solved by using methods for obtaining approximate results. The advantage of the Bayesian network method is the ability to obtain a realistic model of reality and orientation in the most probable course of events. Therefore, considering the above it was decided to use the Bayesian analytical tool for the proposed group decision support system as it will not only help users make effective decisions, but also test and evaluate users' knowledge at the same time [26,27].

The article represents developed distributed group decision support system based on Bayesian network that allows to solve most of the conflict situations that occur during the decision-making process without the need to repeat the consideration of the same alternatives. Developed system simultaneously allows to teach and evaluate users during the decision-making process. The work objective is an experimental research of the developed distributed group decision support system and its implementation details [28].

The analytical and informational base of the proposed distributed group decision support system

Let's focus on the majority principle method and the Bayesian network method's usage in group decision making process. Both of these methods have different features of their application and purpose.

The main purpose of using the majority principle method in group decision support systems is to monitor the behavior of a group of individuals, their ability and desire to interact to achieve a common goal, and to test users' knowledge. The main purpose of using Bayesian network methods in group decision support systems is to avoid the disadvantages of the majority principle method, for example, eliminating conflicts that lead to the same decision being made when the majority was not formed, while simultaneously testing and evaluating users' decisions.

The distributed group decision support systems are designed to provide collaborative user experience and enable users to interact in real-time [23, 24]. For greater mobility and flexibility of the system and the connection of geographically distributed users, it is necessary to use the latest technologies that allow the connection of users into a single network. It is also necessary to take into account possible time delays while using distributed technologies. The process of group decision support in such a system contains a large number of elements that need to be considered while developing a group decision support system, especially if the system allows to connect geographically distributed users. This raises the need to identify and formalize these elements by developing an informational model of the system. Let's determine the input and output parameters of the model and the relationship between them.

The input parameters of the model can be defined as follows:

$C = \{c_1, c_2, ..., c_n\}$ is an array of users' computers;

$Z = \{z_1, z_2, ... z_n\}$ is an array of active connections;

$U = \{u_1, u_2, ... u_n\}$ is an array of users of the system;

$V = \{v_1, v_2\}$ are the options of the group decision-making methods (the majority principle and the Bayesian network modes);

$A = \{a_1, a_2, ... a_n\}$ is an array of available alternatives;

$L = \{l_1, l_2, ..., l_n\}$ is an array of cause and effect relationships between alternatives;

$T_u = \{t_{1u}, t_{2u}, ..., t_{nu}\}$ is the time of decision making by users;

$T_d = \{t_{1d}, t_{2d}, ..., t_{nd}\}$ is the time of delay of the system response to user actions;

$T_s = \{t_{1s}, t_{2s}, ..., t_{ns}\}$ is the implementation time of group selection in users' decision-making process

T_g is the total system operation time for a complex decision.

The output of the model would be the complex decision of all users, which is the set of all the decisions made during the system operational time.

$D_g = \{d_1, d_2, ..., d_n\}$.

Based on the defined input and output parameters of the system, their components, and after providing them with the relevant connections, it is possible to build an informational model of a distributed group decision support system. Let's mark the informational model of the distributed group decision support system as M_s and present it in the following form [22]:

$$(2) \quad M_s = \{A_0, C, Z, U, V, A, L, T_g, M, D_g, H, \Psi\}$$

where A_0 is the main purpose of the distributed group decision support system to make an optimal decision at any specific point in time; $C = \{c_1, c_2, ..., c_n\}$, $n = \overline{1, N_c}$ is an array of users' computers; $Z = \{z_1, z_2, ..., z_n\}$, $n = \overline{1, N_z}$ is an array of active connections; $U = \{u_1, u_2, ..., u_n\}$, $n = \overline{1, N_u}$ is an array of users of the system; $V = \{v_1, v_2\}$ are the options of the group decision-making methods, where v_1 is the majority principle mode, v_2 is the Bayesian network mode respectively; $A = \{a_1, a_2, ..., a_n\}$, $n = \overline{1, N_a}$ is an array of available alternatives; $L = \{l_1, l_2, ..., l_n\}$, $n = \overline{1, N_l}$ is an array of cause and effect relationships between alternatives;

Let's define the interdependencies for decision-making time by users, the system, and the total time of the system work:

$T_g = \sum_{i=1}^{M}\sum_{j=1}^{N_u} t_{uij} + \sum_{k=1}^{M} t_{sk} + \sum_{k=1}^{M} t_{dk}$ is the total time of the system work, where

$T_u = \{t_{1u}, t_{2u}, ..., t_{nu}\}$, $n = \overline{1, N_{tu}}$ is the time of decision making by users;

$T_s = \{t_{1s}, t_{2s}, ..., t_{ns}\}$, $n = \overline{1, M_{ts}}$ is the implementation time of group selection in users' decision-making process

$T_d = \{t_{1d}, t_{2d}, ..., t_{nd}\}$, $n = \overline{1, N_d}$ is the time of the delay of the system response to user actions;

M is a number of decision-making iterations to form the final complex decision;

$D_g = \{d_1, d_2, ..., d_n\}$, $n = \overline{1, N_d}$ is acomplex decision of all users, which is the set of all the decisions made during the system operational time.

$H : U \times A \times L \rightarrow D$ is an operator that defines the ratio of multiple alternatives to multiple links. The efficiency evaluation index operator Ψ correlates the set of initial definitions of the model to the set of values of the accordance coefficient of the chosen alternatives to the system decision.

$$\Psi = \begin{cases} \sigma = \sqrt{\dfrac{1}{N_u}\sum_{i=1}^{N_u}\left(k_i - \bar{k}\right)^2} \rightarrow \max \\ T_g = \sum_{i=1}^{M}\sum_{j=1}^{N_u} t_{uij} + \sum_{k=1}^{M} t_{sk} + \sum_{k=1}^{M} t_{dk} \rightarrow \min \end{cases} \quad (3)$$

Where σ is the coefficient of accordance of the selected alternatives, which is calculated using the intermediate coefficients k_i:

$$k_i = \frac{N_V}{N_A},$$

where: N_V is the number of decisions made, that corresponds to the most likely alternatives. N_A is the total number of alternatives.

$$\bar{k} = \frac{1}{N_u}\sum_{i=1}^{N_u} k_i .$$

The Bayesian network construction and output methods are used to determine the ratio of multiple alternatives to multiple connections, regardless of which group selection method was chosen.

The implementation support of the distributed group decision making system

Twelve major software objects are the basis of the developed group decision support system. A generalized model of the software objects is presented in Fig.1.

The main software objects are: Output object, Input object, Information structure, with the information about each user's USB device, Decision making object, USB device interface object, Device type object, Decision-making results object, System management object, Retrieval of information from USB devices object, Construction and calculation of Bayesian network object, Code parsing object and Output of service information in files object. The procedure of processing the received data from USB-devices of users is carried out to find the resulting complex decision of the system based on the data obtained from the parser and users. Let's review the major software objects that support the group decision support system.

The Output object is used to adjust and modify graphical and textual information and display it to users' monitors. Graphical information contains images of cursors, decision blocks, etc. Textual information contains the content of decision-making blocks. The Input object is designed to receive signals from input devices such as a mouse, keyboard, etc. The object continually processes input from input devices and allows new devices to be connected and serviced in real time. The Decision-making object is designed to manage the decision-making process of the system. The object effectively interacts with the Output object by using the link to display the results of the decisions taken. The Decision-making object receives the information from Bayesian network construction and calculation facility, which in turn calculates the values of the network parameters and passes them back to the Decision-making object. The Decision-making object can operate in one of two modes: majority principle mode and Bayesian network mode. In majority mode, the object does not interact with the Construction and calculation of Bayesian network object and makes its own decisions. The decision-making object is linked to the subsidiary Decision-making results object.

The Input object interacts with the Retrieval of information from USB devices object using the USB interface. The Device types object contains all the device types that the decision support system can interact with: a mouse, a keyboard or both. The value is passed to the corresponding functions of all the objects that work with the input devices. The Decision-making results object allows the system to display the results in a user-friendly way. The main System management object allows the system to start, prepares it for the operation and launches other objects at needed times. The System management object always runs first, creates and initializes the rest of the objects. The Retrieval of information from USB devices object is implemented through a dynamic library and can be used independently in other projects to reuse the function of working with multiple input devices. This receiving object uses a callback function call indicator and a data transfer function from the input device. The Construction and calculation of Bayesian network object allows the system to form a Bayesian network of a particular configuration and calculate its parameters. The Code parsing object is used to highlight the main structural blocks of the program and to form the alternatives for decision-making process. The object also allows the system to determine the likelihood of using certain elements of a code at a particular time to train the Bayesian network. The Output of service information in files object logs all events that occur during the collection of information from all the devices.

All software objects of distributed group decision support system are implemented using C# programming language.

The experimental results of proposed distributed group decision support system

Distributed group decision support system can be represented as a software complex based on developed analytical and informational models.

The system provides technical and informational support for decision making process, while also allowing to teach and evaluate users. Developed system is specifically relevant for students of the Software Engineering and Software quality departments as it allows development and analysis of the quality of software code.

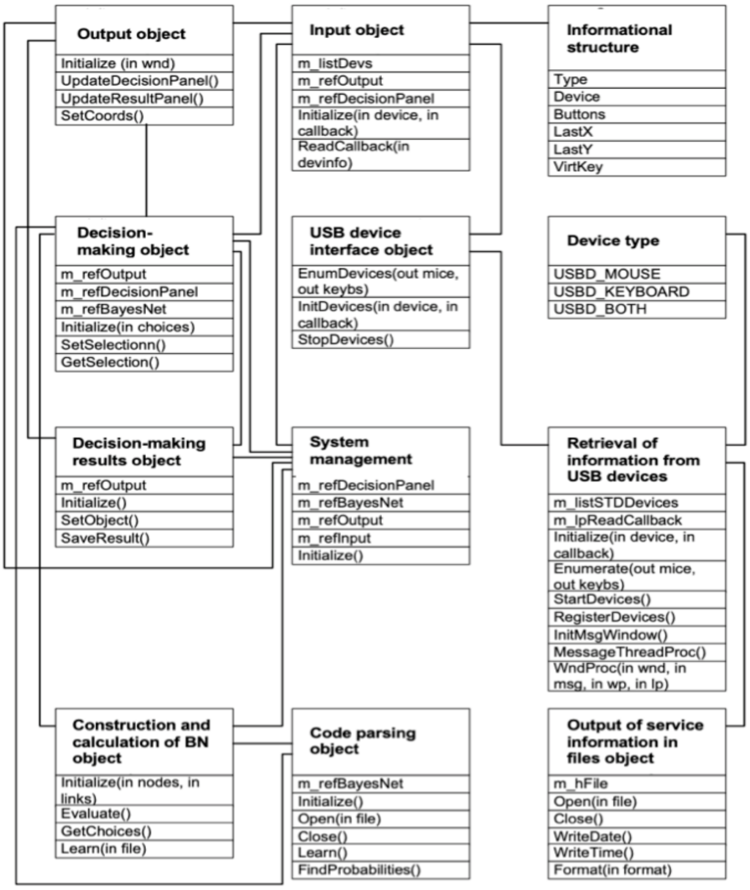

Fig.1. Generalized model of distributed group decision support system's software objects

Among the main features of a distributed group decision support system are the following:

1. The system allows users that are geographically distributed to participate in real-time decision-making process via an internal network or wi-fi connection.

2. The system provides the ability to log the sequence of actions of all users at each decision-making stage in the appropriate log file for further analysis and evaluation of user decisions.

3. The system allows users to make collective decisions via one of the system's modes of decision support: the majority principle mode and the Bayesian network mode. The majority principle mode allows users to work as a single team and test the general knowledge of the group of users. The Bayesian network mode allows users to work separately but using the help of Bayesian network that displays the most probable alternatives on each of the decision-making steps.

4. The system not only allows users to practice their programming skills, but also to test the level of knowledge of each user and a user group as a whole.

The main purpose of the research was to increase the efficiency of distributed group decision support systems and reduce the amount of conflict situations during the decision-making process. The software to implement proposed analytical and informational models was developed. The main interface of the distributed group decision support system is shown in fig.2.

To test the efficiency of the developed distributed group decision support system a series of experiments were conducted [25]. The results of the experiments are presented below.

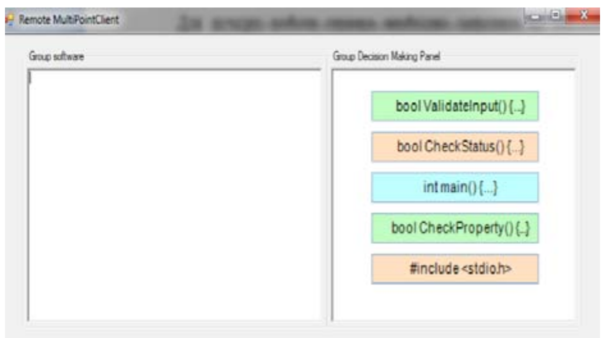

Fig.2. The main interface of the distributed group decision support system

Let's summarize the data of the total decision time of each user during the execution of the test task with the Majority principle mode (Fig.3).

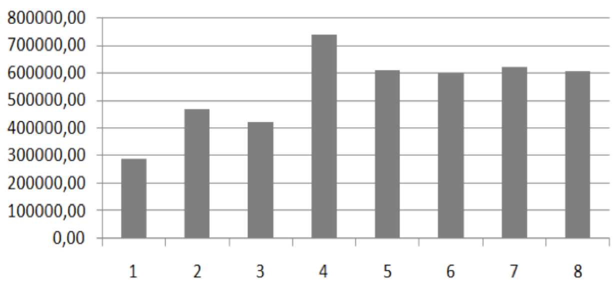

Fig.3. Generalized users' decision-making time with the Majority principle mode (in ms)

Next, let's analyze the quality of the decisions made by each user while completing the test task, to determine the total number of correct users' decisions on each stage of choosing alternatives with the Majority principle mode (Fig.4).

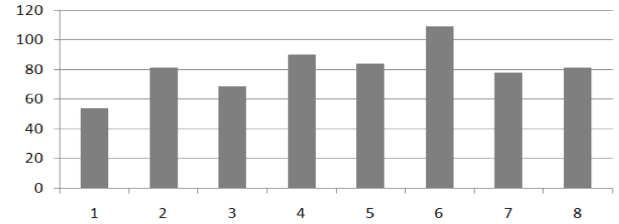

Fig.4. The number of right decisions made by users during the Majority principle mode

Summarized results of a system time for decision making of each user's data while using the majority mode is shown in Fig.5.

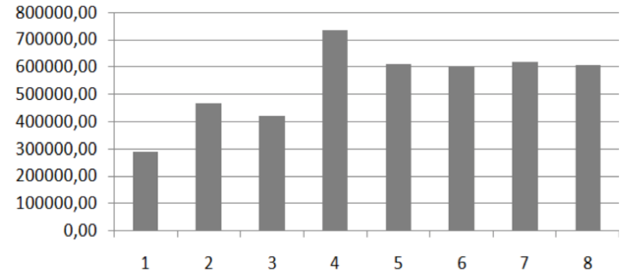

Fig.5. Generalized system's decision-making time for each user with the Bayesian network mode (in ms.)

Total decision time of each user during the test task while using Bayesian network mode is shown in Fig.6:

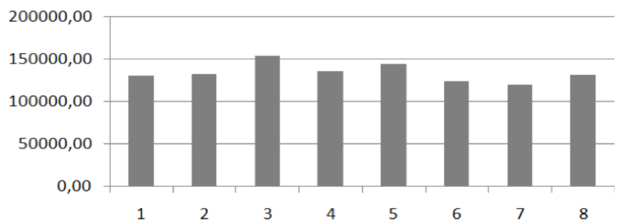

Fig.6. Generalized system's decision-making time for each user with the Bayesian network mode (in ms.)

The total number of correct user responses when completing a test task using Bayesian network mode is shown in Fig.7.

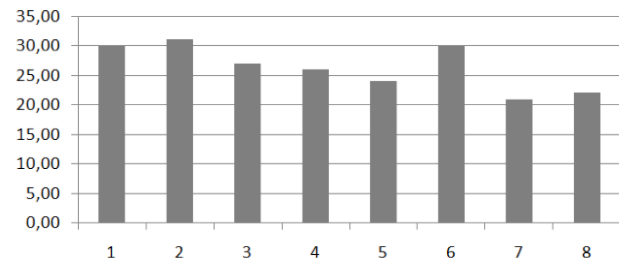

Fig.7. The number of right decisions made by users during the Bayesian network mode

Let's determine the total time of decision making by the system at each stage while using Bayesian network mode (Fig.8):

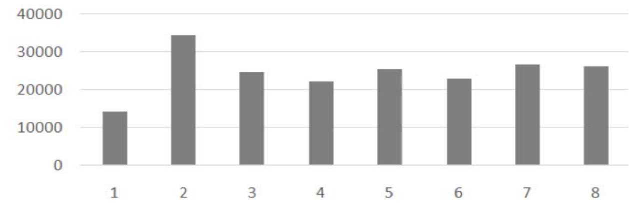

Fig.8. Generalized system's decision-making time for each user with the Majority principle mode (in ms.)

Let's review generalized results of the decision-making process during the Majority principle mode of the system by defining whether or not the system made a decision on each step of the users' decision-making process (Fig.9). The system makes a decision (marked as 1), if the users of the group form a majority on each particular step of the decision-making process. The system doesn't make a decision (marked as 0), which means that it needs to redo the decision-making step for the identified alternatives, if the users of the group don't form a majority on each particular step of the decision-making process or if there is a conflict within the group.

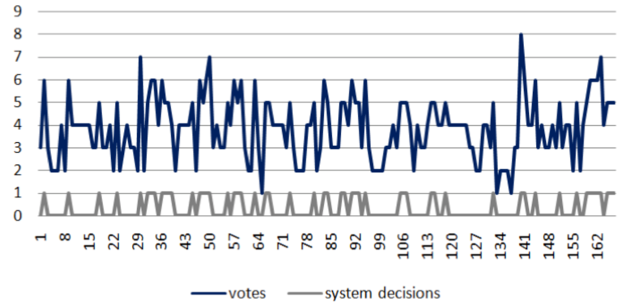

Fig.9. Generalized results of the decision-making process during the Majority principle mode)

Let's review generalized results of the decision-making process during the Bayesian network mode of the system by defining whether or not the system made a decision on each step of the users' decision-making process (Fig.10). As shown on the fig. the system makes a decision (marked as 1), on each step of the decision-making process, which means that the decision will be made in 100% cases and the system will move to the next step saving time and avoiding conflict situations.

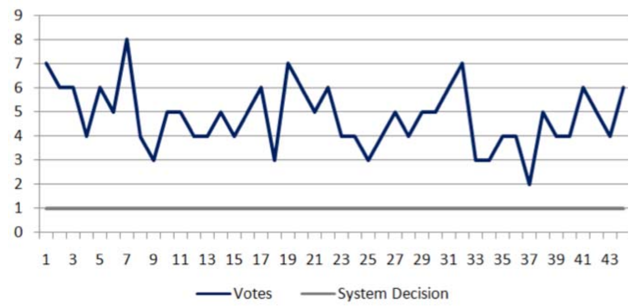

Fig.10. Generalized results of the decision-making process during the Bayesian network mode

From the above experiment results it was concluded that the developed distributed group decision support system is highly effective in supporting groups of users in educational environment allowing them to learn and evaluate the results at the same time.

Conclusions

The implementation of the distributed group decision support system requires consideration of multiple factors and methods to be able to provide high quality support of the decision-making process. In this article authors presented analytical, architectural and informational base for the developed distributed system. Software realization of the proposed system was implemented and can operate by the majority principle or with the Bayesian network usage that allows the system to be tailored for the specific usage need. Experimental research has shown the efficiency of the proposed system due to significantly reduced amount of conflict situations during the decision-making process. The proposed distributed group decision making support system can be used in Software development learning process to teach and evaluate users of the system.

Authors*: Roman N. Kvyetnyy, Vinnytsia National Technical University, Khmelnytsky Hwy, 95, 21021 Vinnytsia, Ukraine, E-mail: rkvetny@sprava.net; Natalia F. Kuzmina, Vinnytsia National Technical University, Khmelnytsky Hwy, 95, 21021 Vinnytsia, Ukraine, E-mail*: natalia.kopolovets@gmail.com*, Ph.D. Olexander A. Poplavskyy,* State University for Transport Economy and Technologies, *E-mail: apoplavskyi@gmail.com, M.Sc., PhD, Candidate of Philological Sciences, docent Vira A. Drabovska, Vinnytsia Cooperation Institute, Vasyl Stus Donetsk National University, Ukraine, E-mail: faithvaganova@gmail.com; senior lecturer Valentyna B. Kuzmik, Vinnitsa State Pedagogical University named after M. Kotsyubynsky, e-mail: valentina777808@gmail.com; dr hab. inż. Konrad Gromaszek, Politechnika Lubelska, Katedra Elektroniki i Technik Informacyjnych, ul. Nadbystrzycka 38A, 20-618 Lublin, E-mail: k.gromaszek@pollub.pl; dr Aliya Kalizhanova, Institute of Information and Computational Technologies CS MES RK, Almaty, Kazakhstan; University of Power Engineering and Telecommunications, Almaty, Kazakhstan, Email: kalizhanova_aliya@mail.ru; dr Saule Smaillova; East Kazakhstan State Technical University named after D.Serikbayev, Ust-Kamenogorsk, Kazakhstan, Email: saule_smailova@mail.ru.*

REFERENCES

[1] Larichev O., Decision theory and methods, *Logos*, (2002), 1-53
[2] Chernorucky I., The decision-making methods, St Petersburg, (2005), 103-314
[3] Peterson M., An Introduction to Decision Theory. Second Edition, Cambridge University Press, New York (2017), 1-10
[4] Blumin S., Shuykova I., Models and methods of decision-making under uncertainty, *Lipetsk, LEGP*, (2001), 23-85
[5] Mulen E., Cooperative decision-making: axioms and models, *Mir*, (1991), 203-464
[6] Kitaev N., Group expert grades, *Znaniye*, (1975), 20-60
[7] Faynzilberg L., Bayesian scheme for collective decision making in contradiction, *Problems of management and informatics*, (2002), No. 3, 112–122,2002
[8] Faynzilberg L., Learning system of collective decision making by independent experts, *Operating systems and machines*, (2003), 57-62
[9] Bhajantri L.B., Cluster based optimization of routing in distributed sensor networks using Bayesian networks with tabu search, Int. Journal of Electronics and Telecommunications, vol 60, 2(2014), 199–208
[10] Tanenbaum E., Van Sten M., Distributed systems: Principles and paradigms, St Petersburg, (2003), 145-313
[11] Petukh A., Kuzmin E., Voytko V., Katelnikov D., The modeling of local human-machine systems of collective collaboration, *Universum*, Vinnitsa, (2007), 100-162
[12] Petukh A., Kuzmin E., Voytko V., Kuzmina N., Principles of implementation of group decision-making in interactive systems of collective collaboration, *New technologies*, Kremenchuk, (2008), 160–166
[13] Petukh A., Kuzmin E., Voytko V., Bevz S., Kopolovets N., The models of group decision making modes of users in interactive system of collective collaboration, *Optic-electronic informational-energetic technologies*, Vinnitsa, (2007), 80-86 (in Ukrainian)
[14] Petukh A., Voytko V., Katelnikov D., Kopolovets N., The interface elements of collective teaching and testing system, *Measuring and computing technology in technological processes*, (2007), 98-106 (in Ukrainian)
[15] Little I., Models and managers: The concept of a decision calculus, *Management science*, (1970), 466–485
[16] Krukov S., Bayesian networks as a tool for modeling uncertainty in investment decisions, *Economic bulletin of Rostov state university*, (2007), 106–111,
[17] Barsky A., Neural networks: recognition, management, decision making, *Finance and Statistics*, (2004), 50-164
[18] Jensen F., An introduction to Bayesian networks, Aalborg. University Denmark. Springer, (1996), 29-120
[19] Tolpin D., Probability networks for describing knowledge. Review of ideas, *Informational processes*, (2007), 93–103
[20] Smolarz A., Lytvynenko V., Wojcik W. et al., Multifractal spectra classification of flame luminosity waveforms, Proceedings of SPIE, vol. 1080813, 10808 (2018), 178-186.
[21] Ben–Gal I., Bayesian networks. Encyclopedia of statistics in quality and reliability, *John Wiley & Sons*, (2007), 1-6
[22] Petukh A., Kuzmin E., Voytko V., Kuzmina N., Automated group decision support system, *Bulletin of Vinnitsa polytechnic institute*, (2009), 76-79 (in Ukrainian).
[23] Nosova Y., Shushliapina N., Kostishyn S.V., Koval, L.G., et al., The use of statistical characteristics of measured signals to increasing the reliability of the rhinomanometric diagnosis, *Proc. SPIE*, 10031 (2016)
[24] Omioitek Z., Prokop P., The construction of the feature vector in the diagnosis of sarcoidosos based on the fractal analysis of CT chest images, IAPGOS, vol. 9 (2019), No.2, 16-23
[25] Semenov A.A., Semenova O.O., Voznyak O.M., Vasilevskyi O.M., Yakovlev M.Y., Routing in telecommunication networks using fuzzy logic, 17th *International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices, EDM*, (2016), 173-177.
[26] Serkova V.K., Pavlov S.V., Romanava V.A., et all., Medical expert system for assessment of coronary heart disease destabilization based on the analysis of the level of soluble vascular adhesion molecules, *Proc. SPIE 10445*, (2017), 104453O.
[27] Pavlov S. V., Information Technology in Medical Diagnostics (red. Waldemar Wójcik, Andrzej Smolarz), *CRC Press*, (2017), 1-210
[28] Wójcik W., Pavlov S., Kalimoldayev M., Information Technology in Medical Diagnostics II.,*Taylor & Francis Group, CRC Press, Balkema book*, London, (2019), 1–336.