Journal of Theoretical and Applied Information Technology
15th February 2021. Vol.99. No 3
© 2021 Little Lion Scientific
ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DEVELOPMENT OF MATHEMATICAL AND INFORMATION SUPPORT FOR SOLVING PREDICTION TASKS OF A RAILWAY STATION DEVELOPMENT

[1]MAILYBAYEV Y., [2]UMBETOV U., [3]LAKHNO V., [1]OMAROV A., [1]ABUOVA A., [1]AMANOVA M., [4]SAUANOVA K.

[1]Kazakh university ways of communications, Kazakhstan
[2]Khoja Akhmet Yassawi International Kazakh-Turkish University, Kazakhstan
[3]National University of Life and Environmental Sciences of Ukraine, Ukraine
[4]Almaty University of Power Engineering and Telecommunications named Gumarbek Daukeyev, Kazakhstan

E-mail: [1]ersind@mail.ru, [2]uumbetov@mail.ru, [3]lva964@gmail.com, [1]kups1@mail.ru, [1]akbala86@gmail.com, [1]kups_212_kab@mail.ru, [4]klartag@mail.ru

ABSTRACT

The article proposes a method and model of railway station (RWS) infrastructure management, based on the complex implementation of decision support systems (DSS) in the prediction tasks of the development and current assessment of the railway efficiency. The proposed solutions differ from the existing ones by the ability to automate the procedure for generating control action variants using DSS and Microsoft Forms questionnaires. The model described in the chapter allows, on the basis of the modified Delphi method, to conduct a survey and approve expert opinions, taking into account various interval assessments of the degree of development of the railway infrastructure and metrics that assess the degree of efficiency of various technological processes on a particular railway. There were developed and tested in real operating conditions at the railway station the software package "Decision Support System for Control and Prediction of Railway Station Development" and Microsoft Forms for questioning external analysts and internal specialists. DSS and Microsoft Forms are adapted for online work of experts.

Keywords: *decision support system, mathematical support, control, railway station, questionnaire.*

1. INTRODUCTION

The main condition for the development of effective design and technological solutions is a detailed and systematic study of the properties and processes of objects functioning on which their implementation is carried out. One of the most complex transport infrastructure objects are mainline and industrial railway stations (RWS) and junctions. Their examination is an obligatory stage before the projects for their development, implementation of automated control systems (ACS), improvement of operation technology, research on the state of traffic safety, etc. The main importance of the pre-design survey stage is due to the fact that as a result of its implementation, not only the initial data for the further work of the designers are obtained, but also there is established the need for changes in the technical equipment and technology of the railway system, and there are formed the customer's requirements for the content and volume of such changes

When the task is to examine a complex object in a comprehensive manner, it is advisable to conduct several types of surveys. The specific procedure for carrying out these activities will depend on the nature of the tasks and the formulation of the research plan. However, in most cases, it is advisable to start interviewing personnel at railway enterprises with interviews with the management team. Also at the initial stage, it is advisable to interview the most qualified specialists of the enterprise. This will help to establish the features of the work of a particular railway enterprise, to identify the main problems in its work. On the basis of the interview results processing at the next stages, it is possible to develop plans for conducting more detailed surveys, to formulate more specific questions on the organization of the enterprise's work, etc. Such information, as a rule, becomes the basis for conducting subsequent interviews or preparing more narrowly focused questionnaires.

It should be noted that questionnaires are the most formalized forms of surveys. The method of obtaining information using written answers on a system of pre-prepared and standardized questions in questionnaires and with a precisely specified method of answers is widely used today in the survey of complex technical systems [1].

The advantage of the questionnaire in comparison with other methods of the survey is that it allows to quickly find out the opinion of a large group of respondents. In addition, it is convenient to analyze the results of the questionnaire using the methods of mathematical statistics.

The main tool for this type of survey is the questionnaire. A questionnaire is a structured sequence of questions organized in such a way as to find out facts or relationships, which are a tool for recording data. Questionnaires are standard forms on which you can write facts, comments and opinions [2].

The relevance of the research direction lies in identifying new trends in the automated processing and assessment of data from questionnaires and surveys, which in the long term can have a significant impact on the development of railway transport in future. For this purpose, in the process of implementing the procedure for the formation of alternative scenarios, solving prediction tasks, it becomes necessary to involve methods of expert assessment, among which the Delphi method stands out mainly [3]. In order to support the prediction process using the Delphi method, it becomes necessary to create automated tools for the design of complex objects and tools for in-depth analysis of complex subject areas, for example, for railway transport.

In order to solve the set tasks, it becomes urgent to create and intensively develop modern models, methods, techniques and to formalize the modified Delphi method in order to determine the technological properties and production capabilities of the innovative activity of the RWS.

The latter ensures the effective use of modern information technologies (IT), but requires the development, formalization and use of automated tools for conducting the survey.

2. LITERATURE REVIEW

The need for scientific methods of designing and organizing the work of railway stations (hereinafter - RWS) appeared already at the early stages of the functioning of railway transport (hereinafter - RWT).

The use of information systems and technologies (IT) is one of the priority areas for the development and improvement of the transportation process control, the operation of infrastructure and other processes at the RWT.

The main goal of railway transport informatization is to provide the necessary information to the performers of all technological processes, to create an information basis for achieving maximum efficiency of the industry. The result of automation at the RWT is the intensive introduction of automated information and information control systems (respectively, AIS and ICS) of the network, road and linear levels, which form the information environment of the RWT.

The papers [4-6] are devoted the theoretical foundations of the directions for improving the operational work of the RWS. The authors also consider the principles of using computers in RWT systems, which will ensure traffic safety and improve the transportation process control.

In the works of modern researchers, a separate place has been allocated to the RWS technological process. For example, in [7-9], there are shown the basic principles of the technological process based on the effective use of technical means and rolling stock of railway transport. A large number of works are devoted to the problems of RWS informatization, formalization of its operation and automation of workplaces.

In works [10-12], there are considered general concepts of control theory and automation systems, basic principles of IT application on RWT. In addition, there are presented materials on the automation of technological and technical regulation of the transportation process in a systematic form, described the use of ACS, integrated and information-reference systems (IRS).

In works [13-16], there are proposed methods of implementing a decision support system (DSS) for the operational RWS flows control with distributed artificial intelligence, the basic principles of the theory of fuzzy sets and fuzzy logic.

Integral communication technologies are increasingly used in various types of RWT. They also integrate with other sectors of the economy, for example, energy, construction, etc. This is done to achieve greater efficiency in both physical and informational and transactional flows. Highly qualified workforce, proximity of the enterprises location and an integral communication infrastructure determine the occurrence of knowledge-intensive innovative clusters of enterprises. This, in turn, predetermines a positive interaction between the material infrastructure and the knowledge-intensive environment.

Intelligent or "smart transport systems" have become a key factor in the rapid development of the fifth techno-economic paradigm today, which is based on microelectronics, software, computer technology, the component base of radio-, telecommunication-, laser equipment, etc.

3. THE GOAL OF THE WORK

The development of mathematical support and software for solving prediction tasks based on the modified Delphi method (MDM) with the ability to conduct an online survey of experts.

4. METHODS AND MODELS

The block diagram of a systematic approach for solving prediction tasks using the expert assessment procedure based on the modified Delphi method (MDM) is shown on Figure 1.

During the process of implementing a railway station development (RWS) project, a critical part of the development is the correct ways to solve the tasks associated with conducting object surveys.

The proposed method of object survey, by which the RWS is meant, includes the following stages:

Stage 1. Analysts divide the RWS tasks into categories. For example:

Category 1: the formation of requirements for automated control systems (ACS) and information systems (IS) of RWS, based on the characteristics of a particular RWS;

Category 2: systematization and updating of information arrays for ACS and IS of RWS;

Category 3: analytics, control and analysis of mechanisms for ensuring the efficient operation of RWS, taking into account the automation of technological processes;

Category 4: working out (adjusting) solutions for RWS development control, including the development of automation systems for technological processes at RWS.

Stage 2. Formalization of the requirements for the processes of RWS operation control, including, on the basis of a questionnaire survey of personnel. Logical rules are formed for ACS and IS, as well as for decision support systems (DSS) in the tasks of RWS activity control.

Stage 3. With the involvement of experts of RWS services, the knowledge base (KB) for the DSS is being filled.

The implementation of a systematic approach to the tasks of RWS operation control using DSS, in particular, in online mode (when, for example, there is no possibility of attracting qualified specialists on small RWS), is represented by the formalization of the accompanying process in the form of software modules for DSS in the prediction tasks of the RWS development, Fig. 2. Maintenance of the process of polling experts (analysts) in DSS in the online mode determined the choice of the interactive-dialog mode of the system. The main emphasis is on the tasks of assessing the parameters of the functioning of the automation systems of RWS technological processes, as well as predictive assessment of the situation transformation in the course of identifying disadvantages.

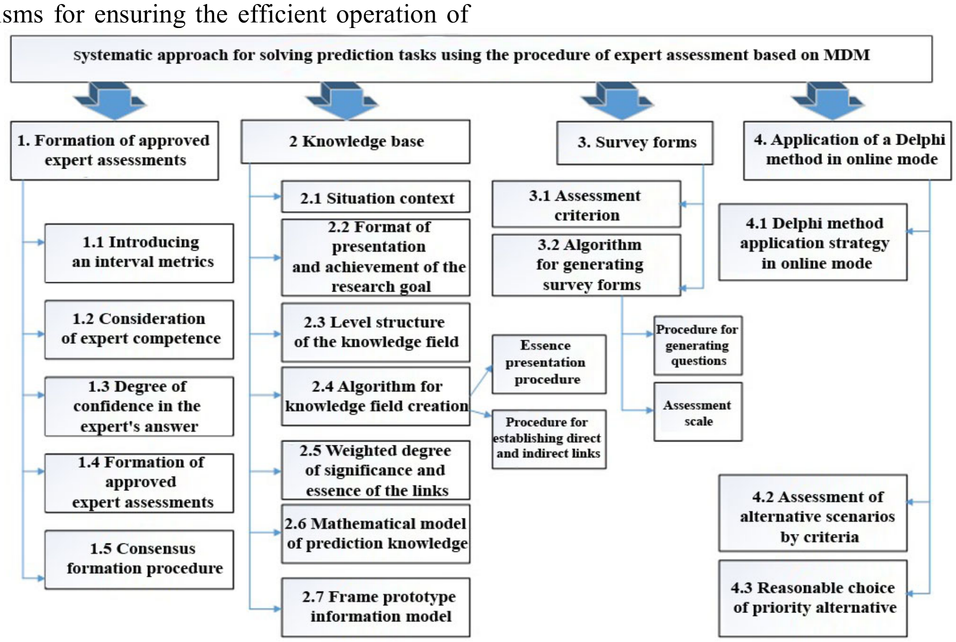

Figure:1 – Block diagram of a systematic approach for solving prediction tasks using the procedure of expert assessment based on MDM

External experts assessing various parameters of RWS can use a PC and, for example, Google Forms or Microsoft Forms (shown in green on Fig. 2) using DSS, or to independently provide the necessary assessment of the situation related to the development of RWS.

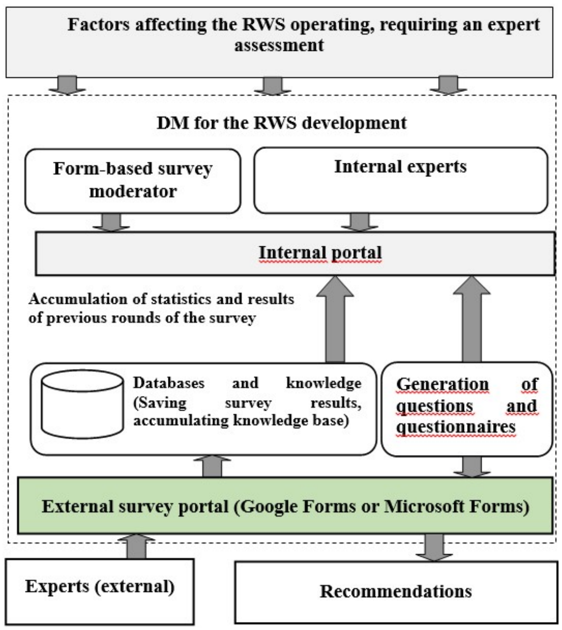

Figure:2 – Block diagram of the platform for RWS operation expert assessment and ways of its development (using the DSS in the online mode)

When registering on the portal associated with DSS, a user account is created on the server. In future, this allows the analyst to take part in surveys and research, including expert assessment of the situation on RWS after making adjustments to its operation.

For example, experts, independently or with the help of DSS, are invited to determine the parameters for improving the quality of operation of automation systems for technological processes at the RWS.

In the questionnaire form, experts independently or in cooperation with DSS fill in matrices of the following form:

$$e_i = \begin{bmatrix} 11 & \dots & MI \\ \vdots & \ddots & \vdots \\ N1 & \dots & NMI \end{bmatrix}, \quad (1)$$

where N – number of automation means for technological processes at the railway station;

MI –number of ways to improve the efficiency of automation means for technological processes at the railway station;

i – number of experts working with DSS.

Before the stage of approval the experts opinion (e) in a round (r) and before reaching a consensus, the final matrix has the following form:

$$e_r = \sum_{i=1}^{n} \begin{bmatrix} 11 & \dots & MI \\ \vdots & \ddots & \vdots \\ N1 & \dots & NMI \end{bmatrix}. \quad (2)$$

The processing of expert opinions in DSS is implemented on the basis of the modified Delphi method (MDM) [17]. A distinctive feature of the developed system is the ability to dynamically generate survey forms using frames in each round of the survey in online mode.

When filling in survey forms on a Web page (Google Forms or Microsoft Forms) connected to DSS, tabular and graphical results appear dynamically.

Stage 4. Systematization of the obtained data according to the minimum significant constituent parts of the investigated factors affecting the RWS operation. The procedure for assigning defined classifiers by categories 1 - 4 is being implemented. As a result, there is formed metadata for knowledge bases and synthesized principles for the formation of new knowledge or rules for DSS.

Stage 5. Taking into account the dynamics of the occurrence of new factors affecting the efficiency of the RWS operation, there is determined the degree of adjustment of the rules for ACS, IS and DSS. At this step, there are formed logical rules for the dynamic change of expert assessments by possible classifiers.

Achieving a consensus between experts in the online DSS is based on the use of MDM.

The proposed method is supplemented by a model for the expert assessments approval, taking into account various interval assessments and RWS metrics.

Interval assessments of the situation transformation associated with the RWS assessment are described as follows:

$$\overline{ER}_{ps} = \left\{ \overline{ER}_{pse} \mid e = \overrightarrow{1, E_{ps}} \right\}, \quad (3)$$

$$\overline{ER}_{pse} = \left\{ \left[\overline{ER}^{-}_{psew}; \overline{ER}^{+}_{psew} \right] \middle| \, w = \overrightarrow{1, W} \right\}, \quad (4)$$

where ER_{pse} – expert assessment for the w-th level, of the e-th expert, regarding the s-th indicator for the estimated parameter p.

Interval assessments are correlated with RWS metrics [1, 2].

In accordance with [3], metrics are set for interval assessments of the RWS operation (similarly for other parameters), for example, to assess the degree of automation for technological processes at RWS:

$$me_{g_{pse_i w}, g_{pse_j w}} = \left(1/W \right) \cdot \sum_{w=1}^{W} me_{g_{pse_i e_j w}}, \quad (5)$$

where $g_{psew} = \left[g^{-}_{psew}; g^{+}_{psew} \right]$.

The importance of the e-expert opinion was assessed as follows:

$$op_{pse} = \left(1 - me\left(\overline{ER}_{pse}, \tilde{ER} \right) \right) \cdot C_{pse}, \quad (6)$$

where C_{pse} – expert competence regarding the analyzed RWS metric.

Expression (6) allows to analyze the results when one group of experts used the DSS, and the other - not (for example, the survey was conducted using traditional questionnaires). However, the compared results differ.

The average interval assessment is calculated as follows:

$$\overline{ES}^{-}_{psw} = \left(1/E \right) \cdot \sum_{e=1}^{E_{ps}} \overline{ER}^{-}_{psew}; \quad (7)$$

$$\overline{ES}^{+}_{psw} = \left(1/E \right) \cdot \sum_{e=1}^{E_{ps}} \overline{ER}^{+}_{psew}. \quad (8)$$

Integral expert assessment in DSS:

$$\overline{\overline{ER}}^{-}_{psw} = \arg \min_{\overline{ER}^{-}_{psew}} \left(\left| \overline{ER}_{psew} - \overline{ES}^{-}_{psew} \right| \right); \quad (9)$$

$$\overline{\overline{ER}}^{+}_{psw} = \arg \min_{\overline{ER}^{+}_{psew}} \left(\left| \overline{ER}_{psew} - \overline{ES}^{+}_{psew} \right| \right). \quad (10)$$

In the analytical DSS module, the confidence interval of the first round of the expert situation assessment was determined as follows:

$$\overline{\overline{ER}}^{+}_{psw} = \arg \min_{\overline{ER}^{+}_{psew}} \left(\left| \overline{ER}_{psew} - \overline{ES}^{+}_{psew} \right| \right). \quad (11)$$

where T – time of transformation of the situation associated with the RWS parameter assessment – p.

For the first round of a survey of experts using DSS, the final confidence interval determines the radius of the set of expert assessments:

$$RA^{(T_{3s})} = \max_{\overline{ER}_{pse}} \left(\tilde{me} \right). \quad (12)$$

The confidence interval in subsequent rounds was determined as follows:

$$\overline{ER}_{pse} \in T_{ps}, then \;\; \tilde{me} < RA^{(T_{ps})}. \quad (13)$$

The final expert assessment in DSS was determined as follows:

$$\hat{ER}_{ps} = 0{,}5 \cdot \left(ES^{+}_{psw\left(\hat{ER}_{ps}\right)} + ES^{-}_{psw\left(\hat{ER}_{ps}\right)} \right). \quad (14)$$

The Python programming language was used to implement notification modules and graphical presentation of results.

Therefore, a model that allows to approve expert opinions and takes into account the interval assessments and metrics of RWS, makes it possible to fill in the DSS knowledge base. It is also possible to adjust the knowledge base in case of revealing new knowledge or contradictions between expert assessments.

Stage 6. Rules are developed for assessing the compliance of actions aimed at the future development of RWS. Thanks to the developed DSS, it is possible to correct decisions based on an operational assessment of the current state of RWS.

Stage 7. There are generated basic management concepts, regulations and guidelines for the response and timely application of preventive, control, corrective and other actions on events related to the current and future development of RWS.

Stage 8. Perspective plans for the development of complex IPS for IO are being developed.

If necessary, steps 1–8 can be repeated taking into account the adjustment of the DSS knowledge base.

First of all, when choosing a survey tool, it is necessary to take into account the following factors: interface; data collection and analysis capabilities; automatic generation of survey results; online sending of questionnaires to respondents; simplicity in creating questionnaire templates.

Any person gets acquainted with the traditional (paper) questionnaire even during the period of various sociological surveys and studies. This method has been used for more than a dozen years, and therefore it is well tested and does not cause complications in organization or conduct.

However, there are also disadvantages:

small audience coverage or significant time losses. In a short time, it is possible to question only those respondents who are in the immediate vicinity to the organizers. If you need to get information from another city (or even a country), you have to wait for it for quite a long time, which is critically important for many studies that are limited in time;

significant labor and financial costs. Researchers need to prepare materials for the survey, find people who will be engaged in conducting it and calculating the results;

high percentage of error.

The Fig. 3 shows the structure of the developed automated DSS with an intelligent interface. The ideology of the system is based on the concept of a formal representation of knowledge about the state and development prospects of RWS. The software implementation, which is described in more detail in Chapter 4 of the work, includes databanks of experts, dictionaries of definitions of standard and acquired parameters obtained during the RWS survey, as well as an approval terminology module and results generation.

The interface block (Fig. 4) provides the analysis of queries and their reduction to the canonical form, the formation of data and knowledge banks, the collection of expert information, including on the basis of an online questionnaire, which is later processed using the application library.

The control block organizes the work of DSS as a whole.

The collection of diagnostic data for RWS for decision-making with the help of the automated DSS developed by us is carried out by interviewing respondents using online questionnaires created in the environment of the automated system questionnaire constructor. The questionnaire can contain single or multiple choice questions, as well as open-ended and combined questions. The constructor of test questionnaires consists of a block for generating features, the values of which are determined during the survey; editors of the questionnaire structure, passport of questions and rules (in predicate form) for processing survey results based on the modified Delphi method. The questionnaire structure editor provides the user with the ability to: create a new questionnaire; modify (change) an existing questionnaire; to store the questionnaire under the same or a new name, i.e. to rename it, to print the questionnaire; set parameters of the questionnaire; receive statistical information about the edited questionnaire (namely, the connection of the questionnaire questions with the features of the survey object (i.e., a specific DSS) and the connection of the features with the questionnaire questions); change the order of the main (root) questions of the questionnaire by moving them with the mouse; add to the edited questionnaire the questions contained in the banks of standard questions of the knowledge base (KB) of DSS or KB of the user (expert); place the created basic questions together with their clarifying questions in the bank of standard user questions; delete previously created questions (when deleting the main question, all questions that are asked to clarify the answers to this question are simultaneously deleted), visualize all or only the main questions of the questionnaire in the structure editor window. In the block for generating features for the questionnaire, a list of features of the survey object is set, the value of which is determined in the process of interviewing the respondent. Features can be selected from a knowledge base, for example, ACS or IS of RWS or KB of DSS.

In the questions passport editor for each question of the questionnaire, users are asked data about the question. Namely: the question formulation, the type of question and the answer variants for the questions of the choice type. If it is not planned to clarify the answer for it, a feature is selected from the list of features of the questionnaire, the value of which changes when this answer is selected by the respondent. In the editor of the rules for questionnaire processing, a set of rules is formed, each of which has a predicate form. At the end of the survey of the respondent, these rules are used to analyze the meaning of the features of the survey object and to obtain a conclusion.

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To simplify the process of questionnaires construction and unambiguous interpretation of questions and certain concepts, there are used the interpretations from the DSS database.

For the software implementation of questionnaires for DSS, there were chosen Microsoft Forms, which made it possible to develop an intuitive interface for the questionnaires, Fig. 5, 6.

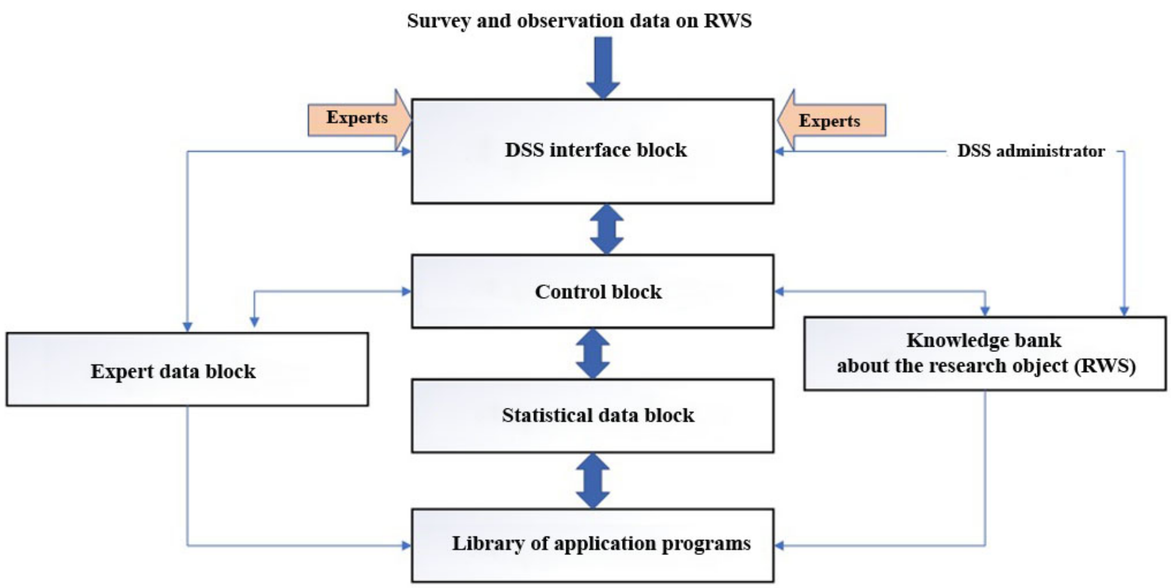

Figure:3 – General scheme of an automated DSS on the RWS operation

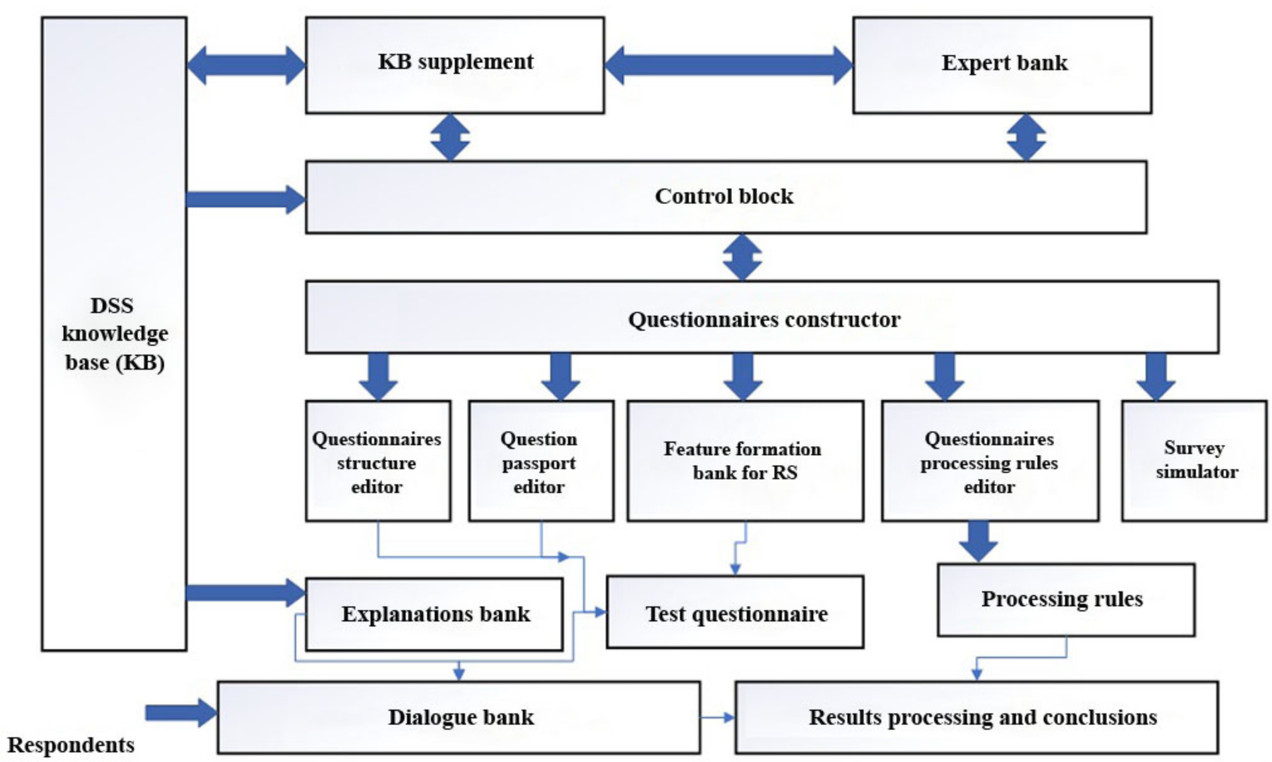

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Figure:4 – Functional diagram of the interface block of the automated DSS

Microsoft Forms Questionnaires.

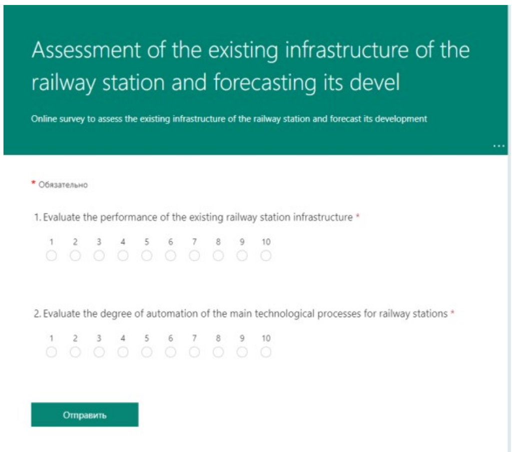

Figure:5 – General view of questionnaires for the work of experts in online mode

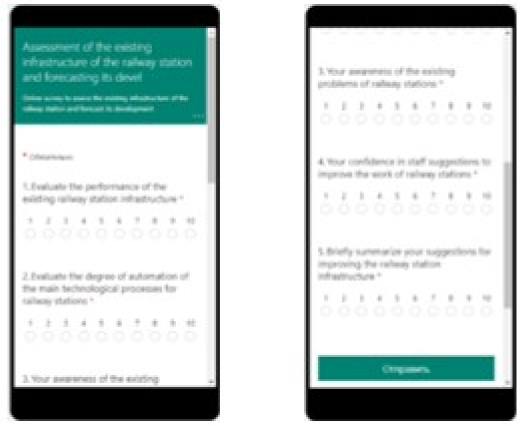

Figure:6 – General view of questionnaires for the work of experts in online mode

The algorithm of expert assessments approval in accordance with the developed model is shown on Figure 7.

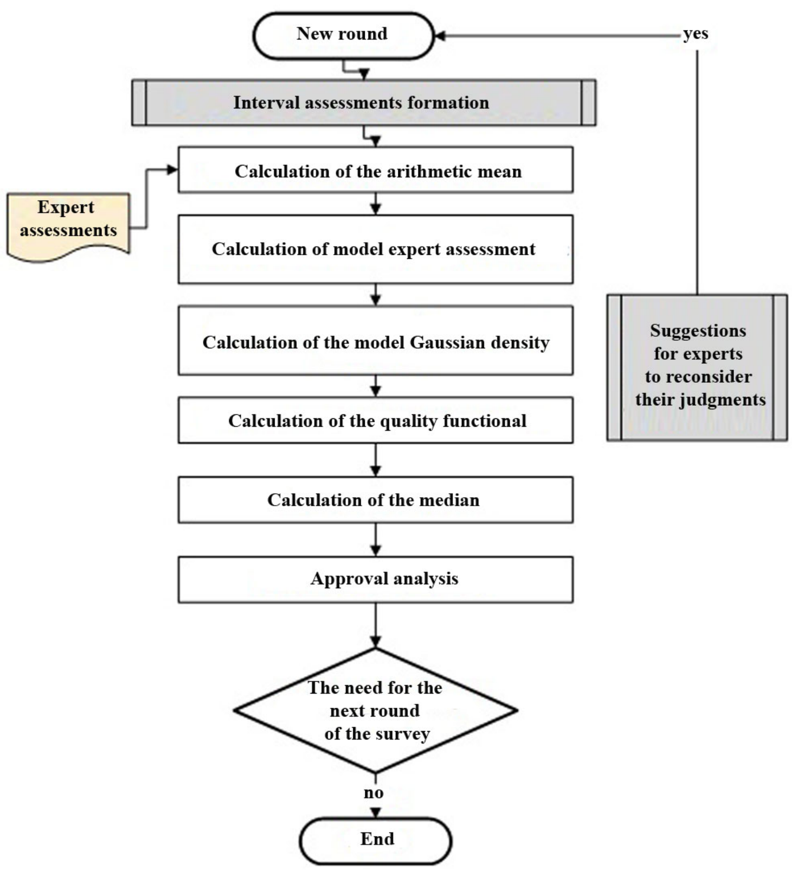

Figure:7 – Block diagram of the algorithm for expert assessments approval during the online questionnaires processing in RWS survey

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5. RESULTS OF EXPERIMENTAL VERIFICATION OF THE METHOD AND MODEL

Figures 8 and 9 show the comparative results obtained in the course of a survey of experts independently on the basis of the traditional method of conducting a survey and questionnaires with a paper form (position 1) and using Microsoft Forms (position 2).

For enterprises that took part in testing DSS and Microsoft Forms, from 5 to 11 experts were involved. There were invited experts with experience in the field of RWS and RWT operation for at least 5 years. Without the DSS, the experts filled in paper questionnaires (see Appendix A), assessing the parameters of the analyzed RWS. At the second stage of the study, the experts were asked to make an assessment of the RWS operation using DSS and Microsoft Forms.

The Fig. 8 shows the results of the experts assessment independently and using DSS and Microsoft Forms of the degree of automation of the most important technological processes of RWS.

The Fig. 10 shows the assessment results of the organization of current maintenance and technical repair of locomotives at the railway station in Kiev. The reference value of the assessed parameters (p) is taken equal to 1. If the parameter assessment is 0, the automation of the most important technological processes at the railway station is completely absent, i.e. the corresponding RWS infrastructure is outdated and needs modernization.

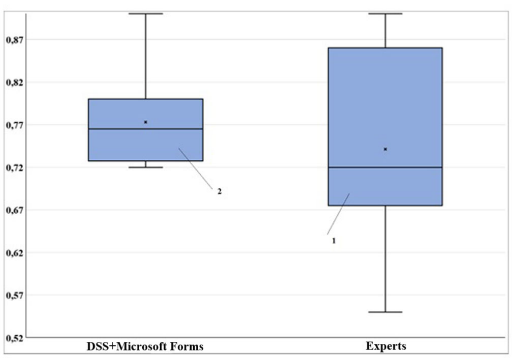

Figure:8 – Experts assessment results independently and using the Microsoft Forms interface of the degree of automation of the most important technological processes of RWS

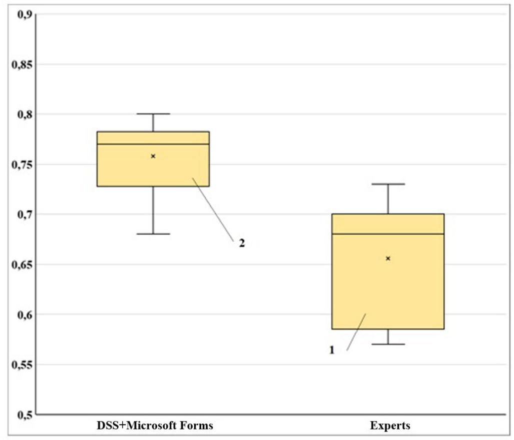

Figure:9 – Assessments results of the organization of current maintenance and technical repair of locomotives at the railway station in Kiev

On Fig. 8, 9, it can be seen that the discrepancy in the experts opinion who used DSS and Microsoft Forms (position 2) is about 15–18% less than for the assessment variant without using DSS (position 1), i.e. on the basis of traditional paper questionnaires.

The Fig. 10 shows the experts assessments results independently (red columns) and using DSS and Microsoft Forms (blue columns) of the RWS infrastructure.

The obtained results show that without the use of DSS and Microsoft Forms, experts are more optimistic about the state of the RWS infrastructure. However, the subsequent audit of the infrastructure for the analyzed RWS did not always confirm the expert assessment, and the assessments obtained were more consistent with the variant with the use of DSS and Microsoft Forms. At the same time, analysts with at least 10 years of experience in the field of RWS operation took part in the audit of the RWS infrastructure.

The Fig. 11 shows a histogram comparing the time (in minutes) spent by experts independent assessment (red bars) and using the DSS interface and Microsoft Forms (yellow bars) to assess the infrastructure of a particular RWS.

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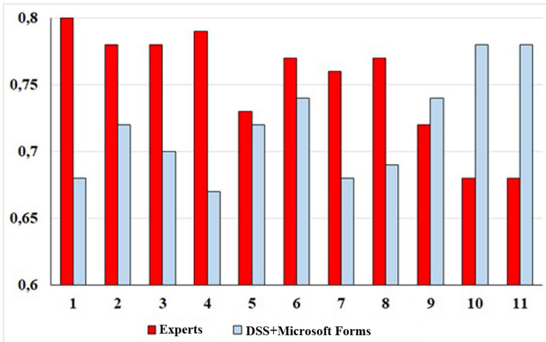

Figure:10 – Experts assessments results independently and using the DSS interface and Microsoft Forms of the RWS infrastructure

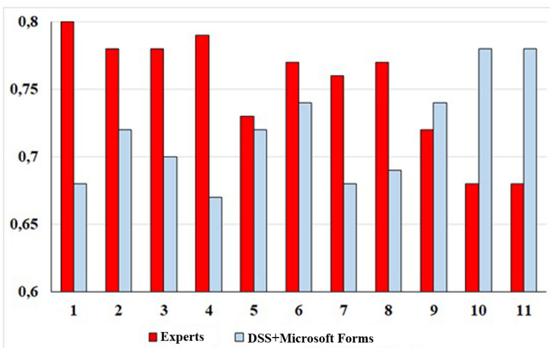

Figure:11 – Time spent by experts independently and using the DSS interface and Microsoft Forms to assess the infrastructure of a particular RWS

6. DISCUSSION OF EXPERIMENTAL RESULTS

Time necessary for experts to process data using DSS and Microsoft Forms is 35-50% less compared to independent analysis by the analyst. In addition, the number of rules involved in the DSS inference process is 1.5 times larger. The result of using the DSS interface was a reduction in the cost for organizing a more efficient RWS operation by 32–35%. Reducing the time spent by 11-14% during the assessment (using DSS and Microsoft Forms) and responding to the facts of deviations of technological processes at RWS, allows to speak about an increase in the efficiency of the RWS control system. In the course of the DSS testing, there were also tested the mechanisms of interaction between experts and Microsoft Forms toolkit during the process of synthesizing guidelines in the tasks of automation of RWS management.

The proposed method and model form a set of basic rules for automating the procedures of RS operation survey based on the automation of the collection of primary data using various online platforms. Expert assessment (with the help of DSS and Microsoft Forms) of the impact on the prospects for the specific RWS infrastructure development, and the approval of experts' judgments, make it possible to predict the development of RWS for both already operated and designed ones. During testing, the time spent on assessment of the individual parameters and the RWS as a whole was reduced by 11–12%. The use of DSS and Microsoft Forms has reduced the cost of organizing a comprehensive survey of RWS by 12-15% in comparison with alternative methods [2]).

The described solutions supplement the existing research [3], in the context of solving the tasks of RWS management on the basis of the implementation of automated procedures for specialists questionnaires processing and assessing the infrastructure and technological state of technological processes.

Compared to similar solutions, DSS and Microsoft Forms have the following advantages:

it is possible to integrate the developed software into the existing methods of carrying out the procedure of RWS survey;

the efficiency of decision-making in the tasks of RWS infrastructure management is improved;

flexible configuration of DSS and Microsoft Forms is possible, taking into account the specifics of a particular RWS.

7. CONCLUSIONS

1. For the first time, there have been developed a method and model of RWS infrastructure management, based on the complex implementation of decision support systems in the prediction tasks of the development and current assessment of the RWS efficiency. The proposed solutions differ from the existing ones by the ability to automate the procedure for generating control action variants using DSS and Microsoft Forms questionnaires. The model described in the chapter allows, on the basis of the modified Delphi method, to conduct a survey and to approve expert opinions, including taking into account various interval assessments of the degree of the RWS infrastructure and metrics development that assess the degree of efficiency of various technological processes on a particular RWS.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2. Developed and tested in real RWS operating conditions the software package "Decision Support System for Control and Prediction of Railway Station Development" and Microsoft Forms for questioning external analysts and internal specialists. DSS and Microsoft Forms are adapted for online work of experts. It has been established that the DSS and Microsoft Forms "DMSSCSE" allow to increase the efficiency of applied organizational and technical measures to improve the efficiency of RWS operations and to optimize its infrastructure, as well as to reduce the cost of organizing surveys and questionnaires by 12-15% compared t o existing solutions.

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