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The journal covers international practices as well as today's tendencies and trends in the sphere of automation and control systems based on information and communication technologies in industry, construction, transportation, economics, education, etc.

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Журнал освещает мировой опыт и современные тенденции в области автоматизации и управления на основе информационно-коммуникационных технологий в промышленности, строительстве, транспорте, логистике, экономике, образовании и других областях.

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# INTELLIGENT QUESTION-ANSWERING SYSTEM "MIVAR VIRTUAL CONSULTANT"

*Adamova L.E., Protopopova D.A.*

*The paper deals with the process of designing question-answering system "Mivar Virtual Consultant" using specialized information-technology platform for understanding meaning of text in the natural Russian language. The system is capable of accumulating knowledge from texts in the natural Russian language and managing this knowledge. The methodology for training virtual consultant is described.*

***Keywords:*** *mivar; mivar networks; text meaning understanding; Mivar virtual consultant; artificial intelligence.*

## 1. Introduction

Currently question-answering systems are increasingly widespread. These are information systems capable of understanding questions and answering questions in a natural language [1–3]. Such systems provide the basis for designing virtual consultants (VC), which are applied to guide users through websites. VC can perform the following functions: communicating with users, guiding users through the website, virtual secretary, service desk or call-center specialist, etc.

The structure of VC can change depending on the approach used and the goals of the application. But in this systems it is possible to identify the following basic components:

- user interface for communication with the virtual consultant;
- the mechanism for processing user's questions and searching for answers;
- knowledge base of the virtual consultant.

The paper considers the process of designing the virtual consultant on the specialized platform Tel!Mi.

Virtual consultants refer to knowledge-based systems. The basis of such systems is structured semantic model of the subject domain, according to this model search for answer to the question is implemented. The source of information for models can be texts in a natural language. To convert text into such a model specialized systems are developed, that is, semantic parsers. There are different approaches to data storage and data accumulation in semantic models: semantic networks, conceptual dependencies, scenarios, frameworks, Resource Description Framework (RDF), etc. To solve tasks described above the platform Tel!Mi uses mivar-based approach [4–6], based on the following:

1) the technology of data representation on the basis of epistemological model VSO (the Russian abbreviation of the triple "Object-Property-Relation");
2) the technology of logical-and-computational data processing;
3) the use of previously accumulated models of subject domains (context).

The use of mivar-based technologies for designing virtual consultants allows us to carry out morphological, syntactical, and semantic text processing, as well as give answers to questions on the basis of knowledge [7–11]. It is known that there are methods of automatic question answering through search and retrieval of the answer phrase from huge collections of text information (IR technologies). These methods proved efficient for searching the necessary document relevant to the user's query in large text bases. This approach relies on enormous amount of information available as text on the Internet or specialized text collections. Having obtained the question from the user, the information retrieval techniques extract the answer in the form of a text fragment directly from these documents, guided by the text of the question.

Using this approach, firstly, the question is processed to determine the most likely answer type and queries for search engine are formulated. The search engine returns ranked documents divided into suit-

able passages. Finally, candidate answer strings are extracted from the passages and ranked.

However, users often want to get not the whole document, but a short answer to the question. To carry out accurate search for answers in the documents it is necessary to use methods that analyze text information flexibly and in more detail.

The majority of question-answering systems have a standard structure: they formulate a query from the user's question, implement query search to select parts of the documents that are most likely to contain the answer and then determine the most likely answers from these passages. Answers to short questions pose a problem to such systems operating on the word level (IR) and semantic-syntactic level (NLP), since it is difficult to find a few short answer segments. As a rule, IR methods lead to the use of huge statistics, whereas NLP methods result in entering a large number of rules into the knowledge base manually. To improve performance and adequacy of such systems it is necessary to increase the number of rules about the language and the world.

Mivar-based technologies allow us to implement natural Russian language understanding and give answers to questions on a higher semantic level. Firstly, mivar-based technologies allow us to process large texts, rather than separate sentences. Secondly, on preliminary stages of text processing mivar-based technologies allow us to use traditional syntactic parsers and other methods of traditional mathematical linguistics. Thirdly, mivar-based approach allows us to use several statistically trained traditional parsers simultaneously and compare the obtained results.

## 2. Mivar information-technology platform

The information-technology platform Tel!Mi has been developed on the basis of mivar technologies in the field of text meaning understanding in the natural Russian language. This platform allows us to store large amount of information, systematize and manage knowledge reasonably.

One of the goals of the system Tel!Mi is designing virtual consultants. Capabilities of VC depend on the set of knowledge that it has been taught. The set of knowledge of the consultant includes texts, glossaries, mivar networks with different type of connection and a list of predefined questions. Virtual consultant training in Tel!Mi is implemented using methodology for training a child, but the child is specific, he cannot touch an object, hold it in the palm, hear how a particular musical instrument sounds [10]. The training process is based on the methodology described in the next section.

Tel!Mi uses mivar-based technologies including the space VSO and mivar networks, which allows us to process texts in the natural Russian language. Tel!Mi allows us to develop the VSO model of a large enough text in short time. For example, the time of automated processing of a large text (Ojegov's Explanatory Dictionary) is:

0.05 (average processing time of one article) * 100 000 dictionary entries = 5000 seconds = 83 minutes.

It should be noted that Tel!Mi allows us to build a model of "Ojegov's Explanatory Dictionary" and other additional texts. Currently, total amount of knowledge base in the format of VSO model named "The picture of the world" accounts for 160 000 nodes and 600 000 arcs. Search for the answer to the user's question is executed on such an extremely large VSO model in less than a minute. In fact, the tasks of searching for a subgraph in the graph and finding the path between the nodes of the graph are solved.

Information-technology platform has allowed us to reduce text adaptation for virtual consultant training. Therefore, mivar virtual consultant is capable of operating texts in a living natural language.

## 3. The process of virtual consultant development using mivar-based technologies

The software suite of question answering system based on mivar technologies will be named "mivar virtual consultant" (MVC).

The process of developing the virtual consultant on the basis of the information technology platform Tel!Mi using mivar-based technologies can be divided into several stages:

1) Context analysis of the subject domain.

This is the major stage in the process of designing MVC, since it determines the specific subject domain of the virtual consultant. Depending on the selected subject domain, VC will have different amount of knowledge.

2) Developing and training the mivar knowledge base (KB) of the mivar virtual consultant. KB of the virtual consultant is built on the basis of concepts and networks. Concept is regarded as a word or a word combination that conveys the meaning of the term or terms. Concept network is connections between concepts in the picture of the world [10]. To form the concept network it is necessary to teach the virtual consultant's knowledge base concepts according to the analysis of the subject domain and interconnect these concepts into a single network, that is, the picture of the world. If the context is unambiguous in the selected subject domain, the process of developing concept network is considerably simplified.

If there is a lack of data obtained on the second stage, additional training should be done through concepts similar to the previous stage or through texts. To provide training through texts graphemic, morphological, syntactic and semantic analysis of input information should be carried out. Graphemic analysis is regarded as segmentation of the obtained text into paragraphs, each paragraph is divided into sentences, sentences are divided into word combinations and words. Then morphological analysis should be carried out in each sentence obtained as a result of graphemic analysis. The result is an array of word forms with a set of morphological characteristics (initial form, gender, number, etc.) within one sentence. In the process of morphological analysis Tel!Mi uses a morphological dictionary, which contains word forms with a set of morphological characteristic. Current-

ly, such a dictionary contains more than 3 million word forms. If in the process of morphological analysis the required word form is not found, the possibility of expanding morphological dictionary is provided. Moreover, automatic word form generation is provided taking into account rules of the Russian language (declension, conjugation). Then syntactic analysis is carried out, when using the sentence the graph is build that connect words in the sentence. The final stage of text analysis is semantic analysis, that is, defining the meaning of the entered information. Access to the concepts and concept networks available in the knowledge base of MVC is implemented. The steps of parsing the sentence "A boy found a beautiful flower under the tree" are represented in (**Fig. 1, 2, 3**).

3) Designing the dialog box interface.

The implementation of this stage depends on technical specification and type of the virtual consultant in particular (personalised, impersonalised, technical). If VC is personalised, the system Tel!Mi provides training in answering general questions and personal questions.

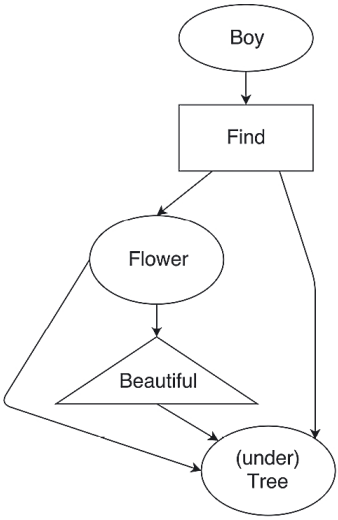


**Fig. 1.** Words

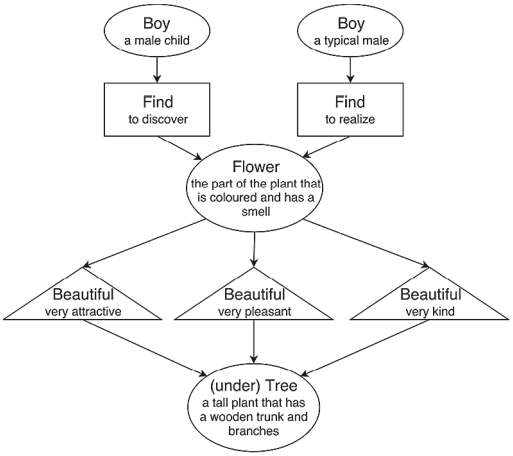


**Fig. 2.** Concepts

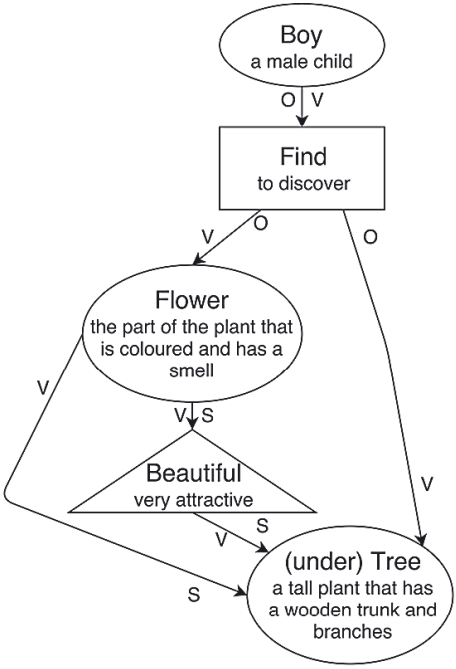


**Fig. 3.** VSO-model

4) Developing answer output algorithms.

Answer output algorithms depend on the type of user's query (a question to the consultant). The first stage involves the analysis of question type.

The following types of questions are identified:

– general questions, that is, questions that do not refer to the subject domain
– personal questions
– subject domain questions
– approval/ disapproval scenarios and etc.
– greeting/goodbye

After determining the question type, scenario manager, that is answer output algorithm, runs the appropriate scenario. Scenario is regarded as a sequence of steps to search for an answer to the question of a particular type. The result is the output of a certain answer in the consultant's dialogue box.

5) Testing.

The testing stage involves verifying correctness of data stored in the knowledge base of the MVC and debug of answer output algorithms. Using Tel!Mi allows us to design VC with required functions for entirely different subject domains.

## 4. the principles of methodology for training virtual consultant based on mvar technologies

MVC is necessary for human-computer communication, for example, answering questions on the websites, portals and analogous modern automatic systems. MVC development is based on using children training techniques on the basis of cause-effect rules (production rules) and thorough descriptions of the outside world.

MVC training is implemented constantly, continuously considering context involved in the training. Thus, context is a social environment of the virtual consultant. The context in the process of MVC

training is as important as in real human communication. MVC has its knowledge base, on the basis of which context understanding is implemented. Context understanding is based on the main principles and methods of remedial and rehabilitation training.

Virtual consultant training has its methodology developed on the basis of analysis of children training techniques and specific features of mivar-based technologies. This methodology involves several principles:

- teaching VC data in the form of dictionary entries;
- building mivar networks using texts;
- teaching VC groups of answers and questions;
- identifying mivar networks from dictionary entries with different types of relation (general –particular, the part –the whole, etc.)
- teaching VC concepts.

## 5. Conclusions

The application of mivar-based technologies to developing virtual consultants can boost operation of contact-centers and services aimed at mass market. Communication between the user and the virtual consultant is implemented on the semantics level. Virtual consultants designed using Tel!Mi are easily trained: they are capable of understanding written human speech, texts of books, adapted literary works. On the basis of taught knowledge MVC is capable of making decisions in different situations of communication with service's user.

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# ENSURING THE SAFETY OF ROAD TRANSPORTATION OF GOODS

*Andronikova L.N., Atrokhov N.A., Moroz D.G.*

*The article investigates Russian and foreign regulatory documents, governing the issues of cargo securing in road transport, and sets out recommendations to ensure the safety of road transportation of goods by means of their attachment.*

***Keywords:*** *road freight transportations; securing of cargo; security of transport.*

## Introduction

Road freight transportation is a source of increased danger. However, not only the vehicle poses a threat to the safety of others, improper stowage and securing of cargo in the vehicle does no less harm. Improper placement and securing of cargo affect its safety and the timeliness of its delivery, the safety of the vehicle, as well as endanger the live sofa driver and third parties, the property, may cause harm to the environment. According to the opinion of independent experts, the cause of 70% of unsafe carriages of goods is inadequate cargo securing. Moreover, the cause of 40% of road accidents involving one vehicle, is the loss of control of vehicle due to shifting of improperly secured cargo [1].

A lot of things depend on the decisions made within the framework of the process of organization of safe road transportations. Not only such an important issue as the preservation of wealth (transported items, vehicles), but also the safety of the driver and other road users are among them.

One of the ways to organizing a safe road transportation is the correct stowage and securing of transported goods.

**State regulation of securing of cargo**

According to the Federal Law №259-FZ of November 8, 2007 (ed. By 06.11.2011), "Statute of road transport and urban land-electric vehicles" [2] the obligation to prepare the cargo for transportation rests on the shipper. Organization of cargo handling and shipping must ensure the safety and security of cargo, as well as prevent damage to the vehicle. The Statute of road transport refers to the general conditions of the organization of transportation, however, it does not regulate the issues of cargo securing technology.

Questions concerning securing of cargo on road transport are partially regulated by the RF Government Decree of April 15, 2011 №272 (ed. From 03.12.2015) "On approval of the Rules of cargo transportation by road transport" [3]. The Rules give advice about selecting the means for securing cargo in the back of the vehicle, which are necessary to ensure traffic safety, security of cargo and the vehicle, and also lists the attachments which aren't allowed to use. Responsibility for the securing of cargo rests on the shipper if the contract of carriage doesn't (the provision of freight forwarding services) provide otherwise.

It's pointed out in the traffic rules, approved by the RF Government Decree of 23.10.1993 N 1090 (ed. By 30.06.2015) [4] that before and while driving the driver must control the placement, fastening and condition of the goods in order to prevent them from falling and creating disturbances to traffic (p.23.2). It should be noted that in this document the sequence of actions of the driver on validation fastening and stowage is not registered. Thus, the driver must control the condition of the goods at his discretion.

A complete list of legal acts, which addresses the issues of cargo securing, is presented at Table 1.

*Table 1.*

**Legal acts which address the Securing of cargo**

| № | Name of legal act | Legal regulation of carriage of goods | Lashing regulation technology |
|---|---|---|---|
| **1** | The Civil Code of Russian Federation (chapter.40) | • indicates the general provisions on the carriage of goods and passengers;<br>• regulates the conditions of conclusion and execution of contracts of carriage<br>• determines the carrier's liability for breaches of obligations | • load securing issues are not affected |
| **2** | Statute of road transport and urban land-electric vehicles (Federal Law №259-FZ of November 8, 2007 (ed. of 13.07.2015) | • regulates relations arising at rendering of services;<br>• defines the general conditions of carriages by trucks<br>• regulates the obligations for preparation of goods for carriage | • shipping and handling operations should provide:<br>➢ safety and security of cargo<br>➢ no damage to the vehicle<br>• the issues of cargo securing technology are not regulated |
| **3** | RF Government Decree of April 15, 2011 №272 (ed. of 03.12.2015) «On approval of the Rules of cargo transportation by road transport» | • establishes the procedure for the organization of transportation of various cargoes<br>• regulates the conditions of transportation of goods and the provision of vehicles for the transportation of goods | • sets out recommendations of the choice of means of securing of cargo in the vehicle body<br>• the issues of cargo securing technology are not regulated |
| **4** | Rules of the Road (the RF Government Decree of 23.10.1993 N 1090 (ed. by 30.06.2015) | • establishes a common procedure for the traffic on the entire territory of the Russian Federation | • it sets the duties of the driver:<br>➢ to control the placement of cargo in the body of a vehicle<br>➢ to control the attachment and the conditions of the goods<br>• the algorithm of driver's actions on verifying the accuracy of placement and fastening of cargoes is not established |
| **5** | GOST (State Standard) 26653-90 "Preparing of general cargoes for transportation. General requirements» | • establishes general requirements for the preparation of general cargoes for transportation | • preparation of cargo for transportation should provide:<br>➢ safety and security of cargo<br>➢ ease of freight operations, fixing and placing in vehicles<br>• the funds, schemes and methods of cargo securing are not shown |

*End of the Table 1.*

| | | | |
|---|---|---|---|
| **6** | Transport strategy of the Russian Federation for the period up to 2030 (approved by the RF Government of 22.11.2008 №1734-p) | • defines the priorities of the state transport policy of the Russian Federation<br>• determines the main directions of development of transport infrastructure of the country<br>• examines the main problems of development of the transport system and the directions of their decisions separately for every mode of transport | • It indicates the need to work out the requirements to means of securing of cargo on vehicles |
| **7** | Technical Regulations of the Customs Union «On Safety of Wheeled Vehicles» (TR CU 018/2011) (approved by the decision of the Commission of the Customs Union of 9.12.2011 №877) | • specify the requirements for vehicles in service | • then extissues are not allowed:<br>➢ damage and loose of some parts of the cargo securing<br>➢ the destruction of carcasses of boards and devices for securing of cargo<br>➢ the absence or non-functional state of fastening mechanisms<br>• the funds, schemes and methods of cargo securing are not shown |
| **8** | The Rules for ensuring the security of transportation of passengers and goods by road and urban land-electric vehicles and a list of measures for preparing workers of legal entities and individual entrepreneurs engaged in transportation by road and by urban land-electric vehicles for safe operation and the vehicles for safe exploitation (the Order of the Ministry of Transport of the Russian Federation of 15.01.2014 №7) | • defines the main objectives and requirements for ensuring the security when organizing and implementing the transportations of goods by road | • describes the requirements for the selection of means of securing<br>• lists the factors which are to be considered when determining the methods of cargo securing<br>• the methodology for determining the amount and type of securing devices is not written |

The most far-reaching document, which details the issues of cargo securing, describes the requirements for the selection of means of cargo securing and lists the factors that should be considered when determining the methods of cargo securing is the order of Ministry of Transport of Russia from 15.01.2014 N 7 "On approval of the Rules of ensuring the safety of passenger and freight transportations by road and by urban land-electric vehicles and of a list of measures to prepare workers of legal entities and individual entrepreneurs engaged in transportation by road and by urban land-electric vehicles for safe operation and the vehicles for safe exploitation "(Registered in the Ministry of Justice of Russia 05.06.2014 N 32585) [5].

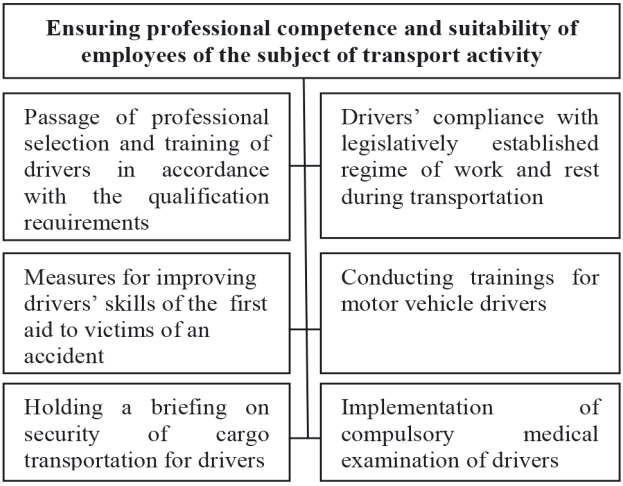


**Fig. 1.** Measures for ensuring professional competence and suitability of the employees of the subject of the transport activity

It follows from the legal act mentioned above that in order to ensure safe transportation of goods by means of attachment you must meet the following requirements:

- firstly, the maintenance of professional competence and suitability of employees of the subject of the transport activities;

- secondly, ensuring the safety vehicles in use;
- thirdly, ensuring safe conditions for transportation of goods.

The list of activities aimed to ensure professional competence and suitability of the employees of the subject of the transport activity is represented as a block diagram in Figure 1.

Measures to ensure the safety of vehicles in use are shown in block diagram form in Figure 2.

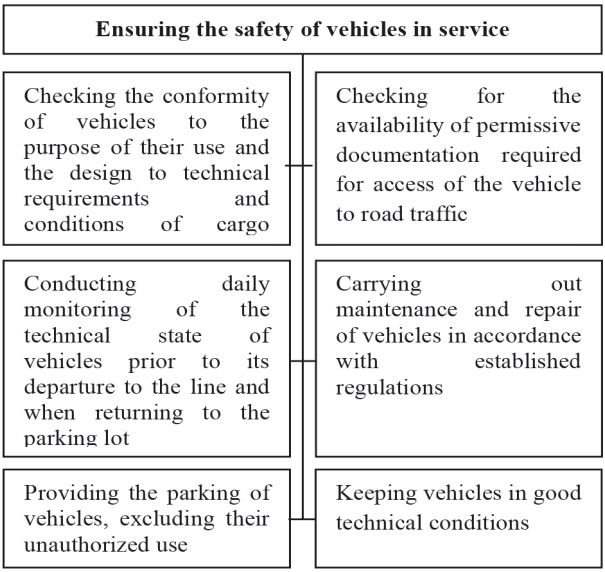


**Fig. 2.** Measures for ensuring the safety of vehicles in service

In order to ensure safe conditions of cargo transportations it is necessary to perform activities described in the flowchart of Figure 3.

Analyzing foreign experience in regulating of safe fastening of cargo on road transport it can be concluded that a number of countries have their own legislation, which establishes the rules of cargo fastening. Documents of several countries [6 ... 8] governing the issues of securing of cargo on road transport are presented in a block diagram in Figure 4.

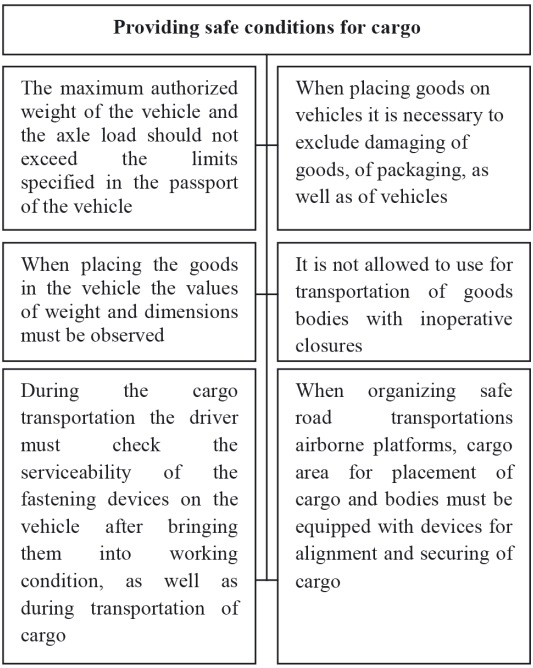


**Fig. 3.** Measures for ensuing safe conditions for transportation of goods

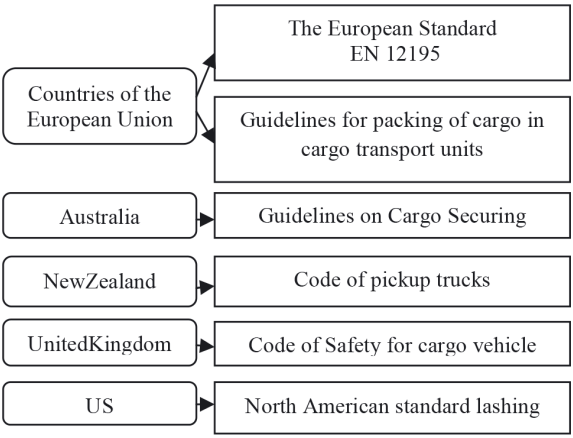


**Fig. 4.** Foreign experience of regulation of safety on road transport by means of freight attachment

## Conclusion

In accordance with the foregoing in order to provide safe road transportation of goods by means of their attachment you need to:

- undertake a detailed review and analysis of the existing foreign experience in the field of safety of road transportation of goods by means of their fastening;
- use vehicles for transportations of goods which meet the requirements of their safe exploitation;
- develop national regulations on securing of cargo on vehicles, maximally harmonizing them with the existing foreign analogues, taking into account the characteristics of goods and the conditions of their transportation;
- develop a control system for securing of cargo and to specify measures of responsibility for violation of the established requirements;
- work out measures for ensuring professional competence and professional suitability of employees of the subject of transport activities in terms of securing of goods;
- legislate the basic requirements on stowage and securing of cargo, requirements to the professional competence of a driver and other persons responsible for performing loading and unloading works, in placing and securing of loads.

Thus, the implementation of recommendations mentioned above will improve the level of safety of transportation of goods by road.

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# DESIGNING ALGORITHMS FOR SOLVING PHYSICS PROBLEMS ON THE BASIS OF MIVAR APPROACH

*Chuvikov D.A., Nazarov K.V.*

*The paper considers the process of designing algorithms for solving physics problems on the basis of mivar approach. The work also describes general principles of mivar theory. The concepts of parameter, relation and class in mivar space are considered. There are descriptions of properties which every object in Wi!Mi model should have. An experiment in testing capabilities of the Wi!Mi software has been carried out, thus the model has been designed which solves physics problems from year 8 school course in Russia. To conduct the experiment a new version of Wi!Mi 2.1 software has been used. The physics model deals with the following areas: thermal phenomena, electric and electromagnetic phenomena, optical phenomena.*

***Keywords:*** *algorithm calculation; mivar; Wi!Mi 2.1; «physics» subject domain; expert system; mivar networks; mivar-based approach.*

## 1. Introduction

The developing information systems and technologies require new automated and intellectual software systems such as ACS (Automated Control System), ADPS (Automated Data Processing System), APCS (Automated Process Control Systems) and DSS (Decision Support Systems) [1]. Currently, there are many approaches to data processing and data representation. It should be noted that mivar-based approach becomes increasingly popular. This approach processes large volumes of data in real time, which allows us to describe various subject domains

the most comprehensively. Each solution is unique for each specific situation and built automatically without the need of expert involvement.

## 2. Description of mivar theory

Mivar theory is rather wide and due to its universality covers many objects of everyday life [2]. For example, it covers the field of ADPCS (Automated Data Processing and Control Systems) and its modelling.

One of the main features of mivar theory is data representation in the form of semantic graph "Object-Property-Relation" (VSO) [2–15].

Mivar space represents a set of axes, a set of axes elements, a set of points of space and a set of values of points [9]. Let us introduce $A = \{a_n\}$, $n = 1..N$, where $A$ is a set of mivar space axis names and $N$ is a number of mivar space axes. Then

$$\forall a_n \exists F_n = \{f_{n i_n}\}, n = 1..N, i_n = 1..I_n,$$

where $F_n$ is a set of axis $a_n$ elements, $i_n$ is set $F_n$ element identifier, $I_n = |F_n|$. $F_n$ sets form multidimensional space: $M = F_1 \times F_2 \times ... \times F_n$. $m = (i_1, i_2, .., i_N)$, $m \in M$, where m is a point of multidimensional space, $(i_1, i_2, .., i_N)$ are coordinates of point m [6].

There is a set of values of multidimensional space points of M:

$C_M = \{c_{i1},i_2,..,i_N \mid i_1 = 1..I_1, i_2 = 1..I_2, .. ,i_n = 1..I_N\}$, where $c_{i1},i_2,..,i_N$ is a value of the point of multidimensional space M with coordinates $(i_1,i_2,..,i_N)$. For every point of space M there is a single value from $C_M$ set or there is no such value. Thus, $C_M$ is a set of data model state changes represented in multidimensional space. To implement a transition between multidimensional space and set of points values the relation has been introduced: $C_x = \mu(M_x)$, where $M_x \subset M$, $M_x = F_{1x} \times F_{2x} \times ... \times F_{Nx}$.

To describe a data model in mivar information space it is necessary to identify three axes:

- The axis of relations «O»;
- The axis of attributes (properties) «S»;
- The axis of elements (objects) of subject domain «V».

The axes «V», «S», «O» are presented in **Fig. 1** [6]. These sets are independent. The mivar space can be represented by the following tuple:

<V, S, O>

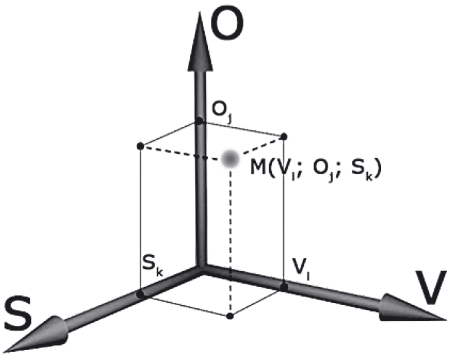


**Fig. 1.** Mivar information space

The point with certain coordinates corresponds to each relation attribute value in multidimensional space. Relations connect elements of the space. The set of all multidimensional space points corresponds to the data model. The structure of the model in mivar approach is defined by space points that store corresponding relation attribute values. Mivar network can be represented in the form of a bipartite graph [5–6].

One of basic concepts of the proposed mivar-based approach is the concept of mivar network [6]. Generally, mivar network provides formalization and representation of human knowledge in the form of connected multidimensional space. That is, mivar network is a method of representing a piece of mivar space information in the form of a bipartite directed graph. The mivar space information is formed by objects and connections between them, which in total represent the data model of the subject domain, moreover, connections include rules for objects processing. Thus, mivar network of subject domain is a part of mivar space knowledge in this domain.

Mivar networks can be represented in the form of a bipartite graph consisting of objects-variables and rules-procedures. First, two lists are made which form two nonintersecting partitions of the graph: the list of objects and the list of rules. Objects are denoted by circles. Each rule in mivar network is extension of productions, hyper rules with multi-activators. It is proved that from the perspective of their further processing, all these formalisms are identical and in fact they are nodes of the bipartite graph which are denoted by rectangles [12].

### *2.1. Parameters and classes in mivar space*

Parameter is a single terminal object that has meaning on this abstraction level. The length of the side AB of the triangle ABC can be used as an example. Parameter is a leaf in the element hierarchy tree in the model. Parameter can be connected with only one internal node (class) [1].

Class is an internal node of the hierarchy tree. Class has no meaning and can contain other internal nodes (other classes) or/and leaves (parameters). For example, class can be a “triangle” that stores parameters of the sides and angles. Class can be a “division”, which can contain not only its parameters (name, list number, location, etc.), as well as other classes, for example, rotas. The introduction of classes allows us to simplify description of the model containing several objects of the same type. The user does not have to enter all the information again and search for parameters in the whole model. It is sufficient to copy and enter a new instance. One more difference between class and parameter is that class can contain the list of internal rules of the class.

Internal rule of the class is a rule enabling only parameters that are descendants for a particular class. For example, internal rule for a triangle will be “angle C =180 – angle B” since all these angles are descendant parameters of the class “triangle”. Introduction of internal class rules allows us to simplify development of similar objects according to the pattern, as internal rules will be automatically generated

for a new class instance. Except for this, they do not differ from simple rules.

### *2.2. Relations in mivar space*

Relations are a renewed element of mivar space. Relation describes interconnection between abstract variables. For example, “a=b-c” is an abstract subtraction formula. Relation stores its type, the list of input variables and the list of output variables, types of used variables and description.

Relations can be as follows:

1. Mathematical. A simple formula “a=b-c” can be an example;
2. Conditional. For example, “if y is 10, then x is 14, else x is 7”;
3. Programmable. Software code with its inputs and outputs can be used as an example.
4. String. For example, “loves”, “connected”.
5. System. “The part-the whole”.
6. Location. For example, “over”, “right”, etc.

The rule contains the link to the relation and connects particular objects from the model. It is designed to simplify description of subject domains and repeated use of the same even complex programmable properties. For example, we have a mathematical relation with the formula “a=b-c”. It can denote account balance after paying something, as well as the number of apples, if we had 10 apples and gave one to somebody.

Rules contain at least:

1. The list of input variables;
2. The list of output variables;
3. Relation identifier.

It should be noted that the mivar constraints mechanism has been proposed, which allows us to transmit information about the real world more accurately and track its change. Due to constraints it is possible to signal any emergency in Automated Process Control Systems or indicate wrong input data [1].

### 3. Description of model design in the system Wi!Mi

There is special Wi!Mi software, which allows us to represent all the data in the form of the mivar semantic graph VSO [2–14]. Using the Wi!Mi software, the user can design a model of his subject domain, which will be a logical kernel for a particular modelling task.

When designing a model in the Wi!Mi system, each object should have the following properties:

- It should have the unique identifier (UID);
- It should have a name;
- It can have a description;
- It should have a type (number, text, flag, etc.);
- It can have value;
- It should have constraints for values;
- It should have one or several characteristics that either belong to the object or they are inherited through connection (using object-oriented approach). It is also necessary to designate the object from which inheritance is implemented.
- It can be located on a certain level in the hierarchy (using object-oriented approach)
- It can have any number of connections with other objects of the model.

Thus, the following conclusion can be drawn: Wi!Mi platform is a convenient designer for describing logical rules of any subject domains. The user is only required to set parameters for a particular subject domain.

### 4. Designing algorithms for solving physics problems.

As an experiment in testing capabilities of Wi!Mi software, the model has been designed, which allows us to solve physics problems from the year 8 school course. To carry out the experiment a new version of software product Wi!Mi 2.1 was used. Structurally the model consists of three subclasses corresponding to the subject matter of the problems being solved:

- Thermal phenomena;
- Electrical and electromagnetic phenomena;
- Optical phenomena.

### *4.1. The subclass "Thermal phenomena"*

The subclass "Thermal phenomena" is used to solve problems related to change in body temperature and interrelated processes. This subclass in described in the **Table 1**.

*Table 1.*

**The description of the subclass "Thermal phenomena"**

| № | Symbol | Type | Description |
|---|---|---|---|
| | Q | number | The quantity of heat [J] |
| | m | number | mass [kg] |
| | Δt | number | $(t_2 - t_1)$ – difference of temperature [°C] |
| | t1 | number | Initial temperature [°C] |
| | t2 | number | Final temperature [°C] |
| | c | number | Specific heat capacity [J /kg ·C] |
| | q | number | Specific heat of fuel combustion [J /kg] |
| | λ | number | () specific heat of fusion [J/kg] |
| | L | number | Specific heat of vaporization [L/kg] |
| | Q fusion | number | The quantity of heat during fusion [J] |
| | Q heating | number | The quantity of heat during heating [J] |
| | Q combustion | number | The quantity of heat during combustion [J] |
| | Q vaporization | number | The quantity of heat during vaporization [J] |
| | V | number | Volume of body/liquid/gas [$m^3$] |
| | ρ | number | Density of body/liquid/gas[$kg/m^3$] |
| | COP | number | The coefficient of performance [%] |
| | A useful | number | Useful work [J] |
| | A done | number | Work done [J] |

Let us solve the following problem:

Determine the COP of tractor engine that required 1,5 kg of fuel with specific heat of combustion 4,2·107 to perform work of 1,89·107 J.

Enter the corresponding numbers into the fields "Values" (**Fig. 2**).

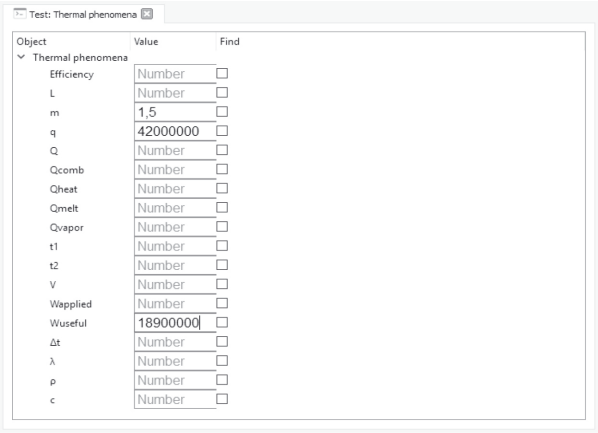


**Fig. 2.** Fields with corresponding numbers in the subclass "Thermal phenomena"

Next, click on the checkbox "Find" in the row with the required parameter. In this case this parameters is "COP" as it is required to find this parameters according to the problem statement.

After clicking on the "Run" button, the Wi!Mi 2.1 software will implement the calculation. The corresponding parameters will acquire given values (they will be highlighted in red) (**Fig. 3**):

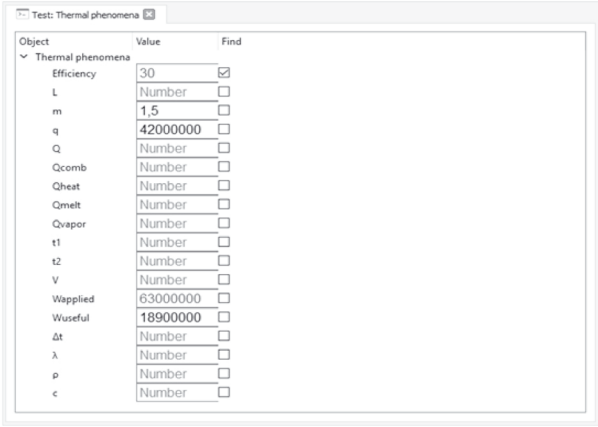


**Fig. 3.** The result of the calculation in the subclass "Thermal phenomena"

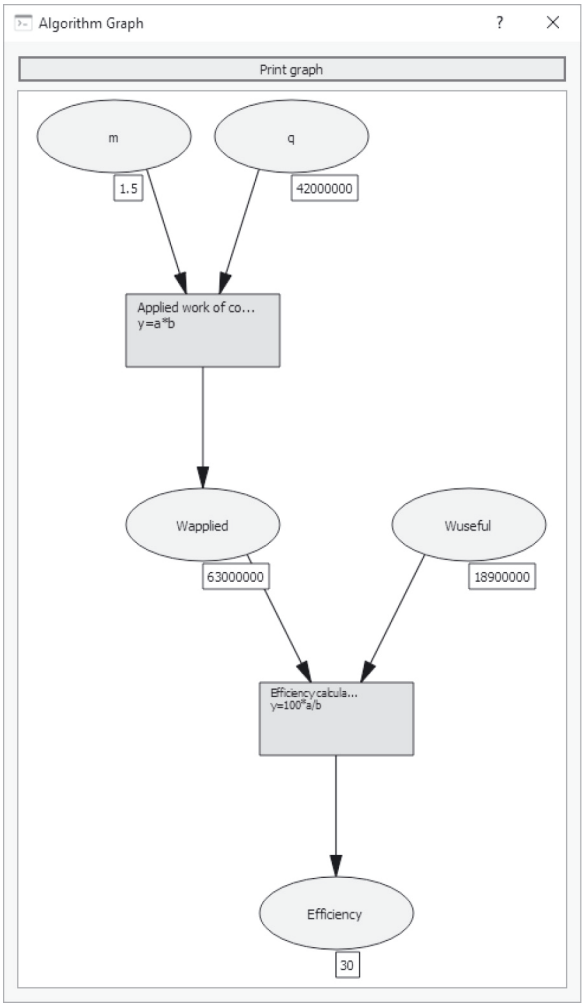


**Fig. 4.** Algorithm for finding COP parameter in the form of the graph

The corresponding output will appear in the tab “Console”:

Step № 0

Rule description: The calculation of the work done during combustion (A done = mq)

Input parameters:
m=1.5;
q=42000000;
Formula:
y=a*b
Result: A done=63000000;
---
Step № 1
Rule description: The calculation of COP using the known work (n=A useful/A done*100)
Input parameters:
A useful=18900000;
A done=63000000;
Formula:
y=100*a/b
Result: COP=30;
---

**Fig. 4** represents the result of the calcultion in the form of a graph. The obtained result corresponds to analytical solution:

$$COP = \frac{A_{useful}}{A_{done}} \cdot 100\% = \frac{A_{useful}}{qm} \cdot 100\% =$$

$$= \frac{1{,}89 \cdot 10^7 \cdot J}{4{,}2 \cdot 10^7 \frac{J}{kg} \cdot 1{,}5kg} \cdot 100\% = 0{,}3 \cdot 100\% =$$

$$= 30\%$$

### *4.2. The subclass "Electrical and electromagnetic phenomena"*

The subclass "Electrical and electromagnetic phenomena" is used to solve problems associated with concepts of current intensity, voltage, resistance. This subclass is described in the **Table 2**.

*Table 2.*

**Description of the subclass "Electrical and electromagnetic phenomena"**

| № | Symbol | Type | Description |
|---|---|---|---|
| | I | number | Current intensity [A] |
| | q | number | Electric charge [Kd] |
| | t | number | time [s] |
| | U | number | voltage [V] |
| | A | number | work [J] |
| | R | number | resistance [Ohm] |
| | ρ | number | Specific resistance [Ohm·mm$^2$/m] |
| | dl | number | length [m] |
| | s | number | cross-sectional area [mm$^2$] |
| | Ai | number | Work of current [J] |
| | P | number | Power [W] |
| | Qi | number | The quantity of heat generated by the conductor [J] |

Let us solve the following problem:

The current intensity in the iron conductor with the length of 150 mm and cross-sectional area of 0,02 mm2 is 250 mA. What is the voltage at the ends of the conductor, if specific resistance of iron is 0,098 ohm·mm2/m. Enter the corresponding numbers into the fields "Values" (**Fig. 5**).

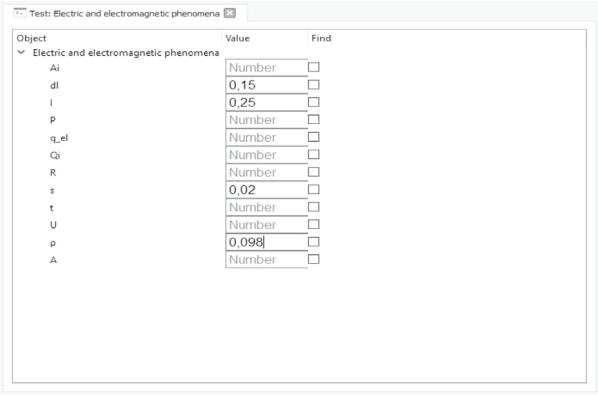


**Fig. 5.** Fields with corresponding numbers in the subclass "Electrical and electromagnetic phenomena"

Next, click on the checkbox “Find” in the row with the required parameter. In this case this parameters is “U”(voltage) as it is required to find this parameters according to the problem statement.

After clicking on the “Run” button, Wi!Mi 2.1 software will implement the calculation. The corresponding parameters will acquire given values (they will be highlighted in red) (**Fig. 6**):

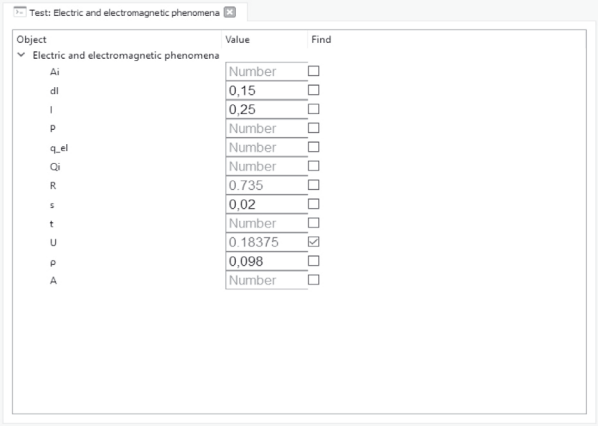


**Fig. 6.** The result of the calculation in the subclass “Electrical and electromagnetic phenomena”

The corresponding output will appear in the tab “Console”:

Step # 0

Rule description: The calculation of resistance using the known parameters of the conductor (R=ro*dl/s)

Input parameters:

ρ=0.098;

dl=0.15;

s=0.02;

Formula:

y=a*b/c

Result: R=0.735;

---

Step # 1
Rule description: The calculation of voltage using Ohm's law (U=IR)
Input parameters:
I=0.25;
R=0.735;
Formula:
y=a*b
Result: U=0.18375;
---

**Fig. 7** represents the result of the calculation in the form of a graph.

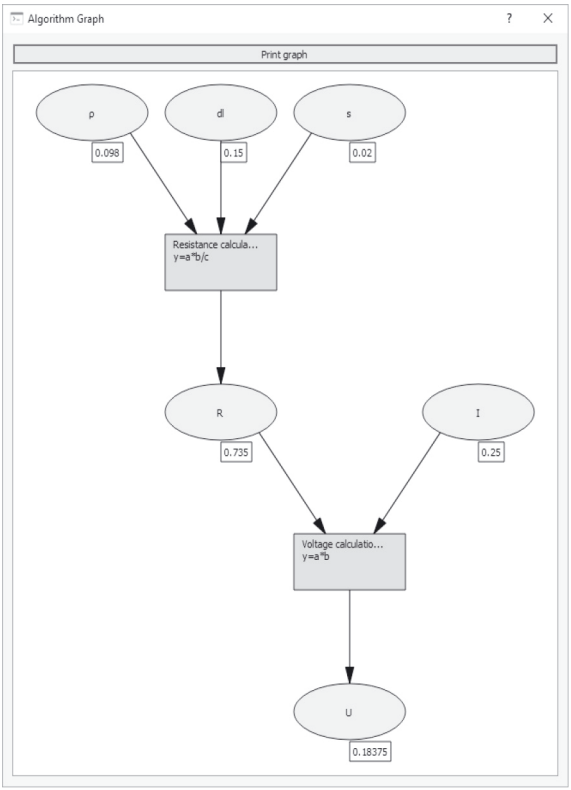


**Fig. 7.** Algorithm for finding U parameter (voltage) in the form of a graph

The obtained result corresponds to analytical solution:

$$U = IR = I\frac{\rho \cdot \Delta l}{S} =$$

$$= 250 \cdot 10^{-3} A \cdot \frac{0{,}098 \frac{Ohm \cdot mm^2}{m} \cdot 150 \cdot 10^{-3} m}{0{,}02\, mm^2} =$$

$$= 0{,}18375 V$$

### *4.3. The subclass "Optical phenomena"*

The subclass "Optical phenomena" is used to solve problems related to the calculation of lens parameters. This subclass is described in the **Table 3**.

*Table 3.*

**Description of the subclass "Optical phenomena"**

| № | Symbol | Type | Description |
|---|---|---|---|
| | D | number | optical power of a lens [dioptre] |
| | F | number | lens focal length [m] |
| | d | number | the distance from the object to the lens [m] |
| | f | number | the distance from the lens to the image [m] |

Let us solve the following problem:

The distance from an object to the thin lens is 5 m, the distance from the lens to the image is 20 m. Determine the focus of the lens and its optical power.

Enter the corresponding numbers into the fields "Values" (**Fig. 8**).

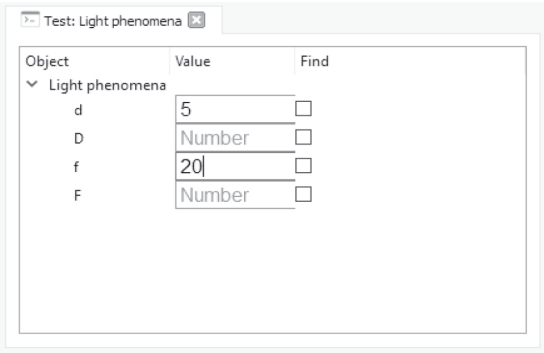


**Fig. 8.** Fields with corresponding numbers in the subclass "Optical phenomena"

Next, click on the checkbox “Find” in the row with the required parameter. In this case this parameters is “D”(optical power) and “F” (focal length) (as it is required to find this parameters according to the problem statement.

After clicking on the “Run” button, Wi!Mi 2.1 software will implement the calculation. The corresponding parameters will acquire given values (they will be highlighted in red) (**Fig. 9**):

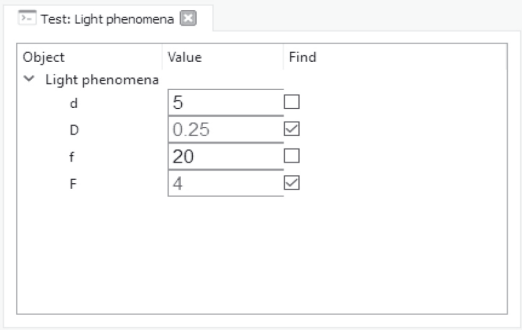


**Fig. 9.** The result of the calculation in the subclass “Optical phenomena”

The corresponding output will appear in the tab “Console”:

Step # 0
Rule description: The calculation of focal length using known distances to the lens (F=df/(d+f))
Input parameters:
d=5;
f=20;
Formula:
y=a*b/(a+b)
Result: F=4;
---
Step # 1
Rule description: The calculation of optical power using the known distances to the lens (D=(d+f)/df)

Input parameters:
d=5;
f=20;
Formula:
y=(a+b)/a/b
Result: D=0.25;
---

**Fig. 10** represents the result in the form of a graph.

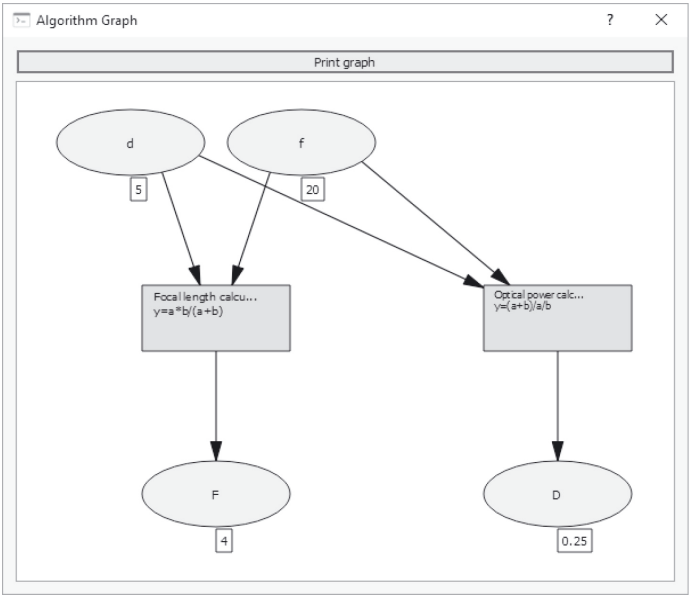


**Fig. 10.** Algorithm for finding parameters "D" (optical power) and "F" (focal length) in the form of a graph

The obtained result corresponds to analytical solution:

$$F = \frac{d \cdot f}{d + f} = \frac{5m \cdot 20m}{5m + 20m} = 4m$$

$$D = \frac{1}{F} = \frac{1}{4m} = 0{,}25 dioptre$$

## 5. Conclusions

Mivar-based logical inference method is universal. It can be used not only for writing simple subject domains, but also for solving complex multi-level tasks. [1]. Mivar-based approach is applied to simulation modelling. Research has been carried out, which has proved the prospect of combining mivar logical kernel and simulation modelling system [16]. Such synthesis will allow us to model behavior of objects of considered subject domain, which will allow us to test algorithms in different set conditions virtually.

The mivar theory has been considered and described in the paper. The concepts of parameters, relations and classes have been addressed. The paper also describes the process of algorithm construction for solving physics problems from the year 8 school course in Russia on the basis of software product Wi!Mi 2.1. Thus, the paper proves the value of using mivar-based method for designing expert systems.

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# ECONOMIC INDICATORS OF ROAD SURFACES RECONSTRUCTIONS IN THE WORLD USING NON-WASTE TECHNOLOGY

*Izmaylova D.K., Seliverstov N.D.*

*The article describes the cost formation of restoration of road surfaces using the methods of replacing and processing the damaged layers. There is a mathematical model of cost of the one unit of production including the cost of building materials with delivery. The estimation of the total cost of repairs in the variable amount using the technology of full replacement of the surface and processing technology of the 50% of the material on the site.*

***Keywords:*** *pavement; repair; processing; cost of unit; delivery price; non-waste technology.*

## 1. Introduction

Costs of building and reconstruction of roads are steadily growing. Total length of paved roads is increasing, the technology of production is improving and the costs of construction materials production are also growing. Average life of Russian roads is about 10–13 years. For comparison, in China and the developed European countries – 20 years, in the US and Germany is up to 30 years. The average cost of building of 1 kilometer of highway in Russia is 2–3 times lower than in Germany and the United States. The cost of individual construction projects can differ by 20–30 times.

The comparison is indicative, in various countries there are different factors affecting the total cost: the costs structure of construction and installation works; design standards of geometric elements

of road; rules for design loads and model construction pavements; the conditions of highways construction (terrain, climate). The average costs of building of 1 kilometer of highway in different countries are given in Table 1.

*Table 1.*

**The average costs of building of 1 kilometer of highway in different countries**

| № | Country | The cost of 1 km strip not including the VAT, mln rubles | | |
|---|---|---|---|---|
| | | Average | Minimal | Maximal |
| 1 | Russia | 41 | 30 | 73 |
| 2 | USA | 72 | 20 | 166 |
| 3 | China | 35 | 42 | 92 |
| 4 | Canada | 82 | 65 | 185 |
| 5 | Germany | 122 | 80 | 162 |
| 6 | Finland | 40 | 22 | 66 |
| 7 | Spain | 50 | 30 | 76 |
| 8 | France | 101 | 73 | 174 |

High-speed and high-quality construction of roads requires high technology and high-tech equipment. Reducing the cost of restoration of the damaged road surfaces is achieved through the use of new means of mechanization and processing technology of asphalt concrete material layer [3]. The volumes of recycled road surfaces are constantly growing [5]. Non-waste technology is provided by recycling of the existing pavement material cyclically using asphalt mixing plants or continuously by means of special technological complexes – «recyclers». Cyclical cold processing is a set of operations implemented by the technological complex: road milling machine, wheel loader, mixing machine, tipper for material transportation, asphalt paver, road roller.

Analysis of the enterprise economic mechanism functioning at all stages of the production process helps to increase the competitiveness of products. Reduction of the cost of road construction works is the main feature that leads to the increase of the competitiveness of organizations, improves the efficiency of enterprises and profitability. Reducing the cost of construction, repair and reconstruction of road surfaces is

provided at the project planning stage, due to the optimization of complex mechanization, optimization of parameters and operating modes of individual units. Dislocation of asphalt mixing equipment considering the working place determines the means of mechanization.

The cost of restoring of the road surface made up of the machine-hour cost and the cost of construction materials delivered to the work site.

$$C_{ЕП} = \frac{C_{МЧ}}{П} + C_{МД}, \text{ rubles/m}^3, \quad (1)$$

$C_{МЧ}$ – the cost of machine-hour, rubles/hour

$П$ – technical complex capacity, m$^3$/hour

$C_{МД}$ – the cost of building material delivery, rubles/m$^3$

To estimate the cost of road surface reconstruction works using non-waste technologies there are discussed several ways to implement the recycling process – 1) on the remote mixing equipment (stationary/mobile plant/asphalt mixing plant); 2) using the «recycler» in process of work while removal/installation surfaces in conjunction with machinery for feeding a binder and/or water-cement slurry. In the first case for transporting materials between the cycles used tippers and wheel loaders. In both cases, there is a pre-set percentage of the material in the recycling of the new mixture.

## 2. Calculating the machine-hour cost

Calculating the machine-hour cost of the «recycler» (refiner) of pavement, road milling machine and paver includes calculation of the following types of costs: depreciation, labor costs of drivers and mechanics, the cost of fuel and lubricants for construction machinery, the cost of the hydraulic fluid, the cost of tires, the cost of relocation of the machine, the costs for maintenance and repair. Cost of machine-hour is defined as:

$$C_{МЧ} = C_{А} + C_{ОТ} + C_{ГСМ} + C_{ГЖ} + C_{ШГ} + C_{ПЕР} + C_{ТОР}, \text{ rubles/hour} \quad (2)$$

Depreciation depends on the value of purchased machines and annual operating mode, which establish monthly depreciation rate and the depreciation of 1 machine-hour. Labor costs of drivers and mechanics are calculated considering the employee's hourly rate with premiums and insurance premiums. POL (petroleum oil lubricants) costs of machinery are determined by the cost of materials and standards of fuel consumption in liters per one machine-hour. Costs of hydraulic fluid depend on the capacity of the hydraulic system, the hydraulic fluid density, complete replacement frequency (times/year) and fluid flow rates per one machine-hour. Calculation of the cost of tire of considers the average annual mileage of the car, tire price, the cost factor in the tire delivery, as well as the cost of norms for the restoration and repair of tires considering a normative mileage. Costs for relocation of a machine on a trailer depend on the fuel consumption per 100 km, fuel price in the region. Relocation of machinery is available under its own power. Costs on maintenance are based on the estimated replacement costs, balance of the working time and annual costs.

The level of machine-hour costs of mechanization on expenditure is presented in Table 2.

*Table 2.*

**Calculation of machine-hour costs of road machines**

| Expenditure | Level of mechanization costs, ruble/hour | | |
|---|---|---|---|
| | Milling machine W2000 | Paver Vogele super 1800-2 | «Recycler»WR 2000 |
| Depreciation | 1684,66 | 2059,6 | 4350,58 |
| Labor costs of drivers and mechanics | 273,45 | 273,45 | 215,12 |
| POL costs of construction machines and mechanisms ** | 1729,39 | 501,42 | 1245,02 |
| Cost of hydraulic fluid | 132,77 | 137,2 | 141,62 |
| Tires expenditures | - | - | 84,74 |
| The cost of relocation of the machine on trailer | 78,41 | 78,41 | 78,41/866,58* |
| Maintenance | 1768,9 | 1213,2 | 2020,75 |
| Total | 5666 rub/h | 4264 rub/h | 8923 rub/h |

* – relocation under its own power.

Constructional and estimated productivity. Maximum technical productivity is established by minimizing the duration of work operations and machine cycles that are considered in [1, 2]. At the stage of pre-calculations for estimating the road surface restoration costs used construction productivity of the complex which is determined on the basis of technical specifications and recommended modes of work:

$$П = 60 \cdot B \cdot h \cdot V_i, \text{ m}^3/\text{h};$$

$B$ – width of the road surface, m;

$h$ – depth of the layer, m;

$V_i$ – speed of machinery arriving, machine/minute.

### 3. Calculations of the material delivery costs

Cost of construction material delivery is calculated considering specific transportation conditions of individual components and asphalt mixtures according to the formula:

$$C_{МД} = \sum_{i=1}^{n} \left(C_М + C_Д\right)_i, \text{ rubles/m}^3, \quad (3)$$

$C_{МЧ}$ – cost of i-th material, ruble/m$^3$;

$C_Д$ – delivery cost of i-th material, ruble/m$^3$.

Delivery cost of asphalt mixture or the i-th component of the mixture (rubble, sand, asphalt emulsion, cement, lime, water, etc.) by transport is determined by the formula:

$$C_Д = \frac{C_{МЧД}}{П_Д} = \frac{C_{МЧД} \cdot l}{Q_{ТС} \cdot V_{ТС}}, \text{ rubles/m}^3, \quad (4)$$

$C_{МЧД}$ – machine-hour cost of transport, ruble/hour;

$П_Д$ – transport productivity, m$^3$/hour;

$l$ – transportation distance, m;

$Q_{ТС}$ – volume of transport, m$^3$;

$V_{ТС}$ – speed of transport, m/hour.

Based on calculations (3) (4):

$$C_{МД} = \sum_{i=1}^{n} \left(C_{МДii}\right)_i = \sum_{i=1}^{n} \left( C_{Mi} + \frac{C_{МЧД} \cdot l}{Q_{TC} \cdot V_{TC}} \right)_i, \text{ rubles/m}^3, \qquad (5)$$

In the case of delivery of the required volume of material several times the total cost of m$^3$ is calculated according to the formula:

$$C_{ДОбщая} = \frac{C_{МЧД} \cdot l}{Q_{TC} \cdot V_{TC}} \cdot N = \frac{C_{МЧД} \cdot l \cdot Q_M}{Q_{TC}^2 \cdot V_{TC}}, \text{ rubles/m}^3, \qquad (6)$$

$N = \dfrac{Q_M}{Q_{TC}}$ – quantity of times during the delivery;

$Q_M$ – total material volume, m$^3$;

$Q_{TC}$ – volume of transport, m$^3$.

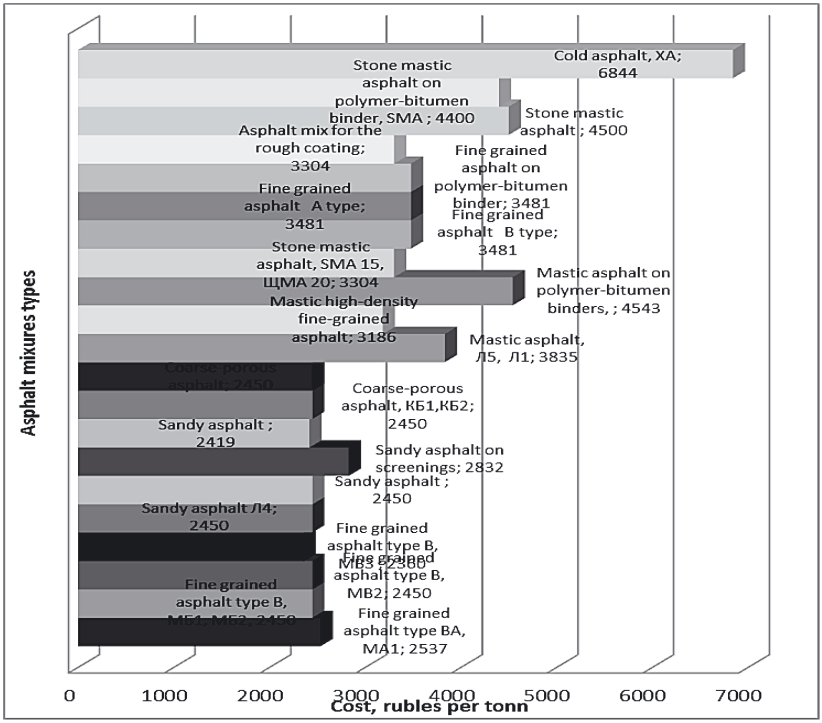


**Fig. 1.** Cost of 1 tone of asphalt mixture

Figure 1 shows the values of cost of the various types of asphalt mix, including cold asphalt, mastic asphalt on polymer-bitumen binders, stone mastic asphalt (SMA) on a different binder.

The ability to re-use and the desired composition of the asphalt mixtures of materials in processing of road surfaces are determined by the laboratory analysis [4]. Then, the analysis of volumes and transportation conditions of necessary components and mixtures of materials is taking place (Table 3).

*Table 3.*

**Material and mixture component data**

| № | Component of the mixture | Price rub/ $m^3$ | Total material volume, $m^3$ | Transportation distance, m | Transportation speed allowed, km/h |
|---|---|---|---|---|---|
| 1 | Gravel | 1500 | 10 000 | 10 000 | No limits |
| 2 | Sand | 800 | 100 | | 60 |
| 3 | Bitumen | 19 000* | 10 | | 60 |
| 4 | Mixture | 10 000** | 120 | | |

* – The average density of bitumen is 0,95-1,50 g / cm3, the average density of bitumen emulsion – 1 g / cm3 = 1000 kg / m3, the price is 19 rubles / kg.

** – The average density of asphalt mix is 2500 kg / m3, the price Stone mastic asphalt mix - 4000 RUR / tone.

Table. 3 helps to calculate the total cost of materials, work mechanization and implementation of the project. On the basis of (6) there are determined total costs of materials:

$$C_{МД}^{\Sigma} = \sum_{i=1}^{n} \left( C_{МДi} \cdot Q_{Mi} \right), \text{ rubles,}$$

$$C_{МД}^{\Sigma} = \sum_{i=1}^{n} \left( C_{Mi} \cdot Q_{Mi} + \frac{C_{МЧ} \cdot l \cdot Q_{Mi}^2}{Q_{TC}^2 \cdot V_{TC}} \right), \text{ rubles.}$$

Total costs of the work:

$$C_{ЕП} = \frac{C_{МЧ}}{П} \cdot Q_{РАБОТ}.$$

Total project costs:

$$C_{ЕП}^{\Sigma} = \frac{C_{МЧ}}{П} \cdot Q_{РАБОТ} + \sum_{i=1}^{n} \left( C_{Mi} \cdot Q_{Mi} + \frac{C_{МЧ} \cdot l \cdot Q_{Mi}^2}{Q_{TC}^2 \cdot V_{TC}} \right), \text{ rubles}$$

**Evaluation of pavement restoration costs**

Considering the layer width of 2m and depth of 0.1m the speed road milling machine is equal to the maximum speed of paving the mixture considering the working hours of pre-sealing aggregate:

$$V_Ф = V_У = 10 \text{ м / мин.}$$

The average maximum speed of milling and mixing unit recycler arrival is: $V_C = 5 \text{ м / мин.}$

Replacing and recycling the layer width of 2m and the depth of 0.1 m structural productivity of road milling machine $П_Ф$ and paver $П_У$ comparable:

$$П = П_У = П_Ф;$$

$$П = 60 \cdot B \cdot h \cdot V_i = 60 \cdot 2 \cdot 0{,}1 \cdot 10 = 120 \text{ м}^3/\text{ч};$$

The damaged material is removing from the surface, transported from the work site or transported to the asphalt plant for processing. New asphalt concrete mixture is transported from the plant back for paving.

$$C_{ЕП} = C_{ЕПФ} + C_{ЕПУ} + C_{МД} = \frac{C_{МЧФ} + C_{МЧУ}}{П} + C_{МД}, \text{ rubles/m}^3.$$

At equal productivity unit cost of production of milling plant and paver is based on the data of Table 1 under the formula:

$$C_{ЕПФ} + C_{ЕПУ} = \frac{C_{МЧФ} + C_{МЧУ}}{П}, \text{ rubles/m}^3.$$

Analyzing the nature of the changes in unit costs for the given conditions of material delivery (Table 2) at a variable transportation distance $l$ = var (Figure 3):

$C_{МЧД}$ = 2000, ruble/hour; $C_M$ = 10000, ruble/m$^3$; $Q_{TC}$ = 15, m$^3$; $V_{TC}$ = 45, km/h.

Provided that there is no removal of damaged material, the delivery cost of the material is determined by the ratio:

$$C_{МД} = \sum_{i=1}^{n} \left( C_{Mi} + \frac{C_{МЧД} \cdot l}{Q_{TC} \cdot V_{TC}} \right)_i = 10000 + \frac{2000 \cdot l}{15 \cdot 45000} = 10000 + 2{,}96 \cdot 10^{-3} \cdot l$$

Cost of production units for milling-paving material in a volume of 120 m$^3$:

$$C_{EП} = \frac{5666 + 4264}{120} + 10000 + 2{,}96 \cdot 10^{-3} \cdot l, \text{ rubles/m}^3;$$

$$C_{EП} = 82{,}75 + 10000 + 2{,}96 \cdot 10^{-3} \cdot l, \text{ rubles/m}^3.$$

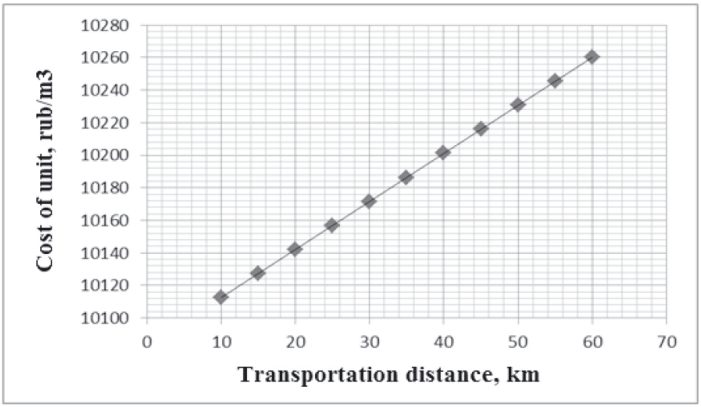


**Fig. 3.** Increase of the replacement cost of a 120 m$^3$ of asphalt surface with increasing transportation distance of a new asphalt mix

An analysis of the graph in Figure 3 shows that the unit cost of production of road milling machine and paver is largely determined by the price of asphalt mix. The volumes of work have little effect on the cost of replacing a 1 m$^3$ of material.

There are two cases:

Case 1: Replacement of the surface layer, removal of the damaged layer by the road milling machine. New asphalt concrete mixture is brought up from the factory and paved by the paver;

Case 2: Replacement of the surface layer, removal of damaged layer. Some material is processed on place, mixed with new asphalt mixture, which is brought up from the factory and the resulting mixture is placed in coating. All process steps are carried out by one machine.

To assess the cost-effectiveness of the compared technologies, consider the overall changings of replacement costs of the 1000 m3. Total costs for reconstruction work in the volume of 1000 m3 for the technology of complete replacement of the asphalt pavement:

$$C_{EП}^{\Sigma} = \frac{C_{МЧ}}{П} \cdot Q_{РАБОТ} + \sum_{i=1}^{n} \left( C_{Mi} \cdot Q_{Mi} + \frac{C_{МЧ} \cdot l \cdot Q_{Mi}^2}{Q_{TC}^2 \cdot V_{TC}} \right), \text{ rubles.}$$

$$C_{EП}^{\Sigma} = 10082750 + 197{,}5 \cdot l.$$

Total costs for reconstruction in the volume of 1000 m3 at 50% of the processing technology of asphalt pavement:

$$C_{EП}^{\Sigma} = 5148700 + 49{,}38 \cdot l.$$

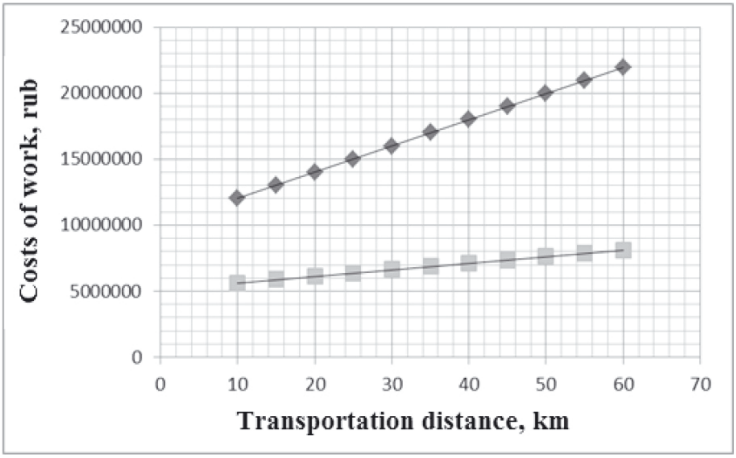


**Fig. 4.** Comparison of the cost of repairs to a volume of 1000 m$^3$ using the conventional method (1) and with the method of processing and reuse of 50% damaged material (2)

An analysis of the graph in Figure 4 shows that an increase in repair cost of recycled material occurs at a lower intensity compared to the technology of full replacement of coating layers. The intensity of the increase is graphically shown in Figure 5.

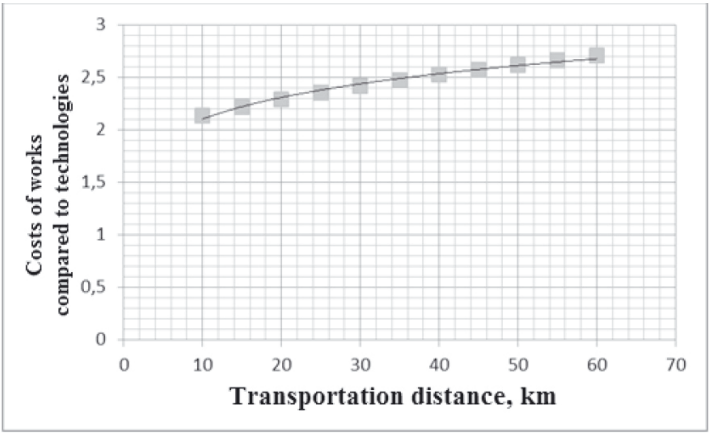


**Fig. 5.** Analysis of the cost of repairs to a volume of 1000 m3 using the conventional method and with the method of processing and reuse of 50% damaged material

## Conclusion

In the planning phase of capital investments for restoration of the road surface using the non-waste technology cost savings are achieved through the rational distribution of construction sites relative to the base production / processing of road-building material. In certain operating conditions, processing technologies became priority in the repair and reconstruction of road surfaces.

Unit cost of coating layers repairing is determined primarily by the cost of asphalt mix. The dynamics of the direct total cost of repairs is determined by the degree of re-use and workload.

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# ECONOMY OF A NON-WASTE ROAD REPAIRING AND COVERING TECHNOLOGY IN DIFFERENT COUNTRIES

*Izmaylova D.K., Seliverstov N.D.*

*The article questions the economic feasibility of the use of a non-waste repairing and restoration technology for the road surfaces. While writing this article there were conducted several analyses, for example: analysis of consumption volumes of mineral components of asphalt mixtures based on the geography of the commodity market, analysis of changes in cost of materials considering transport conditions. Also defined the conditions and preferential types of asphalt concrete processing in different countries.*

***Keywords:*** *non-waste technology; paving; repair; restoration; transportation material; mineral material.*

## 1. Introduction

Construction, renovation, restoration and maintenance of highways require a significant investment of the Russian Federation budget. Implementation of non-waste technologies of construction, renovation and restoration of asphalt concrete road surfaces is ensured by reuse of mineral materials of damaged layers during processing at workplace or at asphalt concrete plants. According to the CIA total length of roads, paved roads and highways in different countries is shown in Table 1 [10].

Asphalt base layer or coating is a mixture of binder and sorted mineral materials (mineral powder, natural and / or crushed sand, gravel and / or crushed stone) [3]. Composition of the mixture for the base

layer is selected in a way that the storage density and particle size distribution layer could no longer vary under the influence of transportation load. The size of the sorted mineral grains selection depends on the thickness of the layer.

*Table 1.*

**Total length of roads, paved roads and highways in different countries**

| *№* | *Country* | *Total length, thousands of km* | *Paved roads, thousands of km* | *Highways, thousands of km* |
|---|---|---|---|---|
| 1 | Russia | 1283 | 928 | 43 |
| 2 | USA | 6587 | 4306 | 80 |
| 3 | China | 4116 | 3454 | 100 |
| 4 | Japan | 1219 | 993 | 84 |
| 5 | Canada | 1042 | 416 | 17 |
| 6 | France | 1028 | 1028 | 15 |
| 7 | Germany | 645 | 645 | 13 |
| 8 | Sweden | 580 | 135 | 2 |
| 9 | Finland | 454 | 50 | 1 |
| 10 | Poland | 412 | 281 | 3 |
| 11 | Great Britain | 395 | 395 | 5 |
| 12 | Turkey | 386 | 353 | 2 |
| 13 | Hungary | 204 | 77 | 2 |
| 14 | Czech Republic | 131 | 131 | 1 |

During the processing on the plant there are taken into account qualitative characteristics of the mineral materials of damaged layers that define the possible share of the use of recycled raw materials for the hot mix asphalt concrete. Samples of the materials that are arriving at the asphalt concrete plant selected according to the rules of acceptance and certification: crushed stone – «GOST 8267-75», crushed gravel – « GOST 10260-74», gravel from metallurgical slag – «GOST 3344-73», gravel – «GOST 8268-74», sand – «GOST 8736-77», bitumen – «GOST 2517-69». The quality of surfactants and activators are checked due to the construction standards («VSN 59-68»).

## 2. Material volumes

Mineral material (gravel) is the major component of the mixture of various grades of asphalt concrete and is about 90% of the mixture. The development of gravel market is determined by the needs of industries of road and civil construction. Road construction industry is steadily developing, funding for the road industry in 2012 amounted to 392 billion rubles, in 2013 to 452 billion rubles and in 2014 to 477 billion rubles. The plan of commissioning new public roads is displayed on figure 1.

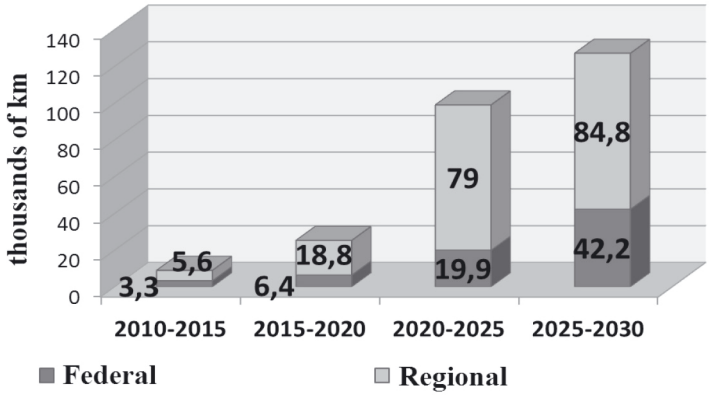


**Fig. 1.** The plan of commissioning new public roads

According to the Russian Transport Strategy the length of roads in 2030 will reach 1.7 million km. Positive outlook of increasing construction volumes and volumes of road repairing works, restoration and reconstruction leads to incentive growth of demand on mineral material-gravel, sand, mineral powder.

On the North-West, Central and Southern federal districts in each administrative district there are mined deposits of sand and sand and gravel materials which provide the road construction industry. The price of non-metallic building materials including transport costs increases to 30% for crushed stone and gravel and up to 90% on sand as a result ex-

port of extracted materials in other regions of Russia (except for the border regions),becomes uneconomical for suppliers and buyers. The entire volume of products produced on the region territory is implemented in the region or in the border regions of neighboring areas.

The volume of natural sand mining is an indirect indicator of the scale and speed of building complex. The volume of natural sand production in real terms is about 130 millions $m^3$ per year. The largest volume of sand production among all federal districts is in Central Federal District: in Q3. 2015 there were produced 13.2 million $m^3$ of natural sand which is 25.9% of the total volume. The second place with a share of 22.9% is the North-Western Federal District, the third place – Ural Federal district with a share of 21.4%. The share of all the other districts combined is only 30.6%.

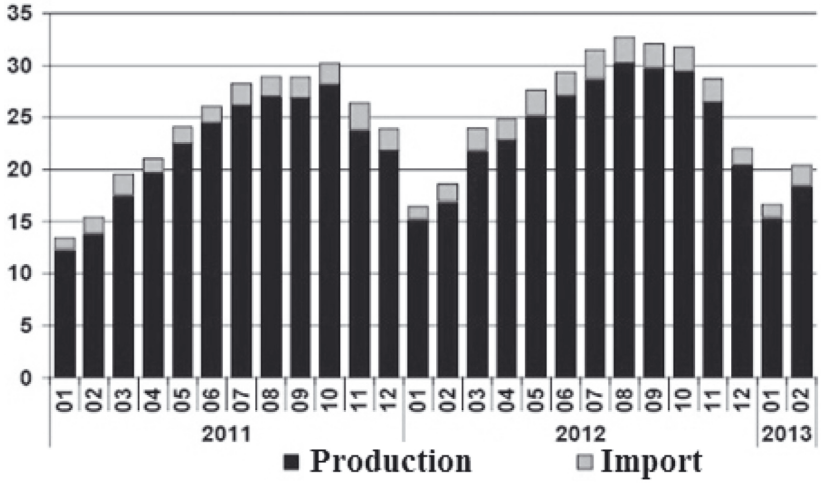


**Fig. 2.** Dynamics of consumption of pebble, crushed stone and gravel in Russia in 2011–2013

According to «Rosstat» rubble consumption in Russia is increasing by about 7% per year that is approximately 320 millions of tons. Imports are also showing positive trend and increasing by about 10% per

year. Dynamics of consumption of pebble, crushed stone and gravel in Russia are displayed in Figure 2.

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### 3. Cost of materials with delivery

The average selling price of one ton of rubble is about 600 rubles and stable in regions. In cases of building material shortages in some regions a steady growth in prices appears between 50–70%. Rubble and sand price changing depends on the volume of the purchased consignment. The most expensive kind of rubble is considered to be granite. The highest price purchasing more than 500 $m^3$ is set at 2000 rubles per 1 $m^3$ of granite rubble of 5–20 mm fraction. The most expensive type of sand is considered to be quarry sand which price is about 900 rubles per 1$m^3$. The cost of river sand is almost two times lower than the quarry one and is about 500 rubles per $m^3$. Average cost of asphalt mixture is 3000 rubles per ton.

Transportation of the material is carried by open wagons, mineral fertilizer hoppers and dump cars, the average rental rate of which is more than 1000 rubles per day. The cost of mineral material including the delivery to the end user increases up to 100% due to the constant growth of railway tariffs, transportation taxes, petrol, diesel and gas fuel prices. In terms of production asphalt mixtures on mobile and stationary plants, increasing prices of mineral materials including delivery lead to the costs increase of the finished mixture and repairing.

### 4. Technologies

Transportation costs take a significant part of the cost of purchased components of asphalt mixture and sometimes exceed their cost (for

example, delivery of construction sand and bitumen). Economically effective method of repairing and restoration of road surfaces is processing the mineral material of the damaged layer and re-using it by making new asphalt concrete paving using the non-waste technology. Volumes of cold milling granular asphalt and its re-use share in process of reconstruction of damaged road surfaces in the EU are increasing [4]. Local recycling provides cost savings on new building materials and their transportation.

The maximum effect is achieved by using high-performance systems such as "recycler", which for decades produced by leading foreign manufacturers of road machines – Wirtgen Group, Caterpillar, Roadtec, Heijmans. Dynapac, Volvo Construction Equipment, Terex and others [7]. These mechanization provides stabilization of road bases, production of hydraulic binders and new building mixes for base and the surface layers.

Table 2 shows the data of the European Association of asphalt pavements (EAPA) about the use of non-waste restoration coatings technologies in different countries and preferential types of processing asphalt concrete that determine how the implementation of the technology used and the types of mechanization [5, 6].

*Table 1.*

**Use of non-waste restoration coatings technologies in different countries and preferential types of processing asphalt concrete**

| Country | Asphalt that can be recycled | Types of recycling, % | | | | The use of recycled material for the CEO,% |
|---|---|---|---|---|---|---|
| | | Hot recycling | Warm recycling | Cold recycling | Disconnected layers | |
| Austria | 750000 | 95 | 0 | 3 | 2 | - |
| Belgium | 1500000 | 61 | - | - | - | 51 |
| Czech Republic | 1450000 | 18 | 37 | 25 | 20 | 10 |
| Denmark | 790000 | 83 | 0 | 0 | 17 | 58 |
| Finland | 860000 | - | - | - | - | 20 |
| France | 6900000 | 64 | - | - | - | 65 |

*End of the Table 1.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Germany | 11500000 | 90 | 0 | 0 | 10 | - |
| Greece | - | - | - | - | - | 0,03 |
| Great Britain | 4000000-5000000 | - | - | 10 | - | - |
| Hungary | 88000 | 80 | 0 | 10 | 10 | 20 |
| Iceland | 15000 | - | - | - | - | 3 |
| Ireland | 150000 | - | - | - | - | - |
| Italy | 10000000 | 20 | - | - | - | - |
| Luxembourg | 330000 | 90 | 0 | 10 | 0 | 50 |
| Holland | 4500000 | 76 | - | - | - | 70 |
| Norway | 686000 | 21 | 0 | 5 | 74 | 20 |
| Romania | 22000 | 20 | 20 | 20 | 30 | 10 |
| Slovakia | 26000 | 90 | 0 | 5 | 5 | - |
| Slovenia | 26000 | 26 | 0 | 20 | 54 | 5 |
| Spain | 205000 | 85 | - | 7 | 8 | 1,3 |
| Sweden | 900000 | 80 | 5 | 5 | 10 | 70 |
| Switzerland | 1370000 | 48 | 17 | 15 | 8 | 27 |
| Turkey | 1200000 | 3 | 1 | 1 | 95 | 1 |
| Japan | - | - | - | - | - | 76 |
| USA | 69000000 | 92 | 0 | 0 | 8 | - |

Processing is carried using hot, warm and cold technology. Disconnected layers are strengthened by the methods of cold stabilization. Currently there is a tendency of reducing of hot mix production that demonstrate the effective way of using warm asphalt mixes, which are prepared and mixed at a temperature of about 100 to 140°C and preferably cold mixtures that are prepared without heating the mineral material, bitumen emulsion or foamed bitumen. Cold processing is provided by the use of a special bitumen emulsion, which is stabilized by compaction or during mixing and eventually increases the adhesion strength between the particles of the material [4, 8]. Cold mixtures can be made using the innovative self-propelled milling and mixing units and mobile mixing plants, operating modes of which are determined by operating conditions [1, 2, 7].

## Conclusion

The geographic boundaries of the commodity market of new mineral materials are determined due to the location producing fields and dislocation of stationary asphalt plants. The full development of the new field of mineral material in the region requires large capital investments. In the case of remoteness of the road construction object from asphalt plants and / or remoteness of plants from mineral deposit it is economically advantageous to use recycling technology. Asphalt concrete is considered to be the most processed material, as it holds the strengths during the whole life cycle of the road surface.

As the main criteria of the efficient reuse of non-metallic building materials (rubble, gravel, sand, etc.), are taken the following factors: the quality of the mineral material of the damaged surface, the presence of explored and developed deposits; the ability to move goods between the territories; consumer safety properties during transportation; the absence of restrictions on importation or exportation of goods; established link between producers and consumers; price policy; transportation costs for the delivery of the components of asphalt mixture to the plant and the delivery of the final mixture to the consumer.

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# DESIGNING ALGORITHMS FOR SERVICE ROBOTS ON THE BASIS OF MIVAR APPROACH

***Panferov A.A., Zhdanovich E.A., Yufimychev K.A., Chuvikov D.A.***

*Opportunities of mivar-based approach for robots have been analyzed. Mivar-based method of rapid logical inference for calculating random algorithms of service robot functioning has been tested successfully. The logical model of office robot-guide functioning with the application of mivar-based method of rapid logical inference in the software environment "KESMI" (Wi!Mi 1.1) has been developed. Formalized map of the office for service robot has been described in mivar matrix, 63 objects for 100 rules. Simulation of robot functioning in the software environment V-REP has been performed.*

***Keywords:*** *algorithm calculation; artificial intelligence; MIVAR; service robotics; robot; simulation modeling.*

## 1. Introduction

The International Federation of Robotics (IFR) divides all the robots into industrial robots and service robots [1].

Industrial robots are automatically controlled, reprogrammable, multipurpose manipulators, which may be either fixed in place or mobile for use in industrial automation applications [1]. Industrial robots are designed to operate in a strictly controlled environment carrying out a limited set of production tasks. At the stage of implementation a highly limited set of specific algorithms and perception models of the outside world is required to ensure proper operation of industrial robots. It is important that such robots are capable of operating only within their algorithms and models.

Service robots are defined as mobile autonomous programmable or trained robots designed to operate in uncontrolled environment as well as interact with human. The autonomy of service robots is regarded as their capability to perform set tasks fully autonomously without involvement of an operator. Currently, capabilities of modern service robots are limited. Robots have not achieved reflex level of animals, whereas it is necessary to develop the level of 'a reasonable man'. Nowadays, new mivar-based technologies have made considerable advances in this area.

## 2. Analysis of mivar-based technology capabilities for robots

Mivar-based technologies have combined and integrated evolutionary databases with logical-and-computational processing with the linear complexity of logical inference [2–30]. Mivar-based technologies of information accumulation and information processing, which have been developing in Russia since 1985, have allowed us to create logical artificial intelligence or in other words 'brains' for robots [2–3]. For example, it is obvious that mivar-based technologies of information accumulation allow us to develop evolutionary models for real life with extremely large amounts of data. To ensure text meaning understanding the graph consisting of 160 000 nodes and more than 600 000 arcs has been designed in mivar-oriented information space [30].

From the perspective of robotics, it is important to underline mivar synthesis of models and methods for online diagnostics [17], which allowed us to justify the possibility of developing control system for autonomous mobile robot teams in 2004 [18]. Since 2012 mivars have allowed us to generalize logic in the field of AI and solve tasks of natural Russian language understanding [19], taking into account results of mivar intelligent system development [20], active reflection theory [21], evolutionary knowledge bases [22]. Modelling processes of text meaning understanding, speech and image understanding [23] has allowed us to use the results of logical and computational information processing for real-time simulators [24]. Research of mi-

vars on multi-processor computational cluster was carried out in 2009 [25] and the UDAV software was developed [26]. In the process of modelling text meaning understanding, speech and image understanding by computers [27] the automatic image tagging system based on mivar-based technologies has been developed [28] and the analysis of technologies of three-dimensional modelling and 3D object development has been carried out [29]. Thus, efficiency of mivar expert system application to solving tasks of text understanding and image recognition has been proved [31].

It should be noted that there is the expert system designer KESMI (Wi!Mi 1.1), which is a convenient tool for designing decision support system (DSS) for robot. Moreover, research has been carried out [8-10], which demonstrated the prospect of combining mivar logical kernel and simulation modelling systems [7]. Such synthesis will enable us to model behavior of industrial robots, which will allow us to test DSS algorithms in different set conditions.

Consequently, all the necessary conditions for development of autonomous intelligent robot with mivar 'logical brains' currently exist in Russia.

### 3. Research levels of intelligent robots and service robots

From the perspective of system approach, it is important to note that development of autonomous intelligent robots involves many problems, which can be divided into the following information processing levels:

1) reflex level – the capability of a robot to perform its main functions analogous to functions of animals (to stand, move, run , see obstacles etc.);

2) logical level ("level ME") – the capability of a robot to understand cause-effect connections or if-then relationships on the logical level and solve intelligent tasks analogous to functions of a single human;

3) social level – ("level "WE") – the capability of a robot to interact with a multi-robot team and make joint decisions considering the impact of the environment and other possibly hostile multi-robot teams, mechanisms and people.

Service robots should have the following properties:

1. Service robots should be mobile and autonomous;

2. Service robots should be capable of operating in dynamically changing environment that is difficult to forecast;

3. Service robots should be capable of performing different tasks, adopting and training.

4. Service robots should be capable of interacting or communicating with a human;

5. Service robots should be capable of functioning in heterogeneous teams where functions can be distributed between robots depending on situation.

## 4. Problems of service robot control

As a rule, service robot algorithms are long and complicated network of rules written separately for different environmental conditions. The number of possible variants of algorithms in service robot's library is limited due to the necessity of formalizing them manually and can reach 5000 for modern control systems. However, such a large number of predefined algorithms do not exhaust all possible situations in which a service robot has to make decisions.

According to their goals and properties, service robots require a flexible system of synthesizing algorithms to solve tasks in unpredictable situations. A required robot action algorithm should be calculated anew each time, when robot failed to find a suitable variant in its library of predefined algorithms in the process of solving task in certain environment.

Therefore, one of the major problems of service robot control is the task of calculating robot action algorithms from the set of possible commands in real time.

Theoretical basis of proposed solution to the problem of service robot control uses mivar-based approach to developing artificial intelligence. This is a new modern approach to developing intelligent systems and algorithms [2–30], which has been developing in Russia

since 1985. Whereas traditional approaches to information processing separate storage in databases, logical inference and computational processing, mivar-based approach allows us to design multidimensional and evolutionary systems processing information in real time and combining logical inferences with computational processing. The basis of multidimensional evolutionary mivar-based approach is representation of the real world description in the form of three-dimensional space, the axes of which are concepts: object, property, relation (VSO) [2–30].

Due to mivar–based method of rapid logical inference it is possible to calculate optimal robot operation algorithms depending on environmental conditions, which ensures that robot makes rational and optimal decisions [2–30].

## 5. Practical application of mivars to motion control of a service robot

Let us consider the problem of ensuring service robot motion in the office. The robot-secretary is designed to guide visitors through the building. For example, a job applicant came to the office and it is necessary to guide him to the interviewer.

The robot can perform the following elementary actions: moving forward, backward, turning to the left, to the right. Mivar motion control model integrates elementary actions into four commands:

- Move_left – movement to the left;
- Move_right – movement to the right;
- Move_down –movement down;
- Move_up – movement up.

There is map of the office in the robot's memory. In the map the space is divided into discrete areas corresponding to geometrical dimension of the robot. Then according to this geometrical model the graph is built, where connections between discrete areas corresponds to authorized movements of the robot (forward, left, wright, backward), if motion between discrete areas is forbidden, there is no

connection. A rule is represented in Fig. 1, which demonstrates the possibility of transition between discrete areas and direction of this transition. This structure is a basic element, from which the model of the office is constructed.


**Fig. 1.** An example of bipartite movement graph

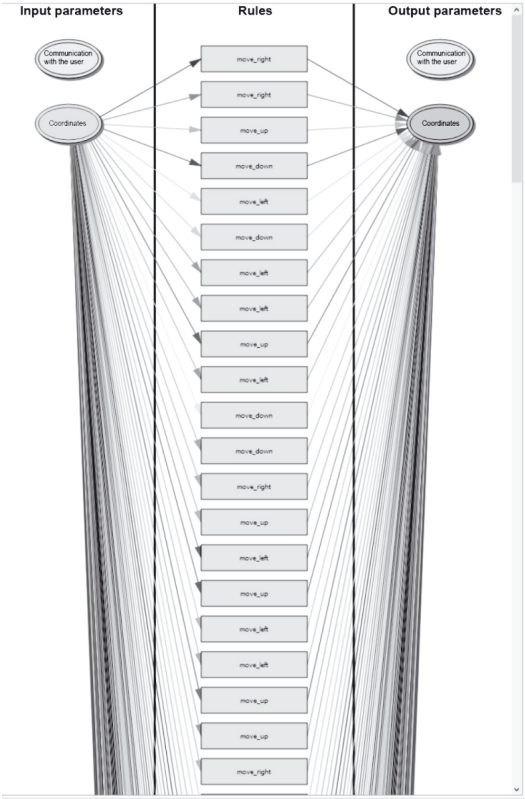


**Fig. 2.** Bibartite graph of robot motion

The form of the model is represented in Figure 2, the number of rules is 100, the number of parameters is 63 (discrete areas are regarded as parameters).

To design robot motion algorithm the mivar-based method of rapid logical inference is used. Using this method it is possible to construct sequences of elementary robot movements designed to move from random points in the building to the required ones. There is an opportunity to reconsrtuct the motion algorithm when obstacles occur in the path of the robot.

Modelling of mivar motion control model in the V-REP environment has been implemented (Fig. 3).

Table 1 shows the correspondence of desks and coordiantes of the mivar model.

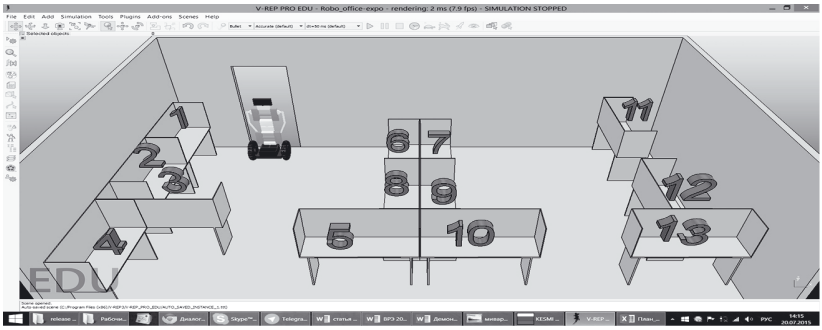


**Fig. 3.** The robot is at the entance of the room

*Table 1.*

**The correspondence of desks and coordiantes of the mivar model**

| | | X coordinates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Y Coordinates | 0 | 1 | | | | | | | | |
| | 1 | | | | | | | | | |
| | 2 | 2 | | 6 | | | 7 | | | 11 |
| | 3 | 3 | | | | | | | 12 | |
| | 4 | | | 8 | | | 9 | | | |
| | 5 | | | | | | | | | |
| | 6 | 4 | | 5 | | | 10 | | 13 | |

It is necessary to obtain service robot motion algorithm in the environment KESMI (Wi!Mi 1.1). To do this it is necessary to click on the checkbox with coordinates (5;6) that corresponds to the desk No.9 (Fig. 4).

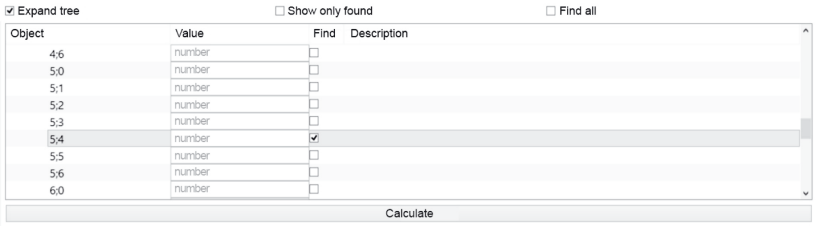


**Fig. 4.** The tab «Smart calculator»

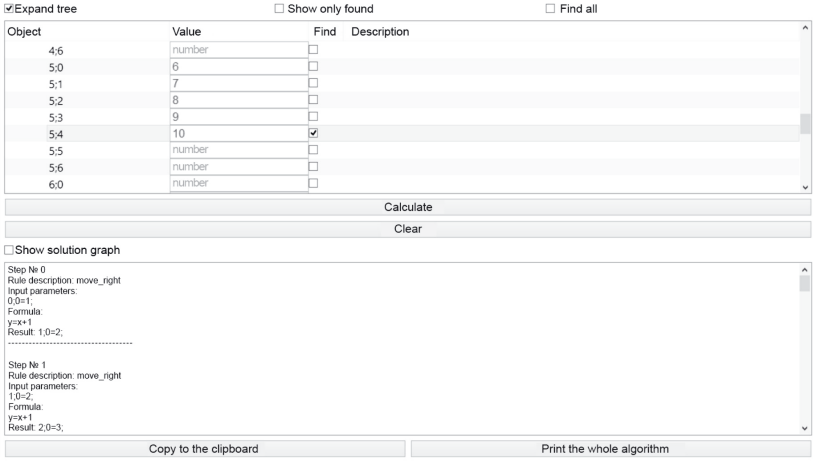


**Fig. 5.** The calculation of motion algorithm in the KESMI environment

Then the obtained algorithm for motion from the entrance of the room to the desk No.9 is represented (Fig. 6):

Step № 0: move_right

Step № 1: move_right

Step № 2: move_right

Step № 3: move_right

Step № 4: move_right
Step № 5: move_down
Step № 6: move_down
Step № 7: move_down
Шаг № 8: move_down

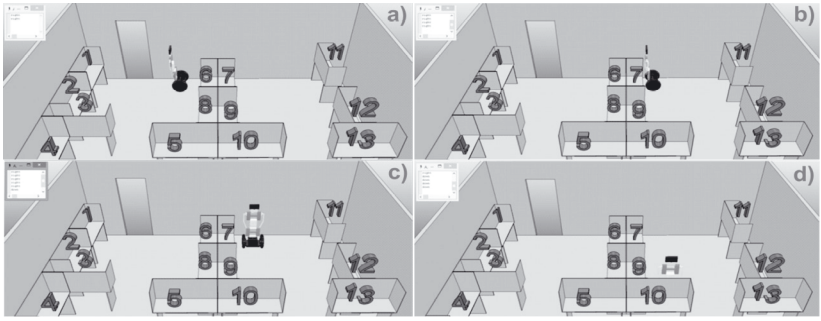


**Fig. 6.** The application of the algorithm in the V-REP environment: a) – step No.0 is implemented: move_right; b) – step No.4 is implemented: move_right; c) – step No.5 is implemented: move_down; d) – step No.8 is implemented: move_down

## 6. Conclusion

Thus, mivars have developed a new tool, which opens up entirely new opportunities for intelligent robotics.

Manual formalization of all possible robot operation algorithms used for industrial robots can not be applied to service robots due to a large number of robot action algorithms depending on the set task and environment.

Mivar-based approach to developing artificial intelligence and mivar-based method of rapid logical inference allows us to calculate optimal algorithms taking into account the impact of the environment.

The calculation of algorithm in the KESMI (Wi!Mi 1.1) environment is carried out rapidly with the linear complexity, which soves several important problems of modern robotics:

- accelerating the calculation of robot reaction algorithm in real-time;

- the possibility of applying less powerful and, consequently, energy-efficient and cheap calculators (without loss of calculation speed).

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# STUDY OF THE EXPERIENCE OF USE OF INTERMODAL TECHNOLOGY IN THE ORGANIZATION OF PASSENGER TRANSPORTATIONS

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*This article examines the practice of applying intermodal technology and a single transportation document in the organization of passenger transportations, contains a review of the projects on the use of intermodal technology from theoretical point of view, an analysis of the implemented models.*

***Keywords:*** *intermodal transportations of passengers; carriers' cooperation; a single transportation document; passengers' demand.*

## Introduction

Currently, the transport sector is developing rapidly, it's being reorganized, and it's undergoing significant changes. This is due to the increase in needs for constant movements with minimum time costs, as well as due to the changes in consumer preferences.

Much attention is paid to the development of the passenger transport system in the Moscow region. In particular, the lecturers of MADI investigate the issues of improving the organization of taxi transportations in the Moscow Agglomeration by solving the problems of territorial forecasting and planning [1], developing approaches to establishing the optimal number of taxi cars in megalopolis [2], [3]. There are also studies in the field of security of transportation by taxi-cars [4]; the problems and the prospects for the development of the transport system of the Moscow Agglomeration are studied, and

new approaches and concepts for the modernization of the transport industry are proposed [5], [7].

Improving the work of certain types of transport is an important direction of development of the transport industry, but it isn't sufficient for meeting consumers' requirements (the main requirements are comfort, safety, minimum time expenses, the cost of transportation, and, if available, the possibility of purchasing tickets via Internet). To meet these requirements and to organize passenger transportations "from door to door" it is necessary to build an effective system of cooperation between different modes of transport in which transportation would be "seamless", i.e. providing maximum comfort for the passengers in the moment of docking. Docking shouldn't create difficulties for passengers and give inconveniences.

This task is fulfilled by the organization of intermodal / multimodal passenger transportations.

Intermodal passenger transportations should be regarded as the carriage of passengers, baggage and hand luggage from origin to destination by more than one mode of transport under a single transportation document, in which the responsibility for the entire transportation process, including docking in interchange nodes, is carried by a specific carrier / s or by a third-party operator [6].

Seeing the specifics of the technology of organization of this type of passenger carriages, as well as seeing the existence of different needs of passengers depending on the type of traffic (urban, suburban, intercity and international) it's more appropriate to use intermodal technology for organization of passenger transportations over long distances with the participation of such transport modes as aviation, rail, automobile and sea transport. This is due to the presence of a person responsible for docking in interchange nodes, which involves the release of a passenger from the necessity to solve the problem himself and from financial losses arising from the loss of docking, and the presence of obligation of a responsible person to

resolve the failure situation and to deliver passengers to their point of destination.

This article investigates the experience of implementing of intermodal technology in foreign countries, as well as the Russian practice of using a single transportation document as one of the key components of intermodal / multimodal passenger transportations, and identifies the fundamental principles of this type of transportations.

## 1. Overview of documents on the issues of construction of intermodal passenger transportations

In Europe to the development of intermodality is paid much attention. Taking into account the specifics of European transport network (high level of development of rail network), the main mode of transport for long-distance transportations is railway, not bus.

The issues of implementation of intermodal technology of passenger transportations and of determination of its effectiveness, evaluated by economic component, technical and environmental aspects, are the subjects of investigation of many projects carried out by the European Commission's request.

These include the " Review of the current intermodality situation" [14].

This paper analyzes the current state of the development of intermodal transport in Europe on the basis of the composed scenarios for the evolution of the European transport network and on the determination of the ratio of social expenditures and incomes according to these scenarios. In this project there is conducted a study which aims to analyze what role will be referred to intermodal transport, or what value intermodality between air transport and other modes of transport will be in the airport of the future.

There are two types of intermodal transportations involving the airport:

1. transportation from the airport to the city center;

2. integration of the airport to the regional or national networks of other modes of transport.

In the description of various types of cooperation between air and other modes of transport (bus and rail) and in the analysis of passenger demand for such intermodal transportations the importance of such differentiation is emphasized.

In addition to the examples of intermodal cooperation between different modes of transport, implemented in practice, in this project a theoretical description, calculations, analysis of results and recommendations for the organization of intermodal transportations are presented. In the study there were developed several models to estimate the demand for intermodal transportations, which are based on different criteria, expressed through a system of quantitative indicators with varying degrees of accuracy, there was conducted an analysis of the dependence of the region of service from the time it takes to get to the airport, and there were identified appropriate schemes of intermodal transportations. Calculations of the amount of investments to the implementation of the project and of the economic impact were also carried out by experts.

These design, technological and research solutions can serve as a basis for the organization of intermodal passenger carriages in Russia. Factors affecting the demand, transportation options will change due to the specifics of the Russian transport system, but the approaches and methods used in these studies may be the same.

The project "Intermodal passenger transport in Europe" [21] is also dedicated to the research of intermodal technology. It highlights the main principles that should be implemented in the organization of intermodal passenger transportations:

- a high degree of integration of the carriers operating different modes of transport;
- news alert of passengers throughout the transportation "from door to door";

- integrity;
- cooperation of different modes of transport, implying common rules and requirements;
- maximizing the use of the benefits of each transport mode involved in intermodal transportation;
- a unique information space;
- the cost benefit for the consumer compared to the total cost of carriage on individual segments.

In this paper the insufficiency of the number of studies (lack of statistical data, failure to prove the efficiency of these traffic to reducing the impact on the environment, the lack of effect assessment methods) is highlighted.

There are many documents on the development of intermodal passenger transportations in specific European countries. Models are built there using the methods used in research aimed at the development of intermodality in Europe in whole, also scenarios for the development of intermodal transport, taking into account features of a particular country describes are described. All the documents lead to the same conclusion – the need to use intermodal technology in passenger transportations. Tools and approaches to the study differ as well as the conclusions [16], [17], [18], [19].

## 2. Models used in the projects

According to the standard travel demand analysis conducted in "Review of the current intermodality situation" [14], the methodology of identifying passengers' demand on intermodal carriages is based on the linear price-duration model, where the utility of the traveller depends on the total travel time and the price of the tickets. In this approach only two factors are taken into account as the main elements of choice for a passenger, when deciding whether to travel and when choosing a travel mode: travel price and journey time (frequency is considered to be another dimension of time of travel). Travel time

includes several parameters. Among them in the case of an air journey are: time spent on the travelling to the airport, time spent in the airport on completing departure formalities, time on the plane, time spent reaching the final destination, and also time lag between preferred time of arrival and actual time of arrival. This last element is directly linked to the frequency of services. This is the reason why frequency is linked to the journey time component of the travel.

This model is expressed through a function:

$$U(t, c) = Q_t * t + Q_c * c, \quad (1)$$

where t is the total travel time, and c is the total travel cost.

The traveller will choose the mode with a larger utility.

It means that mode i is chosen if $U_i > U_j$.

Usually faster modes are more expensive and therefore the choice will depend on how sensitive to time the passenger is. From this model they derive the "value of time", which can be defined as the value of one hour of travel time: it is the price the traveller would be willing to pay in order to decrease its travel time by one hour.

$$V_t = -\frac{Q_t}{Q_c} \quad (2).$$

Another way of defining the demand is to compute the generalized cost of travel. The mode chosen is the mode with the smaller generalized cost. The generalised cost takes into account as well the ticket fare than the value of time for the passenger converted into monetary value:

$$C_g = p + v * t, \quad (3)$$

where:

$C_g$ – is the generalized cost;

v – is the passenger value of time;

t – is the transport journey time.

There is also another parameter which should be evaluated – the indifference value between two transport modes (1 and 2). It is the value of time for which the passenger is indifferent between taking one of these modes, i.e. for which the generalized cost is the same.

$v_0$ is such as $p_1+v_0*t_1= p_2+v_0*t_2$. (4)

$$v_0 = \frac{p_2-p_1}{t_1-t_2}. \quad (5)$$

Another methodology gives more accurate value [22].

The demand on transportations depends on passengers' sensitivity-fix parameters. Variable parameters influencing transport choice are grouped into 3 main categories: time, expenses and attractiveness and quality (as one parameter). The demand distribution model suggested by this source consists of these parameters each of which includes a number of characteristics. The demand equation is the next: C is a total cost, T is total time and S is attractiveness and quality.

$$D=C+T+S \quad (6).$$

$$C = -[Q*C_{ia}+\varepsilon*Q_{ia}], \quad (7)$$

where $C_{ia}$ – a sum of journey cost from departure "i" to destination "a";

Q – passengers' sensitivity to journey cost;

$Q_{ia}$ – cost to/from airport/station;

ε – passengers' sensitivity to cost to/from airport or station.

$$T = -[\alpha*T_{ia}+\gamma*A_{ia}+\delta*W_{ia}], \quad (8)$$

where $T_{ia}$ – the sum of journey time;

α – passengers' sensitivity to journey time;

$A_{ia}$ – time to/from airport/station;

γ – passengers' sensitivity to time to/from airport or station;

$W_{ia}$ – walking/waiting time;

δ – walk/wait time sensitivity.

The first two factors, cost and time, have negative values, the smaller the value the better for the passenger.

$$S = \beta*H_{ia}+\lambda*P_{ia}+\mu*S_{ia}, \quad (9)$$

where $H_{ia}$ – the sum of frequency;

β – passengers' sensitivity to frequency;
$P_{ia}$ – competitiveness;
λ – passengers' sensitivity to competitiveness;
$S_{ia}$ – on-board services;
μ – passengers' sensitivity to on-board services.

Attractiveness is the only attribute with a positive value, since the higher the quality the better from the passenger point of view.

### 3. Methods and results of the suggested models

The first model is based on the idea of identifying the demand on transportations through the indicators of utility, value of time and the indifference value between two transport modes. At first there should be collected data about passengers' sensitivity to the parameters.

So far, only time and price have been taken into consideration; in fact other dimensions can play a role in the choice made by the passenger. There are other complementary elements of choice, related to quality of travel mode, which should be taken into account, such as:

- Connection issues at interchange points;
- Comfort and on board services;
- Service integration between modes or between operators;
- Information services;
- Security, reliability and delays.

For example, the ratio of comfort can be identified by some integral value. To get this indicator there should be held passengers' surveys in which passengers give marks to different parameters which are valued by some conditional scale, each indicator should be assigned its measure of significance.

The second model takes into account much more variable parameters, which are grouped in 3 categories. Fix parameters were introduced above as passengers' sensitivity to travel attributes. To study the sensitivity of passengers to eight different travel factors (ticket price,

price to/from airport/station, travel time, time to/from airport/station, walking/waiting time, frequency, competition, on-board services) a questionnaire should be undertaken. All the factors used in demand model vary on 10-point scale in order to allow the same importance to each factor.

Variable factors considered for the described demand distribution model are the following:

- Journey Cost (it consists of flight cost, journey cost by rail);
- Cost to/from airport/station;
- Time (flight time, time to/from airport/station, and walking/waiting time);
- Competitiveness;
- Frequency;
- On-board services;
- Seat ratio.

The second model gives a more accurate value of the demand as it takes into account more factors. After comparing each factor separately the result shows a percentage of passengers choosing the examined transport mode. The form of equation is such that the model will always forecast passenger distribution between 0% and 100%. This model was constructed for the cooperation between air and rail transport. But for other kinds of transportation there should be created a familiar model with other factors and parameters. The ways of identifying the value of each parameter will be different. But the approach will be the same. It can be suggested to create a different questionnaire asking passengers to rank their priorities instead of assigning an importance to each attribute. The place of survey is very important. Passengers given the choice to travel both modes will be the main source of information. Surveys can be conducted at travel agencies to get a better understanding of passengers' trade off between various travel factors. Passengers' feedback and awareness of their expectations will help to identify the reduction in demand.

## 4. Overview of the practice of the organization of intermodal passenger transportations

### *4.1. Foreign practice*

One of the prerequisites of intermodal transportation is the presence of a single transportation document. A number of companies use an integrated (single) ticket for intermodal passenger transportations over long distances.

As already noted, due to the specifics of the EU transport sector, consisting in a highly developed railway network, in most cases, the cooperation takes place with the participation of this type of transport.

The most interesting in terms of passenger service and baggage handling technologies are experimental Intercity train (Intercity Experimental (ICE) train) Lufthansa; AiRail service (cooperation of Lufthansa and Deutsche Bahn AG (DB) – railway operator in Germany); Air France – Thalys International trains.

In 1985, Lufthansa became the first airline that had applied rail correspondence instead of the air in the frameworks of AiRail service. Rail correspondence was organized between the airports of Frankfurt and Düsseldorf, between Frankfurt Airport and the main train station in Cologne. For these rail links the Intercity Experimental (ICE) trains were used.

The services of these express trains could only be used by Lufthansa passengers; they were offered the same services as on board an aircraft: a reservation system for seats; luggage check-in at the railway station; food and drinks on board. In 1993, Lufthansa stopped operating these trains due to high costs [20].

However, in 2001, Lufthansa, in cooperation with DB, as well as with American Airlines and Emirates airlines, entered into an agreement to create an AIRail service. As part of this cooperation, Lufthansa had the opportunity to reserve seats on DB trains, rather than the whole carriages, as when using Intercity experimental trains.

To date, AIRail service is also offered on the links between the main station in Stuttgart and the Frankfurt International Airport and between the main station of Cologne and Frankfurt.

All passengers receive boarding passes for connecting flights from Frankfurt International Airport, at the check-in desks, located on the railway station.

The product of interaction between Lufthansa, DB and other airlines allows passengers to register their luggage at the railway station and use the high-speed train service. At that they do not need to carry their luggage from the train to the airport themselves. The development of this service required not only the cooperation of Lufthansa and DB, but also the interaction with Frankfurt International Airport in terms of safety, due to the introduction of new requirements by ICAO (International Civil Aviation Organization) for mandatory examination of baggage before being fed into the baggage system of the airport.

In case of flight cancellation, passengers have the right to return back by train and exchange the air ticket for a valid train ticket either at Lufthansa or DB counter.

In 1994, thanks to the cooperation of Air France and SNCF (national society of railways in France) within the framework of the TGV Air agreement, there was launched a railway communication between Lille and Charles de Gaulle airport. On this line high-speed trains TGV operated [15].

The agreement was based on the condition that Air France cancelled flights from Lille to Charles de Gaulle. Such a bimodal product didn't concern the luggage registration, but allowed passengers to purchase a single ticket for an international flight, preceding or following TGV journeys. The tariff for travelling by train is displayed in the Air France reservation system. To date, according to the display rules of the reservation system, which presuppose the priority of offers with minimal time costs, air transportation is first displayed separately, only then the TGV + airplane.

The ticket contains at least 2 coupons: one for the TGV train (abbreviation Train à Grande Vitesse – high-speed train), the other for an international flight. However, the drawback of this ticket is that not all requisites needed for railway transportation are indicated in this ticket. In this regard, the passenger must in order to avoid delay arrive at the station in advance (more than 20 minutes) and exchange this coupon for the SNCF railway ticket. Unlike a passenger itinerary receipt, a railway ticket includes the number of the seat and the same of the carriage.

The second disadvantage is the possibility of checking-in passengers only at a limited number of railway stations without concerning the luggage. In this regard, passengers are forced to carry luggage to the airport building on their own. The time interval between the TGV train arrival and the flight departure depends on the terminal of departure and can reach up 1.5 hours.

Thus, this scheme does not fulfill the principle of minimizing time costs and does not provide a high level of quality of transport services.

In 2001, Air France cancelled flights between the airport Charles de Gaulle and Brussels. All passengers of Air France were transported from Brussels to Charles de Gaulle by an international operator of high-speed trains Thalys International trains, which, for its part, was obliged to reserve at least one carriage for Air France passengers and to increase train frequencies. This agreement differs from TGV AIR in that passengers are checked-in at the main train station in Brussels, their baggage is checked in, weighed, labeled and transported to the airport in a separate luggage compartment, but the passengers need to carry their luggage to the airport building themselves. To date, the range of airlines participating in the agreement has significantly expanded, the number of railway routes has also increased. The SkyTeam Alliance has signed a code-sharing agreement with Thalys International trains on the transportation of passengers by rail from Amsterdam Schiphol Airport to the central railway station in Belgium

Antwerp-Centraal and the southern railway station in Brussels Bruxelles Midi / Brussel Zuid.

### *4.2. Analysis of russian practice*

This type of transportation is actively used in foreign countries, there are only a few examples in the Russian Federation. Until recently, only Russian airlines were participants in such transportations. Recently, a correspondence with an air segment was organized to the airport "Simferopol" and a bus correspondence from the international airport "Simferopol" to the cities of the Crimea [8].

In the Russian Federation there are 4 vivid examples of the use of a single transportation document for transportation by various modes of transport with the participation of Russian transport companies:

- single ticket "Aeroexpress + metro";
- single ticket "Aeroflot + DB";
- "Troika","Strelka" and the combined card "Troika" and "Strelka";
- a single ticket "Fly & Bus" of Pobeda airline and bus carriers.

Aeroexpress LLC offers 3 variants of single tickets, including a trip / several trips by Aeroexpress and a trip /trips by metro, MCC (Moscow Central Circle) or bus / trolley or tram: "Plus Metro", "Between airports", and "Business trip". These tickets differ in the number of included trips by Aeroexpress and by metro, MCC, bus / trolley / tram [9].

Disadvantages of all types of tariffs are the cost characteristics and the lack of the possibility of purchasing through the Internet. Tickets for these tariffs are sold only through ticket offices, ticket machines and turnstiles.

From an economic point of view, this ticket is unprofitable, since its cost corresponds to the total cost of tickets purchased through a terminal or a cash desk, it is more convenient and quicker to purchase an electronic ticket for Aeroexpress and a ticket for the metro in the ticket

machine separately. Thus, the principle of intermodal transportation, which consists in reducing financial costs, is not fulfilled.

The technology of a single transportation document has also been implemented by Aeroflot in cooperation with the Deutsche Bahn in the "Rail & Fly" programme [10].

The advantages of this programme include:

- large route network (more than 600 destinations);
- the possibility of booking a seat on the train on the airline's website;
- a single ticket;
- the possibility of selecting the mode of transport for a trip to the destination at the booking stage;
- a single reservation number, which implies connecting the DB to the Saber reservation system.

The disadvantages include the need for a passenger to print a railway ticket, similar to a boarding pass, in the terminal after arrival. To solve this problem, DB company can introduce electronic tickets like electronic boarding passes. However, this will require large financial investments.

Currently, ticket agglomeration system is represented by cards "Troika", "Strelka" and the combined card "Troika" and "Strelka" [11], [12]. Troika" enables passengers to pay for travelling by metro, by the MCC, by Moscow ground passenger transport, by suburban trains, in Aeroexpress, etc. "Strelka" is valid in Moscow Region and the combined card – in Moscow and in Moscow Region.

These cards are also examples of the use of a single transportation document. The inability to implement via the Internet, which is substantiated by the technology used for reading, can be attributed to the disadvantages of these transportation documents. These maps are used in urban and suburban communications and are not personal.

The service "Fly & Bus" assumes the use of a single ticket "airplane + bus", which allows passengers to get from the airports to the nearest major cities on a special transfer [13].

Purchasing of the Fly & Bus service guarantees the transportation of the passenger to the destination even in case of late arrival of the transfer to the airport.

The main idea of interaction between bus carriers and Pobeda airline is to reduce the cost of transportation and ensure comfortable transportation to the final destination for passengers. It also has a result in the form of development of the route network of the airline and the attraction of additional passenger traffic for bus companies. Reduced tariff is achieved by choosing the least loaded airports with lower airport charges and then organizing a special transfer for passengers to major cities. The bus service is organized from Bratislava airport to Vienna and back, and also in the directions: Bergamo – Milan – Bergamo, Allgau – Memmingen – Munich / Zurich – Allgau-Memmingen, Gyumri – Yerevan – Gyumri, Pisa – Florence – Pisa.

Despite the fact that this ticket is unified, it consists of two separate documents: the passenger itinerary receipt for the flight and a document confirming that the bus transfer to the final destination will be provided to the passenger at the airport of arrival. This is due to the peculiarities of the ticket sales system of air transport and the Air Transport Settlement System (ATSS). The form of the itinerary receipt is unified and uniformed for all airlines. Therefore, it is not possible to make changes and add additional information to the form to date. In addition, this would require the connection of bus carriers to ATSS, which would require significant financial investments. At the moment, this is inappropriate and inefficient. In connection with the foregoing, the most logical and at the same time the only variant of providing a single ticket is to compose two separate documents and send them in one letter to the passenger's e-mail.

A bus correspondence from the international airport "Simferopol" to the popular cities in the Crimea back has been arranged in Russia within the framework of the Fly & Bus project with the participation of PJSC Aeroflot-Russian Airlines. Autoexpress "Fly & Bus" departs from the

airport terminal area, the time of departure / arrival of buses is docked with the flight arrival / departure schedule (including at night). The disadvantage of this service is that at the moment passengers have to buy separately a ticket for the plane to the airport of Simferopol and a ticket for the autoexpress. It is possible to buy tickets online, but in this case the passenger has to enter his data and pay twice. In case of flight delay, the passenger has to inform the bus carrier himself, the Fly & Bus controller will offer the passenger a trip on the nearest flight of the Autoexpress. The absence of the option of automatic informing of the bus carrier about the flight delay indicates that the interaction scheme is inadequate.

Thus, this transport cannot be classified as intermodal, since the principle of a single ticket is not implemented.

## Conclusion

At present, one of the main tasks of the development of the transport industry is the creation of a system of interaction of various modes of transport to meet the requirements of passengers and carry out the transportation of passengers "from door to door."

The organization of intermodal passenger transportation represents an innovative and promising direction for the development of the transport industry. This technology allows you to combine the advantages of each mode of transport and make transportation more efficient.

The examination of models, described above, shows that to make an adequate model it is necessary to work out a good questionnaire which would include all the parameters that influence on passengers' demand, to choose the appropriate place of survey. Value scale is also important. There can be offered different kinds of valuing, e.g. asking passengers to assign an importance to each attribute, the 2nd variant is to ask them to rank their priorities. The other variant is to combine both approaches.

The study of the experience of the organization of intermodal passenger transportations and of the practice of use of a single transportation

document leads to the conclusion that due to the varying degree of development of ticket-sale and reservation systems of different modes of transport, as well as due to the peculiarities of functioning of the aviation industry, a single transportation document for the organization of intermodal transport involving air transport must include at least two forms: one for an air segment, the second for another mode of transport. The principle of a single ticket in this case will be realized due to the fact that a passenger gets the transportation document in one letter by e-mail, the passenger data is entered once, the payment is made by one payment.

The introduction of intermodal technology will meet the requirements of passengers, increase the attractiveness and efficiency of the transport industry.

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# DETERMINE THE PROBABILITY OF PASSENGER SURVIVAL IN AN AVIATION INCIDENT WITH FIRE ON THE GROUND

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*Conducting the risk level of aviation incident with fire and the impacts of contingence affecting factors on people. Base on statistical data of aviation incident, the model of aircraft fire situation on the ground was offer.*

***Keywords:*** *aircraft; aviation incident; statistical model; probability of getting in an aviation incident; probability of survival in an aviation incident.*

## 1. Introduction

Emergence of every aviation incident usually a consequence not because of individual reason, but because of chain result of the relevant prerequisites. The initiator causal chain in the aviation incident usually because of people mistake with deficiently professional preparedness, refusal of technics and equipment or unauthorized external effects. The predominant role of human factor in the formation of the primary prerequisites according to different sources hesitate from 60–70% in industry, others civilian facilities and 80–90% in aviation [1, 7].

ICAO initiated on determining risk that aimed at improving level of fly safety, which based on operation information of fly safety [4,8]. During the period 2006 to 2010 aviation incident related with safety operation on runway, make up 59% of the total number of incidents,

29% of all incidents fatalities and 19% of it dead. While incidents cause by loss control in flights is only 4%. Fly safety also related with the survival of people during aviation incident that can end without death as well as the presence or absence of fire on the ground.

## 2. The main reasons and fire situations in aviation incidents of aircrafts

Regardless of the type of aircraft (VS), the main reasons are poor control over the aircraft at low altitude, landing, taxiing, and fire/smoke after hitting the ground. The main factors leading to the death and injury of people in AI are increased shock overload – 80% fatalities and 75% injuries, poisoning from smoke and toxic gases – 16% fatalities and 14% injuries, and other factors – 3% fatalities and 10% injuries.

Obviously, the passenger can survive only if the AI is on the ground (or water). At the same time, eliminating the death toll from aircraft depressurization, shock, or pain because of ill health, the survivors still have to face with the problem of survival in case of fire of aircraft in the open vicinities of aviation incident.

Depending on the combination of these factors in [2] a typical amount ten cases of emergency state is presented. Presented cases are based on the generalization of AI materials that took place in the territory and or in the terminal area, i.e., in the area of accident rescue teams (ART) of airport.

In Table 1, these cases are arranged in order of complexity of fire-fighting and rescue conditions (evacuation) distressed passengers.

A list of events in case of fire emergencies on the ground [2] (Table 1).

As you can see, the main factors hampering rescue or self-rescue is the condition of the fuselage, the volume of the fire (its intensity, ignition area), and the passengers the ability to perform self-rescue. It should be noted that these factors must be added to the remoteness of the place of accident and rescue services from the airport (ACC) [2].

*Table 1.*

| № AI | Factors characterizing AI | | |
|---|---|---|---|
| | The position and condition of the fuselage | The nature of fire on aircraft | Status of passengers |
| 1 | Located on the landing gear completely, no damage | Fire engine | All or most of the passengers are capable of independent movement and evacuation |
| 2 | | Burning parts falling | |
| 3 | | low-intensity fire outside of the fuselage | |
| 4 | | Fire under the fuselage of jet fuel spilled | |
| 5 | Fuselage (passenger cabin) partially damaged | Fire spilled jet fuel around the fuselage of medium intensity | Some of the passengers are not able to self-rescue |
| 6 | | Fire spilled fuel under the fuselage of medium intensity | |
| 7 | | The fire inside the fuselage | |
| 8 | The fuselage is significantly damaged | Fire spilled under the fuselage of jet fuel, the fire inside the fuselage | Most of the passengers are not capable of independent movement and evacuation |
| 9 | The fuselage is on the ground, the passenger cabin is significant damage | | |
| 10 | The fuselage flipped, does considerable damage | | |

Ensuring the survival conditions of the people and reducing the severity of the consequences of the AI with the fire on the ground can be achieved if follow this requirements [3].

- Extinguishing the fire on the aircraft should begin prior to exceeding the maximum permissible value of fire hazards;
- Localization fire time and fire extinguishing primary combustion area must not exceed the set value;
- Localized fire containment time should be sufficient for the evacuation of the emergency aircraft.

In addition, you must be guided by the principle and building forces and means involved in firefighting in the aircraft.

Mathematical modeling makes it possible to measure that and it is important to compare the relative frequency of occurrence of the

danger and the fire situation, the probability of passengers death in a given situation, and to identify the most immediate dangers in terms of fire safety types of aircrafts and airlines.

Impacts of fire hazards at the AI can be determined based on the results of available statistical data relating to similar incidents. To determine the probability of survival in a fire because of the AI offers a simple probabilistic model of survival for passengers caught in AI. To determine the parameters of such a model it is necessary to analyze and process the statistical data on the AI with a fire on the ground. The most common indicators used to assess the static level of flight safety are the number of AI and the number of casualties in them. Therefore, to identify the main factors of AI, it is necessary that we use the statistical data on incidents registered during a sufficiently long time. Obviously, for a correct assessment of the model, parameters should strive to handle a more uniform data on the class and type of aircraft, be excluded from the statistical data sampling, instances of terrorist attacks, military operations, fire in the air, aircraft mid-air collision and etc. [1].

## 3. Probabilistic model situations of fire in aircraft in aviation incidents

The probability of survival for the passengers in case of fire in aircraft on the ground depends on:

- The number of passengers and evacuation (depending on the type of aircraft and flight qualification of the personnel);
- Proximity of the airport to the place of the AI;
- The value of the ground breaking the fuselage and especially the passenger cabin;
- The ability of passengers to self-rescue;
- The nature and intensity of the fire (fuel spill, fire, power plant, the fire inside the passenger cabin, etc.).

These parameters determining the survival of the passengers in case of fire in aircraft on the ground should be assessed in the analysis

of statistical data and the organization of their collection. It is obvious that the proposed model will consist of a matrix of an emergency event and the probability of survival of the passengers.

Then the matrix event of emergencies (Table 2) will be as follows:

*Table 2.*

**Emergency events Matrix**

| State of emergency (i) | 1 | 2 | … | … | i | i+1 | … | … | n-1 | n |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_i$ – the likelihood of passenger survival in the i-th situation | $P_1$ | $P_2$ | … | … | $P_i$ | $P_{i+1}$ | .. | … | $P_{n-1}$ | $P_n$ |
| $N_i$ – probability of i-th situation | $N_1$ | $N_2$ | … | … | $N_i$ | $N_{i+1}$ | .. | .. | $N_{n-1}$ | $N_n$ |

The number of states n, generally can be taken from Table 1, where n = 10. Suppose that the event matrix (Table 2) is focused on the most favorable situations (i = 1). AI made almost within the precincts of the airport runway, the destruction of the passenger cabin is virtually absent, almost all the passengers are able to self-rescue, fuel spilled is minimal to catastrophic (i = n). AI occurred in a remote area of the airport, substantial damage to the passenger cabin, the majority of passengers struggled to self-rescue, extensive spilled fuel.

Obviously, the probability of survival of passengers Pi in favorable situation is the greatest, and catastrophic – the smallest, ie:

$$P1 > P2 > \ldots Pi \text{->} Pi \ldots . \text{->} Pn$$

where $\sum_{i=1}^{n} P_I = 1.0$ (1) is the probability of falling into a particular situation $N_i$. Logically it can be assumed that the most common situation is close to catastrophic and beneficial. The intermediate situation is likely to occur much less frequently:

$$N_{(1.2.3 \ldots)} > N_i \ldots < .. N_{(n-1,\, n)}$$

Just as in (1) $\sum_{i=1}^{n} N_I = 1.0$ (2)

In this setting of full matrix emergency events will have a minimum of 16 – 24 cases; 4 situation, with two extreme values:

– Close to airport – far from the airport;
– Fuselage lightly broken – badly damaged fuselage;
– Little spilled fuel – fuel spilled and ignited extensively;
– Passengers can evacuate on their own – passengers require help evacuating.

Such statistics are not present in the media – although in principle the organization collecting such statistics would be of some benefit, and given the opportunity to apply the methods of multivariate statistical analysis.

Therefore, assuming that the ability of passengers to self-rescue and degree of fuel spill directly correlated with the degree of destruction of the fuselage, simplify the array of events to nine states:

– AI degree of proximity to the airport, "airport" – "near the airport" – "at a distance from the airport."

– The degree of destruction of the fuselage with the AI: "low" – "medium" – "significant"

Matrix events (Table 2) will become as follows (Table 3).

*Table 3.*

**Grouped alarm events Event matrix**

| Degree of destruction | Distance from the airport | | |
|---|---|---|---|
| | In an Aeroport, i = 1 | Near the airporti = 2 | Far from the airporti = 3 |
| Small, j =1 | $\mathbf{P}_{11}$ | $\mathbf{P}_{12}$ | $\mathbf{P}_{13}$ |
| Central, j = 2 | $\mathbf{P}_{21}$ | $\mathbf{P}_{22}$ | $\mathbf{P}_{23}$ |
| Much, j=3 | $\mathbf{P}_{31}$ | $\mathbf{P}_{32}$ | $\mathbf{P}_{33}$ |

We continue further simplification of the model associated with the necessity of treating the available statistical data. Let us assume that the state of emergency situations are divided into I – «favorable» – with a high degree of probability of survival, and II – «adverse» – with

a moderate degree of probability of survival. III – «catastrophic» – unlikely to survive in these situations. These groups are respectively highlighted in green, yellow, and red in Table 3. The probability falling into a dangerous situation of danger I, II or III (Table 3) denote respectively $N_I$, $N_{II}$ and $N_{III}$. In this case, the source table alarms statuses event matrix (Table 3) takes the following form:

*Table 4.*

**Matrix grouped emergencies**

| State of emergencies (•) | I | II | III |
|---|---|---|---|
| The probability of N (•) of an emergency (•) | $N_I$ | $N_{II}$ | $N_{III}$ |
| passenger survival probability P (•) if it enters the emergency (•) | $P_I$ | $P_{II}$ | $P_{III}$ |

Thus, the total probability of survival of passengers in contact with the ground in a situation with a fire on the ground can be calculated using the formula:

$$P_{alive} = \sum_{I=1}^{I=3} P_I N_I \qquad (3)$$

or the average estimate of the probability to survive a passenger, got into the AI with fire.

Of course, to formulate a probabilistic conditions of an emergency N (•) is very difficult and not so important in principle. But, the probability of survival, P (•) can be calculated by an adaptation for flight accidents methods of calculation of survival in fires in civil and industrial buildings [5].

## 4. Analysis of statistical data to assess the probability of survival of passengers in an emergency with fire

Let us try to evaluate the given parameters of the proposed model (3) according to the available statistical data [4,8]. Consider the data conditionally accepting state groups, depending on the distance (group I to III) AI from the airport.

*Table 5.*

**Statistical data on the AI to fire depending on the distance from the airport**

| Group states j | I | II | III | Total |
|---|---|---|---|---|
| $N_{fire}$ | 69 | 31 | 47 | 147 |
| $N_{deaths}$ | 301 | 614 | 937 | 1852 |
| $N_{alive}$ | 4041 | 456 | 688 | 5185 |
| $N_{passangers}$ | 4342 | 1070 | 1625 | 7037 |

where

$N_{fire}$ – number of fires;

$N_{deaths}$ – who died in a fire on the ground

$N_{alive}$ – surviving a fire on the aircraft

$N_{passengers}$ – the total number of passengers who find themselves in a situation with a fire on the aircraft.

We estimate the probability of occupant survival *Pj,* who turned in AI group – *j*

group I $\boldsymbol{P = \frac{N^{alive.}}{Npass} = \frac{4041}{4342} = 0.93}$

group II $P = \frac{N^{alive.}}{Npass} = \frac{456}{1070} = 0.42$

group III $\boldsymbol{P = \frac{N^{alive.}}{Npass} = \frac{688}{1625} = 0.42}$

Rate $N_j$ hit passengers trapped in the AI group – *j*

Group I: $\boldsymbol{N = \frac{N^{fire}}{\sum n^{fire}} = \frac{69}{147} = 0.47}$

Group II: $\boldsymbol{N = \frac{N^{fire}}{\sum n^{fire}} = \frac{31}{147} = 0.21}$

Group III: $\boldsymbol{N = \frac{N^{fire}}{\sum n^{fire}} = \frac{47}{147} = 0.32}$

The data show that all AI with fire is likely to occur at the airport (or near) – Group I situations, or away from it (Group III situations),

see (2). In addition, the possibility of passenger survival is greatest in the case of situations of group I, the compositions according to the model (3) matrix states and survival, we get:

*Table 6.*

**The initial matrix event of emergencies**

| Group states - *j* | I | II | III |
|---|---|---|---|
| $P_{i\ alive}$ | 0.93 | 0.42 | 0.42 |
| $N_{i\ situation}$ | 0.47 | 0.21 | 0.32 |

Based on the data, the average (full) probability of survival of passengers (3) is equal to

$$P_{alive} = \sum_{I=1}^{I=3} P_I N_I = 0.660 \qquad (4)$$

Despite that when the data was taken into account only the distance AI from the airport received a full passenger survival probability based on the probability that in a particular situation is equal to 0.660, while the calculation of the probability of survival without regard to conditions hit probability in an emergency situation (arithmetic mean) we have:

$$P_{\text{survivors. = N is alive. / N passengers}} = 5185/7037 = 0.737 \sim 0.74 \qquad (5)$$

which is almost 15% overstates the estimate of survival.

## 5. Determine the probability of passenger survival rate in an emergency per year

Determine the probability can be obtained based on one of three approaches:

1) Direct determine based on statistical data processing;

2) Analysis the model that relates to the likelihood of the considering event with probabilities of other events;

3) In the analysis, based on expert judgment

Let's conduct an analysis of statistical data on the ratio of the amount of aircraft emergencies per year for the group companies in the US [4.8].

*Table 7.*

**Initial data for the AI with a fire in the period of 1995–2004**

| Index | AI with fire |
|---|---|
| Number of accidents | 112 |
| Number of passengers involved in fire | 7017 |
| Amount of deaths | 1917 |

It is evident that the number of passengers caught in a fire in AI equaling 7017, during the same period as passengers that died in 1917, averaging 112.

Simple range probability of survival according to the formula:

$$P_{alive}=\frac{N^{pass}}{N^{fire}} = \frac{7017-1917}{7017} = 0.73 \quad (6)$$

Presented probability of survival for a group of companies under consideration almost equal to the arithmetic mean of the probability of survival for all US airlines [4.8]. Statistics examined airlines presents data on the hit rate of aircraft in different emergencies (see. Table 1), which is shown in Table 8.

*Table 8.*

**Table initiating event of emergencies**

| The reason for the AP ( situation i) see Table 1 | Number of AP in a situation i Ni |
|---|---|
| i = 1 | 15 |
| i = 2 | 14 |
| i = 8 | 12 |
| i = 10 | 10 |

Then estimate the probability of contact with AI event group *j,* (I = 1,2,3) for the consideration of the airlines.

*Table 9.*

**Table probability event of emergencies**

| Group states - j (Table 1) | I group | | II group | III group | | Total |
|---|---|---|---|---|---|---|
| Status - i | 1 | 2 | - | 8 | 10 | - |
| number of accidents | 15 | 14 | - | 12 | 10 | 51 |
| Probability situatsii - i | 0,294 | 0,275 | | 0,235 | 0,196 | |
| *Ni - the probability of j-th group of states* | 0,57 | | - | 0,43 | | - |

Knowing the probability of occurrence of situations and the likelihood of falling into a dangerous situation from the model (3), we can determine the probability of passenger survival for the companies under consideration:

$$P_{survivors} = 0.66 \quad (7)$$

To estimate the probability of a passenger entering the AI with fire and their survival in it for the companies under consideration, we will determine the number of passengers transported per trip.

Total passengers trapped in the AI *with fire:* $N_{pass} = 7017$;

Number of *fires:* $N_{fire} = 112$.

It is obvious that the average number of passengers per flight who have fallen in the AI with fire.

$$N_{pass.} = \frac{N_{pass}}{N_{fire}} = \frac{7017}{112} = 63 \text{ (aircraft type, close to the medium)}$$

*Table 10.*

**The total number of flights of one airline per year [4.8]**

| Amount of one type aircraft, K | Average flight of one aircraft per year , $N_i$ | Total number of flights per year , $N = K * N_i$ |
|---|---|---|
| 39 | 1300 | 50700 |

Then all airline passengers transported under consideration per year

$N_{pass} = 50700 * 63 = 3.2$ mil.pas./year

The number of passengers who find themselves in a situation with a fire (in a year):

$N^{fire}{}_{Pass} = \frac{7017}{10} = \mathbf{702}$ Pass. / Year

The probability of the passenger airlines get considered in the AI to fire (in a year)

$$P^{fire.}{}_{Per\ year} = \frac{N^{pass}fire}{N^{allpass}} = \frac{702}{3.2*10^6} = \mathbf{2.2 * 10^{-4}}$$

The probability of the passenger to be in AI with fire and die in it, for the given airlines a year, is equal to:

$P_{death} = P_{fall\ into\ the\ fire.} * (1\text{-}P_{to\ survive\ in\ a\ fire.})$

$P_{death} = 2.2 * 10^{-4} * 0{,}34 = 0{,}748 * 10^{-4}$

Regularly likely to be in the fire and death for people in case of fire of building constructions is $10^{-6}$ [6].

It can be seen that the passenger aircraft during the aviation accident with the fire on the ground (in a year), is 75 times more dangerous to the regulatory risk in the event of fire in the premises of building structures.

## 6. Conclusion

The proposed model makes it possible to assess the risk of the passengers killed in a fire situation on aircraft carriers and airlines and the compilation of the insurance fund for payments to the families of those killed and injured. In assessing, the level of risk of AI, we have to evaluate the exposure level of affecting factors on people in emergencies. With such a task may encounter expert, insurance companies and owners of companies. To assess the level of danger requires AI effects data, the number of casualties, economic damage. In fact, evaluation of the impact of factors affecting people and the aircraft comes down to the definition of two functions: the dependence of the number of fire hazards on the distance to the accident and the damage dependent on the number of factors.

The probability of survival at the AI with post-accident fire is lower than in a situation with a fire in civil engineering. Implementation of the developed model allows to quantitatively calculate the amount of fire hazards in the AI based on probabilistic method by direct process-

ing of statistical data.

The resulting research evidence, increase the objectivity and probative conducted expert studies.

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**5. Заключение.**

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