

ASSESSMENT OF RELIABILITY OF THE TRANSPORT INFORMATION SYSTEMS

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Resume

In this paper is given the definition of the reliability of a transport information system, with features of transport information systems listed. Equations for calculating reliability indicators are given, as well. The developed hierarchical graph model for assessing the reliability of transport information systems and an algorithm for analyzing the graph model, which allows taking into account the specifics of the reliability of the operation of system elements at different levels of the hierarchy, are presented. Using the graph model and the graph model analysis algorithm, it is possible to reasonably predict the strategy for the creation and development of transport information systems.

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1 Introduction

An information system is a system for storing, searching and processing information, including appropriate organizational resources (human, technical, financial and others) that provide and distribute information (ISO / IEC 2382: 2015) [1].

For information systems, reliability is a property of a system to retain in time the ability to perform the required functions in accordance with the specified goals and conditions of use (GOST standard 27.015-2019) [2].

Currently, there are many different information systems. Information systems can be classified by architecture, by the degree of automation, by the method of data processing, by the scale of the tasks being solved, by the scope of application - by the subject area.

Each subject area (sphere of application) has its own type of information systems. For example - economic information systems, medical information systems, transport information systems (TIS) and many others. In turn, transport information systems can be subdivided into information systems for passenger and cargo transportation, logistics information transport systems, automation systems for commercial roads, etc. Currently, integrated intelligent transport systems are rapidly developing, including all the types of transport [3].

It is possible to highlight the main functions of the TIS in the management of transport processes - those are the management and planning of transportation; traffic management; analysis of emergency situations and possible management in such situations; information support for traffic participants.

Some of the properties of the transport information systems are:

- when constructing a TIS, it is advisable to apply a systematic approach and the principle of hierarchy;
- the TIS is a system for collecting, analyzing, processing and transmitting information and it includes software and hardware, which are based on modern information technologies;
- since the transport information systems (as well as practically all the information systems) are characterized by improvement and development, it is rational to use modular decomposition to analyze such systems;
- human participation in information processes depends on the complexity, type and purpose of the TIS.

Transport information systems have become a necessary component of the transport infrastructure, these systems are becoming more complex and have high reliability requirements, therefore the task of assessing the reliability of information transport systems is urgent [4].



2 Features of the transport information systems

Transport information systems make it possible to combine processes for managing traffic flows and logistics, form a single information space for geographically remote objects, carry out photo and video recording of vehicles, identify hazardous events and much more [5-6].

The structure of the transport information systems includes: hardware and software, communication channels, transmitted data (information). The transport information systems can also include vehicles connected to the information system and/or on which information systems are installed.

Distinctive features of transport information systems are:

- complexity;
- information content;
- reliability of functioning - the ability to produce error-free transformation, storage and transmission of information;
- multichannel - the presence of several channels, each of which performs a specific function, particular in relation to the overall task of the system;
- ability to work in the time sharing mode;
- multi-connectivity - a large number of functional connections between system elements;
- ability to search for information about transport, cargo, routes at the request of the user, etc.;
- automatic processing of information, ability to add and edit information;
- high speed of query execution;
- systems should work in an interactive mode and have a user-friendly interface;
- high requirements for reliability.

In connection with the listed features for such a complex system, which is a transport information system, the failure of some of its elements should not cause a complete system failure, i.e. termination of its specified functions, but only possible deterioration in varying degrees of the quality of the system [7-8]. Failure of some elements transfers the TIS from a state with full operability to a state with partial operability. This means that the TIS must be of the fault-tolerant or fail-safe type of systems. Therefore, when developing transport information systems, it is necessary to assess the reliability of the entire system, as well as of its elements. It is necessary to carry out calculations and assess whether a specific transport information system meets the required level of reliability. If the system does not meet the required level of reliability, then it is necessary to take measures to improve reliability, for example, to perform redundancy or duplication of some elements of the system, to choose more reliable equipment and others.

3 Development of a graph model for assessing the reliability of a transport information system

The model for assessing the reliability of a transport information system is expedient to represent in the form of a directed graph $G = (N, L)$ (Figure 1), where N are the vertices of the graph, L are the arcs of the graph. Vertices are the reliability (reliability indicators) of the constituent physical elements of the TIS, arcs are hierarchically organized connections between them. The R_{TIS} top is the reliability of the entire transport information system, including hardware and software, vehicles, communication channels, and transmitted data (information).

The graph model has four levels of hierarchy:

Level 1 - reliability of the entire transport information system (TIS).

Level 2 - are indicators of the reliability of the main elements of the transport information system: all the hardware, all the software, vehicles, all the communication channels, all the transmitted data (information).

Level 3 - the main elements, here the main elements of the TIS are presented in more detail, for example, the reliability of hardware includes reliability of mobile devices (laptops, tablets, sensors, phones, etc.) and the reliability of stationary devices (server, cloud system equipment, stationary panels of system screens Digital Signage and other equipment).

Level 4 is divided into sublevels and includes elements of the sublevels. The number of sublevels 1,2, ..., n is determined by the degree of detailing of a specific problem of reliability assessment. At these sublevels, the reliability of the main elements is analyzed in more detail. The degree of details of the TIS element in each specific case is determined by the purpose of the study and the nature of the selected reliability indicator. For example, one can allocate a processor, input/output devices, etc. for a computer. In turn, a processor consists of ALUs, memory registers, etc.

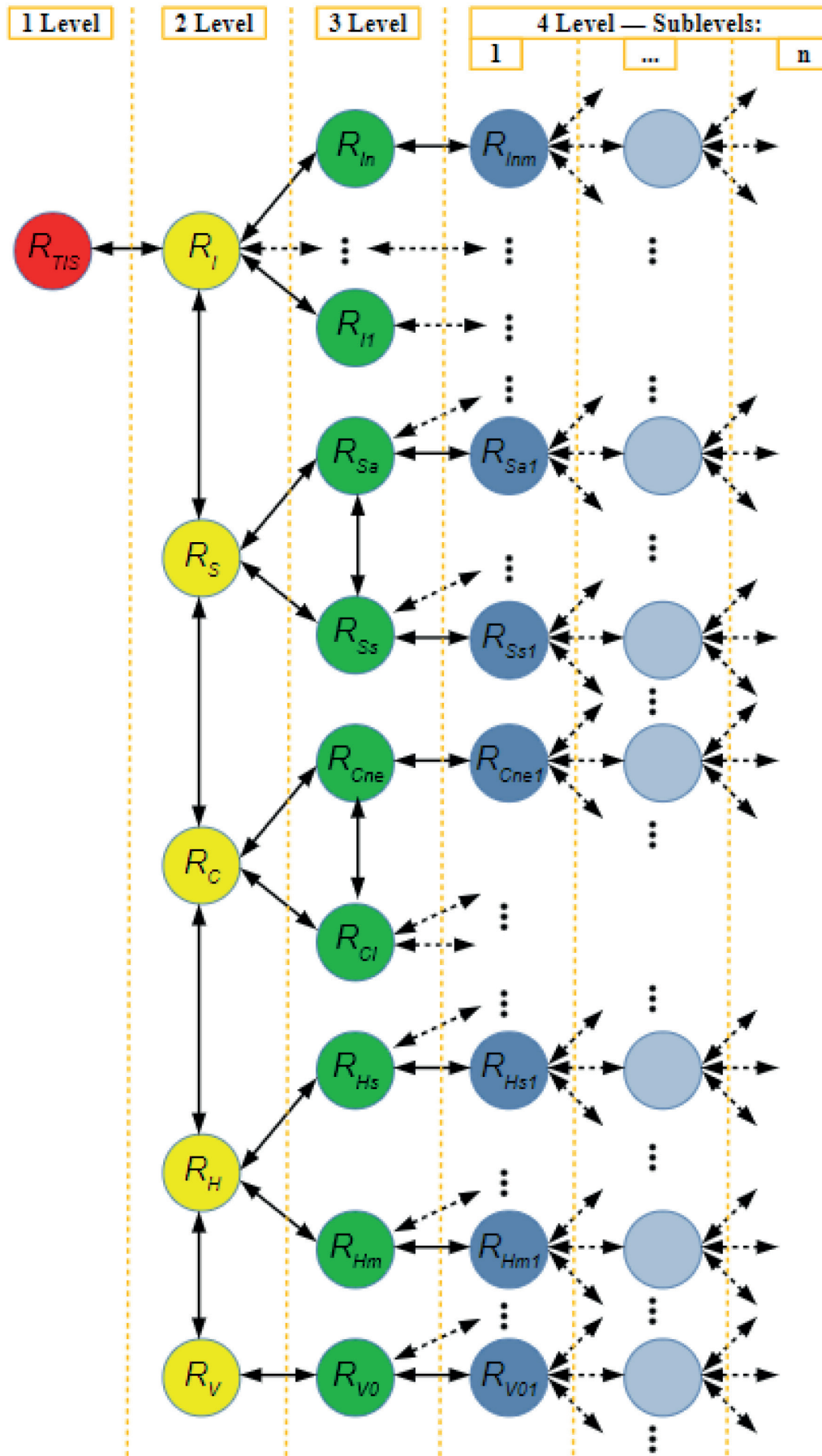
Thus, it is advisable to calculate the reliability of the transport information system based on the graph model using the decomposition procedure.

The reliability of the entire transport information system includes all its constituent elements:

$$R_{TIS} = \{R_V, R_H, R_C, R_S, R_I\}, \quad (1)$$

with R_V - vehicle reliability, R_H - system hardware reliability, R_S - software reliability, R_C - reliability of communication channels, R_I - reliability of transmitted data (information).

The reliability of some transport information systems can be assessed taking into account the reliability of vehicles that use the information systems or that are connected to the information system. R_V - vehicle reliability includes:

Figure 1 Graph $G = (N, L)$

$$R_V = \{R_{V0}, \dots\}, \quad (2)$$

with R_{V0} as the reliability of the vehicle's technical means (element structures, etc.).

R_H TIS hardware reliability includes:

$$R_H = \{R_{Hm}, R_{Hs}\}, \quad (3)$$

with R_{Hm} - mobile devices and their reliability indicators, for example - laptops, tablets, etc.; R_{Hs} - indicators of reliability of the stationary devices, for example - servers, workstations, etc.

R_{Hm} and R_{Hs} , depending on the problem of reliability assessment, can be presented in more detail; for example, the processor or I/O device of a particular data center server, etc.

R_C - reliability of communication channels of the transport information system includes:

$$R_C = \{R_{Cl}, R_{Cne}\}, \quad (4)$$

with R_{Cl} - reliability of communication lines; R_{Cns} - reliability of network equipment.

In turn, R_{Cl} , R_{Cns} can, if necessary, be divided into their constituent elements.

R_S - the reliability of the transport information system software includes:

$$R_S = \{R_{Ss}, R_{Sa}\}, \quad (5)$$

with R_{Ss} is the reliability of the system software; R_{Sa} is the reliability of the application software.

The reliability of the system and application software can be subdivided into the reliability of specific constituent elements of a particular type of software, for example, for R_{Ss} , this can be an element of the operating system used on a computer that is a part of the TIS and for R_{Sa} , a subroutine for evaluating vehicle route parameters.

To assess the reliability of software, the following models can be used: discrete model, Mills model, Bernoulli model, Bayes model, Schumann model, risk models and others [9-12].

R_I - the reliability of the transmitted data (information) includes methods for protecting information:

$$R_I = \{R_{I1}, R_{I2}, \dots, R_{In}, \dots\}, \quad (6)$$

for example: R_{I1} - encryption; R_{I2} - application of reliable data transfer protocols; R_{I3} - use of RAID technology and many others.

4 Reliability indicators of the transport information systems

It is impossible to fully characterize the reliability of such a complex and multifaceted object as a transport

information system by a single indicator, therefore, for a more complete characterization, it is necessary to determine a whole set of reliability parameters, i.e. complex indicators of reliability. One of such complex indicators for assessing the reliability of complex systems is the availability factor, i.e. the probability that the system being restored will be operational at an arbitrary point in time of its intended use.

The availability factor K is determined by the formula:

$$K = \text{MTBF}/(\text{MTBF} + \text{MTTR}), \quad (7)$$

with: MTBF - Mean Time Between Failure; MTTR - Mean Time To Repair.

Availability factor in another entry for the transport information system:

$$K_{TIS} = \frac{t_w}{t_w + t_r}, \quad (8)$$

with: t_w is the total time the TIS is in a working condition; t_r is the total recovery time.

Equation (8) is often used in reliability assessments in practice. For a more accurate assessment of the K_{TIS} , it is necessary to choose a long time interval t_p . The availability factor, as a rule, takes into account such properties as reliability and recoverability. If by refusal one means not only hardware failure, but any failure of the TIS in performing the specified functions, as well, including that caused by software defects, decreased reliability, etc., then K can take into account various properties of the information system.

For vehicles, the value of the technical readiness factor for the mileage per cycle of operation can be calculated:

$$K_T = \frac{D_e}{D_e + D_d + D_a}, \quad (9)$$

with: K_T - calculated coefficient of technical readiness; D_e - days of operation in a cycle; D_d - days of downtime per cycle in maintenance and repair; D_a - days of absence due to repair.

It should be noted that widely known methods can be used to assess the reliability of elements of levels 3, 4. For example - methods of calculating reliability using operating data, structural methods, coefficient method, others [13].

5 Reliability function

According to the graph $G = (N, L)$ in Figure 1, the logical function of the operability of the entire transport information system - F_{TIS} (the 1st level) can be represented as:

$$F_{TIS} = R_V(t) \wedge R_H(t) \wedge R_C(t) \wedge R_S(t) \wedge R_I(t), \quad (10)$$

with t as the specified operating time.

Next, one needs to analyze the F_{TIS} , which consists of the following steps:

- 1) simplification of the obtained logical expression in Equation (10),
- 2) replacement of logical operations by arithmetic,
- 3) replacing the events $R_V(t), \dots, R_I(t)$ (indicators) with their probabilities by values,
- 4) calculating the probability of the operational state of the TIS and the following expression will finally be obtained:

$$P_{TIS}(t) = P_V(t) \cdot P_H(t) \cdot P_C(t) \cdot P_S(t) \cdot P_I(t), \quad (11)$$

with $P_i(t)$ as the probability of failure-free operation of the TIS element.

Level 2 is a system with a serial connection of elements, therefore, it is possible to transform Equations (10) into (11).

For the 2nd and 3rd level (Figure 1), logical functions and probabilities of failure-free operation for the main elements of TIS - vehicles, hardware, communication channels, software, data (information) are:

$$F_V = N_{V0}, P_{V0}(t); \quad (12)$$

$$F_H = N_{Hm} \wedge N_{Hs}, P_H(t) = P_{Hm}(t) \cdot P_{Hs}(t); \quad (13)$$

$$F_C = N_{Ck} \wedge N_{Cnes}, P_C(t) = P_{Ck}(t) \cdot P_{Cne}(t); \quad (14)$$

$$F_S = N_{Ss} \wedge N_{Sa}, P_S(t) = P_{Ss}(t) \cdot P_{Sa}(t); \quad (15)$$

$$F_I = N_{I1} \wedge \dots \wedge N_{In}, P_I(t) = P_{I1}(t) \cdot \dots \cdot P_{In}(t) \dots \quad (16)$$

Here, the 3rd level elements are converted to daisy-chain structures.

For the 4th level elements of different sublevels. Equations (10) - (16) show that the TIS functions when all elements of levels 2 and 3 are working, since these elements are the main in the TIS, the failure of one of them can cause a failure of the entire system. For example - failure of communication channels can cause failure of the entire TIS. The TIS graph model provides that communication channels are in turn divided into their constituent elements - communication lines and network equipment, which at level 4 are also divided into their constituent elements. Failure of one communication line or any router can only cause a decrease in the quality of the TIS functioning. Therefore, when assessing reliability of the TIS elements at level 4 (for various sublevels), the location of the elements and their connections should be taken into account. Logical functions at level 4 (sublevels) must be built for each specific problem of reliability assessment. To do this, one needs to analyze the selected subgraphs $G = (N, L)$. For simple elements of TIS level 4, single reliability indicators can be calculated. For example, failure-free operation and the probability of failure of

any element, the failure rate, and others. For more complex elements, complex reliability metrics can be used.

The probability of failure-free operation of the i -th element of the TIS $P_i(t)$ - is the probability that no failure occurs within a given operating time:

$$P_i(t) = P_i(T \geq t), \quad (17)$$

with T as the random time to failure; t is the specified operating time.

$P_i(t)$ possesses the following properties: before the start of the TIS, the i -th element was unconditionally operable; $P_i(t)$ is a non-increasing function of time; the i -th element of the TIS cannot maintain its operability indefinitely, i.e.

$$\lim_{t \rightarrow \infty} P_i(t) = 0. \quad (18)$$

Failure rate is the conditional density of the probability of failure of the non-recoverable i -th element of the TIS, determined for the considered moment of time, provided that the failure did not occur before this moment:

$$\lambda_i(t) = \frac{f_i(t)}{P_i(t)} = -\frac{dP_i(t)}{dt} / P_i(t), \quad (19)$$

with $f_i(t)$ as the distribution function of the time to failure.

Under the initial condition $P_i(0)=1$, one obtains

$$P_i(t) = e^{-\int_0^t \lambda_i(\tau) d\tau}. \quad (20)$$

If $\lambda_i(t) = \text{const}$, then Equation (20) is an exponential law of reliability. According to this law, the probability of failure-free operation of the TIS elements with a failure rate λ decreases with time along an exponential curve, which is true during the normal operation of the system, i.e. excluding wear. Equation (20) is a reliability function. This function is important for practical use, when it is necessary to know with what probability the TIS elements are able to perform tasks requiring a certain duration of uptime.

The reliability function in Equation (20) can be represented as:

$$P_i(t) = e^{-\lambda t}, \quad (21)$$

with: λ as the average number of failures for a TIS element per unit of time.

Uptime variance is:

$$D[T] = \int_0^\infty (t - 1/\lambda)^2 \lambda e^{-\lambda t} dt. \quad (22)$$

This expression, after integration, gives the value $1/\lambda^2$. In this case, the standard deviation is

$$\sigma = \sqrt{D[T]} = \frac{1}{\lambda}. \quad (23)$$

From Equations (18) - (22) it follows that for the normal period of operation of the TIS, the time of failure-free operation of its constituent elements has an exponential distribution law.

Now, taking into account the characteristic parameters of the elements of the transport information system for levels 3 and 4 (sublevels), the probability of failure-free operation of any i -th element can be written as:

$$P_i(x) = P_1(y_1)P_2(y_2|y_1)...P_j(y_j|y_1,...,y_{j-1}), \quad (24)$$

with \mathbf{x} - input parameters of the i -th element of the TIS (vector) of levels 3 or 4; \mathbf{y} is the vector of the output parameters of the TIS element; $P_j(y)$ is the probability of fulfilling the j -th condition of operability.

Probability in Equation (24) can also be represented as the mathematical expectation of some functional for the output parameters at a given time interval t of functioning of the element i , taking into account y_i - the nominal values of its output parameters.

Let the minimum value of the l -th output parameter of the element i on the time interval $[0, t]$ be denoted as y_{il_min} , namely:

$$y_{il_min} = \min_{\tau \in [0, t]} y_i(x(\tau)), l = 1, \dots, m. \quad (25)$$

The value determined by Equation (25) is random with the distribution density Φ_i , which in the general case is determined by the nominal values of the parameters of the elements, the laws of the distribution of these parameters in time and the time interval.

The set of nominal values of the TIS elements' parameters represents an admissible solution if the corresponding vector belongs to the region of admissible variation of its parameters. Since the values of the parameters of the elements are random, the conditions for their performance can be fulfilled not absolutely, but with one or another probability.

Then the probability of fulfilling the j -th condition for the operability of element i can be written as:

$$P_j(y_i(x_i(\tau))) = \int_0^t \Phi_i(y_{il_min}) d\tau, \quad (26)$$

with $\Phi_i(y_{il_min})$ being the distribution density of the value y_{il_min} , which belongs to the operability area.

The operability zone is the permissible zone for changing the parameters of the TIS elements. In this area, the output parameters have values that do not go beyond the established restrictions on these parameters. The boundaries of the site, as a rule, are determined by the maximum permissible. Some parameters for assessing the reliability of the TIS elements belonging to different levels and sublevels (Figure 1) have different operability conditions. To increase the reliability of the entire system, one can vary the input parameters of the elements, changing them to values at which the

output parameters do not go beyond the boundaries of the operability zone. Among the input parameters, one needs to choose those that, in specific conditions, best reflect the reliability property:

$$y_j(x + \Delta x) \geq y_j(x), \quad (27)$$

where Δx is the permissible change in the parameters x (for the case if any input parameter or parameters need to be changed in order to improve the reliability of the system).

The random variables y_j can represent the values of the output parameters of an element at time t . Thus, the introduction of random variables makes it possible to move from considering random functions (processes) to considering random variables y_j and significantly simplify the problem of assessing the reliability of the TIS elements.

6 Analysis of the graph model for assessing the reliability of TIS

It should be noted that for level 2 all the elements of the TIS graph model, and for level 3 almost all and in some cases for level 4 (on separate sublevels), are mutually dependent. The relationship between the elements of the TIS follows from the task of assessing the reliability and in each case should be considered separately. For example, the reliability of system software (R_{ss} vertex) is influenced not only by its components such as operating systems (R_{ss1} vertex) on individual TIS hardware elements, as well as by the hardware elements themselves (R_{hs} and R_{hm} vertices). Therefore, for this specific task, it is necessary to select the appropriate subgraph, consider which elements of the TIS (graph vertices) are interdependent, select these vertices and analyze the connections between them, that is, construct the corresponding subgraph $G_i = (N_i, L_i)$. The type of subgraph and the number of vertices depend on the specific problem of reliability assessment.

In order to simplify the graph in the TIS model $G = (N, L)$, bidirectional common arcs are depicted, which show hierarchically organized connections between vertices. Common arcs can be used to trace the connection between any selected vertices. In the example, these are the tops $R_s, R_{ss}, R_{ss1}, R_{hs}, R_{hm}$. For these vertices, a subgraph is constructed, shown in Figure 2. The R_c vertex - the reliability of the TIS communication channels can be excluded, since in the example under consideration it is necessary to assess only the reliability of the system software. In Figure 2, the arcs - the communication lines between the analyzed vertices are shown in red.

In order to analyze and take into account more interrelationships between the various elements of the TIS, it is proposed to conduct all assessments only through the elements of the 2nd level of the graph model.

The algorithm for analyzing the hierarchical graph model of the TIS includes the following main stages.

Stage 1. Input of initial data: the TIS elements - types of devices, equipment, software, etc. taking into account the degree of detail required for the problem being solved; T is the analyzed time period; K_{TIS} , K_e , $P_i(t)$, t_w , t_r , ... - specified and necessary reliability indicators for the TIS elements and the system as a whole. Data entry can be made based on the technical specifications, reference tables, technical documentation for TIS and constituent elements and other available information.

Stage 2. Analysis of the input data and formation of a graph model of the TIS - $G = (N, L)$ based on the input data.

2.1. Definition of the set of vertices and arcs of the graph $G = (N, L)$.

2.2. Selection of levels and sublevels of the TIS graph model.

2.3. Determination of the entry and exit vertices of the graph $G = (N, L)$. These peaks can be any peaks, according to the problem of reliability assessment being solved.

2.4. Building a path between the entry and exit vertices.

Stage 3. Selecting a subgraph (subgraphs), for example - $G_i = (N_i, L_i)$, Figure 2 shows an example of a subgraph. This stage is performed when a detailed assessment of the reliability of elements of various levels and sublevels is required, which can be carried out both with and without regard to the reliability of the entire system.

3.1. Formation of subsets of vertices and connections between vertices for the subgraph $G_i = (N_i, L_i)$.

3.2. Determination of entry and exit vertices for the subgraph.

3.3. Building a path between the entry and exit vertices.

Stage 4. Analysis of the graph $G = (N, L)$ and/or the subgraphs $G_i = (N_i, L_i)$.

4.1. Tabular presentation of the graph $G = (N, L)$ and/or the subgraphs $G_i = (N_i, L_i)$. In order to reduce the amount of memory occupied, it is advisable to use a tabular representation of a graph (subgraph), where the row number of the table is the vertex under consideration, i.e. the TIS element and the contents of the line define the connections of this vertex with other vertices.

4.2. Analysis of the tables obtained taking into account the necessary Equations (1) - (6).

4.3. Evaluation of the working conditions of the entire TIS and/or its elements for the graph/subgraphs. Setting the logical function (functions) for the analyzed graph/subgraphs in accordance with Equations (10), (12) - (16), their analysis and simplification by analogy with Equation (11).

4.4. Calculation of the probability of failure-free operation of the TIS elements for the considered levels and sublevels. Calculations are carried out according to Equations (19), (20), (21), (22), (24), (26) and, if necessary, condition in Equation (27) is checked. Here one should take into account the conditions for the performance of the formula elements.

4.5. Assessment of reliability of the transport information system in accordance with Equations (8) and (9).

Stage 5. Verification of the obtained results of the reliability assessment of the F_{TIS} with the necessary (specified). Based on the obtained calculations, it is determined what type of systems the TIS belongs to - an ordinary system, a system of high reliability, fault-tolerant, fail-safe. If the TIS corresponds to the required type, then go to the 7th stage, otherwise - go to the 6th stage.

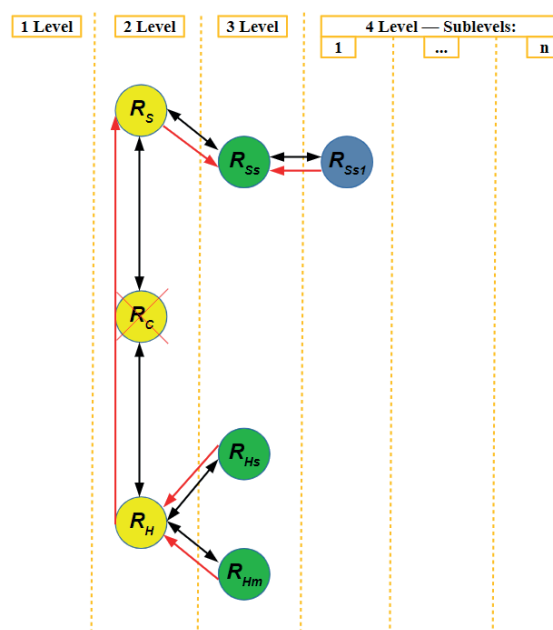


Figure 2 Subgraph example $G_i = (N_i, L_i)$

Stage 6. Taking measures to improve reliability - redundancy or replacement of the TIS elements with more reliable ones. At this stage, it is necessary to take into account that different elements of the TIS affect the behavior of the entire system in different ways. Here it is necessary to determine the measure of importance for the elements or groups/pairs of the TIS elements. The measure of importance can be determined based on the structure of the TIS, the reliability of components and the service life of elements. Reliability importance scores may include: Birnbaum importance, Fussell Vesely importance, joint reliability importance, differential importance measure, reliability achievement worth, total order importance [14]. An individual technical solution is made for each specific TIS.

Go to stage 1.

Stage 7. The end of the algorithm.

The hierarchical graph model for assessing the reliability of the TIS and the algorithm for analyzing the graph model allow taking into account the specifics of the reliability of the operation of elements (devices, communication channels, software, including vehicles) of systems of different levels.

7 Conclusions

The developed hierarchical graph model is designed to assess the reliability of a wide range of transport information systems. Number of vertices in the model graph is determined by the specific problem being solved when calculating the reliability.

Hierarchical graph model meets the following basic requirements: adequacy, versatility, efficiency, accuracy, is visual, has computability.

The implementation of the graph model is based on the two general principles:

- 1) principle of decomposition;
- 2) principle of hierarchy and multilevel reliability assessment, i.e. - the ability to assess the reliability of both the entire transport information system and its individual elements.

Multi-level nature of the model is a consequence of implementation of its development - as a process of sequential detailing and is generated by the following characteristic features:

- limited dimension of tasks solved at each level;
- a more complete description of the TIS at each subsequent level (sublevel) of detail in comparison to the previous one.
- A hierarchical graph model for assessing the reliability of the TIS allows:
- to carry out reliability calculations of the entire TIS, as well as of its individual constituent elements and the assessment of the reliability of the entire system can begin with an assessment of reliability of any of its constituent elements, i.e. graph vertices;
- evaluate the reliability of almost all the elements of the TIS;
- carry out reliability calculations, establishing the required dependencies between the elements of the transport information system;
- analyze the completeness of the initial information and correct the initial data.

Currently, there are software systems for assessing reliability, such as ARBITER, Workstation of Reliability, ASONIKA, AnyGraph, CRISS, BlockSim, ITEM Software, Reliability Workbench, Windchill, AggreGate Network Manager and others. However, the available software systems do not allow taking into account the specifics of transport information systems and the interconnections of their constituent elements. Consequently, these software systems make it possible to carry out only general calculations of reliability without taking into account the features and constituent elements of transport information systems. In contrast to the existing software systems, the developed hierarchical graph model allows not only calculating the reliability of transport information systems, but it also makes possible to analyze the relationships between the elements of the transport information system, identify unreliable elements, assess the feasibility of taking the necessary measures to improve the reliability of the entire TIS and its elements.

Using the graph model and an analysis algorithm, it is possible to reasonably predict the strategy for creation and development of transport information systems.

The developed mathematical apparatus can take into account the characteristic features, structure and composition of transport information systems and can be used in integrated software systems for calculating reliability.

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