THE KEY TO SUSTAINABLE TERRITORY DEVELOPMENT IS A SAFE CONSTRUCTION OF A REGIONAL ROAD NETWORK

Vyacheslav Burlov –
Peter the Great St. Petersburg Polytechnic University, professor
Higher school of technoshere safety, Russia,

Sergey Chernogorskiy –
Peter the Great St. Petersburg Polytechnic University, associate professor Department of fundamentals of economics and management, Russia

Konstantin Shvetsov –
Peter the Great St. Petersburg Polytechnic University, associate professor Graduate school of administrative management, Russia

Alexandra Novikova –
Peter the Great St. Petersburg Polytechnic University, graduate student
Higher school of technoshere safety, Russia

Abstract: The key to sustainable territory development is communications. Without a road network, regional communications are very problematic. The construction of the road network poses severe threats and safety issues to road construction workers. This leads to an obstacle to the sustainable development of the region. Therefore, to eliminate this obstacle, the article presents a methodology for ensuring the safety of road construction and, as a result, the formation of one of the factors contributing to the sustainable development of the region. Improving the safety of road construction is an important research problem. This article addresses the issue of evaluating the effectiveness of ensuring safety processes. Ensuring the safety of road construction is a purposeful activity of a decision maker. In the process of developing an approach to assessing the effectiveness of management by a decision maker, a mathematical model was developed. It is proposed to solve the task based on system integration of the processes of problem manifestation, identification and its elimination to ensure the necessary level of safety. This approach solves the indirect management problem. The article developed network graphs and calculated the main indicators for models of manifestation, monitoring and elimination of a problem. Direct and indirect tasks were calculated. The results show that the essential safety conditions manifest themselves, starting with the probability of identifying and neutralizing the threat is more than 80%. Reducing the time of monitoring and eliminating the problem positively affects the establishment of a higher level of security. An analysis of the results of the object's safe operating system shows that when monitoring and promptly eliminating detected problems, the level of safety increases, and the probability of a problem manifestation decreases.

Keywords: sustainable development of a territory, safety; model; synthesis; efficiency; control system; operations research.

1. Introduction

The basis of sustainable development of a territory is communications. Without a road network, communication in the region is very problematic. Efficient management of sustainable development is based on the application of domain knowledge management methods [1]. The construction of the road network poses severe threats and safety issues to road construction workers as, for example, occupational accidents or injuries. This leads to an obstacle to the sustainable development of the region. Therefore, to eliminate this obstacle, the article presents a methodology for ensuring the safety of road construction and, as a result, the formation of one of the factors contributing to the sustainable development of the region.

Road construction is one of the most important and dynamically developing sectors of the national economy. Road communications unite all regions of the country, which is a necessary condition for its territorial integrity, the unity of its economic space. Road connect the country with the world community, being the material basis for ensuring external economic relations and its integration into the global economic system.

Chen Jianguo, a well-known safety specialist, has shown in his articles that any complex systems of various nature require management organizations to monitor the safety of these systems constantly. Now occupational safety management organizations are feeling the need for analytical models and structured processes to prevent potential threats or hazards [2]. Therefore, in this article, the task of developing an analytical dynamic model for ensuring safety in road construction is set and solved.

2. Literature review

The article [3] developed a system for choosing safe technologies in the areas of road construction works. The results of the study provide a systematic approach to making informed decisions that can improve safety in road construction areas.

In [4], the level of safety of construction workers depends on four factors: the level of safety in the organization, job requirements, job evaluation, and worker safety rating.

The article [5] presents a model for identifying the main causes of accidents, adapted to the needs of the construction industry. Within the framework of the model, accidents are considered occurring due to three reasons: the inability to identify threats that existed before the start of the activity or arose after the activity was started; continuation of work after the employee identifies existing threats; continuation of work even with the initial detected threats.

The article [6] proposes an automated system for detecting and preventing hazards. The purpose of this system is to detect potential threats and to inform someone before an impending collision. The authors have developed an algorithm for detecting dangerous nearness between workers, automated vehicles and construction equipment.

The article [7] discusses various devices that help equipment operators control blind areas in order to prevent collisions with workers and other objects.

The article [8] describes a high-mast lighting system that is safer than portable lighting masts. The authors have shown that a high mast lighting system reduces the risk of injury to construction workers.

3. Materials and Methods

A management of the processes of ensuring the road construction safety, as a factor contributing to the sustainable development of the region, is an important scientific and practical task. The solution of this problem makes it possible to substantiate the required level of road construction safety. Therefore, the article developed a constructive methodology for the system integration of safety management processes in road construction based on the use of a natural-science approach [9,10].

Condition for the existence of road construction is its activity. An activity is an action aimed at satisfying a need. The activity basis is the solution [11]. The purpose of the activity of a decision-maker (DM) is to satisfy the need. The problem always arises before the object (subject) or DM. The problem of the subject (object), this is what requires a resolution (solution). The solution is a condition for implementing of the management object capabilities [8]. Capabilities are quantitative and qualitative characteristics that determine the ability of an object (subject) to solve target problems. The goal is what the object (subject) of activity – DM – strives for. The basis of such activity is the decision of the DM. The decision model characterizes the road construction process [12,13]. In the article, the authors synthesized a mathematical model of the DM solution. The authors have developed and applied a natural scientific approach (NSA) to solve the managerial problems of safe road construction [14].

Therefore, the mathematical model of decision-making allows establishing a formalized relationship to measure the safety index of road construction. The natural science approach is determined by integrating the properties of human thinking, the surrounding world and the universal connection of phenomena [9]. Using the NSA is based on the development of a mathematical model of the solution of the DM. The decision model of the DM is identical to managing road construction under destructive impacts. The development of a management model will be considered in the following parts of the article. A person solves problems based on three categories – system, model, and purpose. In the article [15], the results of solving the problems of ensuring the safety of road construction are obtained.

To consider a target process (TP) of the DM, a methodology has been developed for solving the problems of ensuring safety in road construction. It is based on the system integration of the TP, Problem Manifestation (PM), Problem Identification (PI), Problem Neutralization (PN), and Solution Implementation Performance Indicator (SIPI). To develop a methodology, two problems must be resolved: the development of a model based on synthesis and the inclusion in the model of the main regularities of the subject area.

3.1. Road Construction Safety Management Model

Safety is the property of an object to maintain its purpose during the life cycle in the conditions of the environmental destructive impact. The problem in developing a system for ensuring the safety of an object is to create conditions for the realization of the purpose of the management object – the target process.

The concept of "management decision" is decomposed into three basic elements "environment", "information and analytical work" and the actual "decision" (environment = object, information and analytical work = action, decision = purpose). Then it is necessary to proceed to the synthesis of the decision model, since the decision is the basis of human activity.

A synthesis-based approach provides a guarantee that the goal will be achieved.

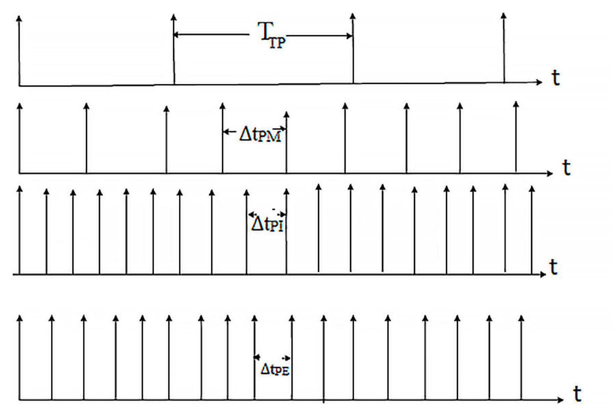
3.2. General Approach to the Synthesis of a Decision Model in Management

The decision of the DM is the basis of the activity. By the object model, we will consider the description or representation of the object corresponding to the object and allowing us to obtain characteristics about this object.

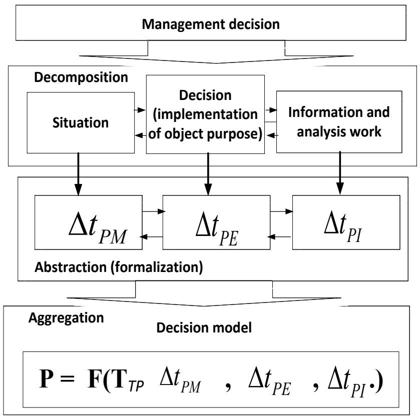
Figure 1(a) shows a block diagram of the process of synthesis of an adequate mathematical model. Decomposition, abstraction, and aggregation methods are used to synthesize the model. Using the decomposition method, the solution is divided into three interconnected elements. Applying the abstraction method, we form three elements corresponding to the elements obtained after using the decomposition method. In this article, the TP of the DM and the process of problem manifestation (PM) describe the «Situation». The mathematical model of the target process (TP) is the average time of the TP of decision maker $T_{TP} = f_0(\aleph_1, \aleph_2, \ldots \aleph_e)$, where the vector ℵ characterizes the states of the target process, $\aleph G_T$. The mathematical model of the PM is the average time for the manifestation of a problem for the DM $\Delta t_{PM} = f_1(x_1, x_2, \ldots x_n)$. The vector X characterizes the PM of the DM, XG_X. The mathematical model of information and analytical work is the average problem identification (PI) time for the DM $\Delta t_{PI} = f_2(y_1, y_2, \ldots y_n)$. The vector Y characterizes status of the DM's problem identification process, $Y \in G_Y$. The mathematical model of the problem elimination process (PE) is the average problem neutralization time for the decision maker $\Delta t_{PE} = f_3(z_1, z_2, \ldots z_n)$. The vector Z characterizes the state of the problem neutralization process of the DM, $Z \in G_Z$. G_T, G_Z, G_X, G_Y – bounded closed sets. The functions $f_0(\ldots)$, $f_1(, \ldots)$, $f_2(\ldots)$, $f_3(\ldots)$ describe the actions (works) that must be performed to achieve the required states of the vectors ℵ,X,Y,Z. Figure 1 (b) shows characteristics of these four processes.

Applying the aggregation method, we obtain the condition for the existence of a solution in the form of the following relation

$$P = F(T_{TP}, \Delta t_{PM}, \Delta t_{PI}, \Delta t_{PE}) \quad (1)$$



P – is an indicator of the effectiveness of management and characterizes the degree of achievement of the activity goal in conditions of manifestation of problems (threats). This is the probability that the problem is identified and neutralized, taking into account the restrictions on information, activity, environment resources.



(a) (b)

Figure 1. (a) Block diagram of the mathematical model synthesis process; (b) Diagram of the decision model taking into account the target process of an activity.

3.3. Synthesis of a management model for the basic process of ensuring the road construction safety

The concept of "managerial decision" is transformed into a mathematical model (1). The basic management decision model has four elements. These are the generalized characteristics of the TP of the DM (T_{TP}), the PM (Δt_{PM}), the PI (Δt_{PI}), PE (Δt_{PE}), arising in the decision-making process.

When solving practical problems, it is advisable to use network models that allow you to link time intervals and states of safety processes with critical time and states of network models [16,17,18].

Figure 2(a) shows a diagram of the management of the safety process, where λ is the reciprocal of the average time for the manifestation of the problem; ν_1 is the reciprocal of the average problem identification time; ν_2 is the reciprocal of the average problem neutralization time; TCP – average TP time.

Figure 2(b) shows a graph of forming a decision, considering functioning of the target object in the conditions of the manifestation of a problem (threat).

To describe the process of changing states on a graph, it is necessary to make assumptions. The article proposes to be guided by the assumptions borrowed from the article [19]. The processes (Figure 1(b)) characterize the TP and processes of PM, PI and PE. The characteristics of these processes T_{TP}, Δt_{PM}, Δt_{PI}, Δt_{PE} satisfy the noted assumptions. The introduced assumptions make it possible to use the system of differential equations (DE) of Kolmogorov [20].

Thus, the decision model of the DM is in four states.

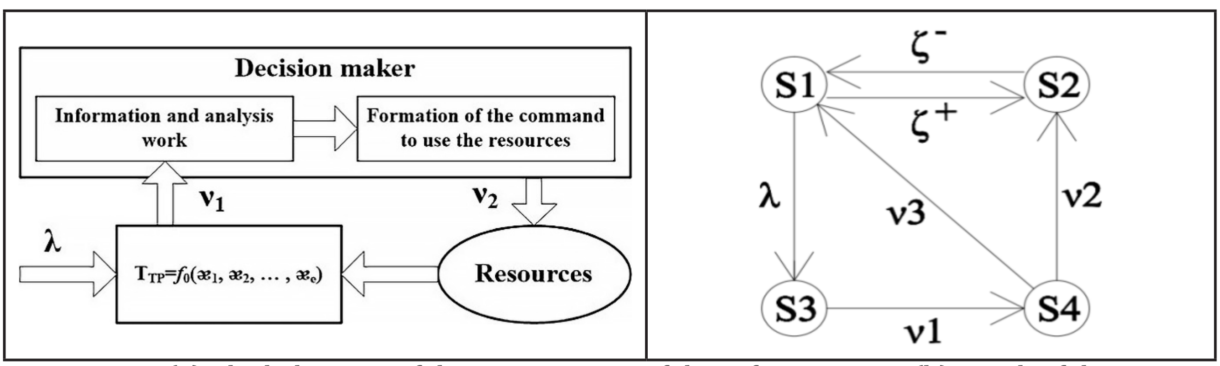


Figure 2. (a) Block diagram of the management of the safety process; (b) Graph of the process of forming a decision of the DM, taking into account the process of functioning of the target object in the conditions of the manifestation of a problem (threat).

S1 – initial state of the DM's decision formation. S2 – the final state of the DM's decision formation in the conditions of identification and neutralization of the problem. It takes time to move the system from state S1 to S2, and this time is TTP. To apply the Kolmogorov equations, we pass from the absolute values of time to the frequency of occurrence of events: $= 1/T_{TP}$, $\lambda = 1/\Delta t_{PM}$, $\nu_1 = 1/\Delta t_{PI}$, $\nu_2 = 1/\Delta t_{PE}$. ν_3 – the frequency of failure of the process of identifying a problem (threat) arising before the DM.

To assess the possibility of failure to achieve the goal of the DM's activity, an indicator of failure to achieve the goal was added into the model . As suggested by the authors of [20, 21, 22] – the DM's right to take a risk, to make a mistake.

S3 – the state of manifestation of the DM's problem;

S4 – the state of identification of the problem to be solved by the DM.

Then a DE system is compiled for our situation. It will have the form shown in Figure 3a. If we assume the process is stationary, and then the initial DE system is transformed into a system of linear algebraic equations (SLAE) presented in Figure 3b.

$$\begin{cases} \frac{dP_1(t)}{dt} = -\left(\zeta^+ + \lambda\right) \cdot P_1(t) + \zeta^- \cdot P_2(t) + \nu_3 \cdot P_4(t), \\ \frac{dP_2(t)}{dt} = \zeta^+ \cdot P_1(t) - \zeta^- \cdot P_2(t) + \nu_2 \cdot P_4(t), \\ \frac{dP_3(t)}{dt} = \lambda \cdot P_1(t) - \nu_1 \cdot P_3(t), \\ \frac{dP_4(t)}{dt} = \nu_1 \cdot P_3(t) - (\nu_3 + \nu_2) \cdot P_4(t). \end{cases}$$

(a) (b)

(a)

$$\begin{cases} 0 = -\left(\zeta^+ + \lambda\right) \cdot P_1 + \zeta^- \cdot P_2 + \nu_3 \cdot P_4, \\ 0 = \zeta^+ \cdot P_1 - \zeta^- \cdot P_2 + \nu_2 \cdot P_4, \\ 0 = \lambda \cdot P_1 - \nu_1 \cdot P_3, \\ 1 = P_1 + P_2 + P_3 + P_4. \end{cases}$$

(b)

Figure 3. (a) DE system for our situation; (b) Basic equations for the formation of SLAE base states.

For the DE(2) system, the following restriction is imposed:

P1(t)+P2(t)+P3(t)+P4(t)=1 (2)

The DE system is solved for the given initial conditions. In the general case, SLAE is used Figure 3b, where the right parts are some constants – the probabilities of finding the system in the corresponding states:

P1(0)=P1; P2(0)=P2; P3(0)=P3; P4(0)=P4 (3)

In the case when the system is in the S1 state:

P1(0)=1; P2(0)=0; P3(0)=0; P4(0)=0 (4)

Having considered the process as dynamic, we identify the possibilities of considering this process as stationary, with no contrary for the generality of reasoning [19].

The solution of SLAE has the form:

(5)

The probability P2 of finding the DM's decision model in the state S2 from relation (5) characterizes the fact that the goal of the DM is achieved in the conditions of identification and neutralization of the problem. The following ratio can represent the result of the system integration of the characteristics of the main processes that characterize the decision-making model of the DM:

P2 = F(, , $\lambda, \nu_1, \nu_2, \nu_3$) (6)

$$P_1 = \frac{\nu_1 \cdot \nu_2 \cdot \zeta + \nu_1 \cdot \nu_3 \cdot \zeta}{\lambda \cdot \nu_1 \cdot \nu_2 + \lambda \cdot \nu_1 \cdot \zeta + \lambda \cdot \nu_3 \cdot \zeta + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \nu_2 \cdot \zeta + \nu_1 \cdot \zeta^+ \cdot \nu_3 + \nu_1 \cdot \nu_2 \cdot \zeta}.$$
$$P_2 = \frac{\lambda \cdot \nu_1 \cdot \nu_2 + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \zeta^+ \cdot \nu_3}{\lambda \cdot \nu_1 \cdot \nu_2 + \lambda \cdot \nu_1 \cdot \zeta + \lambda \cdot \nu_3 \cdot \zeta + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \nu_2 \cdot \zeta + \nu_1 \cdot \zeta^+ \cdot \nu_3 + \nu_1 \cdot \nu_2 \cdot \zeta}.$$
$$P_3 = \frac{\lambda \cdot \nu_1 \cdot \zeta + \lambda \cdot \nu_3 \cdot \zeta}{\lambda \cdot \nu_1 \cdot \nu_2 + \lambda \cdot \nu_1 \cdot \zeta + \lambda \cdot \nu_3 \cdot \zeta + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \nu_2 \cdot \zeta + \nu_1 \cdot \zeta^+ \cdot \nu_3 + \nu_1 \cdot \nu_2 \cdot \zeta}. \quad (5)$$
$$P_4 = \frac{\lambda \cdot \nu_1 \cdot \zeta}{\lambda \cdot \nu_1 \cdot \nu_2 + \lambda \cdot \nu_1 \cdot \zeta + \lambda \cdot \nu_3 \cdot \zeta + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \nu_2 \cdot \zeta + \nu_1 \cdot \zeta^+ \cdot \nu_3 + \nu_1 \cdot \nu_2 \cdot \zeta}.$$

The analytical dependence of the generalized characteristics of the TP (= *1*/T_{TP}), PM (λ = $1/\Delta t_{PM}$), PI ($\nu_1 = 1/\Delta t_{PI}$), PE ($\nu_2 = 1/\Delta t_{PE}$), the risk index of disruption of the TP is established. The sixth characteristic ν3, which characterizes the possibility of disruption of the threat identification process, on the other hand characterizes the qualification of the DM. The ratio for $P_2 = P_{PIE}$ is an equation with several unknowns. (PIE – identification and elimination of the problem). Knowing the characteristics of the TP, PM, to form a model for DM's decision, we proceed as follows. By changing the indicator P_2, the characteristic of the TP and the risk indicators , ν_3, we form the required PI and PE. Thus, we got one equation with two unknowns. By forming the identification process and the neutralization process, we get the opportunity to manage the risk and the risk of not recognizing the threat by DM ν_3. This ratio is a condition for the realization of the purpose of the management object with which the DM works. Having received the model of the DM's solution, we will proceed to the consideration of the mechanism for managing the processes of ensuring road construction safety.

The following ratio describes the probability of problem identification and its elimination:

$$P_2 = \frac{\lambda \cdot \nu_1 \cdot \nu_2 + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \zeta^+ \cdot \nu_3}{\lambda \cdot \nu_1 \cdot \nu_2 + \lambda \cdot \nu_1 \cdot \zeta^- + \lambda \cdot \nu_3 \cdot \zeta^- + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \nu_2 \cdot \zeta^- + \nu_1 \cdot \zeta^+ \cdot \nu_3 + \nu_1 \cdot \nu_2 \cdot \zeta^-} \quad (7)$$

4. Results

4.1. Technology for managing the processes of ensuring the road construction safety

In the previous paragraph, a dynamic model of the solution was obtained. The special feature of the model is that the law of preserving the integrity of the object formed from time characteristics is its basis. Thus, states and some works that help to achieve these states characterize the real process. An interesting engineering problem arises – to build the dependence of the time components in the solution model on the states and work that must be performed to achieve certain states. To achieve this goal, network graphs are suitable. They allow you to establish the relationship between time components of the decision model (the critical paths) and the states of the work performed to achieve these states. We work with the characteristics of four processes = $1/T_{TP}$, $\lambda = 1/\Delta t_{PM}$, $\nu_1 = 1/\Delta t_{PI}$, $\nu_2 = 1/\Delta t_{PE}$).

We will consider only three processes: the process of threat formation (manifestation), the process of its identification (monitoring) and the process of its neutralization.

4.2. Development of a network model of threat generation in the process of road construction

It is necessary to establish a connection between the temporal characteristics, from which the condition for the existence of the safety process is formed, the states and the works that must be performed to achieve these states. For this, network graphs of the processes of threat formation, its identification and neutralization are compiled.

To compile a network model for the manifestation of problems, it is necessary to determine a list of problems that may arise because of certain actions and the time they require to pose threats (Table 1).

Table 1. List of events of problems occurrence in the road construction process.

ID	Events
a_0	Manifestation of a threat in the process of road construction
a_1	Problems in the process of road construction associated with the organization of work on the installation of asphalt pavement
a_2	Problems in the road construction process related to resources
a_3	Problems in the process of road construction because of a decrease in the equipment's reliability
a_4	Problems in the process of road construction associated with the organization of traffic
a_5	Problems in the road construction process due to weather conditions
a_6	Problems in the road construction process associated with personal protective equipment (PPE)
a_7	Problems in the road construction process associated with sand, cement and gravel
a_8	Problems in the road construction process associated with concrete structures
a_9	Problems in the road construction process associated with asphalt concrete mixture (ACM)
a_{10}	Problems in the road construction process associated with equipment for manual asphalt paving
a_{11}	Problems in the road construction process associated with the use of PPE
a_{12}	Problems in the road construction process associated with the non-use of PPE
a_{13}	Problems during road construction related to the ACM temperature
a_{14}	Problems in the road construction process associated with bitumen fumes (ACM)

Because of the threat formation, a failure in the process of road construction may occur because of some negative impact. To compile a list of works leading to the formation of a threat, we make the following assumptions (Table 2) with an indication of time intervals.

Table 2. A list of works linking the events of the appearance of a threat in the road construction process.

ID of Works	Works	Work completion time	Previous works	Subsequent works
A_{01}	Formation of a threat due to problems in the process of road construction associated with the organization of work on the installation of asphalt pavement	5	-	$A_{14}A_{15}$ A_{16}
A_{02}	Formation of a threat due to problems in the road construction process related to resources	5	-	$A_{27}A_{28}A_{29}$
A_{03}	Formation of a threat due to problems in the road construction process because of a decrease in the equipment's reliability	5	-	A_{310}
A_{14}	Formation of a threat due to the traffic organization	15	A_{01}	A_{418}
A_{15}	Formation of a threat due to weather conditions	15	A_{01}	A_{518}
A_{16}	Formation of a threat due to PPE	10	A_{01}	$A_{611}A_{612}$
A_{27}	Formation of a threat due to problems in the construction of roads associated with sand, cement, and gravel	30	A_{02}	A_{718}
A_{28}	Formation of a threat due to problems in the road construction process associated with concrete structures	20	A_{02}	A_{818}
A_{29}	Formation of a threat due to the ACM	15	A_{02}	$A_{913}A_{914}$
A_{310}	The formation of a threat due to equipment for manual asphalt paving	15	A_{03}	$A_{1015}A_{1016}$ A_{1017}
A_{611}	The formation of a threat due to the use of PPE	20	A_{16}	A_{1118}
A_{612}	The formation of a threat due to the non-use of PPE	20	A_{16}	A_{1218}
A_{913}	Formation of a threat due to the ACM temperature	15	A_{29}	A_{1318}
A_{914}	Formation of a threat due to bitumen fumes (ACM)	10	A_{29}	A_{1418}
A_{1015}	Formation of a threat due to occupational noise	15	A_{310}	A_{1518}
A_{1016}	Formation of a threat due to occupational vibration (Hand-Arm vibration or Whole-Body vibration)	15	A_{310}	A_{1618}
A_{1017}	Formation of a threat due to liquid binders heated to a high temperature	15	A_{310}	A_{1718}
A_{418}	Formation of a threat due to disorganized traffic at the place of work	10	A_{14}	-
A_{518}	Formation of a threat due to adverse weather conditions	10	A_{14}	-

A_{718}	Formation of a threat due to the increased concentration of silica dust in the air of the work zone	10	A_{27}	-
A_{818}	Formation of a threat due to physical overload	10	A_{27}	-
A_{1118}	Formation of a threat due to difficult communications	10	A_{611}	-
A_{1218}	Formation of a threat due to the possibility of injury	10	A_{612}	-
A_{1318}	Formation of a threat due to the risk of getting burned	10	A_{913}	-
A_{1418}	Formation of a threat due to inhalation of hot bitumen fumes (ACM)	10	A_{914}	-
A_{1518}	Formation of a threat due to increased occupational noise levels	10	A_{1015}	-
A_{1618}	Formation of a threat due to an increased level of an occupational vibration (Hand-Arm vibration or Whole-Body vibration)	10	A_{1016}	-
A_{1718}	Formation of a threat due to hot drops and splashes of hot materials	10	A_{1017}	-

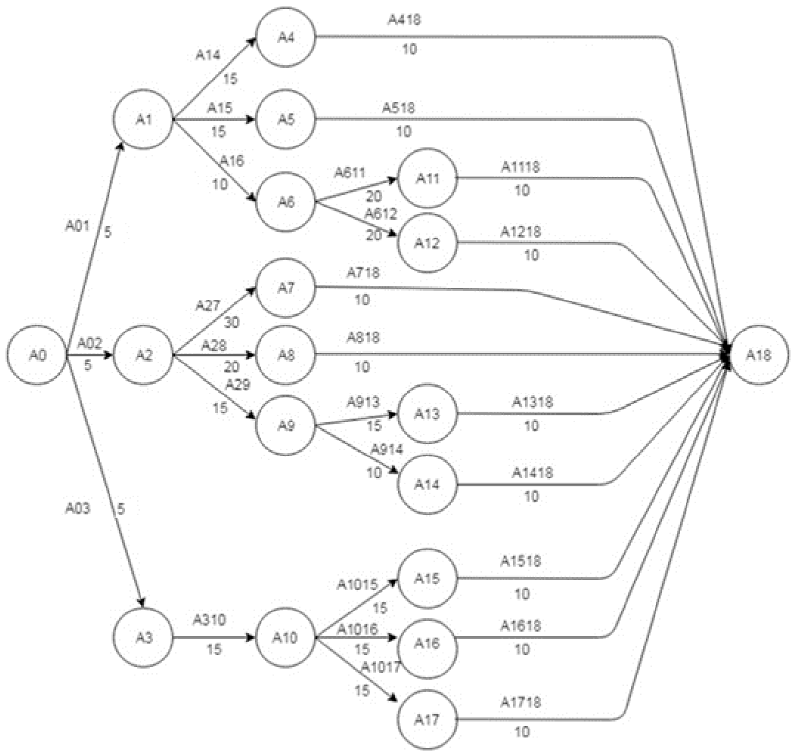


Figure 4. Network graph of threat formation.

Critical path length in time: TCP=45.

4.3. Network monitoring model

To create a network model for monitoring problems, it is necessary to determine a list of problems that may arise as a result of certain actions and the time they require to identify threats.

Table 3. List of monitoring events.

ID	Events
	Start of monitoring
	Check on the organization of work on the asphalt pavement installation
	Resource check
	Checking the reliability of the equipment used
	Checking the organization of traffic
	Checking the weather conditions
	PPE check
	Monitoring during the road construction related to sand, cement, and gravel
	Monitoring during the road construction related to concrete structures
	Monitoring during the road construction related to the ACM
	Monitoring during the road construction related to the equipment for manual asphalt paving
	Monitoring during the road construction related to the temperature of the ACM
	Monitoring during the road construction related to hot bitumen fumes (ACM)
	Monitoring during the road construction related to an occupational noise
	Monitoring during the road construction related to an occupational vibration (Hand-Arm vibration or Whole-Body vibration)
	Monitoring during the road construction related to liquid binders heated to a high temperature
	Preparation of a monitoring report

After that, work is thought out, during which all the necessary monitoring events should occur.

Table 4. List of monitoring works.

ID of Works	Works	Work completion time	Previous works	Subsequent works
A_{01}	Monitoring the organization of work on the asphalt pavement installation	5	-	$A_{14} A_{15} A_{16}$
A_{02}	Conducting a resource check	10	-	$A_{27} A_{28} A_{29}$
A_{03}	Conducting a reliability check of the equipment used	5	-	A_{310}
A_{14}	Conducting a traffic management check	35	A_{01}	A_{416}
A_{15}	Conducting a weather check	40	A_{01}	A_{516}
A_{16}	Conducting a PPE check	55	A_{01}	A_{616}
A_{27}	Conducting an inspection related to sand, cement, and gravel	25	A_{02}	A_{716}
A_{28}	Conducting an inspection related to concrete structures	35	A_{02}	A_{816}
A_{29}	ACM Inspection	25	A_{02}	A_{911} A_{912}

A_{310}	Conducting an inspection of manual asphalt paving equipment	20	A_{03}	A_{1013} A_{1014} A_{1015}
A_{911}	Conducting an inspection related to the temperature of the ACM	23	A_{29}	A_{1116}
A_{912}	Conducting bitumen vapors test (ACM)	25	A_{29}	A_{1216}
A_{1013}	Conducting an occupational noise test	35	A_{310}	A_{1316}
A_{1014}	Conducting an occupational vibration test	15	A_{310}	A_{1416}
A_{1015}	Testing of liquid binders heated to a high temperature	25	A_{310}	A_{1516}
A_{416}	Preparation of a report on the monitoring of the traffic in a work zone	5	A_{14}	-
A_{516}	Preparation of a weather monitoring report	5	A_{14}	-
A_{616}	Preparation of a report on the monitoring of the use of PPE	5	A_{16}	-
A_{716}	Preparation of a report on monitoring the concentration of silica dust in the air of a work zone	5	A_{27}	-
A_{816}	Preparation of a report on the monitoring of physical overloads	5	A_{27}	-
A_{1116}	Preparation of a burn hazard monitoring report	5	A_{911}	-
A_{1216}	Preparation of a report on the monitoring of hot bitumen fumes (ACM)	5	A_{912}	-
A_{1316}	Preparation of a report on the monitoring of occupational noise level	5	A_{1013}	-
A_{1416}	Preparation of a report on the monitoring of occupational vibration level	5	A_{1014}	-
A_{1516}	Preparation of a report on the monitoring of hot materials drops and splashes	5	A_{1015}	-

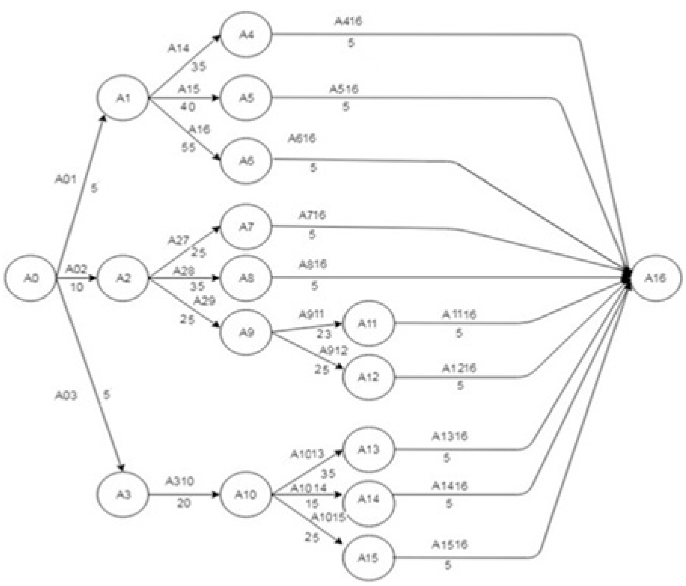


Figure 5. Network graph of monitoring.

Critical path length in time: TCP=65.

4.4. Network model of elimination of threats

To build a network schedule, we develop a preliminary list of events that defines the planned process and without which it cannot take place.

ID	Events
a_0	The beginning of the elimination of identified threats in the process of road construction
a_1	Elimination of problems in the process of road construction associated with inefficient organization of work
a_2	Elimination of problems in the process of road construction associated with resources
a_3	Elimination of problems in the process of road construction associated with the low equipment reliability
a_4	Elimination of problems in the process of road construction associated with poor traffic management
a_5	Elimination of problems in the process of road construction due to weather conditions
a_6	Elimination of problems in the process of road construction due to providing employees with PPE
a_7	Elimination of problems in the road construction process associated with sand, cement and gravel
a_8	Elimination of problems in the process of road construction associated with concrete structures
a_9	Elimination of problems in the process of road construction associated with the ACM
a_{10}	Elimination of problems in the process of road construction associated with manual asphalt paving equipment
a_{11}	Elimination of problems in the process of road construction associated with occupational noise
a_{12}	Elimination of problems in the process of road construction associated with occupational vibration
a_{13}	Elimination of problems in the process of road construction associated with liquid binders heated to a high temperature
a_{14}	Preparation of a report on the elimination of identified threats in the process of road construction

Table 5. List of threat elimination events.

After that, we think over the works, in a number of which all the events must occur.

Table 6. The list of works to eliminate the threat.

ID of Works	Works	Work completion time	Previous works	Subsequent works
A_{01}	Elimination of the threat due to the unefficient organization of work on the asphalt pavement installation	5	-	A_{14} A_{15} A_{16}
A_{02}	Elimination of the threat due to resources	10	-	A_{27} A_{28} A_{29}
A_{03}	Elimination of the threat due to reducing the reliability of the equipment used	5	-	A_{310}
A_{14}	Elimination of the threat due to traffic management	20	A_{01}	A_{414}
A_{15}	Elimination of the threat due to weather conditions	15	A_{01}	A_{514}
A_{16}	Elimination of the threat due to PPE	45	A_{01}	A_{614}
A_{27}	Elimination of the threat due to sand, cement and gravel	35	A_{02}	A_{714}
A_{28}	Elimination of the threat due to concrete constructions	35	A_{02}	A_{814}
A_{29}	Elimination of the threat due to the ACM	40	A_{02}	A_{914}
A_{310}	Elimination of the threat due to a manual asphalt paving equipment	20	A_{03}	A_{1011} A_{1012} A_{1013}
A_{1011}	Elimination of the threat due to an occupational noise	15	A_{310}	A_{1114}
A_{1012}	Elimination of the threat due to an occupational vibration	20	A_{310}	A_{1214}
A_{1013}	Elimination of the threat due to high temperature liquid binders	25	A_{310}	A_{1314}
A_{414}	Elimination of the threat due to unorganized traffic at the work zone	5	A_{14}	-
A_{514}	Preparation of a report on the elimination of identified threats in the road construction process	5	A_{15}	-
A_{614}	Preparation of a report on the elimination of identified threats in the road construction process	5	A_{16}	-
A_{714}	Preparation of a report on the elimination of identified threats in the road construction process	5	A_{27}	-
A_{814}	Preparation of a report on the elimination of identified threats in the road construction process	5	A_{28}	-
A_{914}	Preparation of a report on monitoring the concentration of silica dust in the air of the work zone	5	A_{29}	-
A_{1114}	Preparation of a burn hazard monitoring report	5	A_{1011}	-
A_{1214}	Preparation of a report on the monitoring of hot ACM vapors	5	A_{1012}	-
A_{1314}	Preparation of a noise monitoring report	5	A_{1013}	-

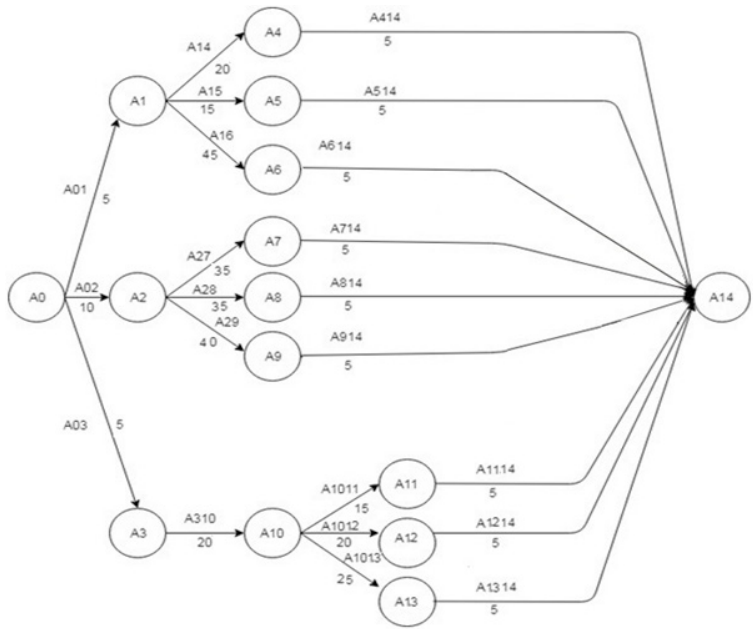


Figure 6. Network schedule of threat elimination.

Critical path length in time: TCP= 55.

5. Discussion

Time to solve the problem (work shift) T=480/(60*24)=0,333 days. Number of problems per shift (output per worker), m/shift $N_1 = 8{,}2$. The number of m/shift for a team of 4 workers $N_2 = 100/3 = 33{,}333$. The average time of manifestation of the problem, days. $\Delta t_{PM} = 45/(60*24) = 0{,}031$. The average of problem identification time, days. $\Delta t_{PI} = 65/(60*24) = 0{,}045$. The average of problem elimination time, days.

$\Delta t_{PE} = 0{,}038$, $\lambda = 1/\Delta t_{PM} = 32$, $\nu 1 = 1/\Delta t_{PI} = 22{,}154$, $\nu 2 = 1/\Delta t_{PE} = 26{,}182$.

The value is the inverse of the average time to complete the target task = *1/T = 3.* The frequency of failure of the plan – failure to complete the task = $N_1/N_2 = 0{,}246$. The DM's qualification indicator is $\nu_3 = \nu_1/1000$.

Probabilities of finding the system in states *S1, S2, S3, S4: P1 = 0,028, P2 = 0,679, P3 = 0,165, P4 = 0,128.*

$$P_2 = \frac{\lambda \cdot \nu_1 \cdot \nu_2 + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \zeta^+ \cdot \nu_3}{\lambda \cdot \nu_1 \cdot \nu_2 + \lambda \cdot \nu_1 \cdot \zeta^- + \lambda \cdot \nu_3 \cdot \zeta^- + \nu_1 \cdot \nu_2 \cdot \zeta^+ + \nu_1 \cdot \nu_2 \cdot \zeta^- + \nu_1 \cdot \zeta^+ \cdot \nu_3 + \nu_1 \cdot \nu_2 \cdot \zeta^-}$$

Thus: ΔtPI = 17 min., ΔtPE = 20 min.

To get a threat elimination probability $P_2 = 0.80$, the time for problem monitoring and its neutralization needed to be reduced. It is necessary to reduce the time to identify the problem from 65 minutes to 17 minutes. It is necessary to reduce the time to neutralize the problem from 55 minutes to 20 minutes.

Modeling the condition of a new task: The average time of manifestation of the problem, days $\Delta t_{PM} = 45/(60*24) = 0{,}031$. The average of problem identification time, days $\Delta t_{PI} = 17/(60*24) = 0{,}012$. The average of problem elimination time, days $\Delta t_{PE} = 20/(60*24) = 0{,}014$. Thus, $\lambda = 32$; $\nu_1 = 84{,}706$; $\nu_2 = 72$. As a result, we obtain the probabilities of the system being in four basic states at a road construction safety level, $P_2 = 0.801$.

$$P1 = \frac{\nu1\nu2\xi^- + \nu1\nu3\xi^-}{\lambda\nu1\nu2 + \lambda\nu1\xi^- + \lambda\nu3\xi^- + \xi^+\nu1\nu2 + \xi^-\nu1\nu2 + \xi^+\nu1\nu3 + \xi^-\nu1\nu3} = 0{,}184$$

$$P1 = \frac{\nu1\nu2\xi^- + \nu1\nu3\xi^-}{\lambda\nu1\nu2 + \lambda\nu1\xi^- + \lambda\nu3\xi^- + \xi^+\nu1\nu2 + \xi^-\nu1\nu2 + \xi^+\nu1\nu3 + \xi^-\nu1\nu3} = 0{,}184$$

$$P3 = \frac{\lambda\nu2\xi^- + \lambda\nu3\xi^-}{\lambda\nu1\nu2 + \lambda\nu1\xi^- + \lambda\nu3\xi^- + \xi^+\nu1\nu2 + \xi^-\nu1\nu2 + \xi^+\nu1\nu3 + \xi^-\nu1\nu3} = 8{,}099 * 10^{-3}$$

$$P4 = \frac{\lambda\nu1\xi^-}{\lambda\nu1\nu2 + \lambda\nu1\xi^- + \lambda\nu3\xi^- + \xi^+\nu1\nu2 + \xi^-\nu1\nu2 + \xi^+\nu1\nu3 + \xi^-\nu1\nu3} = 7{,}091 * 10^{-3}$$

Without violating the generality of reasoning, it is always possible to create a safety system with the required level of safety by forming the processes of identification (monitoring) of the threat and its neutralization. The target process, the process of creating a threat and indicators of the risk of failure of the target activity and the risk of failure to identify threats (an indicator of the employee's qualifications) are known.

Articles [2-8] consider various aspects of road construction safety, present methods for substantiating the decision making model. However, the absence of a mathematical model for solving decision makers did not allow the authors of articles [2-8] to calculate the effectiveness of the process management model.

6. Conclusions

1. An extensive, high-quality road network is a sign of the sustainable development of the region. However, the creation of such a road network is very difficult due to the high level of risks [24]. To overcome this difficulty in road construction, a methodology for guaranteed safety is proposed. The condition for the existence of a safety process is a basis of a safety. This condition for the existence of the process is developed on the basis of the system integration of the target process, the process of creating a threat, the processes of identifying and neutralizing the threat.

2. The proposed mathematical apparatus makes it possible to build a mathematical model of a management decision and to link the three most important processes in the organization of an asphalt concrete pavement. Based on the mathematical model, the conditions for ensuring the safety of road construction are formed.

3. Within the framework of solving the task of forming a person's decision, the problem of establishing a relation between time and state arises. In the process of forming a decision model for a DM, time is a function of the state and work that needs to be done to achieve the result [25,26]. A network diagram is an activity model that reflects the relationship of work (events) and the time parameters of their production.

4. The article developed network graphs and calculated the main indicators for models of manifestation, monitoring and elimination of the problem (threat). The direct and inverse tasks were calculated. The results obtained show that the essential conditions for ensuring safety begin to manifest themselves, starting with the probability of identifying and neutralizing the threat $P \geq 0.8$.

5. The efficiency indicator of the process management model P2 in the first task is 0,702, in the second task is 0,679 (when the manager is a qualified specialist, but the employees are not). Thus, with a decrease in qualifications in the team, the chance that the threat will be recognized and neutralized decreases.

6. The performed calculations show that the time to identify and neutralize the problem should be reduced.

7. The calculations focus on the fact that the process of road construction should be automated as much as possible in order to reduce the possibility of injuries during the installation of asphalt concrete pavement [27].

8. In order to automate the process of problem identification and its neutralization, and, accordingly, to reduce the time for implementing of these processes, it is proposed to introduce an intelligent air monitoring system using the latest robotics and computer vision technologies. Using unmanned aerial vehicles at the stage of data collection makes it possible to carry out road surveys in the shortest possible time. This technology will significantly reduce the time for identifying threats and at the same time eliminate the human factor, for example, due to an exhaustion or tiredness that leads to a decrease in task performance and commitment.

9. In addition, it is possible to install video surveillance equipment on construction equipment. It also may be some kind of video recorders equipped with computer vision to send a signal to the console in case of a process disruption. The technology can be combined with a sound piezo emitter to warn a worker of danger.

10. In addition to various proposed options to improve the safety of road construction, some more ways to achieve this goal are follows:

-occupational health and safety training;

– safe working practices for specific vehicle training;

– using traffic safety measures and signs for road works;

– using traffic signal control systems, signalised crossings, driver information facilities and other intelligent transport system;

– the safe interaction with drivers of asphalt paving machines;

– constant monitoring of the existing response system.

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