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Cognitive simulation of incident risks in the structure of loading and transport enterprise

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Abstract. Organizational and technical system of a manufacturing enterprise was identified, which includes three subsystems: main production, industrial and social infrastructure. Based on the results of cognitive modeling, significant system concepts were identified that reduce the risks of incidents. The internal control influences formed in accordance with level of competence of heads of services, departments, sections, dispatchers, acting on the basis of regulations, job profiles. The second concept influencing the enterprise management system is personnel, which is assessed by the compliance of competencies of crane operators, loader operators, slingers, loaders, and acceptance/delivery agents to job responsibilities and labor functions. At a low level of professional competencies, the personnel does not fully comply with job duties and labor functions, the risk of an incident is maximal. The application of cognitive modeling allows us to identify the essential elements that ensure stable functioning of the system as a whole.

1. Introduction

The loading and transport enterprise (LTE), the structure of which includes a complex of facilities and services providing loading and unloading services as well as cargo shipping expeditions for mines, open pit mines, processing plants, as well as current repair of railway tracks and adjustment of own diesel locomotives, can be regarded as organizational and technical system, which contains three subsystems [1, 2]: main production, production and social infrastructure.

The main production includes the production processes of enterprise, during which materials or raw materials are converted into products. In the context of LTE, such processes are loading and transportation of coal in wagons for sale to consumers.

The production infrastructure consists of a complex of shops, management units and services that provide the necessary conditions for the main activity of the enterprise. At the LTE the production infrastructure includes the rolling stock service, track service, material and technical supply department, communication section, production control and labor protection service, production and technical department, etc.

The social infrastructure unites divisions of the enterprise that ensure the sanitary and hygienic working conditions and the social and everyday needs of workers.

The LTE specific features are the fulfillment of two main processes by the service of freight and field operations: loading and transportation of coal in wagons for sale to consumers, and the remaining processes are auxiliary providing all the technological cycles [3, 4].

In accordance with the management theory of complex production structures, a loading and transport enterprise that performs both economic and social functions can be identified as an organizational and technical system (OTS).

The relevance of study of subsystem interaction patterns in the LTE structure follows from the results of analysis of its economic activity, which confirm a significant gap in technical, organizational and socio-economic levels of development between the OTS subsystems. At the facilities of production and social infrastructure, the level of mechanization and automation is lower, the share of manual labor is much higher, and the level of management is low. It should be noted that during optimization and structural changes at enterprises, first of all, the personnel of production and social infrastructure are reduced, turning it into a "bottleneck" of LTE, negatively affects the economy, leads to an increase in operating costs. Technical progress in the development of loading transportation equipment, organization of processing, coal loading and transportation of wagons requires adequate changes in the subdivisions of production and social infrastructure.

As an object of research the enterprise named United Production and Transport Department of Kuzbass, LLC, was accepted. The general scheme of subsystems interaction in LTE structure is given in [2, 4, 5]. To study the nature of interaction of elements in subsystems, a cognitive approach was adopted that predicts the development scenarios of the facility and making of management decisions taking into account the risks of incidents.

2. Methods of research

Based on the analysis of theory and experience of cognitive modeling [6 - 8], the following main stages of the analysis of interacting factors (concepts) and modeling of possible development scenarios of situation in LTE structure are substantiated [9 - 13]:

- identification of concepts and variables of their state of the research object;
- construction of a conceptual model using uncertain and unreliable information;
- construction of cognitive maps with identification of concepts in graph vertices and connections between concepts;
- determination of values of cause-effect relationships with consideration of state variables of the complex of factors interacting in technological process;
- analysis of cognitive models;
- formation of adjacency matrix;
- calculation of accessibility matrix to evaluate the cognitive map connectivity;
- impulse simulation;
- correction of models;
- making decisions to manage the object state.

3. Results and discussion

Concept is the basic notion for the group (class) of elements of the object under study. The name of the concepts and their states in each class depend on many factors. Within the framework of LTE organizational and technical system the following indicators are distinguished [14, 15]:

1) external influences: control and supervisory bodies, regulatory documents, delivery of wagons, coal to warehouses, etc.;

2) internal control actions: the level of competence of heads of services, departments, sections, dispatchers and other job responsibilities within the framework of delegated authority;

3) conformity of personnel competencies (crane drivers, loader operators, slingers, movers, acceptance/delivery agents, etc.) to job duties and labor functions [16];

4) loading and unloading operations;

5) seasonal changes in the elements of the environment in which the control object operates: extreme negative and positive air temperatures, precipitation, reduction in the volumes of coal shipment during spring-summer period, increased probability of spontaneous combustion of coal stored in storages, seasonal and weather restrictions due to environmental factors;

6) shunting operations;

7) wear of production funds;

8) state and conditions of non-public routes operation;

9) compliance of the actual activity of LTE with its license for loading and unloading activities with regard to hazardous goods transported by railway;

10) wagon transportation;

11) communication and signaling: levels of efficiency, sustainability, continuity, efficiency and reliability of transmitted information;

12) risk of incidents: spillage of oil products from railway tanks during transportation, fire of rolling stock, fire in coal storage, train derailment from railway tracks, etc.;

13) repair works;

14) material and technical support.

Identification of concepts and variables of their state of control object for development of cognitive models was carried out on the basis of expert assessments of specialists from United PTU of Kuzbass, LLC. The interrelation and the significance of the concepts connections in the cognitive map were estimated on the following scale: (+1.0) – affects strongly; (+0.5) – affects; (0.0) – does not affect; (-0.5) – affects negatively; (-1.0) – affects very negatively.

Based on the results of concepts identification a cognitive map and an adjacency matrix were constructed that include 14 interrelated concepts.

At the first stage cognitive modeling was carried out to determine the influence of a single concept on the stability of the system as a whole, and on the second stage – the effect of the system on the concept. The calculations were made when one of the concepts was changed within the range $0 \div 1$ with step $\Delta_k = 0.1$. The sum of the effects of the ith concept on the remaining concepts and the system as a whole for each kth step of the change of ith concept was determined by the formula

$$W_i^k = \sum_1^N v_{jk},$$

where W_i^k – sum of the influences of the ith concept on the remaining concepts of the system at the kth step of change of the ith concept; k – initial (starting) value of the ith concept at the kth step of its change; v_{jk} – numerical value of the jth concept at the kth step of change of the ith concept.

The modeling and calculation results of sums of influence of the ith concept on the remaining concepts of the system are shown in Figure 1, from the graphs of which it follows that for values of concept i within the range $0 < v_i < 0.2$, its effect significantly and gradually decreases, and at $v_i \approx 0.5$, the system becomes stable. At $v_i > 0.7$ instability arises in the system due to the strong influence of the concept i.

The most significant influence on the system is provided by internal control actions (Figure 1), formed in accordance with the level of competence of heads of services, departments, sections, dispatchers acting on the basis of regulations, job descriptions. According to the graphs, the technological and organizational control actions at the concept value $v_{i-2} < 0.3$ have the strongest impact on the state of the system as a whole, additional control actions allow the risk of an incident in the system to be reduced and the system to be brought to an equilibrium state. The system functions normally at the values of the concept $0.4 < v_{i=2} < 0.7$. At $v_{i=2} > 0.7$ additional control actions on the system are not required, as they will lead to an increase in the risk of incidents.

The second strongest impact on the LTE management system is personnel (Figure 1), which is assessed by the compliance of the competencies of crane drivers, loader operators, slingers, loaders, and acceptance/delivery agents, etc., to job responsibilities and labor functions. At $v_{i=3} = 0.1$ the competence of the staff does not fully correspond to the job description and labor functions, the risk of incidents is maximal. This is confirmed by the maximum risk of incident on the graph in Figure 1. It can be argued that at $v_{i=3} < 0.1$, with sufficient competencies for performing production operations, the gradual adaptation of performers to the working conditions takes place in terms of acquiring skills and techniques for performing operations. The adaptation period is intensive, this fact is confirmed by the

graph in figure 1, in which at $v_{i=3}>0.3$ the competencies are sufficient to perform production operation and provide functioning of the entire system in a stable mode. It should be noted that further increase in the competence of personnel at $v_{i=3}>0.7$ the risk of incidents does not increase.

The influence of other concepts on the risks of incidents in the system is smoothly reduced according to the graphs in figure 1.

Almost the same influence of two concepts on the system were revealed:

- external impacts $v_{i=1}$: supervisory authorities, regulatory documents, delivery of coal wagons to storages;
- communication and signaling $v_{i=11}$: the criterion is the risk of an incident due to unsatisfactory communication and signaling.

The influence of these concepts on the risk of an incident in the system decreases monotonically in the range $v_{i=1}=v_{i=11}<0.4$.
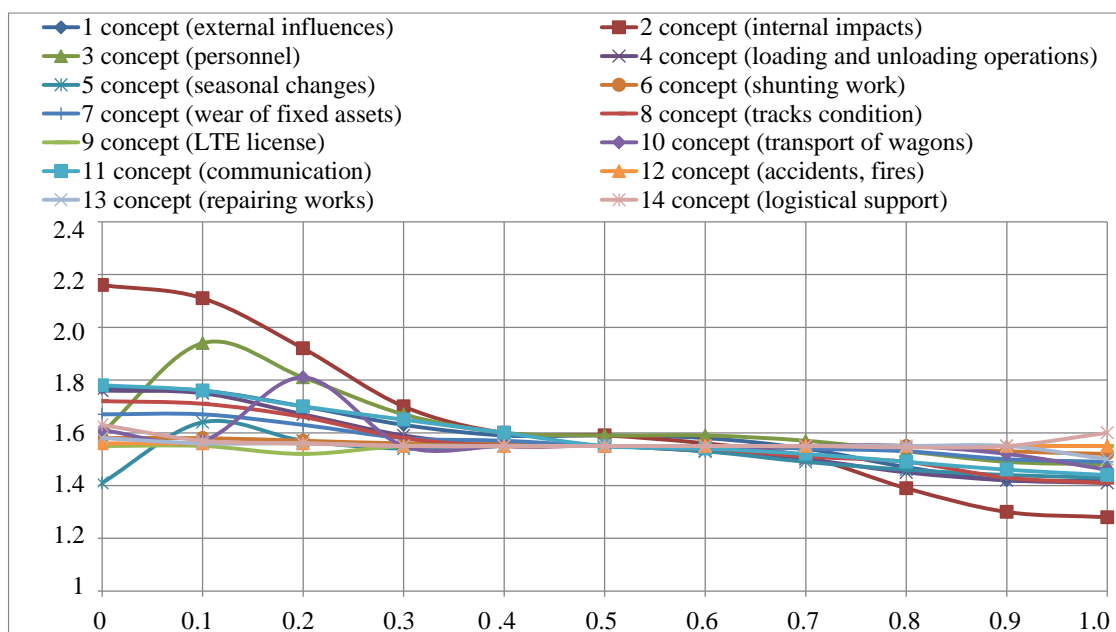

Figure 1. Graphs of variance of concepts action force on the system.

The developed algorithm for constructing functional dependencies between the relevant factors makes it possible to identify not only the influence of individual concepts on the management system, but also the influence of management system on individual concepts. The ranking of concepts by the strength of the system integral impact allows us to identify the concepts most relevant to the system (figure 2).

It should be noted that the graphs in figures 1 - 2 were obtained by varying the values of only one factor (concept) in the range from 0 to 1. In this case, the values of other factors are assumed to be the same, that is, $v_i=0.5$. However, the method of cognitive modeling allows different alternative versions of the state of individual concepts and the system as a whole to be considered.
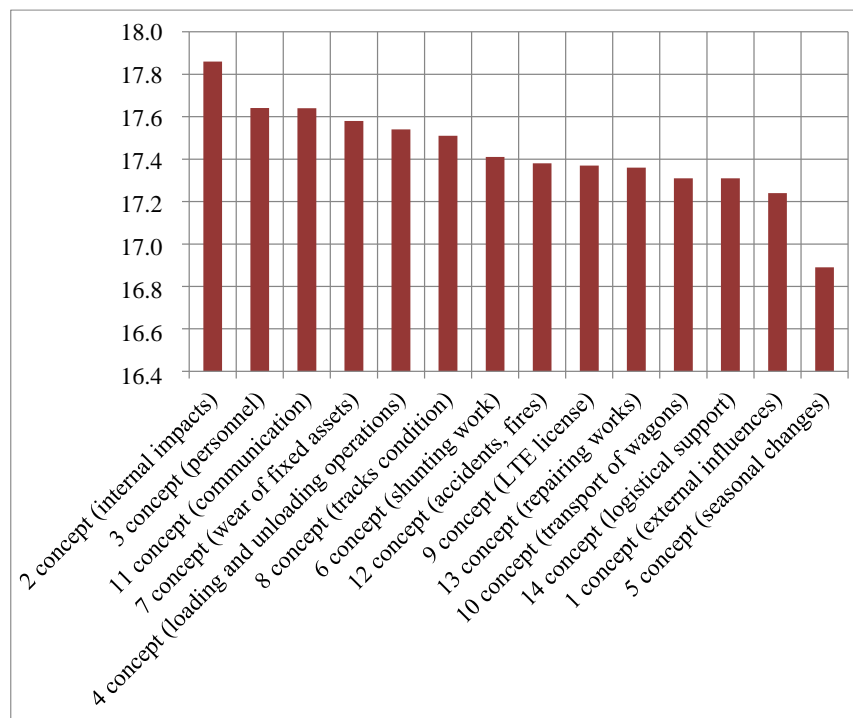
Figure 2. An ordered diagram of action force values of the system on individual concept.

There are possible variants of the worst system state, for example, $v_{i=1\div14}=0.1$ or the best one, for example $v_{i=1\div14}=0.9$.

The results of modeling and comparison of the basic variant at the values of all concepts $v_{i=1\div14}=0.5$ and variants at values of all concepts $v_{i=1\div14}=0.1$ and $v_{i=1\div14}=0.9$ are presented in table 1.

Table 1. Comparison of the forces of concepts influence on the system and influence of systems on the concepts for the three variants of simultaneous impact of all concepts on the system with $v_{i=1\div14}=0.1$; $v_{i=1\div14}=0.5$; $v_{i=1\div14}=0.9$.

Number of a concept	Action force of the ith concept on the system			Action force of the system on the ith concept		
	$v_{i=1\div14}=0.1$	$v_{i=1\div14}=0.5$	$v_{i=1\div14}=0.9$	$v_{i=1\div14}=0.1$	$v_{i=1\div14}=0.5$	$v_{i=1\div14}=0.9$
1	0.61	0.19	0.02	0.00	0.00	0.00
2	0.66	0.29	0.08	0.17	0.09	0.02
3	0.47	0.17	0.07	0.22	0.09	0.02
4	0.35	0.14	0.03	0.23	0.12	0.04
5	0.35	0.17	0.05	0.00	0.00	0.00
6	0.08	0.04	0.01	0.44	0.21	0.06
7	0.15	0.06	0.02	0.48	0.17	0.05
8	0.26	0.14	0.04	0.40	0.15	0.05
9	0.06	0.04	0.01	0.07	0.00	0.00
10	0.13	0.08	0.02	0.53	0.18	0.07
11	0.48	0.15	0.05	0.20	0.04	0.02
12	0.00	0.00	0.00	0.62	0.32	0.06
13	0.10	0.05	0.02	0.44	0.19	0.04
14	0.15	0.07	0.02	0.04	0.02	0.01

According to the results of the simulation given in table 1, a distribution histogram of influence forces of concepts on the system is constructed (figure 3) for the values of concepts $v_{i=1\div14}=0.1$; $v_{i=1\div14}=0.5$; $v_{i=1\div14}=0.9$ (the numbers of concepts correspond to the values shown in figures 1, 2).
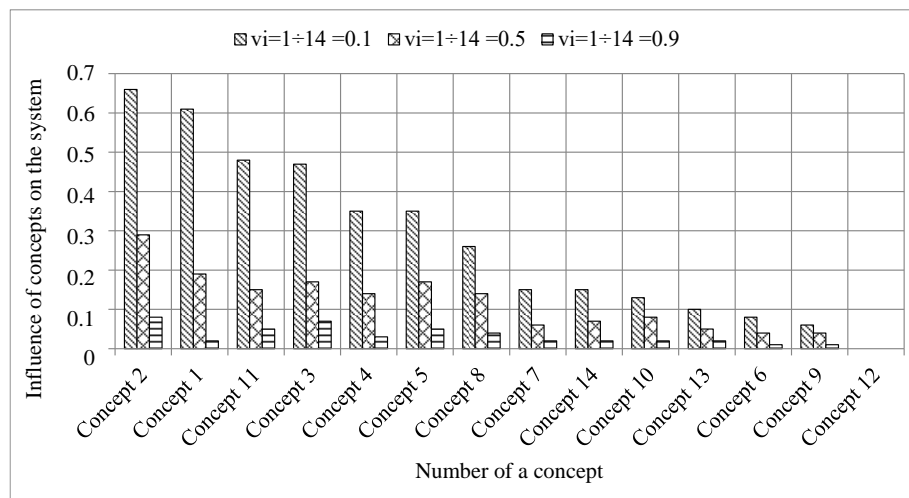
Figure 3. Distribution histogram of concepts influence on the system.

From table 1 and the graphs in figure 3 it follows that for critical values of concepts $v_{i=1\div14}= 0.1$ their influence on the system is ranked as follows (see Table 1): internal control actions (0.66), external influences (0.61), communication and signaling (0.48), compliance of personnel competencies (0.47), loading-unloading operations (0.35), seasonal changes (0.35). The influence of other concepts on the system is not significant in the range 0-0.26. In general, the state of the system at $v_{i=1\div14}=0.1$ should be considered as unstable.

At the influence on the concept system $v_{i=1\div14}=0.9$ their influence varies within the range 0-0.08, i.e. insignificantly (see table 1), the system state is stable, which corresponds to the graphs in figure 1. The boundary of the system transition to high stability is the condition $v_{i=1\div14}=0.5$.

Thus, based on the results of cognitive modeling, the most significant concepts that affect the stability of the system are identified.

4. Conclusions

1. It is established that the application of cognitive modeling methods for the analysis of complex production objects allows the essential elements of the system, that ensure the stable functioning of the system as a whole, to be identified.

2. The most significant impact on the system is achieved by the internal management actions of the heads of services and the compliance of the personnel competencies with job duties and performed labor functions.

3. In case when the personnel competences do not fully correspond to the duties and labor functions, the risk of incidents is maximal. In the process of acquiring additional skills and techniques for performing operations, the risk of incidents is reduced. Competencies sufficient to perform production operarions, ensure the functioning of the system in a stable mode.

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