Use of Network Analysis in Conditions of Critical Infrastructure Risk Management

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ABSTRACT

The issues of critical transport infrastructure can be described as a network problem. Since the topology of critical infrastructure is primarily a network problem, the use of network models is one of the ways how to solve critical transport infrastructure protection. The paper deals with modification and application of the method of optimal network connecting, the method of time consuming activities and Gantt diagram in the special conditions of critical infrastructure risk management.

Keywords: critical infrastructure, transport, protection, risk assessment, network.

1. INTRODUCTION

Critical infrastructure refers to an asset, system or part which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact as a result of the failure to maintain these functions [1].

Critical infrastructure protection includes also ensuring the resilience of transport infrastructures. This sector is considered vital worldwide due to its economic and societal importance and also due to a lot of interdependencies with other infrastructures and sectors.

There are a lot of theoretical methods which are used for the sorting of transport objects, identification of dangers, analysis of risks and the preparation of sets of measures for the increase of transport objects safety. The properly set analysis is the basis of everything. Under the protection of critical infrastructure the analysis can be considered as a strategic planning tool or repression. The protection of critical infrastructure (CI) should give priority especially to the prevention activity. The prevention is generally more economically efficient than repressive intervention according to experience.

The transport sector has got strong specifics. There are usually line constructions (railway lines, highways or roads) and transport objects (railway and bus stations, bridges and tunnels) which are technically very demanding and difficult. There are also included means of transport (vehicles or wagons) and specific control system. Additionally transport is service which has to be provided permanently. It follows the considerable complexity in the selection of objects, identification of real dangers, use of appropriate methods and techniques for the risk analysis. In general the procedure which is presented in the scheme (see the figure 1) can be used.

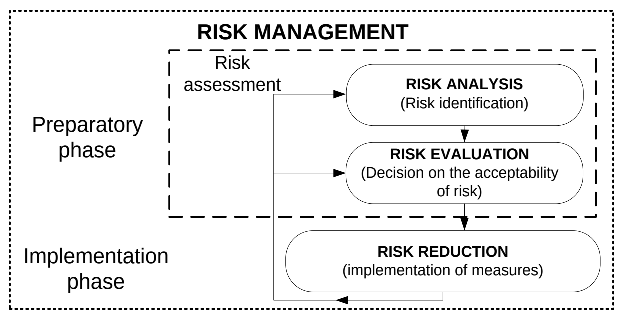

Figure 1 The structure of risk assessment and risk management according to IEC 300-3

2. NETWORK ANALYSIS METHODS

The network analysis constitutes the separate subset of graph theory. It is used in the areas where we evaluate complicated activities which are linked themselves or we track relations or bands in time.

The issues of critical transport infrastructure can be described as a network problem. Transport infrastructure consists of the elements – nodes (railway and bus stations, intersections) and branches (the part of roads or tracks). Each element can have a significant importance for network safety. Because the topology of transport infrastructure is primarily a network problem, the use of network models is one of the ways how to solve transport protection. It is about the seeking of critical nodes by the network analysis and the application of vulnerability analysis. The goal of presented processes is the reduction of risks. The network analysis has got an essential importance in the implementation phase in the field of critical infrastructure.

3. THE METHOD OF OPTIMAL NETWORK CONNECTING

The method of optimal network connecting is the method which may be used in the planning of supply of inhabitants affected by emergency, or in the planning of transport, communication, energetic networks. The basic goal is to find the solution which minimalizes chosen criterion function. In the crisis management the substance of this task is to find such branches (transport roads, lines, etc.) of the evaluated connected graph which link all its nodes (source location, warehouses) and have got the minimal sum of branches evaluation. It follows that solving such tasks cannot contain a cycle. In the process of management of crisis events it means to find so called minimal spanning tree - an optimal solution without unnecessary empty runs.

If we mark evaluation of branch h_{ij} in undirected graph G= {U, H} as kij>0 (i, j = 1, 2,..., n),
then for the minimal spanning tree is valid:

$$Z = \Sigma\, kij \rightarrow \min$$

The algorithm for determining the minimal spanning tree is then determined by the following steps:

1. In the set of branches of graph G, ordered by evaluation of k_{ij} branches, we will find two branches with minimal evaluation and include them into the set of constructed minimal spanning tree,
2. Branches that have been already selected from the graph G are not further considered. From remaining branches, such one which has the lowest evaluation k_{ij} and does not create a cycle with selected branches is included into minimal spanning tree.
3. The second step is repeated until the selection of n-1 branches (n is the number of nodes - resources) that create the minimal spanning tree.

A typical application occurs in the pavement of road linking towns, either directly or passing through other towns. The minimal spanning tree solution provides the most economical design of the road map.

If the solution of crisis phenomenon temporarily requires solving the supplying of inhabitants who were affected by extraordinary incident by the construction of temporary pipelines, the basic task of crisis management is to find optimal solution – optimal tree with using of modified method of network analysis. To ensure uniformity of appearance for the

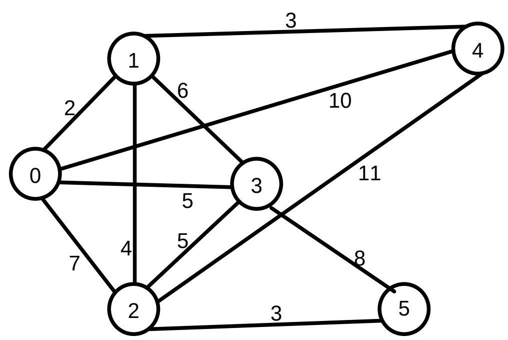

Figure 2 Diagram of possibilities

The procedure of the solution is presented in the table 1.

Tab. 1 The procedure of calculation of connection

step	branch	value
1	k01	2
2	k14*)	3
3	k25*)	3
4	k03 or k23	5
The total consumption of the materials		17

The connection is possible to do by two ways, in the fourth step there were two alternatives of the solution.
If two or several branches have the same evaluation k_{ij} and they do not create the cycle with selected branches, any of them is put in the minimum tree. If this procedure leads to the release one of these branches in next step, then the final tree has several optimal solutions.

4. THE METHOD OF TIME CONSUMING ACTIVITIES

Time consuming activities in the process of solution of crisis phenomena is an important indicator of successful elimination their negative consequences and the minimization of loses. The upper and lower estimate (the pessimistic $\mathbf{b_{ij}}$ and optimistic $\mathbf{a_{ij}}$ duration of the activity) are determined for the determination of the duration of the activity ($\mathbf{P_i}$, $\mathbf{P_j}$). The pessimistic duration of the activity is the maximal duration of activity if we consider all possible reasons for delay (unforeseen development of crisis phenomenon) and the optimistic duration of the activity is the minimum duration of the activity in the most favourable conditions. The expected duration of the activity is calculates according to this formula:

$$t_{ij} = (3a_{ij}+2b_{ij}) / 5 \qquad (1)$$

The presented formula follows from the probabilistic considerations. If we know the most probable estimation of activity duration, then we calculate the expected duration of the activity according to this formula:

$$t_{ij} = (a_{ij}+4m_{ij}+b_{ij}) / 6 \qquad (2)$$

After it straightens out, which presented way is better in the process of the solution of crisis phenomena, the linking of the individual activities follows into the diagram. In the application of Microsoft Office Project 2007 the four basic types of dependencies between two and more activities exist *(Dvořák, 2007):*

- ***Ending – starting*** (after the previous task finishes, the following task will start).
- ***starting – starting*** (it is the type of bond in which several tasks start in one moment).
- ***ending – ending*** (it represents the opposite type of bond to the previous type).
- ***starting – ending*** (it is atypical opposite dependence to the first step, the ending of the previous activity is initiated by starting of the following activity).

It is possible to create the graphical support based on the determination of the type of dependence of the individual activities and the acceptance of the basic rules of the formation of graphs. A crisis manager can only use this support partially; he / she can track simple technical continuities in the simple

graph. He /she cannot manage the starting or ending of the individual activities without time values.
The realisation of business plans in the business environment according to these diagrams has become necessity. The use of the methods of network analysis with the software support is necessary in the decision of crisis management where it often goes about the saving of human lives, the minimizing of consequences of crisis phenomena on the environment or damages on the properties.

In the process of the solution of crisis phenomena there are the activities which do not have to be done immediately. In operating analysis we call these activities as the activities with time reserve.

The total reserve of activities R_c is the maximum number of time units which a crisis manager has for the realisation of the activities if the character of activities admits it without the extending of the duration of a whole process $\mathbf{T^0_n}$. The total reserve of activities means the number of time units about which the beginning of activities may be delayed with respect to the latest possible term $\mathbf{T^0}$ without the prolongation of the total duration of the process. The total reserve of activities is the difference between the term of finishing of the process and the maximum duration of the path, which passes through this activity.

Free reserve of activities R_V is the maximum allowable extension of the duration of this activity (or delay its start with respect to the earliest possible term $\mathbf{T^0_i}$), which does not disturb the possibility so that all activities which come from the node $\mathbf{P_j}$ started in the earliest possible term $\mathbf{T^0_j}$. Free reserve of the activities can be calculated according to this formula:

$$R_v = T^0_j - T^0_i - t_{ij} \qquad (3)$$

It follows that the total reserve equals free reserve in the activities which finish in the nodes and lie on the critical path.

5. GANTT DIAGRAM

In a lot of cases crisis managers meet with the problem to optimise the balancing of the need of the individual sources during the whole period of solving of crisis phenomena. It is necessary to forewarn that we need to have the different sources for the realisation of solving and decision making. There are the demands on the staff, technique, means of transport, the supplies of drinking water and food. In this part it is explained the modification of balancing of the need of one source under the solving of crisis phenomenon whereas it is not about the saving of the source. Before the solution of the problem time demands of individual activities are always known. The intensities of demands for the specific source needed for the realisation of individual activities belong to the input data. Each activity (**P_i, P_j**) in time (hours, days) requires the constant amounts of predetermined source (**k**). The number of activities carried out in time unit is represented by Gantt diagram. From the experience it is known that the needs of sources usually fluctuate from the beginning to the end of the solving of crisis phenomenon. The following model example documents the presented situation. In the table there are daily intensities of the demands on the source which are needed for the realisation of the individual activities.

Table. 2 The daily intensities of the demands on the source

Activity	**Daily intensity of the demands on the source r^k_{ij}**
(P0 P1)	5
(P0 P2)	3
(P1 P2)	7
(P0 P3)	8
(P2 P3)	2
(P1 P4)	10
(P2 P4)	6
(P3 P4)	4

The application of example into the Gant diagram increases the information value of calculations where we enter the intensities of demands on their daily realisation above the individual activities. After entering a simple sum is carried out in the individual days.

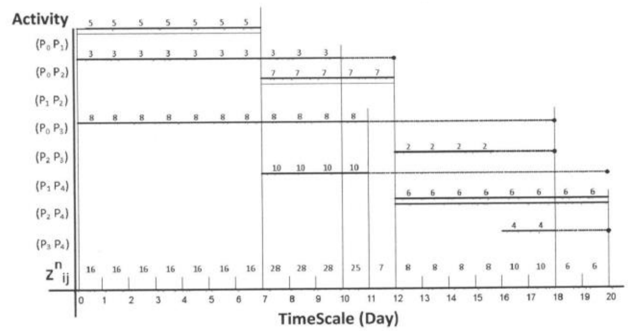

Figure 2 Gantt diagram filled about the intensity of demands on the source

In the case there are more different sources it is necessary to solve the needs individually and separately for the individual sources. In the presented example there is the fluctuation of daily needs of the source in a big interval – from 6 to 28 units. This fluctuation is a big problem in the decision making about the securing of needed sources in the process of solving of crisis phenomenon. The method which equalizes the fluctuation of the needs of the source has the following steps:

1. The first step is the construction of the Gantt diagram in its basic form that is the beginnings of line segments, which represent all activities, are plot on the term of the earliest possible start of activity. The Gantt diagram is filled about total reserves. For simple calculation the diagram is filled about the needs of source for each activity $\mathbf{r_{ij}}$.
2. The sum of the needs of the source in the individual time units $\mathbf{z^n_{ij}}$ is calculated. The sums are raised to the power of two $(\mathbf{z^n_{ij}})^2$ and the sum (**W**) of these second powers through all time units **n= 1, 2, ...d** are calculated.

$$z^n_{ij} = \sum r_{ij} \qquad (4)$$

$$Z = \sum Z^n_{ij} \qquad (5)$$

$$W = \sum (z^n_{ij})^2 \qquad (6)$$

3. In the Gantt diagram the smallest uncritical activity is shifted about one time unit to the term of the duration of the process. After shifting a new calculation of the value W is done. In the case that the calculated value W is higher than the original value, the shifting is not done. It is necessary to check all possible shifts which the total reserve of the corresponding activity offers.

4. The previous step is repeated. In Gantt diagram we proceed all activities upwards to initial activities of the solving of crisis phenomenon.

In a lot of cases the equalisation of sources does not suffice according to the mentioned principle – without the change of input data. The circumstances make crisis managers reduce the needs of sources on the individual time units. This fact can be done by:

- the change (the prolongation) of the duration of the term of the problem,
- the change of the needs of sources on the realisation of the specific activity in the individual time units.

There will be always a time delay in the balancing of demands on the source by changing of the extension of the process. The calculated term of duration with the use of time analysis will not be met. The necessary conditions for the utilisation of this principle are:

- the maintaining of technological continuities of the individual activities which crisis phenomenon consists of,
- the maintaining of the duration of realisation of the individual activities.

The determination of the limiting level of the source per unit of time is the input condition. After the determination of this value it is recommended to use Gantt diagram in the maintaining of deadlines of the process. On this diagram we proceed from the start point that is located on the left side to the end point. In this process the individual activities are proceeded so long until the needs of the source decreases under the limited value. Regarding to the fact that the term of duration is given by the length of critical path (the sum of duration of critical activities which fulfilment follow each other without a break), the realisation of critical activities will not follow immediately. In some cases it is necessary to observe the deadline. In this case it is possible to apply two methods of solution:

- the increase of the total number of sources – in crisis management it is rarely,
- the observance of the total sums of source with the change its utilisation during the realisation of the individual activities.

For example, the activity which takes 10 time units and 3 sources are needed for the realisation, it completely requires 30 time units. If the realisation of this activity enables to deploy 30 time units another way, it is possible to achieve better equalisation of the source under the solution. In practise this way is realised by using the software support.

The presented modifications of the selected methods of operating analysis are only theoretical assumption of the mathematical inputs of the software support of crisis managers in the filling of complicated tasks of transport security. In all cases there is recommended the combination of the support of special software equipment, personal experience or the intuition of a crisis manager.

6. CONCLUSIONS

Critical infrastructure protection means to ensure the maintaining of the continuity of business and social life of the state and the providing of response in the case of the threat or disruption of the basic conditions of life, services and systems which continuity is very important for the function of the state.
The basic goals of in the field of critical infrastructure are:

- the elaboration of the analysis of vulnerability of critical infrastructure and technologies against possible extraordinary phenomena,
- to elaborate the plan on the elimination of the primary risks of critical infrastructure,
- to ensure the system of detection of natural diseases and possible attacks (their possible scenarios) on the critical infrastructure,
- to ensure the plan and the realisation of the response on the losses of functionality of critical infrastructure
- to prepare the recovery plan of critical infrastructure and other activities.

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This work was supported by the European Union within the FP7 project No. 608166 “Risk Analysis of Infrastructure Networks in response to extreme weather”

and

the Ministry of the Interior of the Czech Republic, project number VI20152019049 "RESILIENCE 2015: Dynamic Resilience Evaluation of Interrelated Critical Infrastructure Subsystems"

and

Centre of excellence for systems and services of intelligent transport I and II – ITMS 26220120028 and ITMS 26220120050, projects were co-financed by the European Regional Development Fund.