OPERATION SAFETY AND RELIABILITY IMPROVEMENT OF LARGE TRANSPORT SYSTEMS BY COMPLEX SENSITIVITY INVESTIGATION

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Abstract: Transportation system safety and reliability pertain to the dominant factors affecting present life of human society. In this paper, we describe the method for an analysis and further subsequent optimization of complex transportation system safety and reliability based on their complex sensitivity investigation. Reasonable applications of this theoretical tool can also be used for improvement of complex transportation system resistance against terrorist activities.

Key words: *Transportation systems, sensitivity, reliability, safety, resistance to terrorist activity*

Received: August 31, 2007
Revised and accepted: January 31, 2008

1. Introduction

According to the US Transport Security Administration (TSA), the transportation system can be considered as a set of interdependent links and nodes in which no element is secure as long as it can be affected by any other weaker link.

Since every large transportation system security requires high operation reliability and safety, these being *mutually dependent* properties, our strategy for the reliability and safety improvement must be based on the system perspectives.

Thus, the transportation system can be considered as an *adaptive complex*, alliance of partial systems consisting of interacting elements, which have adapted to each other in the course of time.

The concept of Complex Adaptive System (CAS) was drawn on the basis of the idea know as a "*complexity theory*" offering at least two additional insights:

- The system usually behaves with significant non-linearity, which means that sometimes certain small perturbations in the system can be projected to large outcomes.

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- The system shows "emergent properties", which means that complex patterns can be based on seemingly incidental interactions among some or all elements of the system.

These insights represent the key to understanding why the TSA's mission is to enhance transportation security *while maintaining the free flow of commerce.*

By attacking the system parts resulting in non-linear consequences, terrorists can cause damages being out of proportion to their efforts; and the TSA must prevent the system from such a risk.

When minimizing the security measures impact, the TSA tries to ensure that commerce emergent patterns in our economy will not be disrupted by such accidental events.

Public transport, and especially urban public transport, should be described as an open system on three hierarchical levels:

- public transport infrastructure;
- transport processes;
- information system.

(see Fig 1.)

Assessment of Open System Interfaces – "OSI"

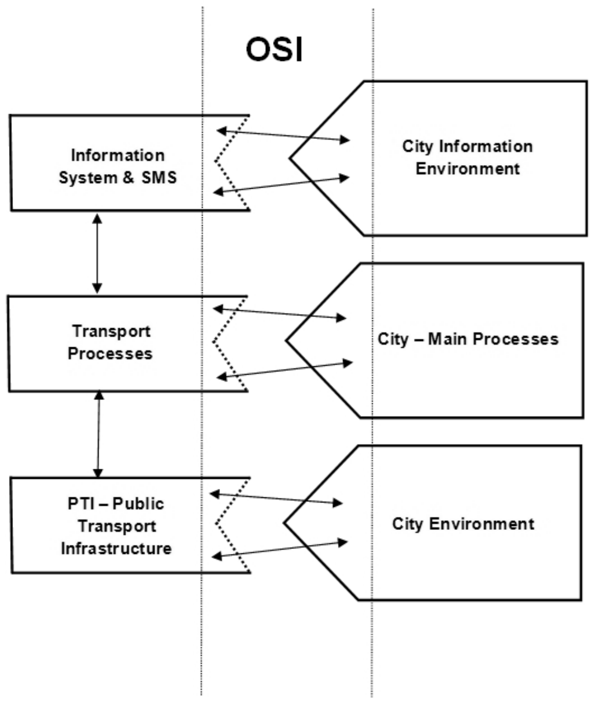

Fig. 1 *Public transport system levels forming the open system.*

From the system analysis point of view, the system behaviour during destructive impacts is of the same importance as an object for structural and sensitivity analysis.

2. Sensitivity analysis [1] – Condition for safety and security management of system design

The resulting system function can be generally expressed as $dF(dF_1, dF_2, \ldots dF_n)$, where the set of input factors is represented by the vector of state variables: $dI(dI_1, dI_2, \ldots dI_n)$.

To have a possibility of modelling the resulting function, the form of matrix equation has to be introduced. It involves the matrix of sensitivities $S[s_{ij}]$, where s_{ij} elements correspond to the individual sensitivities of the process in public transport. The output function of x-iteration matrix equation represents the $x+1$-iteration input function. The complex sensitivity matrix in the equation (1) is a suitable tool for comparison of the main sensitivities when finding the dominant one. The structural concept of system sensitivity analysis is based on the graph theory, especially on the transfer function sensitivity of the graph in the graph structure separate branches and on finding the dominant sensitivity point in the transportation system graph (i.e. finding the critical point in the structure).

Therefore, we can write the equation:

$$\begin{bmatrix} dF_1 \\ dF_2 \\ dF_3 \\ \cdot \\ \cdot \\ \cdot \\ dF_n \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} & \cdot & \cdot & \cdot & \cdot & s_{1m} \\ s_{21} & s_{22} & \cdot & \cdot & \cdot & \cdot & s_{2n} \\ \cdot & & \cdot & & & & \cdot \\ \cdot & & & \cdot & & & \cdot \\ \cdot & & & & \cdot & & \cdot \\ \cdot & & & & & \cdot & \cdot \\ s_{n1} & s_{n2} & \cdot & \cdot & \cdot & & s_{nm} \end{bmatrix} \cdot \begin{bmatrix} dI_1 \\ dI_2 \\ dI_3 \\ \cdot \\ \cdot \\ \cdot \\ dI_n \end{bmatrix} \tag{1}$$

or its simplified form:

$$[F] = [S] \cdot [I] \tag{2}$$

If the sensitivity is expressed in the relative scale, then the parameters are also relative values:

$$x_{ir} = \frac{x_1}{x_{\max}} \tag{3}$$

where x_{max} is the maximal value of the measure.

Relative Stress Sensitivity Matrix is defined by the following equation:

$$F_{i,rel} = Sr_{ij} \frac{dx_j}{x_{j,\max}} \tag{4}$$

where:

$$Sr_{ij} = \frac{dF_i}{dx_j} \cdot \frac{x_{j,\max}}{F_{io}} \tag{5}$$

and where F_i represents a relative change of the corresponding parameter effect in i-component a dx_j represents value x_j deviation.

The coefficients of relative sensitivities can be replaced by fuzzy parameters, or, in the final form, by fuzzy matrices.

$$S_{ij} \in \{1,\ 2\ \ldots 5\} \tag{6}$$

The respective fuzzy stages could be determined by an expert evaluation and classified into various number of groups.

In the table listed below, five groups are used.

x_j	**Measure of influence**	Sr_{ij}
1	No effect	0
2	Small effect	0.25
3	Middle effect	0.5
4	Remarkable effect	0.75
5	Dominant effect	1

Tab. I *The measures of fuzzy description – Sr_{ij}.*

Having used so called "integral measure" of the parameter effect, the time factor will be taken in the account.

Then, the matrix equation is of the following form:

$$FM_{C_i}(T) = \frac{1}{T} \cdot \int_{t_2}^{t_1} \sum_{j=1}^{k} (Sr_{x_j}^{C_i} \cdot W(t) \cdot x_j(t))dt \tag{7}$$

where $T = t_1 - -t_2$ represents time duration of the system parameters monitored in C_i vector, and further, the vector:

$$M_C(T) = [M_{C1}(T), M_{C2}(T), \ldots M_{Cn}(T)] \tag{8}$$

is called the integral measure of input state variables set effects. Having finished the evaluation of the sensitivity matrix parameters, the weakest system component can be subsequently determined.

3. Transport network topologies

According to the TSA, different types of transportation systems will show different types of network topologies. Nevertheless, the respective networks can be classified into two basic categories only: *scale-free networks* and *random networks*.

The "scale-free" networks have nodes possessing a significantly higher concentration of connections than an average node. This type of network often resembles hub and peer-to-peer systems, and they are *very robust* when faced with naturally occurring errors because the odds of disruption hitting the key node are very low.

However, these networks are very vulnerable to attack, because once the key node is targeted, the disruption will affect the whole system.

The "random" networks do not have such a disadvantage.

The network theory tools can be also applied to understand terrorists activities. Many modern terrorist groups organize themselves into almost random networks rather than into hierarchically organized structures because such networks tend to be more agile and resilient in response to their environments, and also more efficient in sharing information. Net-centric adversaries pose a particular problem for traditional hierarchical bureaucracies, which tend to handle ambiguity poorly, and the net-centric terrorist organizations try to exploit gaps between them.

The TSA recognizes that it "*takes a network to fight against a network.*" Therefore, the TSA works on strengthening our network of authorities and industry partners.

By utilizing this network, we will be able to identify the areas of the greatest risk throughout transportation systems, and act to prevent attacks and mitigate their potential consequences.

The further exploring of the methodology presented should be done by means of the concept of Wave Probabilistic Models [10].

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