Entropic analysis of dynamics of road safety system organization in the largest Russian cities

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Abstract. The article presents the method of road safety system organization assessment in cities. The main idea of this method is the usage of entropic analysis in the solution of research problems. Information entropy is a measure of uncertainty and unpredictability of system functioning results. Therefore, it allows to quantitatively assess the quality of management of any city life aspect. In this article, by assessing of system entropy, we estimated dynamics of changes in road safety system organization of two biggest Russian cities – Moscow and St. Petersburg, in 2004–2017. It was established that the level of road safety system organization in Moscow and St. Petersburg has increased during the last 14 years. Comparison of entropy level of road safety provision systems of two Russian megalopolises allows to make a conclusion that level of organization of this system is slightly higher in Moscow than in St. Petersburg.

1. Introduction
Life safety is one of the most important components of life quality. Security issues has become especially significant in the largest cities. In 2017 8907 road accidents (5.25 % of all road accidents in Russia) occurred in Moscow [1]. The share of deaths in road accidents in Moscow was 494 deaths or, in other words, 2.58 % of deaths in road accidents in Russia [1]. Indicators of road accident rate in the second most important city of Russia – St. Petersburg, are less than in Moscow but are also very significant. In the last 12 years, i.e. in the period when federal target road safety programs [2, 3] were actively realized, the level of road accident rate has decreased in the country in general and in the biggest cities in particular. However, we can’t draw far-reaching conclusions based on statistics of road safety first-level indicators (count of road accidents, count of deaths and victims in road accidents). To do this we need to know dynamics of changes in road safety second-level indicators (Human Risk and Transport Risk) [4] and understand how the organization of road accident prevention system changes over time [5]. For this it is necessary to study tendencies of significance change of different sections of the cause-and-effect chain “Population – Vehicle fleet – Road accident – Victims in road accident – Deaths in road accident” [6]. On the basis of this information about structural changes in the studied system, we can make a conclusion about dynamics of systems of traffic safety management organization.
2. About possibility of using the entropic analysis in the assessment of system organization dynamics

The author of information theory C.E. Shannon [7, 8] introduced the concept of information uncertainty – entropy. According to C.E. Shannon, entropy characterizes missing information about the studied system. Information is the primary concept of our world, along with material, energy, space and time, and it can’t be strictly defined [9]. At the same time, the usage of entropic analysis allows to assess the degree of informational organization of system processes. According to C.E. Shannon [7, 8] information is discrete.

The basis of information theory is based on the concept of four initial elements: transmitter, channel lines, receiver and information. The information, transferred by channel line from the transmitter to the receiver, can consistently change its quality. The degree of information loss in the process of passing through the channel is characterized by entropy.

Entropy is low in the highly organized systems and high in low-organized systems. It is important to note that the degree of human-technical systems organization changes over time. In qualitatively managed systems chaos level and entropy value are decreased. The understanding of entropy dynamics allows to find out whether the degree of managed system organization is raising. That is why entropic analysis is an appropriate tool for assessment of the quality of road safety provision processes in the largest Russian cities.

3. Aim, problems and research method

The aim of the research is studying the dynamics of entropy at the road safety provision systems in two largest Russian cities – Moscow and St. Petersburg (2004–2017).

Research problems:
1. Gathering of official statistics by blocks of the cause-and-effect chain “Population – Vehicle fleet – Road accident – Victims in road accident – Deaths in road accident” in Moscow and St. Petersburg.
2. Calculation of transitional coefficients $K_i$ between blocks of chain of road accident rate formation process (fig.1). Describing of studied process as 3 subprocesses with specific coefficients $K_n$ (transformation of population into count of vehicles in transport system), $K_{dp}$ (transformation of vehicle fleet into road accidents count), $K_{pg}$ (transformation of road accidents count into count of deaths in road accidents).

\[ Q = Q_n + Q_{dp} + Q_{pg} = \ln\left(\frac{1}{K_n}\right) + \ln\left(\frac{1}{K_{dp}}\right) + \ln\left(\frac{1}{K_{pg}}\right) = 1 \]  

The physical meaning of the positive of the contribution $Q$ relatively to weights of appropriate elements of examined transformational process within the chain “Population – <…> – Deaths in road accident”. The physical meaning of the positive of the contribution $Q$ of different elements of the chain “Population – <…> – Deaths in road accident” into the final result of road accident rate is the measure of information amount or derivative of examined process entropy.
4. Identifying the structure of weight coefficients $w_i$ for assessing the positive of the contribution $Q$ of different elements of the chain “Population $\rightarrow$ Deaths in road accident”. Availability of calculated values $w_n, w_{dtp}, w_{pg}$ of positive allows to solve the main problem of entropic analysis – assess the impact of different elements of the chain “Population $\rightarrow$ Deaths in road accident” on formation of final road accident rate. Above-stated researches were held for each year from period of 2004–2017.

5. Calculation of entropy $H$ in road safety provision systems of two largest Russian cities – Moscow and St. Petersburg by classic C.E. Shannon’s formula (2):

$$H = -\sum_{i=1}^{n} w_i \cdot \ln w_i$$  \hspace{1cm} (2)

where

$n$ – system elements count (in our case $n = 3$);

$w_i$ – weight coefficients, satisfying the normalization condition, $\sum_{i=1}^{n} w_i = 1$.

6. Calculation of relative entropy (3):

$$H_n = H/H_{\text{max}} = H/\ln(n)$$ \hspace{1cm} (3)

7. Analysis of dynamics of entropy $H$ of road safety provision systems of Moscow and St. Petersburg over the period of 2004–2017.

8. Detection of specific (for researched cities) features of entropy $H$ dynamics over time and formulating final comparative conclusions.

4. Research results

Table 1 shows initial data (2017) and the example of calculation of entropy value at the road safety provision system in Moscow.

Table 1. Initial data and elements of calculation of entropy value at the road safety provision system in Moscow.

| Numerical values of elements of a cause-and-effect chain of road accident rate formation process (Moscow, 2017) | Population | Vehicle fleet [1] | Road accidents count [1] | Deaths count [1] |
|---|---|---|---|---|
| 12380664 | 4704652 | 8907 | 494 |

| Numerical values $K_i$ | $K_n$ | $K_{dtp}$ | $K_{pg}$ |
|---|---|---|
| $4704652/12380664 = 0.380$ | $8907/4704652 = 0.00189$ | $494/8907 = 0.05546$ |

| Numerical values of positives $Q_i = \ln(1/K_i)$ | 0.967584 | 6.271178 | 2.892093 |

| Numerical values of weight $w_i(Q_i)$ | 0.0955 | 0.6190 | 0.2855 |
| Numerical value ( $\ln w_i$ ) | -2.34854 | -0.47962 | -1.25361 |
| Numerical values ( $w_i \cdot \ln w_i$ ) | -0.22433 | -0.29693 | -0.35788 |

Numerical value of entropy $H = 0.8791$

Numerical value of relative entropy $H_n = 0.8002$
Analogously performed calculations for the road safety provision systems in Moscow and St. Petersburg on the basis of the data of 2004–2017 allows forming the Table 2.

**Table 2.** Summary table of results of assessment of entropy at the road safety provision systems in Moscow and St. Petersburg (2004–2017)

| Year | Calculated values of entropy $H$ and relative entropy $H_n$ in road safety provision systems in the largest Russian cities |
|------|---------------------------------------------------------------------------------------------------------------|
|      | Moscow                                                                                                       | St. Petersburg |
| 2004 | 0.9103                                                                                                      | 0.8266         |
| 2005 | 0.9521                                                                                                      | 0.8646         |
| 2006 | 0.9499                                                                                                      | 0.9630         |
| 2007 | 0.9429                                                                                                      | 0.9546         |
| 2008 | 0.9346                                                                                                      | 0.9406         |
| 2009 | 0.9209                                                                                                      | 0.9274         |
| 2010 | 0.9190                                                                                                      | 0.9359         |
| 2011 | 0.9109                                                                                                      | 0.9268         |
| 2012 | 0.9066                                                                                                      | 0.9284         |
| 2013 | 0.8909                                                                                                      | 0.9233         |
| 2014 | 0.8937                                                                                                      | 0.9239         |
| 2015 | 0.8824                                                                                                      | 0.9172         |
| 2016 | 0.8784                                                                                                      | 0.9154         |
| 2017 | 0.8791                                                                                                      | 0.9145         |

5. **Discussion of results**

Fig. 2 shows the dynamics of changes of relative entropy $H_n$ at road safety provision systems in Moscow and St. Petersburg (2004–2017). Level of road safety provision systems organization in Moscow and St. Petersburg has gradually increased during 2004–2017. Relative entropy in Moscow decreased from 0.8666 to 0.8002 (by 7.7%), in St. Petersburg – from 0.8798 to 0.8324 (by 5.4%).

This fact allows us to conclude that actual level of road safety provision system organization and the rate of decline of the entropy of given system in Moscow is slightly higher than in St. Petersburg. In general progress in decreasing the road accident rate is better in Moscow.

6. **Conclusion**

Unfortunately, currently entropic analysis practically is not used in the analysis of the effectiveness of management decisions in the sphere of road safety assessment [5, 10]. People responsible for analytical work (for example, employees of Research Center of the State Road Safety Inspectorate of the Ministry of the Interior of Russia are used to assess progress using the method of simple comparison of actual first-level road safety indicators with the last year’s ones [4].

That does not allow to make serious conclusions, excepting assessment of the simplest tendency. Usage of entropic analysis of road safety provision systems organization allows to estimate quality of professional activity of specialists who organize functioning of transport systems in cities [10, 11].

Analysis of long-term dynamics of road safety provision systems organization in the largest Russian cities – Moscow and St. Petersburg, showed that the level of these systems organization is although relatively slowly, but raising. Entropy, as the measure of disorganization of these systems, is decreasing in both cities. This fact means that dynamics of the condition of road safety provision systems organization in Russian megalopolises is positive and we should develop it [12].
Figure 2. Changes of relative entropy $H_n$ at the road safety provision systems in Moscow and St. Petersburg (2004–2017)

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