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Informational - entropic Analysis of Dynamics of Road Safety Orderliness

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Abstract. The article considers issues of identification of all-Russian and regional (on the example of Kemerovo region) road safety provision (RSP) systems orderliness. Research presents methods of identification of road safety provision system orderliness. The main idea of this methodic is the calculation of relative entropy of formation process of final result of cause-effect chain «Population – The number of vehicles – The number of road accidents – The number of victims – The number of deaths in road accidents» performance. Statistics of road accident rate during 2004…2018 was analyzed for the calculation of relative entropy. The result of research concludes that the level or road safety provision system increases in Russia generally and Kemerovo region specifically. Meanwhile the development of this process in Kemerovo region lags relatively to all-Russian one.

1. Introduction

Every system is an aggregate of cooperating subsystems (elements of the system). It includes plenty of system connections that usually have nonlinear character. During the system functioning hundreds of different subsystems processes form and develop simultaneously. They make an impact on the final system result. It's extremely difficult to identify these processes, model them and assess their degree of influence on the system. Moreover, these actions often don't answer the question how to effectively manage the system. For understanding of changes trajectory of the controlled system in long-term (10 years and more), it is necessary to know the modifications tendency of system orderliness. Orderliness is a consolidating characteristic that describes the quality of system processes management.

2. Formulation of the problem

In the context of the current research *orderliness is a system property identifying the result of the performance of rules and forbiddances that structure the system and limit its changes.* It is a system of restrictions that decreases the chaos n the system and the probability of conflict manifestation.

Applied to the road safety sphere *orderliness is a «degree of rigidity» of transport system functioning management.* The higher the orderliness, the lower the chaos degree in system and vice versa. For assessing of orderliness of road safety provision system (RSP), we will use relative entropy *Hn* or negentropy *(1 – Hn)* [1].

Aforesaid allows to formulate two individual tasks of this research. Firstly, calculating relative entropy in the relation to processes of road safety formation for specific transport systems (for example, for the Russian Federation and Kemerovo region). Secondly, comparison of models *Hn = f(A),* built for road safety provision systems of the Kemerovo region and Russian Federation and making conclusions about current state or road safety provision in the Kemerovo region relatively to all-Russian result.

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3. Methods of problem solving

Methods of identification of road safety relative entropy Hn were previously considered in [2, 3, 4, 5], but in this research they were modified and now consists of:

1. Separation of road accident rate formation process into blocks of the cause-effect chain (fig. 1) «Population (P) – The number of vehicles (N_{Vh}) – The number of road accidents (N_{RA}) – The number of victims (N_V) – The number of deaths (N_D)»

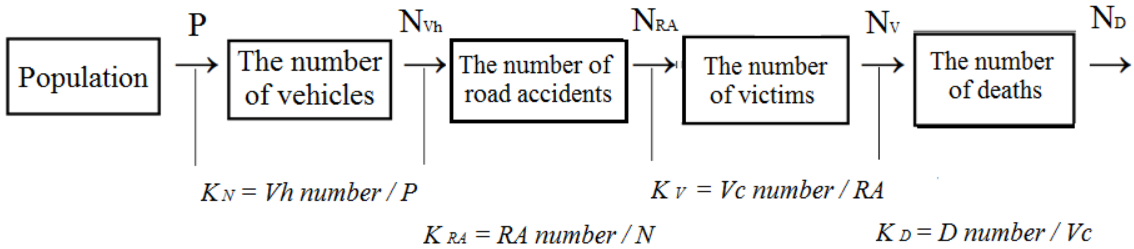

Figure 1. The cause-effect chain of road accident rate formation

2. Gathering of official statistics in the Russian Federation and Kemerovo region for each block of the cause-effect chain «Population (P) – The number of vehicles (N_{Vh}) – The number of road accidents (N_{RA}) – The number of victims (N_V) – The number of deaths (N_D)».
3. Calculation of transition coefficients K_i between blocks of the cause-effect chain of road accident rate formation (fig. 1). We will describe this process as 4 subprocesses that have specific coefficients K_N (transformation of number of population into the number of transport vehicles in transport fleet), K_{RA} (transformation of vehicle fleet into the number of road accidents), K_V (transformation of the number of into the number of road accidents victims), K_D (transformation of the number of road accidents victims into the number of lost in road accidents people).
4. Identifying of the positive of the contribution Q relatively to weights of appropriate elements of examined transformational process within the chain «Population – <…> – The number of deaths in road accident».

$$Q = Q_N + Q_{RA} + Q_V + Q_D = \ln(1/K_N) + \ln(1/K_{RA}) + \ln(K_V) + \ln(1/K_D) \tag{1}$$

The physical meaning of the positive of the contribution Q of different elements of the chain «Population – <…> – The number of deaths in road accident» into the final result of road accident rate is the measure of information amount or derivative of examined process entropy.

5. Identifying the structure of weight coefficients w_i for assessing the positive of the contribution Q of different elements of the chain «Population – <…> – The number of deaths in road accident». Availability of calculated values w_N, w_{RA}, w_V w_D of positive allows to solve the main problem of entropic analysis – assess the impact of different elements of the chain «Population – <…> – The number of deaths in road accident» on formation of final road accident rate. Above-stated researches were held for each year from period of 2004…2018.
6. Calculation of entropy H in road safety provision systems of the Kemerovo region and Russian Federation by classic C.E. Shannon's [6, 7] formula (2):

$$H = -\sum_{i=1}^{n} w_i \cdot \ln w_i \tag{2}$$

where n – system elements count (in our case $n = 4$);
w_i – weight coefficients, satisfying the normalization condition, $\sum_{i=1}^{n} w_i = 1$.

7. Calculation of relative entropy (3) of the road safety provision systems of the Russian Federation and Kemerovo region:

$$H_n = H / H_{max} = H / \ln(n) \quad (3)$$

8. Analysis of dynamics of relative entropy of road safety provision systems in the Russia and Kemerovo region during 2004…2018.
9. Comparison of *Hn* values of road safety provision systems of the Russia and Kemerovo region. Making of conclusions about current state of road safety provision sphere in the Kemerovo region relatively to all-Russian situation.

4. Initial data and results of calculation of relative entropy *Hn* of road safety provision systems in Russia and Kemerovo region

As mentioned above specific methods of assessment of human-technical systems orderliness were previously considered in [2, 3, 4, 5]. This article is presenting only results of estimation of relative entropy *Hn* of road safety provision systems in the Russian Federation and Kemerovo region in dynamics (during 2004…2018). Tables 1…2 show initial data [8] and results of calculation of relative entropy *Hn* of road safety provision systems in the Russian Federation and Kemerovo region accordingly.

Table 1. Initial data [8] that was used for analysis of road safety orderliness dynamics in the Russian Federation and results of calculation of relative entropy *Hn*

Year	Population, thousands of people	Vehicles fleet, thousands of units.	Automobilization, vehicles/1000 people	The number of road accidents in year, units	The number of victims, people	The number of deaths in road accidents, people	Value of relative entropy *Hn*
2004	144168.2	29025.3	201.3	208558	284865	34506	0.789
2005	143474.2	31087.6	216.7	223342	308821	33957	0.784
2006	142753.6	34968.2	245.0	229140	318086	32724	0.781
2007	142221.0	35885.3	252.3	233809	325514	33308	0.780
2008	142008.8	38696.0	272.5	218322	300819	29936	0.768
2009	141904.0	41206.4	290.4	203618	283143	27659	0.760
2010	142856.5	42062.7	294.4	199431	277202	26567	0.757
2011	142865.4	43325.3	303.3	199868	279801	27953	0.755
2012	143030.1	45471.1	317.9	203597	286609	27991	0.751
2013	143347.1	47881.8	334.0	204068	285462	27025	0.745
2014	143666.9	49540.4	344.8	199720	278748	26963	0.739
2015	146267.3	51591.9	352.7	184000	254311	23114	0.732
2016	146544.7	54014.3	368.6	173694	241448	20308	0.727
2017	146804.4	53500.0	364.4	169432	234462	19088	0.728
2018	146880.4	53047.0	361.2	168099	233067	18214	0.730

Table 2. Initial data [8] that was used for analysis of road safety orderliness dynamics in the Kemerovo region and results of calculation of relative entropy *Hn*

Year	Population, thousands of people	Vehicles fleet, thousands of units.	Automobilization, vehicles/1000 people	The number of road accidents in year, units	The number of victims, people	The number of deaths in road accidents, people	Value of relative entropy *Hn*
2004	2872.1	556.0	193.6	3601	5149	610	0.795
2005	2855.0	571.9	200.3	3614	5203	616	0.794
2006	2838.5	590.7	208.1	3612	5229	614	0.792
2007	2826.3	630.1	222.9	3608	5225	612	0.786
2008	2823.5	669.2	237.0	3601	5150	603	0.777
2009	2821.9	712.0	252.3	3413	4939	540	0.773
2010	2763.1	715.8	259.1	3406	4881	533	0.770
2011	2761.3	750.4	271.8	3497	5099	557	0.768
2012	2750.8	786.5	285.9	3913	5552	562	0.764
2013	2742.5	797.4	290.8	3710	5404	550	0.765
2014	2734.1	829.1	303.2	3527	5206	504	0.761
2015	2725.0	831.4	305.1	3232	4759	435	0.758
2016	2717.6	845.4	311.1	3054	4448	341	0.756
2017	2708.8	859.0	317.1	2952	4216	303	0.751
2018	2694.9	874.0	324.3	2780	4107	299	0.752

5. Estimation of dynamics of relative entropy *Hn* of road safety provision systems in the Russian Federation and Kemerovo region

Fig. 2 shows the trend of change of relative entropy or road safety provision systems in Russia and Kemerovo region in 2004…2018. Value of *Hn* decreases in both cases, therefore the degree of chaos declines in compared road safety provision systems and their orderliness increases. However in Kemerovo region this process proceeds slower than on average in Russia (fig. 2).

6. Discussion of results

Classical law of R. Smeed [9] and its later corrections [10] explain the decline of road accident rate with time by growth of motorization. M. Blinkin [11] believes that significant reasons of that phenomenon are «continuous self-education of nation» and progressive evolutional change of road safety paradigms. We will use idea about the connection between relative entropy *Hn* of road safety provision systems and motorization *A* to explain the dynamics of relative entropy of road safety provision systems (fig. 2).

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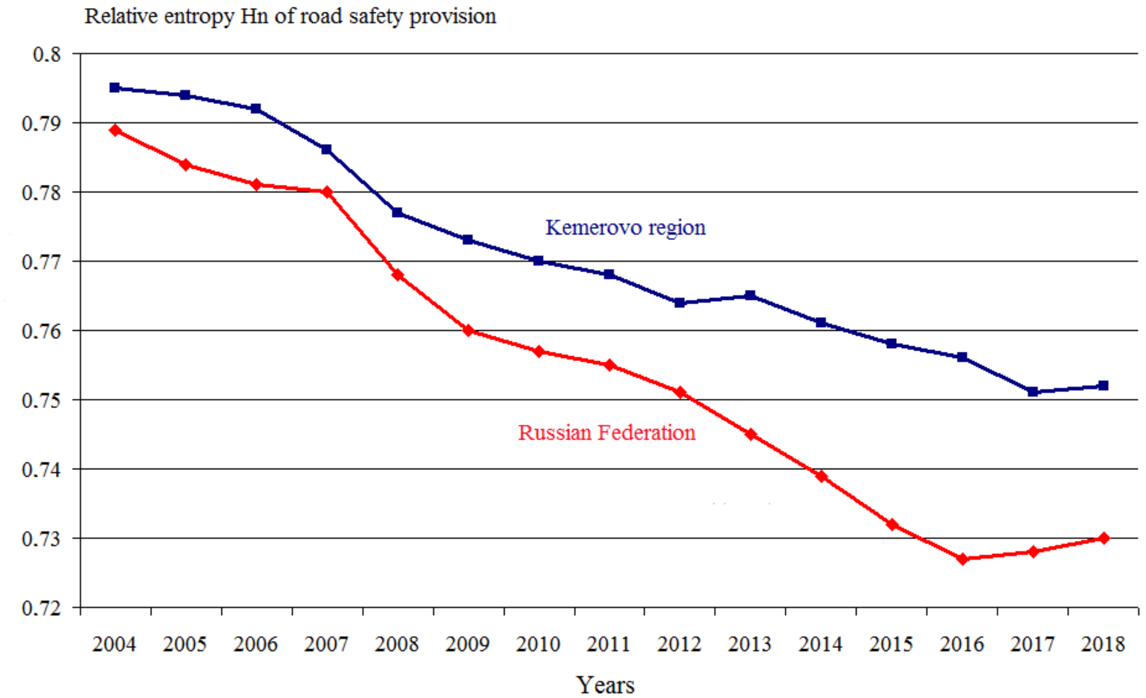

Figure 2. Dynamics of relative entropy *Hn* of road safety provision systems in the Russian Federation and Kemerovo region

6.1 Models Hn = f(A), built for road safety provision systems

Fig. 3 presents the model *Hn = f(A)* for the case of all-Russian road safety provision system. Fig. 4 shows the model *Hn = f(A)* for the case of road safety provision system of the Kemerovo region.

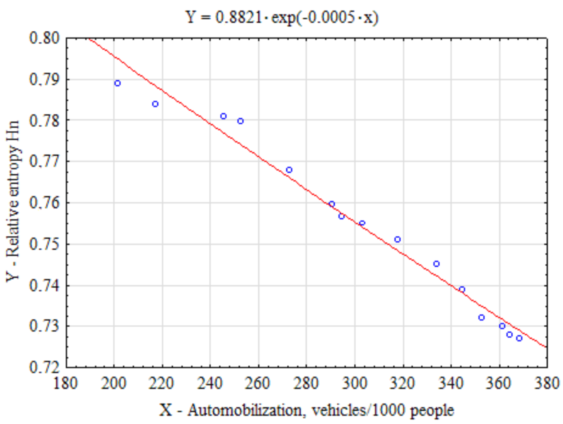

Figure 3. Model *Hn = f(A)* for the road safety provision system of the Russian Federation

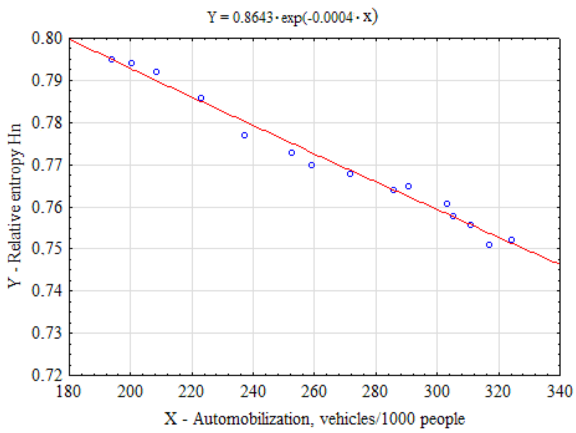

Figure 4. Model *Hn = f(A)* for the road safety provision system of the Kemerovo region

Parameter *b* of the model *Hn = a · exp (b · A)* for the road safety provision systems in the Russia and Kemerovo region equals to 0.0005 and 0.0004 accordingly. It means that modification processes of road safety provision systems orderliness proceed to a lesser degree that in whole Russia.

From this it follows that road safety provision system of the Kemerovo region lags behind all-Russian analogs. It happens due to slow development of vehicle fleet and long transition to more progressive paradigms of road safety provision.

6.2 Identification of the model $Hn_{\text{RSP of Kemerovo region}} = f(Hn_{\text{RSP of the Russian Federation}})$

This model (fig. 5) was built to understand the correlation of trends of formation of relative entropy *Hn* of road safety provision systems.

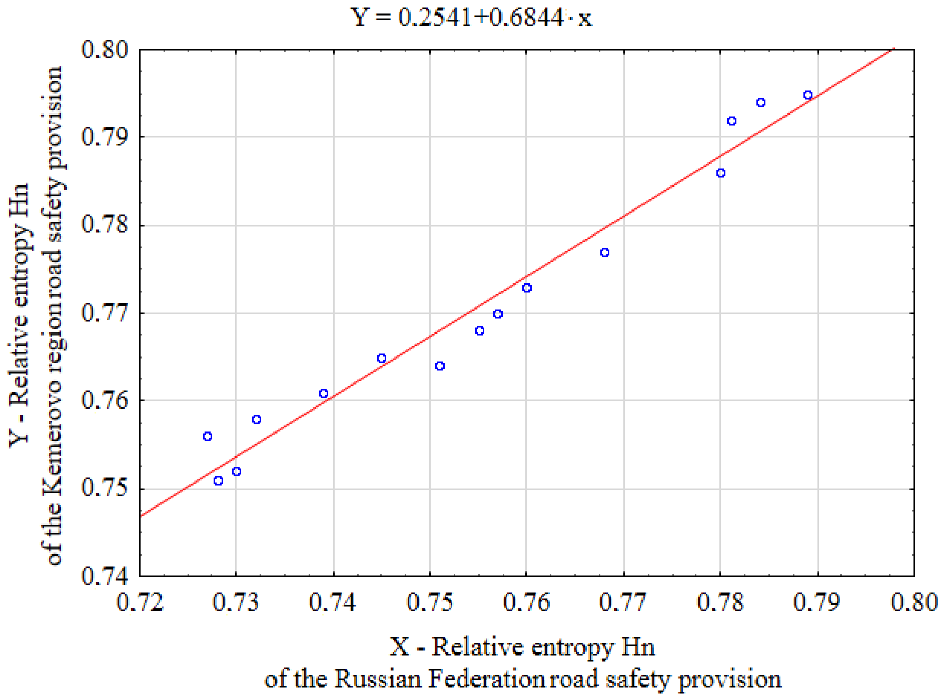

Figure 5. Model $Hn_{RSP\ of\ Kemerovo\ region} = f(Hn_{RSP\ of\ the\ Russian\ Federation})$

This statistical relation can be described by the model $Hn_{RSP\ Kem.\ reg.} = 0.25 + 0.68 \cdot Hn_{RSP\ RF.}$ It describes regional features of lag of road safety provision system of Kemerovo region relatively to all-Russian level with the high level of authenticity ($R^2 = 0.91$).

6.3 Problems of assessing the dynamics of road safety

Unfortunately, currently entropic analysis practically is not used in the analysis of the effectiveness of management decisions in the sphere of road safety assessment [12, 13]. 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 [14].

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 country regions [13, 14].

Analysis of long-term dynamics of road safety provision systems organization in the Russian Federation and Kemerovo region, 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 systems. This fact means that dynamics of the condition of road safety provision systems organization in the Russian Federation and Kemerovo region is positive and we should develop it [15].

7. Conclusion

Comparison of dynamics of relative entropy of road safety provision systems in the Kemerovo region and Russia shows that these processes proceed heterogeneously in different regions of country. The level of road safety provision system orderliness in Kemerovo region lags behind all-Russian state. It can be explained by slow development of motorization and the whole transport culture, determined by the evolution of road safety paradigms, of this region.

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