Organizational complexity and road safety: dialectical contradiction and its behavioural interpretation

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Abstract. The main organizational and technical idea implemented in recent years in Russia in the field of road safety is to reduce the conflict of traffic and pedestrian flows. This is realised through the use of multiphase traffic light cycle modes. The consequence of this is a sharp increase in the duration of the traffic light cycle (up to 180-200 sec) and a decrease in the capacity of the street and road network. However, more surprisingly, it does not lead to an increase in road safety. The article presents the author's view on the non-obvious effectiveness of such attempts to reduce the conflict of traffic and pedestrian flows and the author's reflections on the dialectical contradiction between the organizational complexity of traffic light cycles and the behaviour of road users.

1 Introduction

During 1900...2023, scientific approaches to road safety (RS) were developed within the framework of the First....Fifth paradigms of road traffic safety [1], each of which differed quite noticeably from the previous ones. Today, there is a generally accepted opinion among specialists about the clearly positive role of using organizational and managerial methods in ensuring high efficiency and safety of urban transport systems. The ideological orientation of these methods is more based on prohibitions and restrictions of any actions of road users. The number of all kinds of rules and regulatory and instructional materials on the subject of road safety is growing exponentially. The safety benefits of all kinds of restriction on road user behaviour are virtually unquestioned. Timid attempts to express doubts about the effectiveness of total restrictions and the need for constant complication of the road safety system, undertaken by some opponents [2-6], are perceived by the public quite negatively. The concepts of "common road space" [2-4] and risk homeostasis [5, 6] are considered antiscientific in scientific circles [7]. But are the views of H. Monderman and G.J.S. Wilde so incorrect?

In 2017...2023, the author [8-10] made an attempt to develop a methodology for quantitative assessment of the organised nature of RS systems based on the use of the ideas of C. Shannon's concept of information entropy [11, 12]. It was in the course of this work that the main reason for the difficulty of achieving the European level of road safety in
Russia was grasped - the high level of chaos of the road safety system [13, 14]. Within the framework of the same theory, studies of the dynamics [15] of the characteristic of system chaos, Relative entropy $H_n$, were carried out as applied to road safety systems [11, 12]. The final link of this research was the fundamental work on the assessment of the harmonicity of road safety systems [16].

Numerous experiments with the collection, processing and analysis of accident data in the cities of the Russian Federation allowed us to calculate numerical values of Relative Entropy $H_n RS$, characteristic of specific urban RS systems. The results were quite paradoxical. It turned out that in the dimensionality $H_n RS = [0; 1]$ very significant Relative entropy of urban RS systems $H_n RS = [0.65; 0.71]$ was typical of Russian cities where municipal authorities tried to minimise road traffic conflict in every possible way. Conversely, relatively low values of Relative Entropy of urban road safety systems $H_n RS = [0.58; 0.64]$ were characterised by the cities where road safety seemed to receive less attention.

Vivid examples of antagonist cities illustrating this thesis can be such Russian cities as:

- Tyumen with $H_n RS = 0.709$ (in the city 95% of traffic light objects are characterised by complex multi-phase (from 4 to 8 phases in a cycle) traffic control modes with a mandatory dedicated pedestrian phase);
- Tomsk with $H_n RS = 0.581$ (most traffic light objects are characterised by 2..3-phase modes of traffic regulation; a dedicated pedestrian phase in traffic light cycles is extremely rare).

Of course, the question arises about the reasons for such an apparent contradiction. Why is the level of system chaos (within the road safety system) lower in Tomsk than in Tyumen? After all, it is complex traffic light regulation systems that should reduce the level of chaos by separating traffic and pedestrian flows in time, and thus reducing conflict and the probability of road traffic accidents (RTAs). Why is this not the case? Where is the logic broken? This article attempts to answer these questions.

2 The specifics of road traffic accidents rate in the compared cities

One of the author's recent articles [17] presented the initial data characterising the specificity of road safety in Russian cities, the methodology of determination and calculated numerical values of Relative entropy $H_n RS$ for road safety systems of Russian cities. In this case, let us consider this specificity for Tyumen and Tomsk - antagonist cities, Relative entropy $H_n RS$ of which are fundamentally different (Tables 1-2).

<table>
<thead>
<tr>
<th>no.</th>
<th>Cities</th>
<th>Population, pers.</th>
<th>Road Traffic Accidents (RTA), unit.</th>
<th>RTA Victims, pers.</th>
<th>Fatality cases, pers.</th>
<th>Human Risk HR, died/100 thous. pers.</th>
<th>Severity of RTA, %</th>
<th>$H_{n,3\ RS}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tyumen</td>
<td>816800</td>
<td>1452</td>
<td>2027</td>
<td>51</td>
<td>6.24</td>
<td>2.52</td>
<td>0.709</td>
</tr>
<tr>
<td>2</td>
<td>Tomsk</td>
<td>568508</td>
<td>227</td>
<td>264</td>
<td>17</td>
<td>2.99</td>
<td>6.44</td>
<td>0.581</td>
</tr>
</tbody>
</table>
Table 2. Specifics of road traffic accidents rate in Tyumen and Tomsk (2021), determined by the value of coefficients $K_i$ [17]

<table>
<thead>
<tr>
<th>no.</th>
<th>Cities</th>
<th>$H_{n RS}$</th>
<th>$K_1 = K_{RA}$</th>
<th>$K_2 = K_V$</th>
<th>$K_3 = K_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tyumen</td>
<td>0.709</td>
<td>0.00178</td>
<td>1.3960</td>
<td>0.0252</td>
</tr>
<tr>
<td>2</td>
<td>Tomsk</td>
<td>0.581</td>
<td>0.00040</td>
<td>1.1630</td>
<td>0.0644</td>
</tr>
</tbody>
</table>

Coefficient $K_1 = K_{RA}$ characterises the probability of a road accident for an average resident of the city; coefficient $K_2 = K_V$ determines the average statistical (for one road accident) number of injured persons; the coefficient of $K_3 = K_D$ illustrates the share of road accident fatalities among the injured (Figure 1).

Comparing the values of the coefficients $K_i$, characterising the specifics of the road traffic accidents rate formation process in Tyumen and Tomsk, it is easy to note that the probability of being involved in a road accident for a resident of Tyumen is 4.5 times higher than for a resident of Tomsk. In turn, the probability of being killed in a road accident for a road accident participant in Tyumen is 2.5 times lower than in Tomsk. Thus, a high level of Relative Entropy $H_{n RS}$ The situation in Tyumen illustrates a very contradictory situation of both a high probability of being involved in an accident and a relatively low probability of being killed in an accident. For Tomsk the situation is completely opposite.

3 Problem statement

The problem statement of the research can be formulated as follows: it is necessary to study and try to understand the causal relationship between high relative entropy $H_{n RS}$ of the city's road safety system and peculiarities of road users' behaviour. For this purpose, it is desirable to study the motivation of road users' actions under two fundamentally different approaches to traffic management: minimising potential conflict (model city - Tyumen) and, on the contrary, in the presence of this conflict (model city - Tomsk). For this purpose, it is necessary to compare the behavioural patterns of road users in situations requiring different lengths of time to wait for traffic resolution and, possibly, to try to feel and identify their emotional state affecting specific actions in a particular traffic situation.

The primary level of identification of different road user behaviour patterns is a comparison of actual average section speeds of vehicles $V_a$ on the sections after intersections with different waiting times for the start of traffic.

It is known that the factor of vehicle speed is one of the most significant for the formation of a high probability of emergency dangerous situations [18, 19], some of which
are eventually realised in the form of road accidents. The factor of attentiveness (or its antipode) of distracted attention of road users is also significant [20, 21].

It is assumed that drivers' behavioural patterns (in terms of choosing the speed limit) statistically significantly depend on the waiting time for the permissive traffic signal.

4 Methods

The following methodology was used to solve the problem of comparing behavioural patterns.

The aim of the study is to compare two variants (for intersections I and II) of average section speed values $V_a$ with movement of vehicles that started to move after a forced wait due to a prohibited traffic signal. The average section speed was estimated by stopwatch readings based on the time of passing the first 100 m from the moment the vehicles started driving after switching on the permissive traffic signal. It is the time of overcoming the first 100 m that allows to estimate the acceleration dynamics and emotional state of drivers.

The average section speed of 100 m was estimated by formula (1) and measured in the dimension of m/s.

$$V_a = \frac{100}{T}$$ (1)

Here

- $100$ - is the length of the measured track section from the stop line to the measurement section, m;
- $T$ - time of overcoming the measured section (100 m), sec.

The comparison of average section speeds of vehicles was carried out for Tyumen road intersections No. I and II, which differ fundamentally in the number of phases in the traffic light cycle and, respectively, in the time of the total traffic light cycle and the time of waiting for drivers to start moving.

Traffic light regulation (Fig. 2) at intersection I is organized according to a three-phase cycle ($T_{cycle} = 95$ sec., prohibition time for phases $\#1$ and $\#2$ of the cycle intended for car traffic $T_{prohibition} = 58$ sec.).

![Fig. 2. Intersection I. The mode of operation of traffic lights in the daytime (6:00 - 22:00 weekdays; 9:00 - 22:00 weekends)](image)

Traffic light regulation (Fig. 3) at the intersection II is organized according to a six-phase cycle ($T_{cycle} = 182$ sec., time of traffic prohibition for cars, varies for different phases of the cycle in the range of values $T_{prohibition} = 75...134$ sec.).

The hypothesis of the study was formulated as follows: the average section speed of cars correlates with the waiting time for the driver to start moving, which means that drivers' behavioural patterns may be specific and depend on the complexity of traffic light cycles. In the context of this research, this should be understood as follows - the average
sectional speed of cars at the initial section (100 m) after the start of traffic will differ significantly for conditions with different traffic waiting times.

The study was conducted during the summer time period (June-July 2023), with dry road surface in the morning (7:30...8:30) over several days (in order to recruit the necessary statistics of experimental data (n ≥ 250).

Fig. 3. Intersection II. The mode of operation of traffic lights in the daytime (6:00 - 22:00 weekdays; 9:00 - 22:00 weekends)

The data on the number of experiments performed are presented in Table 3.

Table 3. Data characterising the specifics of the experiment

<table>
<thead>
<tr>
<th>Intersection №№</th>
<th>Number of traffic light cycles per hour</th>
<th>Number of lanes for traffic</th>
<th>Number of pilot measurements per day</th>
<th>Experiment dates in 2023</th>
<th>Number of measurements n</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>38</td>
<td>1</td>
<td>38</td>
<td>26.06-29.06; 3.07-6.07</td>
<td>304</td>
</tr>
<tr>
<td>II</td>
<td>20</td>
<td>2</td>
<td>40</td>
<td></td>
<td>320</td>
</tr>
</tbody>
</table>

5 Results

Table 4 shows the frequency distribution of the actual 100 m times for the 2 experimental intersections.

Table 4. Frequency of distribution of the actual 100 m times for the 2 experimental intersections

<table>
<thead>
<tr>
<th>Intersection №№</th>
<th>Number of movement time values, s.</th>
<th>Range of average precinct speed ( V_a ), m/s</th>
<th>Frequency of case distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6…7</td>
<td>143…167</td>
<td>I 0</td>
</tr>
<tr>
<td></td>
<td>7…8</td>
<td>125…143</td>
<td>I 3</td>
</tr>
<tr>
<td></td>
<td>8…9</td>
<td>111…125</td>
<td>II 0</td>
</tr>
<tr>
<td></td>
<td>9…10</td>
<td>100…111</td>
<td>II 3</td>
</tr>
<tr>
<td></td>
<td>10…11</td>
<td>91…100</td>
<td>II 0</td>
</tr>
<tr>
<td></td>
<td>11…12</td>
<td>83…91</td>
<td>II 3</td>
</tr>
<tr>
<td></td>
<td>12…13</td>
<td>77…83</td>
<td>II 0</td>
</tr>
<tr>
<td></td>
<td>13…14</td>
<td>71…77</td>
<td>II 3</td>
</tr>
<tr>
<td></td>
<td>14…15</td>
<td>67…67</td>
<td>II 0</td>
</tr>
<tr>
<td></td>
<td>15…16</td>
<td>63…67</td>
<td>II 3</td>
</tr>
<tr>
<td></td>
<td>16…17</td>
<td>59…63</td>
<td>II 0</td>
</tr>
</tbody>
</table>
Fig. 4 shows the histograms of distribution of the obtained values of the average precinct speed $V_a$ (m/s) of vehicles travelling 100 m after starting from the stop line.

Fig. 4. Distributions of mean average precinct speeds $V_a$ of vehicle traffic (m/s)

The characteristics of these distributions are presented in Table 5.

<table>
<thead>
<tr>
<th>Intersection №№</th>
<th>Dispersion $\sigma^2$</th>
<th>Mean square deviation $\sigma$</th>
<th>Coefficient of variation $V$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1.565</td>
<td>1.251</td>
<td>15.68</td>
</tr>
<tr>
<td>II</td>
<td>3.083</td>
<td>1.756</td>
<td>18.81</td>
</tr>
</tbody>
</table>

The answer to the question of statistically significant difference in mean average precinct speeds $V_a$ of vehicle movements is determined by the Student's $t$-criterion for independent samples ($t = 11.577$). This value indicates that there were significant differences between the data group “Intersection I” and the data group “Intersection II” in terms of the value of the mean average precinct speed $V_a$ of vehicle traffic (Student's $t$-criterion = 11.577, $p < 0.001$). Mean value of average precinct speeds $V_a$ in the group “Intersection II” is greater than the average value of the group “Intersection I”. Accordingly, the time of passing the measured section of the path (100 m) for group “Intersection II” is shorter than for group “Intersection I” ($T_2 = 11.067$ s.; $T_1 = 12.819$ s.).

6 Conclusions

The presented results indicate a statistically significant difference in the behaviour of drivers forced to wait for the permissive traffic signal for different lengths of time. Forced prolonged waiting leads the driver to an excited psycho-emotional state, the consequence of which is the choice of higher speed modes. And, on the contrary, simple two-three-phase cycles of regulation, the consequence of which is insignificant in time waiting of drivers and pedestrians for traffic authorisation, makes drivers much less nervous. As a consequence, they choose less nervous and safer driving modes.

Perhaps, this is what determines the different level of entropy in the traffic safety system in cities with different principles of traffic organisation (for example, in Tyumensk and Tomsk). It seems to be a paradox, but the attempt to make the traffic system more...
organised leads to the opposite situation, when the level of chaos in the road safety system increases. And this paradox is determined by people's behavioural reactions. The desire to increase the speed of traffic while waiting for a long time to switch on the permissive traffic light signal is explained by the well-known dialectical law of unity and struggle of opposites. Managerial goal-setting, the result of which seems to be an increase in the safety of drivers, at some point begins to work in reverse - safety, on the contrary, begins to decrease. And this is explained, first of all, by the desire of drivers to catch up with the time they lost at the intersection while waiting for the traffic permitting phase of the traffic light cycle.

In view of the above, H. Monderman's and G.J.S. Wild's unconventional views on the principles of traffic safety no longer seem so extravagant and unscientific. Perhaps they were the first to recognise the implicit but threat to the safety of urban road users in the total drive to reduce traffic conflict.

References

9. A.I. Petrov, Entropy, 24, 177, (2022)
17. A.I. Petrov, Information, 14(6), 302, (2023)