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The Analysis of Injuries and Mortality Risks Level as a Result of Road Accident in Regions of the Central and Eastern Europe

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Abstract: *In the article the analysis of the frequency, traumatism and mortality of road accidents has been carried out at the regional level for the countries of Central and Eastern Europe and has made it possible to draw conclusions regarding certain spatial features of the distribution of these indicators and on the non-random nature of the location of their values on maps of the CEE regions featured in the study. On the basis of methods of spatial statistics and econometrics we have demonstrated the existence of a spatial structure in the distribution of the risks and consequences of road accidents in the various regions. Cluster analysis has enabled us to distinguish uniform clusters of regions categorised by the risks, traumatism and mortality rates of road accidents. Based on an analysis of these indicators we have introduced the evaluation of an integrated safety level for regions of the countries of Central and Eastern Europe. This allows us to estimate the complex influence of the risks and their consequences road accidents on the level of safety for certain regions or groups of regions. The results of the research which has been conducted can be used for the improvement of national and regional programs of road and transport safety, and for the development of strategies and actions aimed at reducing the risks and consequences of road accidents in certain regions.*

Keywords: *traumatism, mortality, road accidents, spatial econometrics, cluster analysis, safety index*

JEL Classification: *I18, R10, R41*

1. Introduction

Deaths and injuries as a result of road accidents are among the pressing questions considered within the concept of the European safety [1, 3, 6, 13, 14]. Periodic reports of the World Health Organization [14] pay particular attention to the problem of the rates of mortality and injury as a result of road accidents in different countries of the world by means of a comparative analysis of these indicators. According to Eurostat more than 100 people daily, or about 40 thousand inhabitants of the European Union annually, die as a result of road accidents (RA). More than 40% of all victims (about 17 thousand people) are pedestrians, cyclists, drivers and passengers of motorcycles and mopeds. According to annual surveys in EU countries more than 3 million people annually suffer injuries of varying severity as a result of road accidents [14]. Within the last decades the countries of the EU have managed to achieve a certain amount of progress in decreasing traumatism and mortality on roads; thus in 1972 the quantity of road accidents resulting in death came to more than 93 thousand, and by 2008 this quantity had decreased to 39 thousand, i.e., by more than 50% [14].

In order to coordinate the actions of EU road safety programs, the special European Transport Safety Council (ETSC) was created in 1993. The ETSC unites more than 40 national organizations for road and transport safety from EU countries, Switzerland and Norway; more than 200 independent experts from more than 30 European countries participate in ETSC work [14]. The tasks of the ETSC are: the development of scientific and practical recommendations towards the formation of pan-European and national road safety strategies; a complex investigation of indicators of mortality and injury rates as a result of the use of vehicular transport of all kinds; the identification of zones of increased risk of road accidents and the provision of effective measures for its decrease; the setting up of programs to create safe infrastructure for roads and transport, and to provide for the safety of vehicular traffic; the carrying out of educational programs for road users, police structures, paramedical and emergency medical services, etc.

Over the past few years some large-scale European programs for decreasing the risk of mortality and injury rates on roads were carried out in EU countries. The most well-known programs are the following:

- PRAISE – Preventing Road Accidents and Injuries for the Safety of Employees. The program was begun in 2009 in EU countries in order to provide an exchange of examples of best practice between all workers dealing with road and transport safety, and to create recommendations for the relevant national structures of EU countries.
- ShLOW - "Show me How Slow". The program was initiated in 2008 and its tasks included training students for work with the local population on problems of drivers' exceeding the speed limit in built-up areas.
- Roads to Respect. This program has been under way for four years and is aimed at supporting actions by local authorities to provide a safe road transport infrastructure.
- Safe and Sober and Drink Driving Policy Network. This program was aimed at the activation of social advertising at local, regional and national levels against excessive alcohol intake among various groups of the population. The program set itself the task of decreasing the chance of a road accident connected with alcohol and drug use, and to increase the responsibility of drivers and pedestrians.
- SEC Belt. This program took root in 2004-2006 and was urged to improve safety in the countries of the Central, Eastern and Southern Europe. The program was concentrated on six principal areas: the behavior of road users; vehicle technology and safety; road infrastructure; road technologies; information and databases on road accidents; and the assessment of national policy on ensuring road safety.
- VOICE – Vulnerable Road User Organisations in Cooperation across Europe. The project was implemented in 2006-2008 and was aimed at fulfilling the requirements and maximising the safety of ordinary road users.
- Enforcement Programme. This program was realized in 2004-2007 for monitoring the system of road and transport regulation in EU countries.

These programs and projects represent important experience for the countries of Eastern Europe and Ukraine, where records show higher rates of death and injury on the roads [1, 2, 6, 13, 14].

Due to the importance of safety problem on roads in EU countries, especially in the former post-socialist countries such as Poland, Slovakia, Hungary, etc., there are numerous research programs aimed at the clarification of the situation and the identification of the risks of road accidents and their consequences, at national, regional and local levels. Mathematical and statistical research into indicators of injuries and mortality, and an analysis of the spatial distribution of these indicators using as examples some countries of Central and Eastern Europe (CEE), was carried out in a number of works [2, 3, 5, 7, 12].

At the same time, for the development of complex safety strategies on roads at the national and local levels it is necessary to define the risk factors and to estimate the safety level by means of an integrated characteristic.

2. The Purpose of the Research

In this article we set the following objectives: to reveal the major factors leading to increased danger on roads; to characterize, based on a literature review, the main types of injuries resulting from road accidents and their influence on mortality indicators; to estimate the level of risk of road accidents and their consequences at the regional level using six CEE countries by way of an example; to determine the safety level at the regional level using the same six CEE countries; to formulate, on the basis of the research and on the experience of the CEE countries, general recommendations for the reduction of road accident risk factors and for ensuring a higher level of safety on roads.

3. Materials and Methodology

This research applies methods of comparative analysis, methods of mathematical statistics and spatial econometrics and methods of multidimensional statistical analysis (cluster analysis with the use of the *k*-means method and taxonomic methods based on the calculation of integrated indicators). For calculations we used such packages as Statistica, R and Excel [4, 9, 11]. As the fundamental data set we used the statistical data of Eurostat, materials of reports and articles devoted to problems of injuries and mortality as a result of road accidents, an assessment of possible risks and so forth.

4. Main Results

As a result of road accidents followed by injuries and death we observed the different nature of injury risks for various participants: drivers, passengers, pedestrians, motorcyclists or cyclists. As it appears from these various investigations, the highest risk of injuries and lethal outcomes of a road accident is observed for pedestrians, cyclists and motorcyclists who (in a collision with a motor vehicle) are less protected than drivers or passengers.

In research by Eid H.O. [8], data concerning the nature of anatomic features of the injuries suffered by various participants in a road accident are specified. The analysis of 1070 cases of road accident in 2003-2006 was carried out.

Table1. *Distribution of the number of patients hospitalized as a result of a road accident, subdivided according to the anatomic character of the injury*

Body region	Road user type												p-value for Fisher's exact test
	Driver		Front seat passenger		Rear seat passenger		Pedestrian		Cyclist		Motorcyclist		
	n=395	%	n=153	%	n=130	%	n=229	%	n=80	%	n=73	%	
Head	143	36	45	29	39	30	100	44	32	40	29	40	0.042
Face	111	28	45	29	36	28	46	20	17	21	22	30	0.16
Neck	28	7	5	3	5	4	2	1	2	3	0	0	0.001
Spine	49	12	22	15	16	12	19	8	2	3	5	7	0.002
Thorax	125	32	44	29	36	28	73	32	16	20	15	20	0.15
Abdomen and pelvis	24	6	9	6	16	12	26	11	7	9	4	6	0.07
Upper extremity	124	31	48	31	41	31	80	35	36	45	38	52	0.005
Lower extremity	107	27	43	28	40	31	133	58	44	55	33	45	0.001

Source: *Eid H.O., et al. Factors affecting anatomical region of injury, severity, and mortality for road trauma in a high-income developing country: Lessons for prevention. Injury (2008)*

As seen from the results of calculations of Fisher's exact test, in the majority of cases we are able to reject the hypothesis that the anatomical distribution of injuries is the same for all participants in a road accident. Exceptions to this are injuries to the face and thorax, where Fisher's exact test did not prove the essential distinction between relative indicators.

For more detailed research see the work of Eid *et al.* [8], where the results of injuries were grouped for two categories of road accident participants: 1) drivers and passengers of cars; 2) pedestrians, cyclists and motorcyclists. It was shown that a considerably higher percentage of injuries to the head and to the upper and lower extremities is observed among the second category of road accident participants, while for the first category a higher percentage of injuries to the face, neck and spine is observed. As for the frequency of injuries to the thorax, abdomen and pelvis the difference was statistically insignificant, i.e. approximately identical proportions of these injuries to victims are observed from the first and second categories.

The report of the WHO [14] provides selective data on the distribution of injuries suffered by pedestrians as a result of a road accident in different countries (tab. 2).

As seen from Table 2, there are some, not very significant, differences between countries. On the basis of the given data it is clear that the two commonest types of injuries are injuries to the head and lower extremities; then follow injuries to the thorax, the upper extremities and the abdomen.

Table2. *Comparative analysis of the distribution of the kind of injury sustained by pedestrians as a result of road accidents worldwide.*

Body region	China (%)	Europe (%)	Australia (%)	Japan (%)	USA (%)
Head	31.5	29.5	39.3	28.6	32.7
Face	5.8	5.3	3.7	2.4	3.7
Neck	0.8	1.8	3.1	4.5	0.0
Thorax	10.9	11.6	10.4	8.5	9.5
Abdomen	6.2	3.8	4.9	4.8	7.7
Pelvis	2.6	7.9	4.9	4.5	5.3
Upper extremity	9.4	8.1	8.0	9.0	7.9
Lower extremity	32.8	31.3	25.8	37.2	33.3

Source: *WHO (2004)*

Considering that, in severe road accidents, victims have difficult multiple traumas, the chance of survival significantly depends on the efficiency and competence of those rendering emergency first aid. In turn, the coordination of police services, paramedical staff and emergency aid work depends on many factors and significantly differs in various countries. In economically less developed and poorer countries, more than half of the victims of severe road accidents die during the first hours after the incident. Thus, according to Kumar *et al.* [10], among the victims of severe road accidents in India, 39.84% died on the spot and 28.51% within the first days. Only 8.47% of victims survived for between 4 and 7 days after a severe road accident and only 8.82% for between 8 and 14 days.

In the developed European countries, with well-organized work of various security services on the roads, much lower indicators of mortality or injury in road accidents are observed [3, 13, 14].

In [3, 5, 7] the distributions of road accident mortality rates (per 100 thousand population) for the NUTS2 regions of the studied CEE countries during 2001-2010 were analysed, and it was shown that there were significant differences in road accident mortality rates, both between countries, and in some cases between regions.

Comparing road accident frequencies in the specified countries and in their regions, it should be noted that these indicators differ by factors of up to several dozen. The highest number of registered road accidents per 100 km is observed in Germany and the Czech Republic. In addition, there is a clear substantial increase of road accident frequency in the capitals or the capital regions, where there is daily heavy traffic of vehicles and pedestrians and limited possibilities of traffic intersections. There are also quite high rates of road accident frequency in metropolitan regions and in the regions located at crossing points of intensive transport communications.

The lowest values of road accidents mortality rates are noted in Germany and Austria (up to 2% of the number of victims), and the highest in Poland (up to 12%).

In [5, 7] methods of spatial statistics and econometrics were used for the analysis of the spatial distribution of road accident frequency indicators and the percentage of participants injured and killed in road accidents [4, 9].

For the frequency of road accidents per 100 km we calculated the Moran coefficients, characterizing the degree of spatial autocorrelation, for the 84 NUTS2 regions of the six CEE countries. In 2010 the Moran coefficient came to 0.35, pointing to moderate spatial correlation for road accident frequency. The Moran coefficient for the indicators of injuries in road accidents came to 0.42 in 2010, which also testifies to the existence of moderate spatial correlation of these indicators. A visual analysis of maps distinctly showed the existence of clusters formed by groups of NUTS2 regions with higher or lower numbers of road accident injuries.

In order to study the features of the spatial distribution of these indicators it is necessary to analyze the spatial modes for regions or their separate groups. Here we distinguish four types of spatial régimes: "HH" – regions with quite high rates, surrounded by regions with high rates; "HL" - regions with high rates, surrounded by regions with low indicators; "LL" – regions with low indicators, surrounded by regions with quite low indicators; "LH" – regions with low indicators, surrounded by regions with high rates [4, 9].

In Figure 1 the spatial régimes for indicators of road accident deaths (as a percentage of those involved and per 1 million inhabitants) are presented for the NUTS2 regions of the CEE countries. For these calculations we used data from 2010.

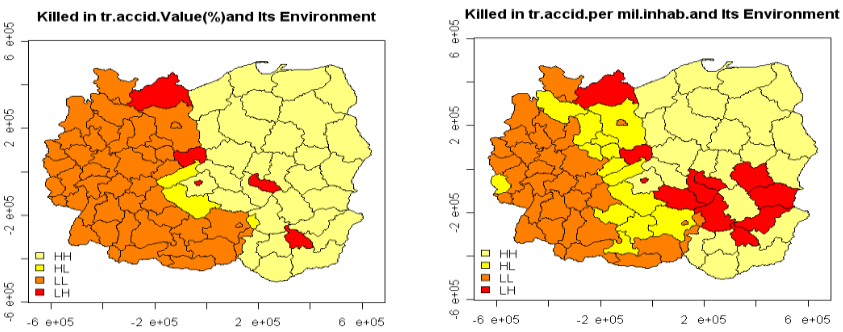


Fig1. *The spatial distribution of those killed in road accidents (as a percentage and per 1 million inhabitants) for the NUTS regions of the six CEE countries*

Source: *data of Eurostat are processed by N. A. Dubrovina in the program R*

In figure 1 we can clearly see the "HH" zones in the territories of Poland, Hungary, Slovakia and the Czech Republic where the regions with quite high rates of people killed in road accidents (both as a percentage of those involved and also per 1 million inhabitants) are surrounded by regions with the same high rates. On the contrary, the "LL" zones are located in the territory of western Germany and Austria. The analysis of areas with the transitional régimes "HL" and "LH" is also of interest.

For more detailed characteristics of regions and for the risk analysis of traumatism and mortality as a result of road accidents we used four indicators: 1) the number of road accidents per 100 km of roads (VAR1 variable); 2) the mortality percentage of victims and people injured in road accidents (VAR2 variable); 3) the number of people killed in road accidents per million inhabitants (VAR3 variable); 4) the number of people injured in road accidents per million inhabitants (VAR4 variable).

Cluster analysis (a method of *k*-means) was used to group the regions taking into account several indicators characterizing the risk of trauma and mortality as a result of road accidents. As a result four clusters were distinguished: statistical characteristics of the observed clusters are provided in Table 3.

Table3. *Means and standard deviations of the VAR1-VAR4 variables for the four clusters*

Variable	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
VAR1	150.04	83.49	4489.83	1511.32	113.6	72.98	95.25	439.64
VAR2	1.12	0.37	0.3	0.07	1.13	0.28	5.54	2.74
VAR3	49.57	17.09	14.94	4.08	66.15	15	88.71	25.48
VAR4	4350.89	422.69	4881.05	514.97	5808.81	602.45	1713.72	553.31

Source: *results of authors' research according to Eurostat data*

Of the 84 NUTS2 regions of the six CEE countries (Germany, Austria, the Czech Republic, Poland, Hungary and Slovakia), 28 regions came into the 1st cluster; 3 into the 2nd cluster; 18 in the 3rd, and 35 in the 4th.

Of the 40 NUTS2 regions of Germany, 28 came into the 1st cluster; 3 in the 2nd and 11 in the 3rd. Of the 9 regions of Austria, 7 came into the 3rd cluster and 2 into the 4th. In the former post-socialist countries (the Czech Republic, Poland, Hungary and Slovakia) all regions appeared in the 4th cluster.

On the basis of the results of separating the regions into clusters it is possible to conclude that in regions of Germany and Austria the risks of road accident injuries and mortality are described by the characteristics of clusters 1-3, while for the regions of the four Visegrád group countries the indicators are located in the 4th cluster.

For the analysis of a generalised measure of risk we calculated an integrated indicator incorporating the frequency of accidents and the measure of injuries and deaths. The idea behind this is based on methods of taxonomy and it is described in detail in works by the Polish scientists Hellwig, Pluta and Młodak, etc. [11]. In our calculations we used an approach based on the method of an integrated indicator with an artificial standard (etalon) whereby among all the standardized values of the variables VAR1-VAR4 the best ones are chosen; these are coordinates of etalon points in multidimensional space, and the Euclidean distance of standardized values from the etalon point is calculated. As different indicators can have different contributions to the formation of an integrated indicator, we noted in our calculations the weighted distance of the standardized values from the etalon for the evaluation of the total risk measure.

The algorithm and formulas which were used for calculations of an integrated evaluation of risk measure based on road accident frequency, injures and mortality rates are given below.

- Calculation of standardized values for the VAR1-VAR4 variables:

$$x_{i,j}^S = \frac{\left(x_{i,j} - \overline{x_j}\right)}{\sigma_{x_j}},$$

where $x_{i,j}^S$ is the standardized i -th value for the j -th variable, $j = \overline{1,4}$ $i = \overline{1,84}$, $x_{i,j}$ is the i -th initial value for the j -th variable and $\overline{x_j}$ is the average value for the j -th variable.

- The choice of the best values – the coordinates of the etalon point – among all standardized indicator data is:

$$x_j^e = \min_i x_{i,j}^S$$

where x_j^e is the j -th coordinate for the etalon point; in this case the best values are the minimum values of the standardized data.

- Calculation of the deviations of the standardized values of variables from all coordinates of the etalon point:

$$\Delta x_{i,j}^S = \left(x_{i,j}^S - x_j^e\right)$$

where $\Delta x_{i,j}^S$ is the deviation of the i -th standardized values of the j -th variable from the coordinate of the etalon point.

- Calculation of the weighted deviation distance of the standardized values from the coordinates of the etalon point for all i values ($i = \overline{1,84}$) and all j variables ($j = \overline{1,4}$):

$$d_i = \left[w_1 \cdot \left(\Delta x_{i,1}^S\right)^2 + w_2 \cdot \left(\Delta x_{i,2}^S\right)^2 + w_3 \cdot \left(\Delta x_{i,3}^S\right)^2 + w_4 \cdot \left(\Delta x_{i,4}^S\right)^2\right]^{1/2}$$

where d_i is the weighted deviation distance of the standardized values from the etalon point and w_j is the weighting coefficient defining the importance of each indicator in the formation of the integrated index.

These coefficients are determined by an expert way. We invited group of experts specialized in the problem of road accidents and safety and ask them to set the weighting coefficients defining the importance of each indicator in the formation of the integrated Safety Index. In our research we use $w_1 = 0.15$, $w_2 = 0.3$, $w_3 = 0.3$ and $w_4 = 0.25$. Thus, indicators of mortality have the greatest importance for risk assessment, then by degree of importance follows the indicator of traumatism (injury rates), and road accident frequency has least impact on an integrated assessment. It should be noted that, in view of the more developed technical infrastructure and the more coordinated work of transport police posts, more road accidents are recorded in the developed countries of Western Europe in comparison with Eastern Europe, beginning with the insignificant accidents in which no trauma or death were caused and finishing with the severe accidents.

- On the basis of values d_i we calculate the quantity *Safety Index* as the integrated assessment of safety based on measurement of risk factors. This value is determined by the following formula:

$$I(SI)_i = 1 - \frac{d_i}{\overline{d} + 3 \cdot \sigma_d}$$

where $I(SI)$ is an estimate of the safety level (Safety Index) in the region from the point of view of road accident risks, $\bar{d}$ is the average value of the d_i, and σ_d is the standard deviation of the d_i.

Table 4 gives the results of the distribution of the calculated values of the safety level in the NUTS2 regions of the six CEE countries.

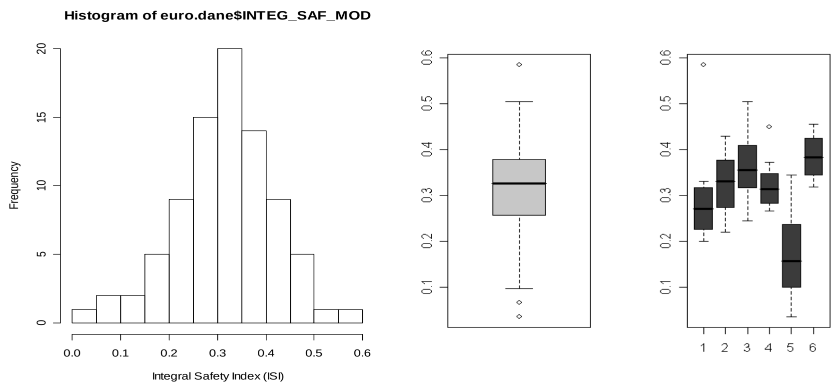
Table4. *Results of the distribution of the calculated values of the safety level* $I(SI)$

	Country	Min. value	Lower quartile	Mean	Median	Upper quartile	Maxim. value
1	Austria	0.2008	0.2264	0.2991	0.2710	0.3169	0.5855
2	Czech Republic	0.2203	0.2821	0.3266	0.3310	0.3643	0.4300
3	Germany	0.2443	0.3214	0.3606	0.3559	0.4094	0.5047
4	Hungary	0.2657	0.2837	0.3277	0.3145	0.3485	0.4495
5	Poland	0.03488	0.1013	0.1752	0.1577	0.2310	0.3452
6	Slovakia	0.3181	0.3591	0.3854	0.3837	0.4100	0.4561

Source: *results of calculations made by authors according to Eurostat data*

The values of the Safety Index vary in the range from 0 to 1. The closer the index $I(SI)$ is to 1, the safer is the situation in the region from the point of view of road accidents and their consequences. And, on the other hand, values of $I(SI)$ close to 0 characterize the lowest level of safety.

As we observe from the data in Table 4 and Figure 2, there are significant differences in the Safety Index between the countries and between certain regions from the point of view of the generalized risks of road accidents and their consequences.



a) The histogram for the whole sample; b) box-and-whisker plot for the whole sample; c) box-and-whisker plot for each country

Fig2. *The distribution of the Safety Index for the whole sample and by country*

Source: *data of calculations are processed by N. A. Dubrovina in the program R*

It should be noted that in general the distribution of the Safety Index for the whole sample is close to the normal Gaussian distribution. At the same time, from the plots presented in Figure 2(c) we see that the regions of Poland have the lowest values of the Safety Index from the point of view of the generalized risks of road accidents.

The Czech Republic, Hungary and Slovakia have a better situation than Poland, as also seen from Table 4 and Figure 2(c). The highest safety rates from the point of view of road accident risks and their consequences are noted in Austria and Germany.

In Figure 3 we present the spatial distribution of regions, clustered according to the integrated Safety Index.

As seen from the maps presented in Figure 3, the lighter areas, corresponding to the fourth cluster of road accidents risks and to the lowest values of the integrated Safety Index, fall in the regions of Poland and partially in Hungary. The safest regions are located in the dark colored zone, belonging to the first and third clusters according to their risk characteristics, and these are the western regions of Germany. It is also seen that in the regions containing the capitals of Austria, the Czech Republic, Slovakia and Hungary, we observe higher rates of the Safety Index. In Germany (Berlin) and in Poland (Mazowieckie voivodeship), on the contrary, safety indicators are rather low.

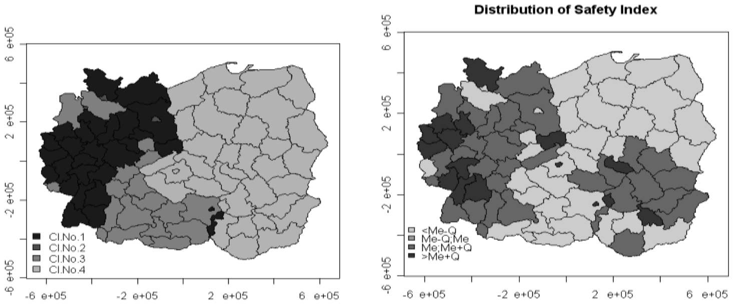


Fig3. *The NUTS2 regions of six CEE countries clustered by risk of road accidents and the spatial distribution of the Safety Index* $I(SI)$

Source: *data for calculations are processed by N. A. Dubrovina in the program R*

For the analysis of the spatial distribution of the Safety Index the Moran coefficient was calculated. This coefficient came to 0.467, testifying to the existence of moderate spatial autocorrelation of $I(SI)$ values. In Figure 4 the spatial régimes of the distribution of $I(SI)$ values are presented.

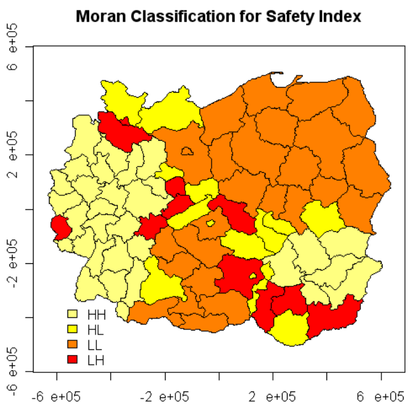


Fig4. *Spatial régimes of distribution of values of integrated safety level* $I(SI)$

Source: *data from calculations processed by N. A. Dubrovina in the program R*

The "LL" zones located in the considerable territory of the Polish regions are quite clearly visible; also shown are the southern, mountain regions of Austria where there are also zones with quite a low level of safety. The "HH" zones presented by the safe regions of western Germany, as well as regions of Slovakia and Hungary with fairly high safety levels, are clearly seen. The maps also shows the transitional régimes "HL" and "LH" with a sharp change of safety level values between the region and its surroundings.

5. Conclusions

The analysis of the frequency, traumatism and mortality of road accidents has been carried out at the regional level for the countries of Central and Eastern Europe and has made it possible to draw conclusions regarding certain spatial features of the distribution of these indicators and on the non-random nature of the location of their values on maps of the CEE regions featured in the study. On the basis of methods of spatial statistics and econometrics we have demonstrated the existence of a spatial structure in the distribution of the risks and consequences of road accidents in the various regions. Cluster analysis has enabled us to distinguish uniform clusters of regions categorised by the risks, traumatism and mortality rates of road accidents. Based on an analysis of these indicators we have introduced the evaluation of an integrated safety level for regions of the countries of Central and Eastern Europe. This allows us to estimate the complex influence of the risks and their consequences road accidents on the level of safety for certain regions or groups of regions.

The results of the research which has been conducted can be used for the improvement of national and regional programs of road and transport safety, and for the development of strategies and actions aimed at reducing the risks and consequences of road accidents in certain regions. It is necessary to establish in more detail the reasons underlying the emergence of these factors at the local, regional or national levels and, by taking these reasons into account, to develop a complex of target actions; according to the recommendations of the Program of the World Health Organization presented in 2004 and devoted to the problem of ensuring road and transport safety, such actions have to be based on interactions between the following five components: 1) tasks for the government; 2) tasks for the health system; 3) tasks for vehicle manufacturers; 4) tasks for representatives of funds and charitable organizations; 5) tasks for representatives of the local population, local social groups and public organizations [14].

The coordinated work of these major components will accord higher status, in the eyes of the state and of the public, to the ensuing road and transport safety programs and will enhance their social and economic efficiency. An example of this is the experience of Germany and Austria, where lower road mortality and a higher level of road and transport safety have been brought about by: the creation of more flexible mechanisms for cooperation between central government and local government; the coordinated work of traffic patrols, rescue workers and emergency medical services; the involvement of volunteers in carrying out educational programs aimed at reducing the risk of road accidents associated with a human factor; and the application of a variety of channels of financing.

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