

AN ANALYSIS OF THE ACCIDENT THREAT AND RISK RESULTING FROM ROAD FREIGHT TRANSPORT ON THE EXAMPLE OF THE REGION OF MAZOVIA

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Summary

The article presents an analysis of the current risk of accidents resulting from road freight transport. This includes calculations that led to the numerical characteristics of the risk caused by the movement of trucks. The characteristics of the threat are presented, taking into account the circumstances of time (day, week, month). The significance of this risk increases with the persistence of a strong and sustained upward trend in road freight transport in Poland. The growth rate of truck traffic for the last 10 years is almost two times higher than passenger car traffic.

Estimation of risk indicators and risk of fatalities was based on an analysis of the collection of accident extracted for this purpose. The event analysis period covers the years 2010-2011 and the numerical values were referred to classical measurements of drivers' working lives. The calculations made it possible to show not only the participation of this category of vehicles in the creation of a substantial part of the accident risk. First of all, they showed a changing nature of this participation and indicated periods of time when there is a concentration of the accident risk and the highest indicator of the mortality risk in accidents involving trucks.

Keywords: road safety, traffic, freight transport, trucks, Mazovia

1. Introduction

Road traffic safety has great economic importance that is more often expressed as the so-called external costs of freight transport [2, 5, 6, 8]. A dominant component of these costs results from road accidents involving trucks. The available statistical data shows a high number of accidents in Poland. Meeting the needs of an emphasized drive towards improving the quality of life and life/health protection, as well as implementing the National

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Program of Road Traffic Safety [5], there was analyzed the threat and risk of accidents in road freight transport. The scope of a detailed analysis was limited to the region of Mazovia, but in a few crucial aspects the results were referred to the value of the whole country.

The basic target is to indicate specific features characterizing the nature of the accident risk in road freight transport. The issue is elaborated on the basis of calculations of numerical characteristics of threats and their analytical models. Even though the nature of these models is general, they facilitate an analysis of fundamental features and course of observed processes which have great variability.

Mastering time characteristics of the accident threat and risk resulting from road freight transport is utterly important in many aspects, such as:

- creating a calculation basis for indicating the participation of road accidents in external costs of transport;
- planning and performing transport tasks;
- planning the work of emergency services, road traffic supervision and traffic organization;
- training drivers.

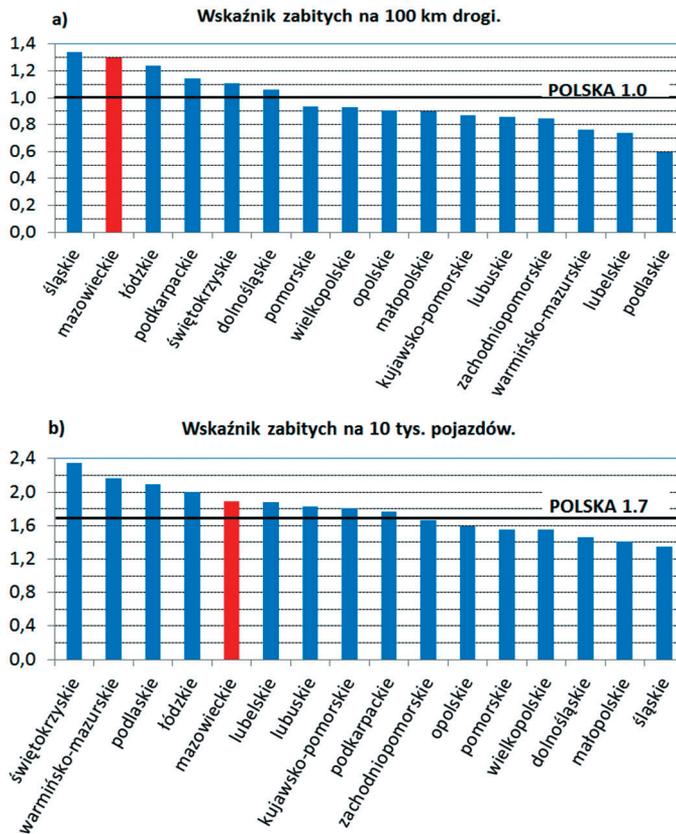
The region of Mazovia, chosen for a detailed analysis, occupies the greatest area in Poland. Simultaneously, it belongs to the group of regions in Poland which are most diversified internally. It consists of:

- the Warsaw metropolitan area which performs the function of a transport node (important in the European perspective)
- the remaining part of the region - characterized by indicators of economic development which are below the country's average [2].

The Warsaw metropolitan area is an important transport node for transeuropean transport corridors (Trans European Network - TEN). Out of ten main corridors within the TEN network, three cross Warsaw [2]. Warsaw is a key node in the transport network of Poland. These circumstances add to an excessive combination of interurban and local traffic and high accident risk. Qualitative characteristics of this threat are presented in an exemplary manner in Fig. 1 and Table 1. For this purpose, there were used values of relative indexes which facilitate the comparison of the safety condition of traffic in Mazovia with other regions and for whole Poland.

Table 1 Number of fatalities relative to the 100000 residents

Year of analysis	Mazovia	Poland
2002	18.7	15.2
2007	18.2	14.6
2010/2011	12.8	10.5



Poland:

Out of 16 administrative regions, the region of Mazovia marked with red.

Fig. 1. Number of road fatalities, relative to the 100km of roads (a) and up to 10000 vehicles (b) in particular regions (average for 2010-2011)

Values of indexes (Fig. 1, Table 1), which refer the number of fatalities to the length of roads, number of vehicles and population of Mazovia, belong to the highest ones in comparison with other regions of the country. For example, values of the index of fatalities of road accidents presented in the Table 1, relative to the number of population of Mazovia, are above the country's average by 20%. These values belong to the highest ones in the country. The level of the accident risk in Mazovia has been much higher than the country's average for many years [2].

2. Methodology of the risk analysis and its indexes and characteristics

The role played by trucks in home economy grows constantly. In the years 2000-2010, the participation of trucks in domestic freight transport increased from 26% to 70% [7].

This justifies the necessity to analyze the specific nature of risks connected with this transport. Calculating the indexes and characteristics, which are necessary for this purpose, requires much numerical information. The prepared research methodology was presented in [7] and includes a few stages:

1. Acquisition of data from primary sources.
2. Grouping and classification of events related to truck traffic.
3. Estimation of indexes of risk and auxiliary characteristics.
4. Analysis of estimation results for the purpose of identifying the features of the risk in road freight transport.

Making use of primary data [10] collected on the basis of a description of each accident, there were isolated accidents with the participation of trucks, considering that traffic of these vehicles is the realization of tasks connected with freight transport. In the process of identifying each accident in Mazovia, there were determined hours, days of the week and months. This helped to create a basic data collection which is the object of the calculations and analysis in this article.

The characteristics and indexes calculated for accidents with the participation of trucks were compared in a few places of this work with data presented annually by KGP [Polish Police Headquarters] [12] concerning all road accidents in Poland. The number of accidents and their victims, which results from truck traffic, is variable and fits the range from 4% to 11% of the total number of accidents in Poland.

The following indexes were used to allow for a numerical assessment of risks resulting from road freight transport:

1. A percentage index of the participation of accidents which involved vehicles of a given *i*-category and took place in particular hours (*j*), days and months, relative to the sum of these accidents for a whole year

$$p_{W_{ji}} = \frac{W_{ji}}{W_{Mi}} 100\% \quad (1)$$

2. An index of morality risk in a road accident involving vehicles of an *i*-category

$$w_{Z_i} = \frac{Z_i}{R_i + Z_i} \quad (2)$$

3. A percentage index of the accident risk resulting from the participation of accidents involving vehicles of an *i*-category in the whole number of accidents involving all categories in an analyzed period of time

$$p_{W_i} = \frac{W_i}{\sum_{i=1}^k W_i} 100\% \quad (3)$$

The following marking were used:

- i - i-category of vehicles;
- k - number of vehicle categories in road traffic which were taken into consideration;
- W_i - number of accidents involving vehicles of an i-category;
- W_{Mi} - number of accidents involving vehicles of an i-category during a year in Mazovia;
- R_i, Z_i - number of the injured or fatalities in road accidents involving vehicles of an i-category.

The analyzed period was established for the years 2010 - 2011. Numbers characterizing accidents and victims connected with truck traffic, after their distribution for definite hours, days, etc., are small and highly variable. Therefore, the analysis uses average values for two years.

3. Characteristics of the distribution of accidents in freight transport on a daily/weekly and annual basis

Road freight transport is predominantly made by professional drivers. Analyses of employees' work efficiency indicate that it is justified to examine the level of accident risk taking into consideration time circumstances [3, 4, 9, 13]. For this reason, the further analysis respects time intervals which are characteristic for the work of professional drivers and realization of transport tasks, namely: day, week, year.

In the Figures 2-4, there is shown a daily, weekly and annual distribution of accidents, involving trucks, which took place in Mazovia (marking: CM). It was shown as percentage value calculated according to (1). Among the chosen measurements of hour/day/week are strongly reflected in the course of changes in the values of risk indexes. First of all, what is visible is a cyclical nature of changes in the accident risk in freight transport related to these time intervals. The cyclicity in an annual period depends considerably on atmospheric conditions and correlated characteristics of traffic congestion.

In each period, however, the distribution of accidents involving trucks differs distinctly from a general distribution of accidents in Poland, i.e. a distribution calculated for all categories of vehicles.

In Figure 2, there is shown a daily distribution of accidents involving trucks in road traffic in Mazovia (lines CM) and a daily distribution of all accidents in road traffic in Poland (lines marked as POL). In the Figure, there are thin dashed lines joining calculation points and bold full lines. These lines show the course of approximating functions (Table 2) determined by using a polynomial model. High values of the coefficient of determination indicate a correct choice of a model for analyzing the problem.

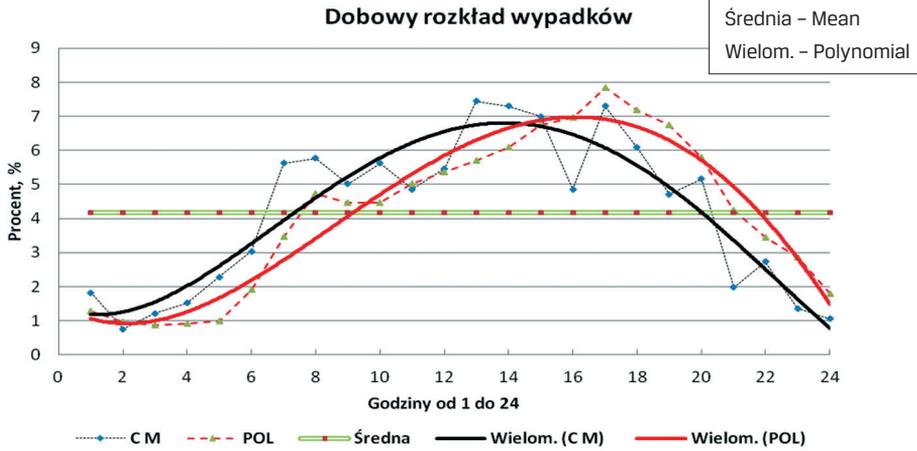


Fig. 2. The percentage of accidents per hour during the day, accidents involving trucks in Mazovia (CM), and all road traffic accidents in Poland (POL)

Table 2 Functions approximating the distribution of daily events (percentage), x-hours

Specification	Approximating function	Coefficient of determination
CM	$y = -0.003x^4 + 0.0801x^3 - 0.6566x^2 + 1.4458x + 8.716$	$R^2 = 0.50$
POL	$y = 0.00008x^4 - 0.0074x^3 + 0.153x^2 - 0.5503x + 1.4674$	$R^2 = 0.95$

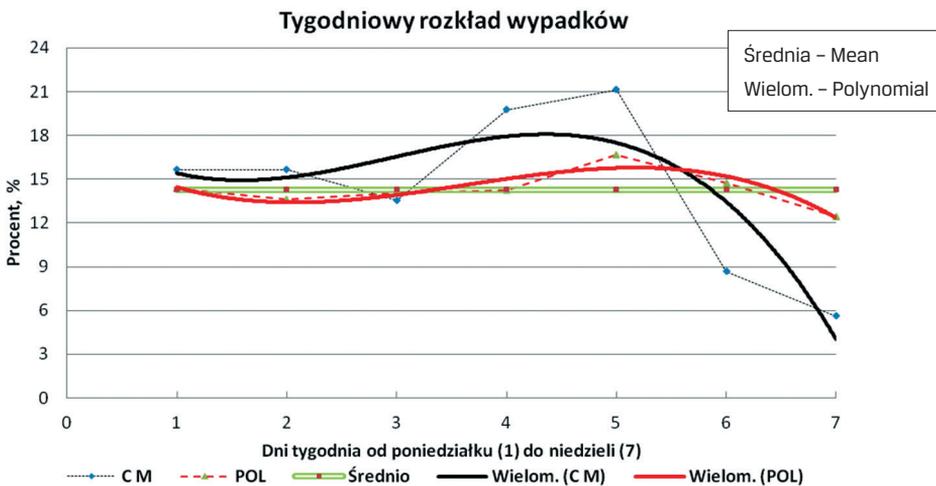


Fig. 3. The percentage of cases for each day of the week, accidents involving heavy goods vehicles (lines CM) and all the events in Poland (POL)

Table 3 Approximating functions weekly schedule of events (percentage), x-another day of the week

Specification	Approximating function	Coefficient of determination
CM	$y = -0.2955x^3 + 2.6342x^2 - 6.1237x + 19.192$	$R^2 = 0.73$
POL	$y = -0.1589x^3 + 1.7266x^2 - 5.1058x + 17.987$	$R^2 = 0.82$

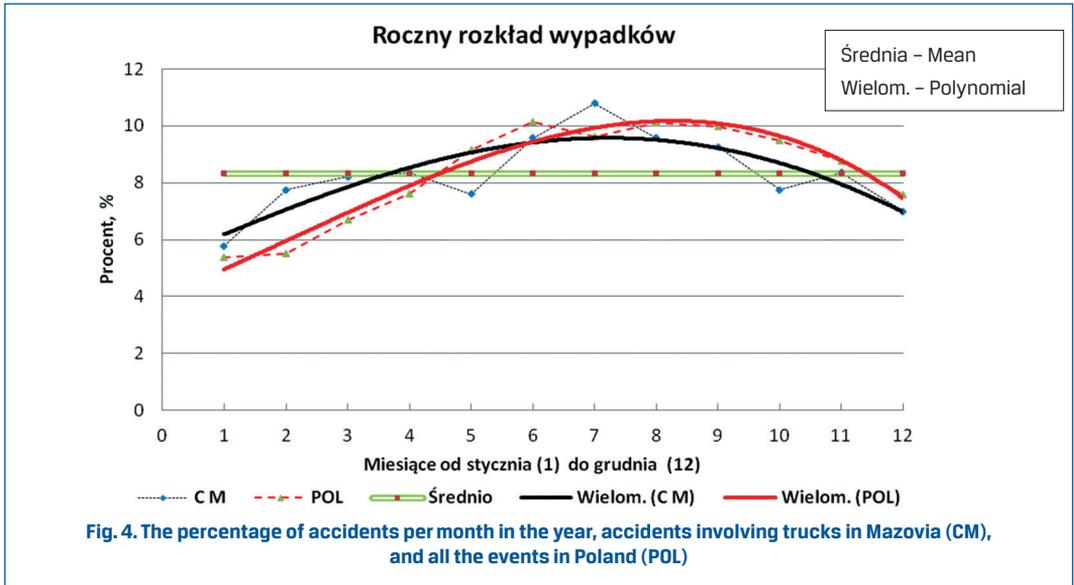


Table 4 Functions approximating the distribution of cases by month, x-consecutive month in the year

Specification	Approximating function	Coefficient of determination
CM	$y = 0.0002x^4 - 0.0092x^3 + 0.0113x^2 + 0.8976x + 5.2858$	$R^2 = 0.72$
POL	$y = -0.0088x^3 + 0.0556x^2 + 0.8838x + 4.0339$	$R^2 = 0.96$

On the basis of the accepted polynomial model and the course of the approximating function, it is possible to determine the characteristics of the distribution of accidents in road freight transport (CM) in a time function, namely:

- distribution of accidents in a time function has a clearly visible areas with the highest and the lowest concentration of accidents (Figures 2-4 and Table 5);
- deviation of the values of a daily and annual distribution of accidents (CM) from the average value of the distribution has values similar to the deviation observed in a general distribution of accidents (POL); the deviation is presented in the Table 5 as a percentage of the average value;
- in the distribution of accidents for the days of the week, we have small deviations of values of the general distribution of accidents (POL) from the average value and three

times higher variability of the distribution of accidents CM; this shows a strong relation between the distribution of these accidents and the nature of professional drivers' activity (precisely: drivers performing road freight transport) during a week;

- analyzed functions of the distribution of accidents have one common point (intersection point in the Figures 2-4) in the examined time intervals (day, week, year);
- on the left side of the intersection point there is a time interval in which a large concentration of accidents involving trucks can be observed (CM) - it is visible in the majority of percentage participation in relation to the distribution of all accidents in Poland (POL);
- on the right side of the intersection point there is a time interval in which a concentration of accidents involving means of freight transport is distinctly smaller than the one observed in the percentage distribution of all accidents (POL).

Table 5 Average participation rate and the observed range of changes that participate in the accepted time intervals

Mazovia CM	Average participation, %	Min value of the distribution	Deviation of the min value from the average	Max value of the distribution	Deviation of the max value from the average
Hours during a day	4.17	0.76 (2h)	-3.31 (79%)	7.45 (13h)	+3.28 (79%)
Days of the week	14.29	5.62 (Sunday)	-8.67 (61%)	21.12 (Friday)	+6.83 (48%)
Months in the year	8.33	5.78 (January)	-2.55 (31%)	10.79 (July)	+2.46 (30%)
Poland (POL)					
Hours during a day	4.17	0.88 (3h)	-3.29 (79%)	7.83 (17h)	+3.66 (88%)
Days of the week	14.29	12.44 (Sunday)	-1.85 (13%)	16.69 (Friday)	+2.40 (17%)
Months in the year	8.33	5.37 (January)	-2.96 (36%)	10.15 (June)	+1.82 (22%)

The average percentage participation was calculated

$$p_{SR} = \frac{1}{n} \sum_{j=1}^n p_j \quad (4)$$

p_{SR} - average participation calculated for an hour, day and month;

n - number of components taken into consideration, i.e. hours, days of the week and months in the year;

p_j - "j" value of the calculated percentage participation, e.g. according to the correlation (1).

4. Analysis of the accident risk in the relation: trucks-passenger cars

The calculation of the value of the indexes of accident risk was performed according to (3) for two categories of cars: trucks (CM) and passenger cars (OM) in road traffic in Mazovia. The presented values of the risk index which result from passenger car traffic are the reference when analyzing the threat arising from road freight transport. Trucks and passenger cars participate jointly in more than 85% of a total number of accidents. A reciprocal position of the diagram's lines (Fig. 5) shows not only the participation of vehicles of these kinds in creating a fundamental part of the accident risk, but especially a variable and definitely different nature of the participation of these dominant categories of vehicles in the whole accident risk in a time function.

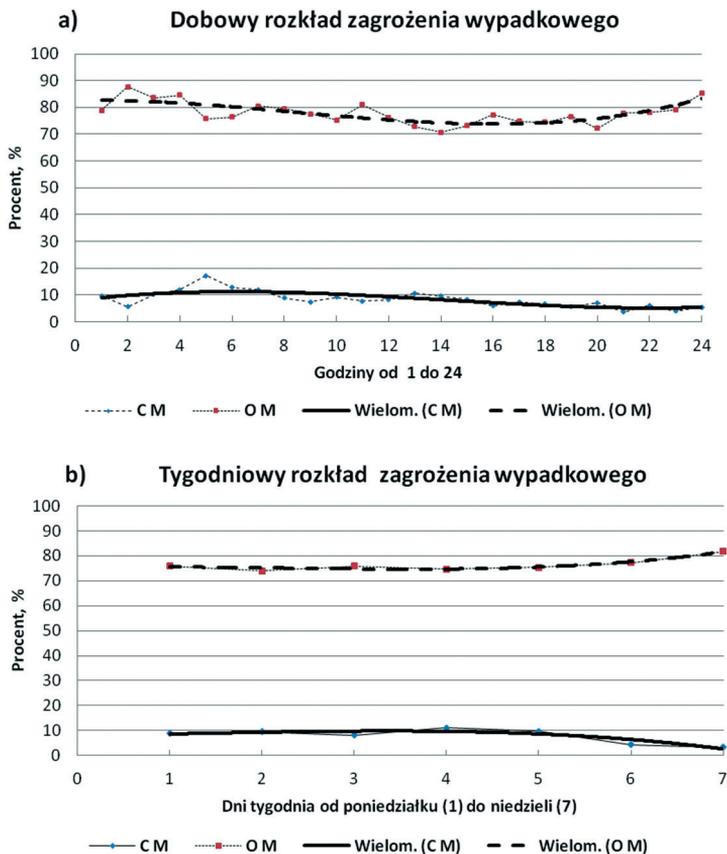


Fig. 5. Distribution of accident risk in Mazovia as a function of time, a-daily, b-week, c-annual

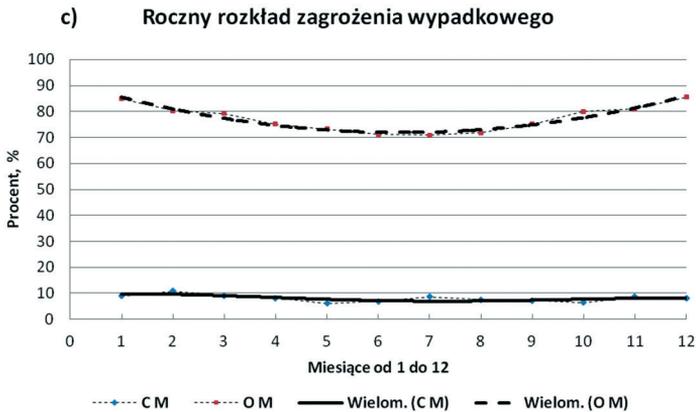


Fig. 5. Distribution of accident risk in Mazovia as a function of time, a-daily, b-week, c-annual, cont.

Table 6. Characteristics of accident risk, which arises from the participation of trucks (CM) and personal (OM) on the road in Mazovia

Category	Trucks	Trucks	Passenger cars	Passenger cars
Value of the participation in the whole risk	Min	Max	Min	Max
Hours during a day	5% (20-24)	11% (5-7)	75% (14-17)	83% (23-03)
Days of the week	4% (Sunday)	10% (Wednesday, Thursday)	75% (Tuesday- Thursday)	82 (Sunday)
Months in the year	7% (June-August)	10% (January, February)	72% (May-July)	85% (December, January)

The Figure 5 and the values in the Table 6 show great variability and a considerable range of values of the accident risk index which result from the participation of the means of freight transport in road accidents. The values of this participation change from the lowest (4-5%) which appears on Sundays, and in the hours 8 p.m.-12 p.m. in the whole week. While the highest level of the participation (10-11%) of trucks in creating accident risk can be observed in the middle of the week in the hours 5-7 a.m.

This range of variability may be referred to the time of professional drivers' activity and terms of making deliveries. A characteristic feature of the analyzed distributions is great variability of the accident risk in road freight transport during a day and a week. The participation of the means of freight transport in creating the accident risk increases during a day from 5% in the hours 8 p.m.-12 p.m. up to 11% in the morning hours 5-7 a.m. becoming, thus, over twice higher than during a night.

The time intervals, in which there is the lowest and the highest participation of the accident risk connected with the passenger car traffic in the whole range of road accidents, are different. The lowest values of the accident risk index in passenger car traffic (72-75%) appear in the months May-July and in the hours 2 p.m.-5 p.m., whereas the highest ones (83-85%) are in the months December-January and in the hours 11 p.m.-3 a.m. The accident risk resulting from passenger car traffic is characterized by little variability of its values on a daily, weekly and annual basis.

The numbers provided above characterize the percentage participation of the two categories of vehicles in creating the whole accident risk. These are important components of the whole accident risk and, additionally, characteristic features of their distribution are (in a few aspects) distinctly different than the often described distribution of the whole of accidents in Poland for hours, days and months [12].

5. Analysis of the values of the mortality risk index regarding road accidents involving the means of freight transport

The calculation results of the values of the mortality risk index regarding road accidents involving the means of freight transport are shown in the Figure 6. The values of the index, which were calculated on the basis of the correlation (2), are the measure of the risk that there will be fatalities in road accidents involving the means of freight transport, i.e. trucks.

The values of the mortality risk index regarding the CM accidents are characterized by high variability. In order to determine the fundamental features of this variability, there was performed the approximation of the calculation results, using a polynomial model. The course of the approximating functions in the Figure 6 is marked with a bold line.

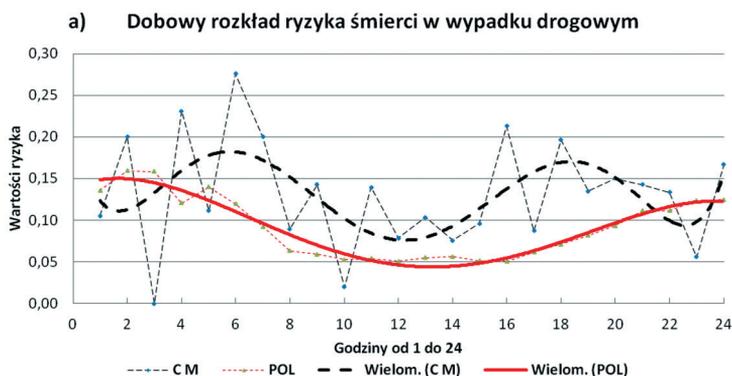


Fig. 6. Distribution of the risk of death in a road accident, a-daily, b-weekly, c-annual

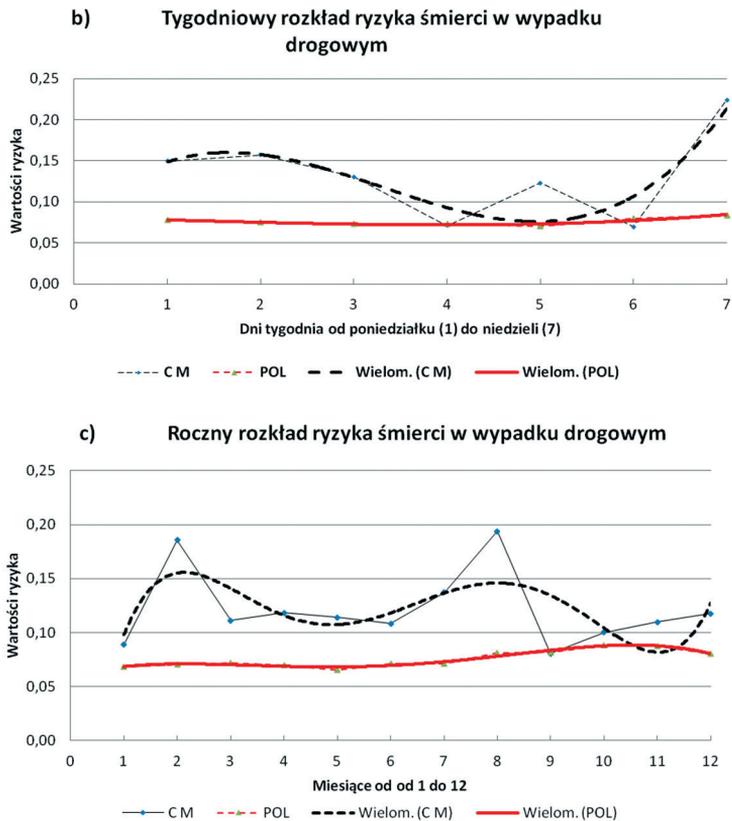


Fig. 6. Distribution of the risk of death in a road accident, a-daily, b-weekly, c-annual, cont.

The calculations showed several crucial features of the analyzed index (the analysis performed on the basis of the course of the approximating function in the Figure 6 and data in the Table 7):

- distribution of the values of the index in a time function calculated for accidents involving trucks (C M) is definitely different than the one calculated for all road accidents (POL);
- average values of the mortality risk index in accidents involving trucks are higher than in accidents involving passenger cars by almost 45% and higher than in all types of road accidents (examined jointly) by 41%;
- in a daily and annual distribution of the values of the mortality risk index in accidents involving the means of freight transport, there are visible two areas of concentration of high values of the mortality risk index, namely in the months of February-March and July-September and in the hours 5-7 a.m. and 5-7 p.m.
- a daily distribution of the mortality risk in all road accidents (POL) has a large fluctuation

of values with a visible maximum point in the hours 12 p.m.-2 a.m. and minimum point in the middle of the day (12 p.m.-2 p.m.);

- In a weekly and annual distribution of the index in all road accidents (POL), the dispersion of values is small and does not exceed 6-10% of the average level;
- high variability of the values of the risk (Table 7) during a day is connected with a typical rhythmic of a daily activity of people and professional drivers' working hours.

Table 7 The average values of mortality risk index and its dispersion characteristics

Specification	Trucks, Mazovia (CM)	Passenger cars, Mazovia (OM)	All accidents, Poland (POL)
Average value	0.13	0.072	0.076
Standard deviation from the average value in a daily distribution; percentage deviation	0.066 51%	0.037 43%	0.037 41%
Standard deviation from the average value in a weekly distribution; percentage deviation	0.053 40%	0.012 17%	0.005 6%
Standard deviation from the average value in an annual distribution; percentage deviation	0.035 28%	0.017 24%	0.008 10%

6. Final summary and conclusions

The accident risk connected with road freight transport was examined as a time function - the measurements of this time are consistent with typical measurements of truck drivers' professional activity. The article includes also a percentage distribution of the accident risk and mortality risk on a daily, weekly and annual basis. The calculations show large variability of the values of accident risk indexes. A cyclical character of changes in the indexes in road freight transport is clearly visible. The distribution of accidents (Fig. 2-4) and accident risk (Fig. 5) in a time function have clearly visible areas with the highest and the lowest concentration of accidents, and their positions on a time scale for accidents of the means of freight transport (CM) are considerably different than the values calculated for all road accidents in Poland (POL).

In a daily distribution, for example, the values of the accident risk index increase from 5% in the hours 8-12 p.m. up to 11% in the morning hours 5-7. Thus, there is over a twofold increase. The compared values of the accident risk index, resulting from passenger car traffic OM, are characterized by a small change in values during a day, week, year.

In the distribution of accidents for the days of the week (Fig. 3), we have small deviations of the values of the general distribution of accidents in Poland from the average value and over threefold higher variability of the distribution of accidents in the analyzed truck traffic in Mazovia (CM). This confirms a strong relation of the distribution of these accidents with the nature of professional drivers' activity during a week.

Results from the analysis of the values of the mortality risk index regarding road accidents indicate primarily the following:

- in a daily and annual distribution of the values of the mortality risk index (Fig. 6) in accidents involving the means of freight transport, there are visible two areas of concentration of high values of the mortality risk index, namely in the months of February-March and July-September and in the hours 5-7 a.m. and 5-7 p.m.
- high variability of the values of the mortality risk in accidents involving trucks (Table 7) during a day is connected with a typical rhythmic of a daily activity of people and professional drivers' working hours.

In each analyzed period, the distribution of accidents, accident risk and mortality risk involving trucks differs distinctly from a general distribution of all accidents in Poland, i.e. a distribution calculated for all categories of vehicles. This confirms the necessity to make a separate calculation of the accident risk and mortality risk for the traffic of the means of freight transport, in particular during an analysis of the external costs of freight transport. The values which are required for this purpose cannot be based on the conclusions resulting from the general distribution of accidents in Poland.

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