ANALYSIS OF THE IMPACT OF ROAD CATEGORY AND DAY OF THE WEEK ON ACCIDENT HAZARD IN THE ROAD TRANSPORT OF GOODS IN POLAND

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Abstract

The current accident hazard caused by road transport of goods has been analysed, with the location (road categories) and time circumstances (specific days of the week) having been additionally taken into account. Calculations were done that made it possible to quantify this hazard, which is chiefly caused by the traffic of goods vehicles. The importance of this problem is increasing in the situation of persisting strong and steady upward trend in the traffic of goods vehicles. In a recent period of 10 years, the rate of growth of the traffic of goods vehicles was almost twice as high as that of the traffic of passenger cars.

The hazard and fatality risk indicator values were estimated by analysing an isolated set of accident data. The period covered by the analysis of the events that occurred in the road transport of goods extended for the years from 2002 to 2011 and the numerical values have been specified in relation to repeatable week-long periods and to four road categories.

The calculated hazard indicator values have been compared with the share of goods vehicles in the whole motor vehicle market, road traffic, and goods transport.

Keywords: *transport safety, road traffic, goods transport, goods vehicles*

1. Introduction

Road transport is the most rapidly developing and very convenient method of the supply of goods. Therefore, it is wise to analyse the possibilities of minimizing the related hazards and to indicate the areas of concentration of such hazards. For the necessary indicators and characteristics to be calculated, many numerical data must be collected. The research methodology prepared for this purpose consists of several stages:

1. acquisition of data from primary sources,
2. estimation of hazard indicators and supporting characteristics,
3. analysis of the estimation results to identify the areas of hazard in the road transport of goods.

Based on the primary data obtained from descriptions of every road accident [10], a procedure was carried out to isolate exclusively the accidents where goods vehicles were involved, with an assumption made that the traffic of such vehicles constitutes the fulfilment of the goods transportation task. Thus, a set of data was created, which is the basic object of calculations and analyses in this study. In the selection process carried out, only the road accidents were selected where vehicles of the following types were involved:

– goods vehicles of maximum mass not exceeding 3.5 tonnes, referred to as light goods vehicles (LGV) or delivery motor vehicles,
– goods vehicles of maximum mass exceeding 3.5 tonnes, referred to as heavy goods vehicles (HGV),
– tractor-trailer and tractor-semitrailer units.

Then, the group of road events thus selected was subjected to identification of the time and

place of occurrence of each of the events (days of the week and road categories). In the final part of the study, the characteristics and indicators calculated for the accident groups thus selected were compared with the available data annually published by the Polish Police Headquarters [12] and concerning all the road accidents that occurred in Poland.

The period to be covered by the analysis was decided to be the decade from 2002 to 2011. At some places of this study, the calculations were compared with the data published by the Central Statistical Office; in such cases, the period under the analysis was adjusted, out of necessity, to the availability of these data. Multiannual research works have shown that it is reasonable to consider the degree of road transport hazard in respect to the three most important groups of factors accountable for the occurrence of accidents: man (direct or indirect perpetrator), road, and time circumstances.

To analyse the time circumstances, a week-long time interval in the work of goods vehicle drivers ("professional drivers" in most cases) was chosen as a basis.
The length of this period may be related to a number of factors:
– the week is one of the measures of drivers' activity and work time,
– the week is an important calendar period,
– in long-range transport, the week often defines the length of the cycle of delivery,
– the cyclic and uniform repetition of the daily rhythm of work is connected with the sequence of days of the week [6, 13].

Pursuant to the classification of roads in the functional road network in Poland, separate consideration was given to the accidents that took place on the roads of four categories, i.e. on national (DK), regional (DW), district (DP), and communal (DG) roads.

2. Indicators and characteristics

The following indicators are taken into account as making it possible to quantify the hazards arising from the road transport of goods [9, 11]:

1. Road accident severity rate, i.e. the number of deaths per 100 accidents with goods vehicles:
$$W_C = \frac{Z}{0.01W}. \tag{1}$$
2. Road accident fatality risk rate, determined for the accidents with vehicles of a specific category:
$$W_S = \frac{Z}{R+Z}. \tag{2}$$
3. Percentage share of vehicles of the i^{th} category in the market (i.e. in the transport work and in the road traffic):
$$p_i = \frac{L_i}{\sum_{i=1}^{k} L_i} \times 100\%. \tag{3}$$
4. Percentage share of the accidents that occurred on roads of the i^{th} category (or in which vehicles of the i^{th} category were involved) in the total number of all the accidents that occurred on the whole road network in Poland (or in which vehicles of all the categories covered by the analysis were involved):
$$p_{Wi} = \frac{W_i}{\sum_{i=1}^{k} W_i} \times 100\%. \tag{4}$$
5. Percentage share of deaths in the accidents that occurred on roads of the i^{th} category (or in which vehicles of the i^{th} category were involved) in the total number of deaths in all the accidents that occurred on the whole road network in Poland (or in which vehicles of all the categories covered by the analysis were involved):

$$p_{Zi} = \frac{Z_i}{\sum_{i=1}^{k} Z_i} \times 100\% \,. \tag{5}$$

These indicators make it possible to define the risk of an accident with casualties (killed) on a road of the ith category in relation to the risk specified for the whole road network in Poland.

The symbols used in the formulas above have the following meanings:

i – the ith category of vehicles or roads,

W_i – number of accidents in which vehicles of the ith category were involved or which occurred on roads of the ith category,

R_i, Z_i – numbers of casualties (injured or killed, respectively) in the road accidents in which vehicles of the ith category were involved or which occurred on roads of the ith category,

R, Z – numbers of casualties (injured or killed, respectively) in all the accidents that occurred in Poland,

L_i – number of vehicles of the ith category or number of kilometres travelled, or amount of the transport work done, by such vehicles.

The changes in the indicator values that took place during the period under analysis were represented at several points by estimation of the regression curve. A polynomial model of the regression curve was adopted for the analysis.

3. Goods vehicles and their share in the road traffic

The role fulfilled by goods vehicles in the national economy has been basically characterized by the numerical data shown in Tab. 1, which include figures representing the share of goods vehicles in the national market, in the road traffic, and in the fulfilment of transport tasks (transport of goods, according to the Central Statistical Office). As an example, the share of goods vehicles in the national transport grew in the period from 2000 till 2010 from 26% to 70%, while the share of such vehicles in the motor vehicle market remained practically unchanged and the share of such vehicles in the road traffic in numerical terms only slightly increased. This shows that the growth in the transport work was achieved to a significant extent by raising the load capacity of the motor vehicles used and by increasing the share of heavy goods vehicles and tractor-semitrailer units in the market. Such trends are widely spread [1, 4, 5].

In the situation of rapidly growing share of goods motor vehicles in the total goods transport, a favourable but slightly declining trend can be seen in the accident hazard; this trend is illustrated by the negative slope of the regression curve. In 2002-2011, the annual average decline of the participation of goods vehicles in accidents and in the number of deaths was -0.33% and -0.40%, respectively.

Tab. 1. The share of goods vehicles in the market and in the road traffic

Description	2000	2005	2010
Number of motor vehicles [thousand units] *)	14 106.3	16 815.9	23 037.1
Number of goods motor vehicles (including LGV and HGV with and without trailers [thousand units] *)	1 879.1	2 304.5	2 981.6
Share of goods vehicles in the market, p_i [%]	13.3	13.7	12.9
Share of goods vehicles (with and without trailers) in the traffic on national roads (DK) [%] [7]	16.1	18.1	19.1
Share of LGV in the road traffic [%] [7]	11.4	10.0	9.5
Share of gods vehicles in the goods transport (transport work): – [million tonne-km] – [%] *)	 75 023 26%	 11 9481 41%	 22 3170 70%
Increase in the traffic intensity on national roads (DK) in relation to the 2000 figures [7]	1.0	1.18	1.44

*) *According to the Chief Statistical Office, Transport*

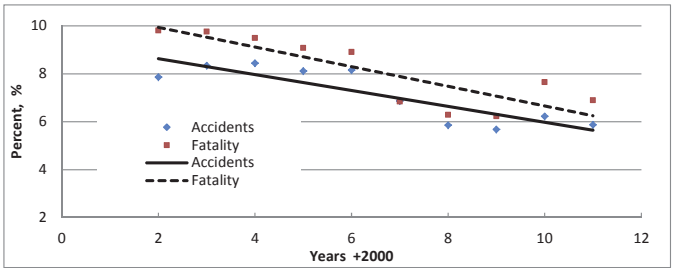

Fig. 1. Percentage share of the road accidents and the resulting deaths caused by goods vehicle traffic in the total numbers of accidents and the resulting deaths in Poland

The biggest share of goods vehicles in road traffic is observed on national roads (DK). According to measurements and calculations carried out for the years 2007-2011, this share exceeded 24% [2, 8] (28% according to the measurements reported in [7]). The upward trends in the traffic of goods vehicles are strong and steady [3, 4]. The highest growth rate is expected to take place in the category of tractor-trailer and tractor-semitrailer units. For 2010-2020, the traffic growth rate for such combination vehicles is expected to be almost twice as high as that for passenger cars and over four times as high as that for delivery vehicles and trucks without trailers or semitrailers. These forecasts provide strong grounds for the need to analyse the specific nature of the hazards related to the transport of goods.

4. Characterization of the accident hazard in the transport of goods

4.1. Analysis of the hazard in terms of days of the week

The week is a characteristic measure of the work time and it has its reflection in the values of accident hazards. The cyclic nature of the accident hazard in the transport of goods had not changed in the decade covered by the analysis. The cycles can be seen in the weekly distribution of the number of accidents with goods vehicles and in the number of casualties of such accidents. Calculation results in the form of the distribution of the annual numbers of accidents with goods vehicles and the resulting casualties to specific days of the week in the years 2002-2011 have been presented in Fig. 2. Although the total number of accidents declined in successive years, the character of the distribution remained in principle unchanged, which can be seen in Fig. 2b, where the distribution of the annual numbers of accidents and casualties to specific days of the week has been presented in percentage terms (to compare with the absolute distribution shown in Fig. 2a).

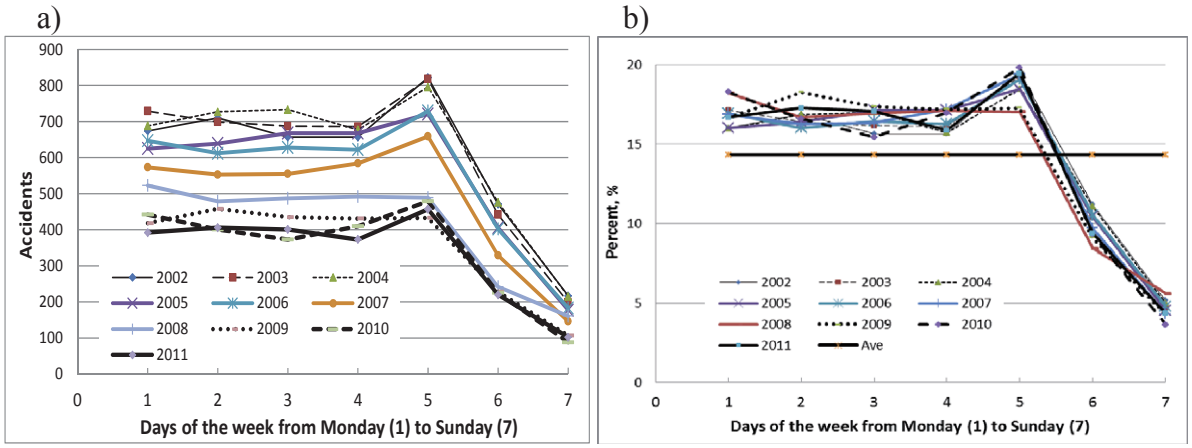

Fig. 2. Distribution of the annual numbers of accidents with goods vehicles to specific days of the week in the years 2002-2011: a) – absolute distribution of the accidents; b) – percentage distribution of the accidents

The characteristic structure of the distribution of the accidents under consideration to specific days of the week had not undergone major changes for the whole decade, but some specific symptoms can be seen:

– in the periods from Monday till Thursday, the numbers of accidents remained on quite a stable level,
– the highest numbers of accidents and deaths were recorded on Fridays, i.e. on the last working day of every week,
– the numbers of casualties recorded on Mondays did not decrease in the last years of the period under consideration,
– on Saturdays and Sundays, the numbers of accidents were definitely lower than those recorded on the working days of the week, which shows the dependence of these data on the standard time schedule of drivers' work,
– the ratio of the number of deaths to the number of casualties in the accidents that occurred on Fridays visibly dropped, from 20% observed in 2002-2004 to 18% in 2009-2011.

The above percentage values should be compared with the weekly average value, which was 14.3% (cf. the "Ave" heavy line in Figs. 2b and 3). Hence, the reduction observed should be considered significant because it exceeded 15% of the weekly average number of deaths.

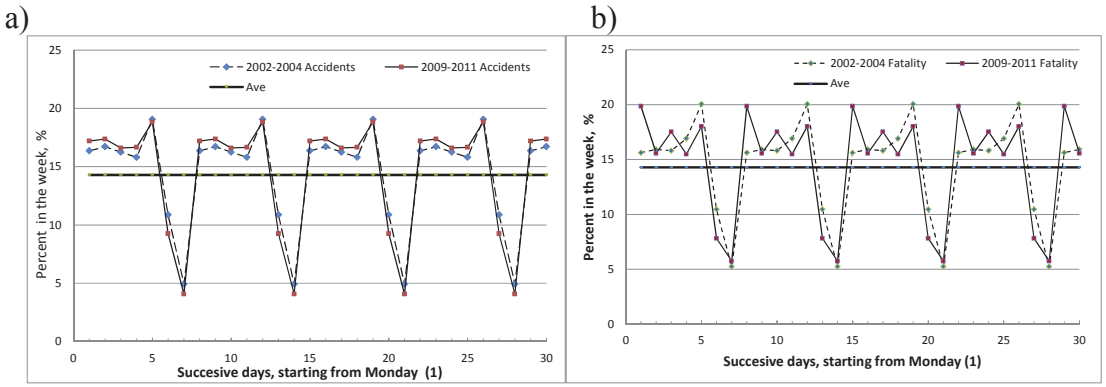

Fig. 3. Illustration of the cyclic nature of the accident hazard in the transport of goods, referred to a sequence of successive days: a) – distribution of the number of accidents; b) – distribution of the number of deaths resulting from the accidents

Figure 3 illustrates the repeatability of changes in the numbers of accidents and the resulting deaths. The figure includes three curves that represent the averaged percentage distribution of the numbers of accidents (a) and the resulting deaths (b) to specific days of the week for the years 2002-2004 and 2009-2011 and the corresponding weekly average values.

The accident hazard, referred to repeatable week-long periods, was also expressed in terms of the fatality risk rate *Ws* for accidents with goods vehicles. The time history of changes in this indicator has been shown in Fig. 4. According to the graph presented, the fatality risk rate values were observed in the years 2002-2004 to remain quite stable on a level of about 9% but now they show an increase on Mondays and Sundays of every week cycle with simultaneous decline in this risk on the days from Thursday till Saturday.

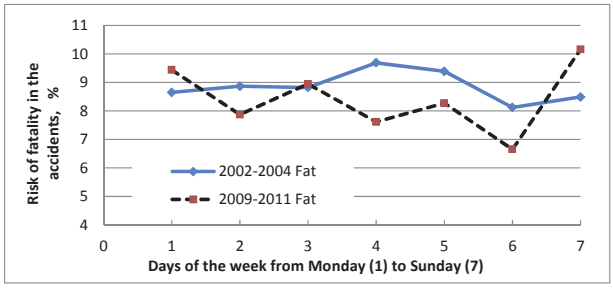

Fig. 4. Values of the risk of fatality in the accidents with goods vehicles Ws

4.2. Road category vs. accident hazard in the traffic of goods vehicles

Public roads in Poland are divided according to their functions in the national road network into four categories as specified in Tab. 2. The categorizing is based on the functions fulfilled by the roads in the transport system. The role played by roads of specific categories has an impact on the structure of vehicle flow, by the types of transport means. Although all vehicle types occur on roads, the frequency with which they appear varies; hence, this is connected with different levels of the accident hazard caused by goods vehicles. Basic information concerning this issue has been presented in Fig. 5 and in Tab. 2.

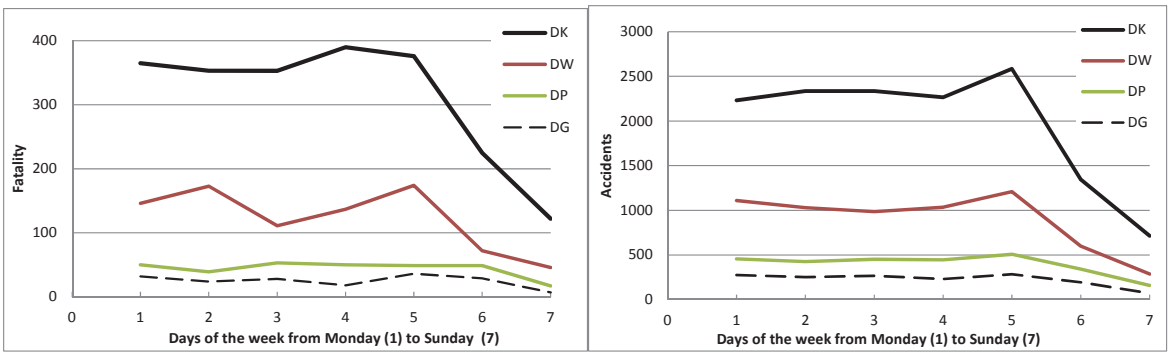

Fig. 5. Averaged distribution of the annual number of accidents with goods vehicles and the resulting deaths to specific days of the week, by road categories: DK – national road; DW – regional road; DP – district road; DG – communal road

Figure 5 represents numerical values averaged for the years from 2002 to 2011; these data illustrate the distribution of the accident hazard posed by the traffic of goods vehicles. The cyclic nature of changes in the distribution of accidents, with Fridays being the mode, can be seen in the graphs.

Tab. 2. Road categories and characteristic values of the accident hazard, averaged for the years 2002-2010

Accidents with goods vehicles					All the road accidents in Poland			
Description	DK	DW	DP	DG	DK	DW	DP	DG
Total length [km]	18 579	28 466	126 599	211 186	18 579	28 466	126 599	211 186
Percentage share in the national network [%]	4.8	7.4	32.9	54.9	4.8	7.4	32.9	54.9
Percentage share of accidents on roads of a specific category in all the road accidents, p_{Wi} [%]	56.5	25.6	11.4	6.4	40.7	25.9	22.8	10.5
Percentage share of deaths in accidents on roads of a specific category in all the deaths in road accidents, p_{Zi} [%]	62.0	24.4	8.7	4.9	49.0	25.5	18.9	6.6
Accident severity rate, W_{Ci} [%]	14.5-17.2	11.2-16.8	9.0-11.7	7.8-15.0	15.1-17.8	13.7-15.5	10.1-13.8	8.3-10.8

The figures given in Tab. 2 show excessive percentage of accidents with goods vehicles on national roads. The transport of goods makes about 28% of the traffic on national roads but 56% of all the road accidents connected with this transport and 62% of deaths in such accidents takes place on the national roads.

The accident severity (or fatality) rate W_{Ci} constitutes an important relative measure of the accident hazard. Having the nature of a relative measure, this indicator is useful for quantifying the safety in goods transport and the accident hazard on roads of various categories.

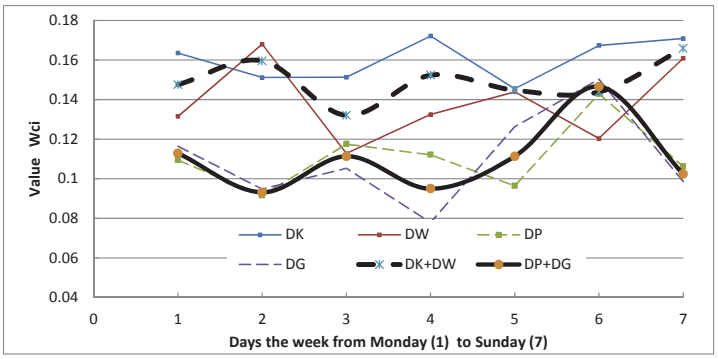

Fig. 6. Accident severity rate W_{Ci} on specific days of the week on roads of the i^{th} category

An analysis of the time history of changes in the severity rate of accidents in the interurban traffic (DK+DW) shows this indicator to have stable values on a level of 0.14-0.16 for the whole week. A different situation takes place on local roads (DP+DG), where the severity rate of accidents with goods vehicles remains on a low level from 0.09 to 0.11 in the periods from Monday till Thursday and rapidly grows (by 25%) on Saturdays. This highlights a peculiar hazard encountered in the local transport of goods.

4.3. Changes in values of the indicators describing the accidents with goods vehicles in 2002-2011

Calculations were carried out to show changes in the accident hazard caused by the road transport of goods during the decade under consideration. The calculation results indicate a drop in the accident hazard in the road transport of goods (compare Fig. 7 and 1). The actual drop in the numbers of accidents and the resulting deaths is significant but the downward trend is not homogenous: fluctuations in this trend can be clearly seen.

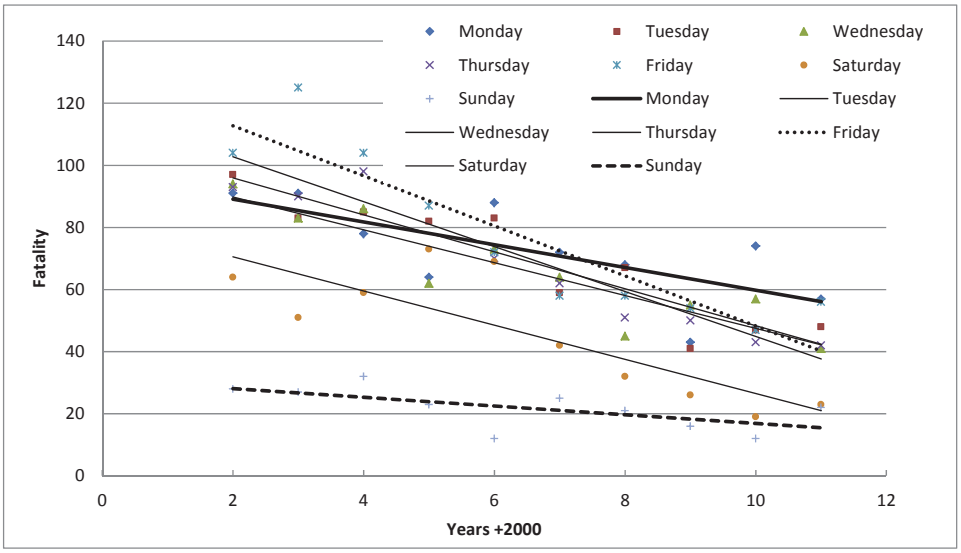

Fig. 7. Changes in the numbers of deaths in the accidents that occurred in the road transport of goods in the years 2002-2011, with the corresponding regression curves

The favourable downward trend in the accident hazard in goods transport is generally confirmed by the following:

– reduction in the number of accidents by 30-40% (the values of this drop depend on the days of the week that are taken into consideration),
– reduction in the accident severity rate from 0.13-0.14 at the beginning of the decade under consideration to 0.11-0.12 at the end of this period.

The use of the regression curves as shown in Fig. 7 makes it possible to reveal the multiannual nature of changes in the processes observed. The calculation results show the trends in changes in the fatality of accidents with goods vehicles. These changes were compared with changes in the total number of accident casualties in Poland. In consideration of significant span of the analysed numbers of the killed in accidents, relative percentage values were used for calculations, with the number of the killed in 2002 being taken as 100%. The year 2002 had already been taken as a reference at previous studies, e.g. in [9]. By modelling the curve of regression of the percentage changes in the form of an equation:

$$y = Nx + b, \tag{6}$$

the slope of this curve was defined as:

$$N = \frac{y}{x}, \tag{7}$$

which represents the annual average percentage change in the number of deaths.

The number of deaths in the road transport of goods declines at a rate (column 2 in Tab. 3) twice as high as that calculated for all the road accidents in Poland (column 4). The average slope of the curve representing the fatality of all the road accidents in Poland is -3.35%. The lowest rate of decline in the number of deaths is observed on Sundays and Mondays, which has resulted in a situation that in the latest years of the period under analysis, Mondays became the days when the largest numbers of deaths were observed in the road transport of goods (cf. Fig. 7, heavy continuous line). The highest rate of decline in the number of deaths was recorded on Thursdays and Fridays, i.e. on the days when the largest numbers of accidents occurred at the beginning of the period under analysis (in the years 2002-2004).

Tab. 3. Characteristics of the regression curves in Fig. 7, which describe the decline in the number of deaths determined for specific days of the week

Description	Slope N of the curve of fatality of accidents in goods transport [%]	Coefficient of determination, R^2	Slope N of the curve of fatality of all the road accidents in Poland [%]	Coefficient of determination, R^2
1	2	3	4	5
Monday	-4.02 (min)	0.51	-1.28 (min)	0.25
Tuesday	-6.13	0.86	-3.43	0.91
Wednesday	-5.64	0.82	-2.55	0.69
Thursday	-7.77	0.84	-3.48 (max)	0.97
Friday	-7.74	0.83	-3.27	0.81
Saturday	-8.60 (max)	0.68	-3.48 (max)	0.97
Sunday	-5.02	0.40	-3.27	0.81

5. Recapitulation

The calculations done have shown a decrease in the share of accidents related to the road transport of goods in all the road accidents in Poland. The accident hazard, measured by the share of accidents and deaths related to the goods vehicle traffic in the total number of accidents and the resulting deaths, dropped from 8.5 to 6% and from 10 to 7%, respectively, for the decade under analysis. The severity rate of the accidents with goods vehicles declined during that period from 0.13-0.14 at the beginning to 0.11-0.12 at the end.

Important findings have emerged from the general characteristic of the share of goods vehicles in the automotive market, road traffic, and goods transport. As an example, the share of goods vehicles in the national transport grew in the period from 2000 till 2010 from 26% to 70%, while the share of such vehicles in the motor vehicle market remained practically unchanged and the share of such vehicles in the road traffic in numerical terms only slightly increased. This shows that the growth in the transport work was achieved to a significant extent by raising the load

capacity of the motor vehicles used and by increasing the share of heavy goods vehicles and tractor-semitrailer units in the market.

Although the total number of accidents declined in successive years, the cyclic nature of the distribution of goods transport accidents to specific days of the week remained in principle unchanged. The ratio of the number of deaths to the number of casualties in the accidents that occurred on Fridays visibly dropped, from 20.0% observed in 2002-2004 to 18.0% in 2009-2011, as against the weekly average of 14.3%. On the other hand, a new phenomenon in this distribution could be seen in the last years of the period under analysis: the number of deaths that occurred on Mondays, i.e. at the beginning of each of the weekly cycles, began to increase.

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