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Marina Zanne

Aleš Groznik

Elen Twrdy

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THE COSTS OF TRAFFIC ACCIDENTS DUE TO THE HETEROGENIZATION OF TRAFFIC FLOWS ON SLOVENIAN MOTORWAYS

MARINA ZANNE[1]
ALEŠ GROZNIK [2]
ELEN TWRDY[3]

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ABSTRACT: *The evolution of modal split of freight transport is causing the heterogenization of traffic flows on motorways, so the aim of the paper is to explore the effects of changing structure of traffic flows on Slovenian motorways on road safety and to assess this effect in a financial way. We have calculated crash costs of accidents that were caused by trucks as well as the crash costs of the accidents involving trucks. In addition, we created two safety performance functions for prediction of the number of traffic accidents on Slovenian motorways.The number and the share of accidents involving trucks on Slovenian motorways is increasing as well as the amount of traffic work done by the trucks is, so it is possible to expect increasing crash costs of such accidents on Slovenian motorways.*

Keywords: *motorways, traffic flows structure, trucks, traffic safety, external costs of traffic accidents, safety performance function*

JEL Classification: R41, R42, O18

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INTRODUCTION

One of the most important elements that describe the functioning of transport system is traffic safety. Traffic safety is commonly expressed in terms of number of accidents and severity of their consequences. An estimation of the World Health Organization is that approximately 1.24 million people die every year on the world's roads, and another 20 to 50 million sustain nonfatal injuries as a result of road traffic crashes (WHO, 2013a). Apart from the human suffering, traffic accidents also cause significant costs.

Road traffic injuries cause considerable economic losses to victims, their families, and to nations as a whole. These losses arise from the cost of treatment (including rehabilitation and incident investigation) as well as reduced or lost productivity (e.g. in wages or unpaid

1 University of Ljubljana, Faculty of Maritime Studies and Transport, Portorož, Slovenia, e-mail: marina.zanne@fpp.uni-lj.si

2 University of Ljubljana, Faculty of Economics, Ljubljana, Slovenia, e-mail: ales.groznik@ef.uni-lj.si

3 University of Ljubljana, Faculty of Maritime Studies and Transport, Portorož, Slovenia, e-mail: elen.twrdy@fpp.uni-lj.si

taxes) for those killed or disabled by their injuries, and for family members who need to take time off work to care for the injured (WHO, 2013b). Crash costs, thus include internal costs, which are damages and risks to the individual traveling by a particular vehicle or mode, and external costs, which are un-compensated damages and risks imposed by an individual on other people (VTPI, 2013). In economic terms, the external costs of road crash injuries are estimated at roughly 1% of gross national product (GNP) in low-income countries, 1.5% in middle-income countries and 2% in high income countries (Armigol *et al*., 2008). Traffic safety is thus clearly one of the major concerns of modern transport.

A road traffic accident results from a combination of factors comprising roads, vehicles, weather conditions and road users. Some of the factors contribute to the occurrence of a collision and are therefore part of crash causation, while other factors aggravate the effects of the collision and thus contribute to trauma severity (WHO, 2006). And while five major causes of traffic accidents namely speed, drink-driving, distracted driving, use of motorcycle helmets and use of seat belts and child restraints have been thoroughly analysed worldwide, the impact of the structure of traffic flows on traffic safety has been marginally researched, especially in developed countries.

Given the fact that important European freight transport routes pass through the Slovenian territory and that Slovenian legislation demands the use of higher category roads for trucks[4] if such roads exist parallel to lower category roads, we decided to examine the traffic safety in regards of traffic flow structure on the Slovenian motorways, with the focus on the involvement of trucks in the accidents. The objectives of the paper are:

- Examination of trends in the structure of traffic flows on Slovenian motorways,
- Examination of the involvement of trucks in traffic accidents on Slovenian motorways,
- Financial assessment of traffic accidents involving trucks on Slovenian motorways, and
- Creation of safety performance functions for Slovenian motorways based on the past safety records.

The structure of the paper is the following: in the next section we present the theoretical introduction to the traffic flow theory followed by the literature overview on the interaction between traffic flow structures and traffic safety. We then describe the data and methodology and this is followed by the description of the results that we obtained. In the last chapter we summarize the results and point out to some indirect safety issues that can arise from the heterogenization of traffic flows on Slovenian motorways.

4 We use the word “truck” for freight vehicles with the permissible weight of more than 3.5 tons

1. THE INTERACTION BETWEEN TRFFIC FLOW STRUCTURE AND TRAFFIC SAFETY

Traffic flow theory seeks to describe the interactions between the vehicles and their operators as well as the infrastructure in a mathematical way. Traffic flow theory distinguishes between microscopic and macroscopic traffic flow variables, where microscopic traffic flow variables focus on individual drivers, while macroscopic traffic flow variables reflect the average state of the traffic flow (see e.g. May, 1990; Papageorgiou 2003; Dadić & Kos, 2007; Hoogendoorn & Knoop 2013). A relation needs to be established between the microscopic behaviour and the macro performance of the flow (Lasmini *et al.* 2013).

Macroscopic traffic flows is further on divided into homogeneous and inhomogeneous or heterogeneous traffic flows. Homogenous traffic flows are composed of vehicles of same characteristics, while the heterogeneous traffic stream consists of vehicles that have different speeds, sizes, and operating characteristics (see e.g. Katz, 2009; Dadić & Kos 2007). The dividing line between homogeneous and heterogeneous traffic flows is not uniquely defined; it is possible to talk about heterogeneous traffic flow if the share of the dominant mode is less than certain percentage, more precisely around 85% during peak time (Katz, 2009) or that there are three types of vehicles using the same infrastructure, namely fast vehicles, slow vehicles and long vehicles (Kerner, 2004). Another definition says that the heterogeneity of traffic flows is expressed in the share of commercial vehicles in the traffic flow, that is with the share of trucks and buses (Dadić & Kos, 2007).

1.1. Literature overview

It is possible to find many articles dealing with the heterogeneity of traffic flows in urban areas of developing countries where the mix of non-motorized and motorized modes exists (see e.g. Mizanur, Nakamura 2005; Sharma *et al.* 2011; Lasmini *et al*. 2013), while there has not been a lot of published work on heterogeneity of traffic flows on motorways and its influence on road safety.

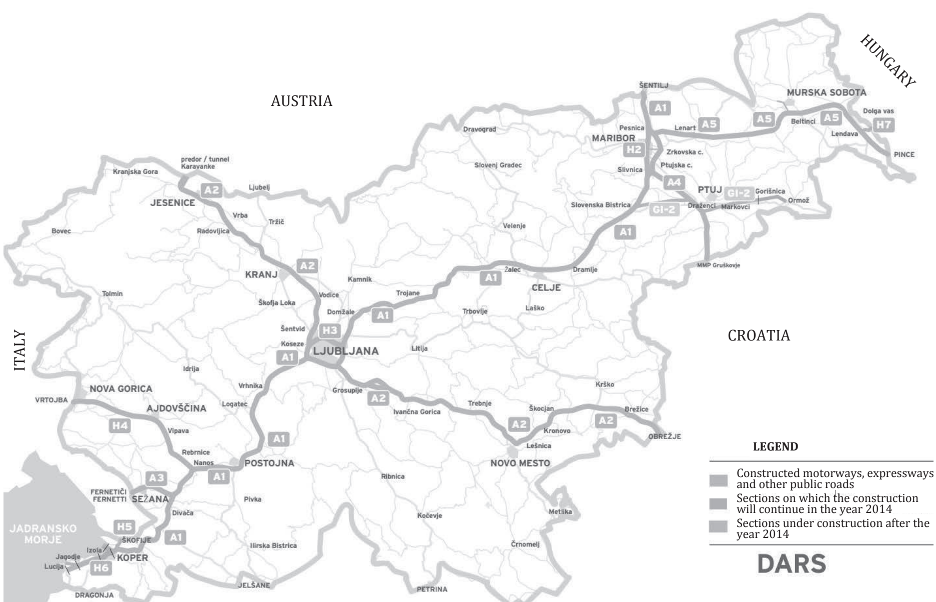
Ferrari has been researching the traffic flows on motorways, and in his recent works he has emphasized the effect of trucks on traffic flows; however, not on traffic safety (see Ferrari, 2009; Ferrari, 2011). Martin (2002) on the other hand, has analysed traffic flows on 2,000 kilometres of French motorways for the period of two years in order to determine the relation between traffic flows and crash occurrence, but with no specific attention to trucks. Marchesini and Weijermars (2010) explored the relationship between congestion and road safety on motorways from the theoretic point of view, while Golob and others (2004) presented strong evidence between flow condition and the likelihood of traffic accidents by type of crash on motorways. Finally, Ramirez and others (2009) investigated the impact of trucks on traffic safety on Spanish interurban roads. They find out that a reduction in total number of accidents would occur as a result in the drop in the number of trucks on all Spanish interurban roads.

Traffic impacts our living environment in many different ways. Besides accidents, it causes congestion, noise, air pollution, climate changes etc. These impacts change with the changes in traffic volume and traffic structure. In past decades several studies dealing with the negative impacts of transport have been created (for example INFRAS/IWW, 2000, 2004; HEATCO, 2005; GRACE, 2008; IMPACT, 2009; CE/INFRAS/ISI, 2011), while the only comprehensive assessment of the external costs of transport in Slovenia was obtained in 2004 with the research Analysis of External Costs of Transport (Lep *et al*., 2004). This study includes also the financial assessment of the impact the involvement of trucks in the traffic accidents.

2. SLOVENIA AND ITS MOTORWAY SYSTEM

The Slovenian motorway system is being constructed since 1970s. Slovenian government gave the priority to the construction of motorways network in the early 1990s when Slovenia became a sovereign state, given the fact that some segments of Slovenian motorway system were already constructed, and considering the broader social and economic importance of motorways in regards to the railways. Today the Slovenian motorways system is pretty much completed while the railways remained in poor condition.

Figure 1: *The motorway system in the Republic of Slovenia*



Source: DARS, 2014

The Slovenian motorway system is divided into five segments as can be seen in Figure 1. These segments are:

- A1 motorway segment is around 245 km long, connecting Sentilj at the Austrian border and Koper on the Adriatic shore. It passes by several important Slovenian cities, including Maribor, Celje, Ljubljana and Koper, and is a part of formal Pan-European Corridor V.
- A2 motorway segment is around 175 km long, connecting the Karavanke Tunnel at the Austrian border via the capital city Ljubljana to Obrezje at the Croatian border, near Zagreb. It connects several major Slovene cities, including Kranj, Ljubljana, and Novo Mesto, and is a part of formal Pan-European Corridor X.
- A3 motorway segment is around 12 km long, connecting Gabrk/Divaca on A1 with Italian border via the city of Sezana.
- A4 motorway segment is around 21 km long connecting Slivnica/Maribor on A1 to Gruskovje at the Croatian border.
- A5 motorway segment is around 80 km long connecting Dragucova near Maribor on A1 and Pince at the Hungarian border via Murska Sobota and Lendava.

3. DATA AND METHODS

3.1. Data collection

Slovenia has a long tradition of traffic accidents data recording; first records on traffic accidents date back to early 1950s. The current data set is composed of two data bases; the first one including the information on the occurrence of accidents and the other one on the participants in these accidents. The two data bases are connected through the accident identification number, and are both provided by the Slovenian Police.

For purposes of this paper we created an integral data base on traffic accidents covering the period from 2001 to 2012. We identified and removed 26 cases with mismatched identification number (same identification number for different cases). The data for the year 2013 served for testing purposes.

The Average annual daily traffic (AADT) and the Vehicle kilometres travelled (VKT) are two very important types of traffic data. These two raw traffic variables, mainly derived from fixed sensors measurements, play a key role in traffic engineering analysis and policy decisions (Leduc, 2008). Fixed automatic counters are installed on several spots on Slovenian motorways and they allow the differentiation among vehicle types. So, in order to link the crash occurrence with the traffic flows we extracted the data on traffic volume and traffic flow structure on Slovenian motorways from the annual publications of Slovenian Roads Agency.

In addition, Slovenian traffic information centre provides data from 587 automatic counters on Slovenian roads in real time over the web portal, but the system does not allow the retrieval of past data. In order to get the picture on how heterogeneity of traffic flows reflects on average speed of vehicles, average time between driving vehicles, and occupancy of the carriageway we recorded the data on traffic flows during March and April 2014.

To express the consequences of accidents on motorways caused by the trucks in monetary terms we used the determined costs of accidents from the study on external costs in Slovenia that was created by Lep and others in 2004. We adjusted these costs by the inflation rates obtained from the Statistical office of the Republic of Slovenia.

3.2. Limitations of the obtained data

It is well known that the reporting of road accidents in official statistics is incomplete and biased (Elvik *et al.* 2009), and even when crashes are well defined in identical terms, there are significant variations in crash data among sources (Shinar, 2007).

Brvar (2010) expressed doubts on the accuracy of Slovenian official road safety statistics, but there is no better publically available data on traffic accidents in Slovenia than data provided by Slovenian police. In addition the Slovene reporting system on traffic accidents does not differentiate on the size of trucks that are involved in the accident.

Another problem regarding traffic accidents database is the fact that the inducer is not indicated in 18.6% cases of traffic accidents on Slovenian motorways.

3.3. Methods

Firstly, we created a time series with monthly data on traffic accidents on Slovenian motorways for the period from 2001 to 2012. Then we used descriptive statistics to get an overall picture as well as to identify trends of traffic flows and traffic safety on Slovenian motorways.

Then we continued with the estimation of crash costs on Slovenian motorways. The value of life can be calculated in different ways (see e.g. VTPI, 2013), that is HC=Human capital; WTP=Willingness to pay; PGS=Pain grief suffering or VSI=Value of serious injury. In the only available study on external costs of transport in Slovenia, Lep et al (2004), the value of life is calculated as WTP. Based on this study, we created an estimation of external costs involving trucks on Slovenian motorways. For this purpose we used the following formula

$$TC = A(b + c) \quad (1)$$

where A is the number of traffic accidents involving the trucks, b is the willingness to pay for the accident risk reduction and c represents the systematic external costs including the costs of hospital treatment and the costs of police investigation at the accident scene.

A common approach to forecast traffic safety is by the creation of safety performance function (SPF). SPF is an equation that is used to predict the average number of crashes per year at a location as a function of exposure and in some cases roadway characteristics. The generalized form of models that are used to forecast the number of road accidents takes the following form(Eenink *et al*. 2008):

$$E(\lambda) = \alpha Q^{\beta} e^{\sum y_i x_i} \quad (2)$$

where estimated expected number of accidents, $E(\lambda)$, is a function of traffic volume, Q, and a set of risk factors, x_i (i = 1, 2, 3, …, n). The effect of traffic volume on accidents is modelled in terms of an elasticity, that is a power, β, to which traffic volume is raised.

It would be good to make the selection of explanatory variables that are included in a SPF based on theory; however, data availability is often a limiting factor, thus formula (2) often takes the following simplified form as suggested by Elvik and others (2009):

$$E(\lambda) = AADT^{\beta} \quad (3)$$

where *AADT* stays for average annual daily traffic, which is a proxy for traffic volume. The presumption of this model is that accidents occur randomly, but at constant rate in regards to traffic activity.

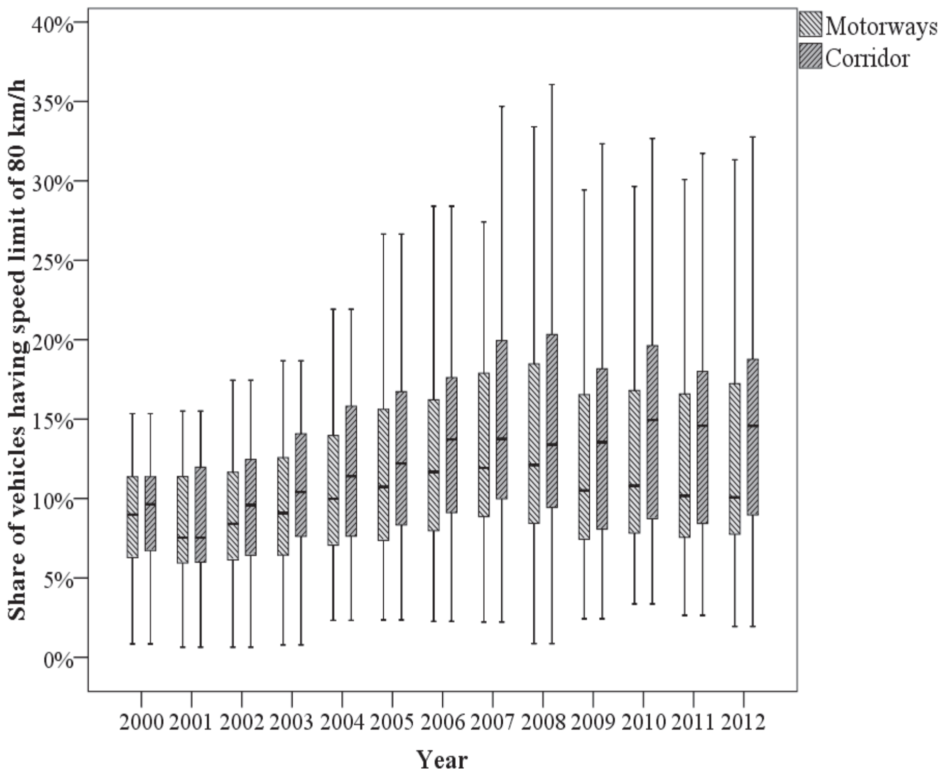
4. RESULTS AND DISCUSSION

4.1. Basic findings

Because of the large expansion of Slovenian motorway network (245 km were built in the period from 2001 to 2012) it was reasonable to convert data on transport volume to data on transport volume per kilometre of road to get first impression on traffic safety trends. Transport volumes have been constantly increasing on Slovenian motorways in the analysed period with average annual growth rate (AAGR) of traffic work per kilometre of road reaching 3.2% and compound annual growth rate (CAGR) 3.1%. However, in the same period, the traffic volume of freight vehicles increased in average by 8.9% per year, to reach 13.1% of all traffic volume done in 2012 in comparison to 7.4% in 2001.

On many sections of Slovenian motorways the share of vehicles having speed limit 80 $^{km}/_{h}$ (that is trucks and passenger commercial vehicles with the maximum permissible weight of more than 3.5 tons) now surpasses 15% as can be seen from Figure 2. This is especially the case on the sections that correspond to the formal corridor V.

Figure 2: *The share of vehicles that have a speed limit of 80 $^{km}/_{h}$ on Slovenian motorways*



Note: Outliers (more than $^3/_2$ times of upper quartile and less than $^3/_2$ of lower quartile) have been removed from the chart
Source: Authors, based on (DRSC, 2013)

In the period from 2001 to 2012 a total of 26,800 of traffic accidents occurred on Slovenian motorways, among which around 20% were injury accidents. The motorways accidents involved almost 48,300 people, 249 (172 on A1) of which have died, 728 were severely injured (478 on A1) and more than 7,500 suffered minor injuries (more than 5,200 on A1).

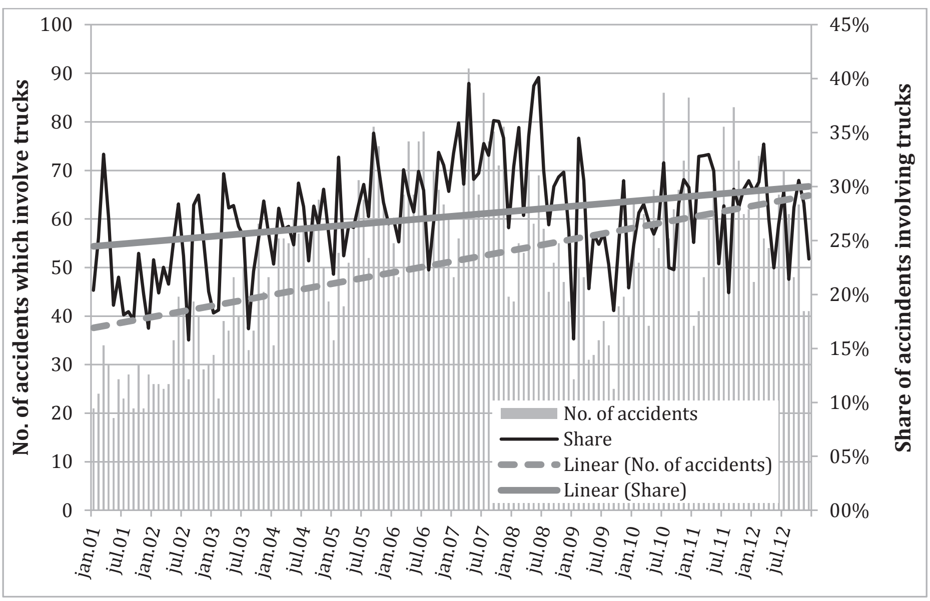
There is an increasing trend in the number of accidents on Slovenian motorways over the analysed period; in average the number of accidents was increasing by 6.6% per year, while the number of injury accidents increased in average by 5.0% per year.

Proportion of the number of people killed on the Slovenian motorways is also growing; in 2001 the share of fatalities on motorways represented only 7% of all road fatalities, while in 2012 this share was almost 14%. However, it should be noted that back in 2001 motorways accommodated barely 21% of all traffic work in Slovenia, while in 2012 more than 44% of transport work was done on motorways, which is significantly above the European average (while accounting for more than one quarter of all kilometres driven, the European motorways contribute only to 8% of to the total number of road deaths (ETSC 2008)). So, in 2001 there were 9 fatalities per billion VKT on motorways and in 2012 this number dropped to 3.1 fatalities per billion of VKT on motorways. Thus, in the aspect of fatality risk it is possible to say that the safety on Slovenian motorways has improved significantly irrespectively of the changes in traffic structure. According to the fatality risk level the motorways represent the safest roads in Slovenia, which is consistent with the theory (see e.g. ETSC 2008).

4.2. The analysis of accidents involving trucks

In the European Union (EU) a heavy truck is involved in 6% of all accidents and in 16% of all fatal accidents (EC 2013). In Slovenia these numbers are somewhat worse; in the analysed period trucks were involved in 27.5% of all accidents (while causing at least 14.5% of all accidents), and in 33.3% of fatal accidents (while causing at least 16.2% of such accidents). Regardless of the legislation (Ur. L. 102/2006), that requires trucks to use motorways wherever possible, still more than 75% of accidents involving trucks occur on lower rank roads.

Figure 3: *The monthly number of accidents involving trucks on Slovenian motorways and the share of these accidents*



Source: Authors, based on (Police 2014)

At least one truck was involved in 7,372 accidents on Slovenian motorways (all together 8,420 truck were involved in these accidents) in the period from 2001 to 2012. This means that in 27.5% of all accidents at least one truck was involved (21.4% in 2001, 27.3% in 2012 with the maximum in 2007 and 2008 with 33.5% and 32.0% respectively), and this share is even higher on A1, where at least one truck participated in 31.4% of accidents (23.0% in 2001, 32.1% in 2012 with the maximum in 2007 and 2008 with 38.2% and 36.9% respectively).

The largest number of traffic accidents on Slovenian motorways involving trucks occurs in in the morning between 7 and 9 AM, and in the afternoon between 1 and 5 PM during week days. The majority of accidents involving trucks occurred during normal traffic condition, while around 22% of these accidents happened during heavy traffic, which can be described by[5]:

- Higher density of vehicles on the fast lane than on regular lane (in 15.0% of measurements on motorways in total, and 26.5% on A1 motorway);
- Inadequate time heading (in 24.3% of cases when there is more traffic on fast lane than on regular lane the time heading is less than 2 seconds);
- High difference between the average speed on fast and regular line (26 $^{km}/_{h}$ (25 $^{km}/_{h}$ on A1) when traffic density is higher on fast lane than on regular lane).

In the Table 1 the crash costs of accidents on Slovenian motorways involving trucks are presented.

Table 1: *The monetary aspect of the injury accidents caused by trucks and involving trucks on Slovenian motorways in the period 2001–2012*

	Costs of accidents caused by trucks			**Crash costs of acc. involving trucks**	**Crash costs of acc. involving trucks on A1**
	Internal costs*	**External costs**	**Total costs**		
2001	581,510	1,022,750	1,604,260	2,680,004	2,313,399
2002	94,685	6,381,557	6,476,242	17,594,961	17,351,485
2003	2,252,540	5,180,865	7,433,404	12,408,225	12,118,218
2004	2,295,487	3,887,777	6,183,264	20,927,662	19,592,935
2005	4,252,651	4,510,051	8,762,702	19,097,799	16,087,095
2006	2,119,187	2,421,854	4,541,041	17,492,418	11,423,087
2007	4,340,587	7,494,248	11,834,834	25,236,927	21,242,023
2008	782,230	4,354,449	5,136,680	8,929,384	7,156,328
2009	763,161	11,391,610	12,154,772	21,760,667	20,553,807
2010	523,955	18,493,673	19,017,627	17,942,079	9,341,421
2011	3,890,986	10,012,019	13,903,005	17,767,480	14,760,206
2012	3,367,881	7,840,394	11,208,275	13,634,076	7,480,459
Total	**25,264,860**	**82,991,246**	**108,256,106**	**195,471,679**	**159,420,463**

Note: * – Internal costs are the costs of injury accidents that were caused by truck drivers to themselves

Source: Authors, based on (Police, 2014), (Lep et al., 2004) and (STAT, 2014)

As the causer of the accident is not reported in almost 19% of cases of traffic accidents on Slovenian motorways, the monetary estimation presented in the Table 1 represents

5 In brackets are presented the results of traffic data recording in March and April 2014 which can serve as a describer of traffic condition in certain periods of day, but cannot be generalized to past or future.

the minimum possible costs of accidents that are caused by truck drivers on Slovenian motorways.

In general, crashes involving trucks lead to higher casualty severities compared to other crashes (Sandin et al., 2014), due to the weight of the vehicle. This is true also in Slovenia, as the crash involving truck leads to 31.8% more fatal consequences than a crash in which no trucks are involved. In average in 90 accidents on Slovenian motorways involving trucks there is one victim.

Accidents are the outcome of mix of various factors; however, increasing traffic volumes are usually related to increasing number of accidents. For the Slovenian motorways we determined the following impact of traffic volume on the number of accidents:

$$E(\lambda) = AADT^{0.7577} \tag{4}$$

This means that the increase of traffic by 1%, generates 0.76% of additional traffic accidents. This model predicted 2,410 accidents on Slovenian motorways in 2013, while official statistics recorded 2,294 accidents.

However, as the particular interest of this paper is given to the influence of the trucks on traffic safety on Slovenian motorways we included the share of trucks (%GV[6]) into the model.

$$E(\lambda) = AADT^{0.8221} \%GV^{0.3110} \tag{5}$$

The model proves that the number of accidents on Slovenian motorways is increasing with the increasing share of trucks in the structure of traffic flows. In fact, the increase of share of trucks by 1%, increases the number of accidents by around 2.5 to 3% if AADT remains unchanged (the actual impact depends on the actual share of trucks; the lower the share is, the impact is greater, and 2.5-3% is averaged for the current traffic structure on Slovenian motorways). This model predicted 2,483 accidents on Slovenian motorways in 2013.

5. CONCLUSIONS

A literature review showed that the topic of traffic flows affecting traffic safety is not often analysed in developed countries, although the problem is actual and analysis, at least in the Slovenian case, draws attention to increasing participation of commercial vehicles in road accidents, and can as such be useful for transport policy makers or at least motorway operators.

Although traffic volume and traffic structure are not the only factors affecting road traffic safety, they are important and measurable ones. Traffic structure on Slovenian motorways

6 The share of traffic work is used as a proxy for the share of trucks in AADT.

is becoming more and more heterogeneous (AAGR = 4.9%) and at the same time the number and the share of traffic accidents including trucks is increasing (AAGR is 10.5% and 6.6% respectively). We have also shown that on Slovenian motorways traffic accidents involving trucks produce heavier consequences than traffic accidents that do not include these vehicles. Consequently the cost of these accidents is increasing as well.

The probability of a truck being involved in an accident increases with the increasing share of these vehicles in traffic structure; however, the studies show that truck drivers themselves create further danger by driving tired, under the influence of drugs or by not obeying the mandatory rules (see e.g. McCartt et al., 2000; Zanne, 2009; Verster et al., 2009; Pennng et al., 2010).

Trucks pose danger due to their huge mass in comparison to other road vehicles; on Slovenian roads the weight of trucks can be up to 44 ton. Another important characteristic that distinguishes trucks from other vehicles on the roads is the speed limit; the speed limit for trucks on Slovenian motorways is 80 $^{km}/_{h}$, which is 50 $^{km}/_{h}$ less than the speed limit for passenger cars, which encourages overtaking and thus causes dangerous situations. This results in the situation when there is greater and denser traffic on the fast lane with spacing between vehicles dangerously declining. In such situations trucks can indirectly cause the traffic accident that is the accident in which the truck alone is not involved. This means that the impact of trucks on road safety is not fully covered within the official statistics; therefore, it is not possible to accurately evaluate their impact in monetary terms. In addition, trucks damage the road surface much more than personal cars; but, their effect on road safety is not easily quantifiable (e.g. the number of accidents due to poor surface condition, or the number of accidents due to road maintenance).

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