EFFECT OF PERIODIC TECHNICAL INSPECTIONS OF VEHICLES ON TRAFFIC ACCIDENTS IN THE SLOVAK REPUBLIC

Juraj Hudec [1,2], **Branislav Šarkan** [2,*]

[1]Ministry of Transport and Construction of the Slovak Republic, Bratislava, Slovak Republic
[2]The Faculty of Operation and Economics of Transport and Communications, University of Zilina, Zilina, Slovakia

*E-mail of corresponding author: sarkan@fpedas.uniza.sk

Resume

The article presents a search for links between the Periodic Technical Inspections of Vehicles (TI) and traffic accidents due to vehicle technical defects in the Slovak Republic. Based on these links, it is sought to assess the justification for TI regarding the road safety. For this purpose, statistical data on traffic accidents, caused by vehicle technical defects as well as data concerning TI carried out were examined. The first finding was that the approaching end of the validity of the TI, the probability of traffic accidents due to technical defects increases for vehicles. The second finding was that with the increasing number of vehicles assessed at the Periodical Technical Inspection Stations (PTI) as temporarily roadworthy and not roadworthy, the number of accidents due to vehicle technical defects was decreasing. The results formulated in this paper show that the TI have a measurable effect on traffic accidents caused by vehicle technical defects, thus positively affecting the road safety and thus having a demonstrable justification.

Available online: https://doi.org/10.26552/com.C.2022.3.A142-A159

Article info

Received 27 January 2022
Accepted 27 19 May 2022
Online 21 June 2022

Keywords:

periodic technical inspections
technical condition of vehicles
vehicle technical defects
road safety
traffic accident

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

1 Introduction

Development of the automotive industry due to the growing demand for vehicles for private or business purposes also contributes to the need for technical inspections of these vehicles, which contributes to the safe operation of means of transport. Vehicles in good technical condition are then a prerequisite for carrying out their transport task [1].

One of the functions of the state is to protect the lives and property of its citizens. Therefore, every civilized state has an interest in ensuring that vehicles in traffic do not endanger road safety and the environment. Consequently, the minimum technical requirements to be met by each vehicle in the road traffic have been laid down and this includes the introduction of periodic technical inspections and regular emission measurements.

Although there are still various discussions being held on this topic in some countries (especially in the US and Australia), most countries in the world have introduced mandatory technical inspections into their jurisdictions. In all the EU countries, this is an obligation and technical inspections of vehicles registered in the EU Member States are carried out at regular intervals in a harmonized way [2].

One of the causes of traffic accidents is the technical condition of vehicles. However, according to national statistics, the proportion of such accidents in the overall causes of traffic accidents varies considerably, ranging from a few tenths of a percent to double digits. Despite the various statistics, there is a common view that the system of periodic technical inspections and vehicle technical defects affect the road safety and the number of traffic accidents. However, this is countered by the views that systems of periodic technical inspections of vehicles are costly for vehicle operators and provide negligible benefits for society. These views are often justified by the fact that development of the automotive technology is progressing considerably and more complex passive and active safety systems are being used. Likewise, the production of more sophisticated cars is facing increasingly stringent type-approval requirements.

However, the effectiveness of national systems of periodic technical inspections, at first sight, appears to be difficult to measure and the input data depend on the sources and methodology of their collection and may vary from one another. Several different studies have already been written on this topic using different research methods, sometimes with conflicting conclusions. That is because it is very difficult to establish a direct causal link between periodic technical inspections of vehicles

and the reduction in the accident rate.

This article, therefore, presents an examination, in an original way, of the periodic technical inspections effect on the occurrence of traffic accidents due to vehicle technical defects, namely in the environment of the Slovak Republic and thus the impact on road safety. Based on the above, it also assesses the effectiveness of periodic technical inspections of vehicles in this state.

2 Literature review

The reason for introducing the obligation to subject vehicles to regular technical inspections is the presumption of eliminating vehicles from the road traffic with serious and dangerous defects that could potentially result in a traffic accident and thus endanger people's health, lives and property. However, the fundamental question is to what extent the poor technical condition of vehicles affects and may affect the accident rate and what are its consequences. Whether it is actually necessary to take measures at a national level to eliminate the consequences of road accidents caused by vehicle technical defects and therefore whether the effort and attention spent on systems of periodic technical inspection of vehicles have a measurable impact on road safety. Discussions are taking place on this topic, either at a scientific level or government level of some countries.

This part of the paper thus deals with the available world literature, articles and studies, which deal with vehicle technical defects as the cause of traffic accidents and the effect of periodic technical inspections on the reduction in accident rate due to vehicle technical defects and which are also looking for answers to questions concerning the justification of periodic technical inspection systems. Due to the complex concept of the issue, the literature was sorted according to selected criteria and from the most recent to the oldest.

2.1 Effect of vehicle technical defects on causes of the traffic accidents in the light of the results of various studies and research projects

The following part focuses on the issue of vehicle technical defects as the cause of traffic accidents. In this

Table 1 *Percentage of vehicles with technical defects that directly caused the traffic accident*

Study	Share
Fazzalaro (2007), USA [3]	1%
Asander (1992) [4]	23% (direct causes or increasing damage or injury) (Finland)
	7-9% (major causal role, a contributing cause, or by increasing the consequences of the accident) (Denmark)
RACQ (1990) [5]	5%
Rompe and Seul (1985) [6]	3-24%
	1.3% (Japan)
Grandel (1985) [7]	2-10%
McLean et al. (1979), Australia [8]	1.5% motorcycles
	2.9% passenger cars
Treat (1977), USA [9]	4.5% passenger cars

Table 2 *Percentage of vehicles with technical defects that contributory caused the traffic accident*

Study	Share
Haworth et al. (1997) (motorcycle crashes), Australia [10]	12% in total
	28% of accidents involving single vehicle
	7% of accidents involving multiple vehicles
Haworth et al. (1997) (single vehicle crashes), Australia [11]	3%
Asander (1993) [4]	23% (direct causes or increasing damage or injury) (Finland)
	7-9% (significant impact, related impact, or increase in connections with traffic accidents) (Denmark)
Case et al. (1991) [12]	5.8%
Rompe & Seul (1985) [6]	4 - 19% (possibly up to 33%)
Grandel (1985), Germany [7]	6.5% traffic accidents involving passenger cars
	5% traffic accidents involving two-wheeled vehicles
CCRAM (1978) Melbourne (Forest and Youngman) [13]	5.8%
	(0.6-1.8% of these defects can be detected by a technical inspection)
Treat (1977), USA [9]	12.6% vehicles

respect, the results of studies of the relevant worldwide scientific literature concerning the traffic accidents caused by vehicle technical defects, as well as other links, were summarized.

In the course of time, several studies, or research projects were carried out in various countries, focusing on the effect of vehicle technical defects on the occurrence of traffic accidents. For the purposes of this paper, 28 of them were examined. In the case of publications in which their results were explicitly quantified, in order to simplify their interpretation, they were summarized in the Table 1 and Table 2 by means of the percentages of vehicles with technical defects that directly caused the traffic accident and the proportions of vehicles whose technical defects only contributed to the occurrence of the traffic accident.

Table 1 shows results of world studies, research and publications focuses on the issue of vehicle technical defects as a main causes of traffic accidents with their percentages expression.

Table 2 shows results of world studies, research and publications focuses on the issue of vehicle technical defects that contributory caused of traffic accidents with their percentages expression.

Table 1 shows clearly that 1.3% to 24% of the vehicles involved in the traffic accident had technical defects that caused the accident [8]. Based on studies in which in-depth accident investigations were carried out [9], technical defects played a causal role in 2.9% to 4.5% of car accidents.

Furthermore, from Table 2 it can be seen that between 3% and 19% of the vehicles involved in the accident had technical defects that played a contributory role in the accidents [7]. Perhaps the most comprehensive studies on the subject show that vehicle defects are a contributing factor in 6.5% to 12.6% of traffic accidents. For motorcycles, it is 5% to 12% of accidents [9].

Research, therefore, shows that the share of traffic accidents arising directly or indirectly from vehicle technical defects, in relation to all accidents, is relatively low, but not negligible. In absolute terms and especially in terms of possible fatality of the consequences, it may even be perceived as significant.

2.2. Effect of introduction of the periodic technical inspections system on reduction in accident rate in the light of the results of various studies and research projects

One of the methods for assessing the effectiveness, and thus the justification for introducing systems of periodic technical inspections for vehicles, as a measure to reduce the number of accidents due to technical defects of vehicles, is to examine their effect on these accidents. The aim of these systems constitutes the preventive removal of defects from a vehicle fleet through a periodic technical inspection of vehicles on a compulsory basis, as well as fixation of any found defect before the vehicle is allowed to operate on public roads [14]. It is assumed that if periodic technical inspections reduce the number of technical defects in the vehicle fleet of a given state, then this will also result in a reduction in the accident rate caused by technical defects of the vehicles.

This section summarizes information on the relevant scientific literature and publications concerning the effects of systems of technical inspections on accident rate, as well as their other related consequences. Studies or research projects were focused on:

- a comparison of states that have the periodic technical inspection of vehicles mandatory with states, where there is no such obligation,
- a comparison of states before and after the introduction of the obligation to conduct periodic technical inspection of vehicles,
- a comparison of countries following the withdrawal of the obligation for periodic technical inspection,
- a comparison of accident rates of vehicles that have undergone periodic technical inspections with vehicles that have not been subject to such inspections within the jurisdiction of the same state,
- an analysis of the accident rate of vehicles undergoing periodic technical inspections, during the time in between such inspections.

For the purposes of this paper, 18 publications have been reviewed. Their results mostly support the positive effect of periodic technical inspections, but in certain cases, they show some differences [15]. One of the reasons may be that the results are influenced by methodological and statistical shortcomings. This is stated by reviewers [16], as well as by the authors of the articles themselves [17].

Another reason for differences in results may be the influence of other factors, such as different levels and types of road safety measures, various traffic intensity in different countries, level of public roads or vehicles operation in different climatic conditions, collection of data based only on police registers, different methodologies of such data collection and assessment of causes of traffic accidents, methodological shortcomings and age of these studies [18]. These factors were not considered in the analyses of the various studies [19]. Differences in vehicle fleets or vehicle wrecks available for the study may also have had an impact on data obtained for a particular jurisdiction [6]. Likewise, the different levels of quality of the periodic technical inspection systems of the countries studied may make it difficult to compare studies [20].

Another major problem when it comes to determining the effect of systems of technical inspections of vehicles on the reduction in accident rate is that the related studies did not directly address this issue. Only study [21] was the closest to it. According to the cited studies, provided that the PTI detect defects in vehicles that must subsequently be rectified, this eliminates the

Table 3 *Effect of periodic technical inspection on the reduction in traffic accident rates*

Study	Percentage reduction in accident rates
Schulz and Franck (2021) [20]	in fatal accident rate and accident rate with no proportion figures given in Punjab (Pakistan)
European Commission (2019) [23]	5 % (in accident rate of mopeds in Spain) 18 % (in fatalities in Spain)
Schulz and Scheler (2019) [24]	40 % (in accident rate in Costa Rica)
Hoagland et al. (2018) [25]	0 % following the abolition of compulsory technical inspections in the state of New Jersey
Schulz and Scheler (2016) [26]	10 % (in accident rate in Tukey)
Keall & Newstead (2013), New Zealand [27]	8 % (during the transition from an annual to a semi-annual frequency of technical inspections)
Rune Elvik (2001), Norway [13]	5-10 % (with an increase in the frequency of technical inspections by 100 %)
Fosser (1992), Norway [28]	0 % (Norway has significant random roadside inspection program)
Asander (1992), Sweden [4]	16 % (in accident rate with serious injury)
NHTSA (1989), USA [16]	10 % (in accident rate) 0 % (in fatal accident rate)
White (1986), New Zealand [29]	10-15 % (in accident rate)
Rompe & Seul (1985) [6]	50 % (in accident rate)
Loeb and Gilad (1984), USA [18]	in fatal accident rate and accident rate with no proportion figures given
Berg et al. (1984), Sweden [30]	14 % (in police reported accidents) 15 % (in accident rate with serious injury)
Crain (1981), USA [31]	reduction in accident rate, but no figures given
Schroer and Peyton (1979), USA [19]	9.1 % (in accident rate, after technical inspection, compared to uninspected vehicles) 21 % (in accident rate, after periodic technical inspection, compared to uninspected vehicles) 5.3 % (in accident rate for inspected vehicles compared to accident rates of vehicles before the inspection)
Little (1971), USA [32]	5 % (in death rates)

Table 4 *Effect of periodic technical inspections on the incidence of defects on vehicles*

Study	Figures
Asander (1992) [4]	7-8 % of vehicles with serious defects replaced with new vehicles
NHTSA (1989), USA [16]	0.25-2.5 % higher proportion of crashed vehicles with technical defects in countries without a system of regular technical inspection compared to countries having such a system 2.5 % Higher rate of tyre failure in states without a system of regular technical inspections

incidence of at least part of the accidents that are caused by vehicle technical defects [22]. It also suggests that periodic technical inspections address only part of this problem [19].

Table 3 provides a summary of changes in accidents' rate due to periodic technical inspections of vehicles, resulting from the results of related publications.

Table 4 provides an effect of periodic technical inspections of vehicles on vehicle defects resulting from the results of related publications.

Table 3 demonstrates that the effect of the technical inspection system on accident rate ranged from no effect to a 16 % reduction and up to 21 % in case of periodic technical inspections. The study [6] with reference to US studies suggests that a system of periodic technical inspections could reduce the accident rate of vehicles with a technical defect by about 50 %.

The effect of the system of periodic technical inspections of vehicles on the incidence of vehicle defects is shown in Table 4. Here it can be seen that the system of periodic technical inspections of vehicles reduces the incidence of defects in a vehicle fleet by up to 2.5 % [16]. In Sweden, it was found that 7-8 % of vehicles with serious defects were replaced with new vehicles after the introduction of a system of periodic technical inspections [4].

Some new studies have shown an important correlation between the PTI and the accidents decrease and improvement of road safety [33]. According to one study, the PTI avoid more than 400 fatalities per year, about 12,000 injured and almost 8,500 accidents during the period 1998-2006 [34]. This study was

an update, which demonstrates that vehicle technical failures contribute about a 6% of the total number of car accidents and an 8% of motorcycles accidents, which annually represents 2,000 fatalities in the European Union and a much higher number of injuries. According to this work, PTI avoided 11,000 traffic accidents, about 11,000 injured and 170 fatalities, which represents an economic benefit of 300 million Eur [35]. Other studies show similar results [36].

Several new studies have also examined the economic effect of introduction of PTI. For example, introduction of the PTI in Costa Rica show that there are considerable economic gains from having such a system in place with high cost-benefit ratios [24]. In the case of Punjab, the introduction of a regulated PTI system has a significant benefit. As already stated in the analysis, about 335 accidents can be avoided by a regulated introduction of a PTI system, 198 of which would be fatal. The economic loss of 198 fatal accidents amounts to 11.6 million USD, which is a considerable amount for a region like Punjab, whose economic power fades in comparison to that of a developed country [20]. A PTI system would also help in preventing the costs associated with serious or minor injuries. Consequently, the economic damage associated with road accidents is incredibly significant. It has been shown in other countries that the introduction of PTI has a significant positive impact on the number of traffic accidents [26]. The purpose of another study carried out for European Commission is to assess the benefit of including two- and three wheelers and light trailers within the framework of periodic inspection of vehicles and to propose the precise way to do so. For the two- and three-wheelers, the study considers the impact of introducing inspection of mopeds in Spain between 2007 and 2010 depending on the region. The report demonstrates that the benefit of this initiative is 4.73 times greater than the costa. With all the considerations taken into account, the costs and benefit analysis has been undertaken with the data of Croatia resulting in a benefit 6.32 times greater than the costs [23].

Thus, the majority of research projects and statistics demonstrate that periodic technical inspection systems, by reducing technical defects in a vehicle fleet, have an impact on the reduction in accident rate of vehicles that could otherwise occur due to technical defects and are therefore justified [30]. However, the numerical expression of this impact is presented differently in various research projects, as well as that it is not always possible to accurately quantify it. Nevertheless, none of the publications directly examined the incidence of accidents in the period between the performance of technical inspections and their end of validity, as well as the link between the results of periodic technical inspections given by the temporary roadworthiness and not roadworthiness and the number of accidents, what was examined in this article.

3 Material and methods

The present article provides an analysis of data concerning the traffic accident rates due to technical defects of vehicles in the Slovak Republic, as well as research on the incidence of traffic accidents in the period in between the performance of technical inspections and the end of their validity. Furthermore, the article examined the effect of the results of periodic technical inspections given by temporary roadworthiness and not worthiness of vehicles on the number of traffic accidents due to a technical defect.

The basic materials and resources for analysis and research consisted of:

- statistical data on all the traffic accidents in the period 2012 - 2020, provided by the Presidium of the Police Force of the Slovak Republic,
- detailed data on traffic accidents caused primarily by a technical defect of vehicles in the period 2016-2020, obtained from the information system of traffic accidents of the Presidium of the Police Force of the Slovak Republic,
- data from the Slovak central automated information system of technical inspections, in which all data on technical inspections of vehicles for the period 2016-2020 are stored,
- up-to-date statistics on the results of the vehicle assessments by the PTI,
- up-to-date statistics on the traffic accidents due to a technical defect provided by the foreign authorities of selected states that have the above-mentioned issue in their competence.

MS Excel and the Data Analysis tool were used for graphical data processing and for correlation and regression analysis.

Processed documents did not contain data on damage events, that is traffic accidents due to technical defects of vehicles, which were not reported to the Police Force, but only to insurance companies.

4 Technical defects of vehicles as the major cause of traffic accidents in the Slovak Republic

The most common major causes of traffic accidents in the Slovak Republic are a violation of driver's duty, illegal speeding, improper driving through an intersection and so on. Their exact ratio is shown in Figure 1.

The exact ratio of the causes of traffic accidents that resulted in the death of a person in 2020 is shown in Figure 2.

From the presented graphs it is clear that vehicle technical defects, as the major cause of traffic accidents (even fatal ones), is listed in the last places in the Slovak Republic. The same applies to other countries.

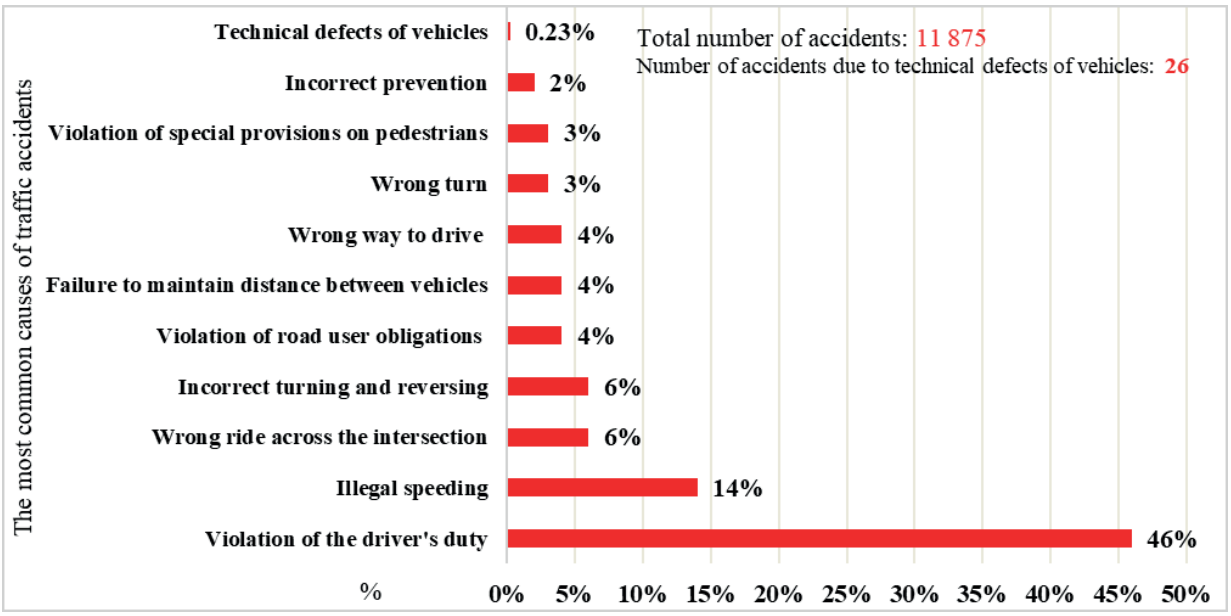

Figure 1 *The most common major causes of traffic accidents in the Slovak Republic in 2020*

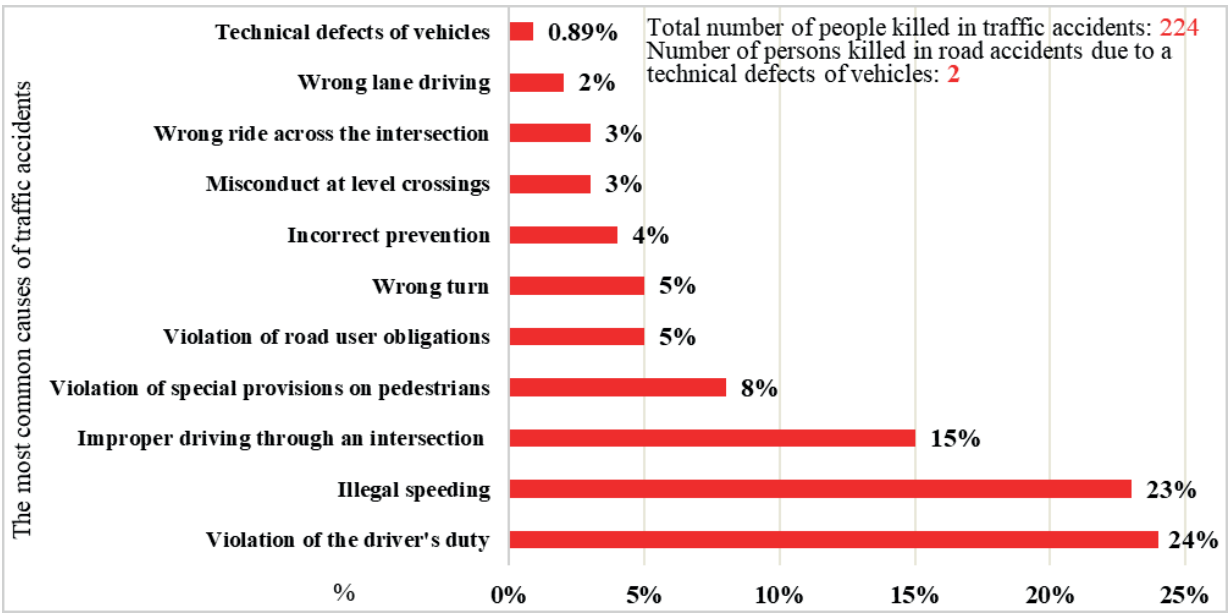

Figure 2 *The most common major causes of traffic accidents in the Slovak Republic that resulted in the death of a person in 2020*

However, their rates vary considerably from one country to another.

Table 5 shows the percentage of traffic accidents caused by vehicle technical defects in selected states and periods.

The presented Table 5 shows that the rate of traffic accidents, caused by vehicle technical defects, as reported by individual countries, varies from one state to another, just as the differences between individual states. For example, in Austria and Germany, the reported accident rate is three times higher than in the Slovak Republic and in contrast to the Slovak Republic, only the traffic accidents that result in injuries are included in it. Likewise, the age of vehicle fleets is different. The reason for this phenomenon is that each state, when determining the cause of the traffic accident, uses a different methodology for assessing technical defects of vehicles as well as assesses these causes differently. For example, in the event of a traffic accident in the Slovak Republic, if a vehicle technical defect is suspected, a court expert from the department of road transport is called in to investigate the cause of the traffic accident. If the expert identifies a technical defect of a vehicle as a major cause of the accident, which, however, has manifested itself on the vehicle for a long time and the driver could and should have eliminated it, the police force will ultimately assess this as a failure to comply with the duties of the driver who used the vehicle that was not supposed to be operated in the road traffic. The same applies to tires. If an accident occurs

Table 5 *Percentage of accidents caused by vehicle technical defects in selected countries and periods*

Country (year)	Proportion of accidents caused by technical defects of vehicles [%]
Slovak Republic (2020)	0.23
Czech Republic (2020)	0.4
Austria (2020)	1.1 (only with injuries)
Germany (2020)	1.2 (only with injuries)
Great Britain (2020)	3.84
USA (average of all the states without the obligation of periodic TI) (2017)	0.83
USA (average of all the states with the obligation of periodic TI) (2017)	0.61

in the Slovak Republic due to loss of adhesion of tires of a vehicle on the road surface in a causal connection with insufficient or inappropriate tire tread, or other wear and tear, or with the vehicle equipped with wheels of the wrong tire size, such a road accident is classified as a non-adjustment of driving to the condition and nature of the road and thus a breach of the driver's duties. Conversely, in Germany, the United Kingdom, the USA and so on, a technical defect of a vehicle is considered to be the cause of road accidents resulting from worn tires with insufficient tread, etc. In the Slovak Republic, only a vehicle technical defect that occurred suddenly and without the possibility of being influenced by a driver, for example by the maintenance of a vehicle, is considered to be the cause of an accident due to a vehicle technical defect. The possible invalidity of the technical inspection and the related non-roadworthiness of the vehicle for road traffic are also not considered. Furthermore, in the Slovak Republic, statistics on the road accidents due to technical defects does not include the so-called damage events, i.e. the traffic accidents, which, under certain conditions, do not have to be reported to the Police, but only to insurance companies (if a person has not been killed or injured, there has been no damage to the road or public utility equipment, there has been no spill of dangerous goods, or some of the vehicles involved, including transported goods, or other property has suffered material damage not exceeding one and a half times the greater damage according to the Criminal Code of the Slovak Republic (in 2021 it was 3,990 euros)). Due to such a procedure, the share of vehicle technical defects in the causes of traffic accidents in the Slovak Republic will inevitably be reflected in the statistics by a low percentage. However, far more such accidents are expected to occur but are not classified as such for the statistical purposes.

For the sake of objectivity, it should also be mentioned that most of the data listed in Table 5 come from countries where the system of periodic technical inspections is in place, which may also have an impact on the declared low accident rates. As far as the USA is concerned, Table 5 contains two figures concerning the USA states. One of them is the proportion of accidents caused by vehicle technical defects, represented by an average percentage for all the US states where the system of periodic technical inspection is not in place and the other is the proportion for all the US states where the system of mandatory periodic technical inspection is in place. The data shows that in the US states where the obligation of technical inspections is in place, the average annual rate of traffic accidents caused by vehicle technical defects was 36 % lower in 2017 than in the US states where there is no such obligation. The difference between the two data groups is statistically significant.

5 Analysis of data on traffic accidents due to vehicle technical defects in the Slovak Republic

Based on data provided by the Presidium of the Police Force of the Slovak Republic on vehicles and traffic accidents caused by vehicle technical defects in the period 2016-2020, as well as other related documents from insurance companies, a detailed analysis was performed. The analysis showed that in the monitored period, 260 technical defects were detected in 183 vehicles that were involved in traffic accidents, which were directly caused by these defects. Specific technical defects that have been identified on vehicles as the main cause of road accidents can be broken down according to Figure 3.

It is clear from the graph above that the most common vehicle technical defect that caused the traffic accidents in the Slovak Republic over a period of five years was tire damage with sudden air leakage (90 cases). It is followed by a wheel failure (44 cases) and steering failure (31 cases). Technical defects that caused the least traffic accidents were taillights failure (3 cases), followed by windscreen damage (5 cases) and a wheel lock-up from a mechanical failure (6 cases). Regarding a service brake failure, which is one of the most essential elements of active safety and directional stability of vehicles and the work of technicians of PTI is of great importance in this respect, as the cause of traffic accidents ranks seventh out of twelve with 23 cases. In comparison to other countries, it should be noted that the most common vehicle technical defects that caused traffic accidents in Germany in 2020 were tires and breaks. In the UK it was brakes, tires, vehicle overload

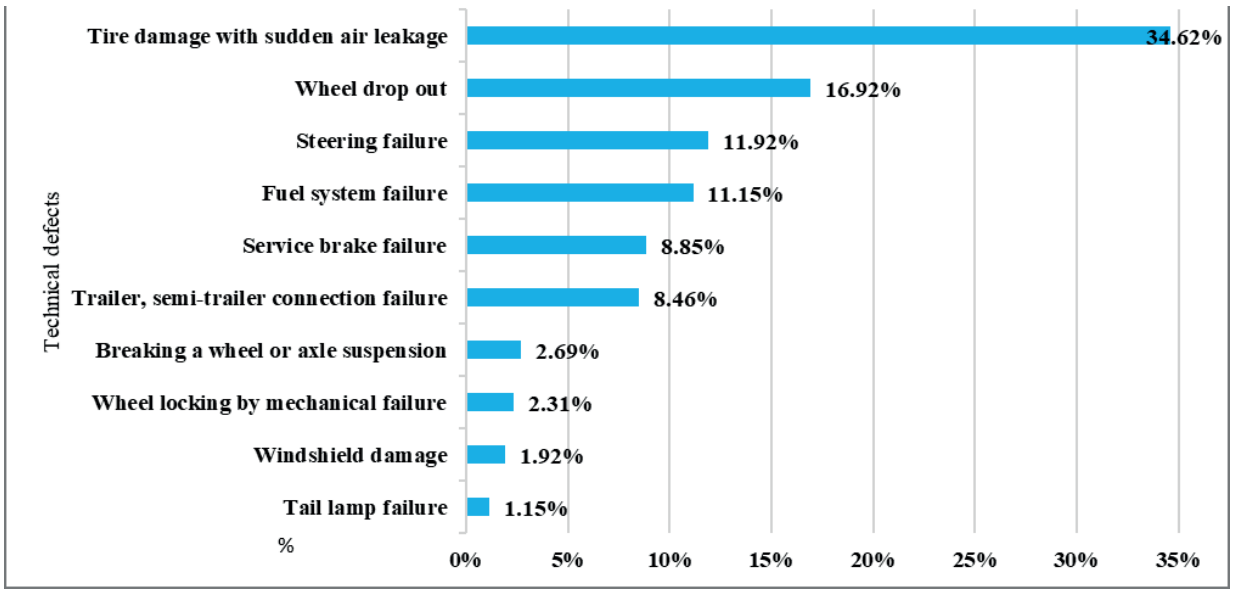

Figure 3 *Technical defects of vehicles that directly caused traffic accidents in the period 2016-2020*

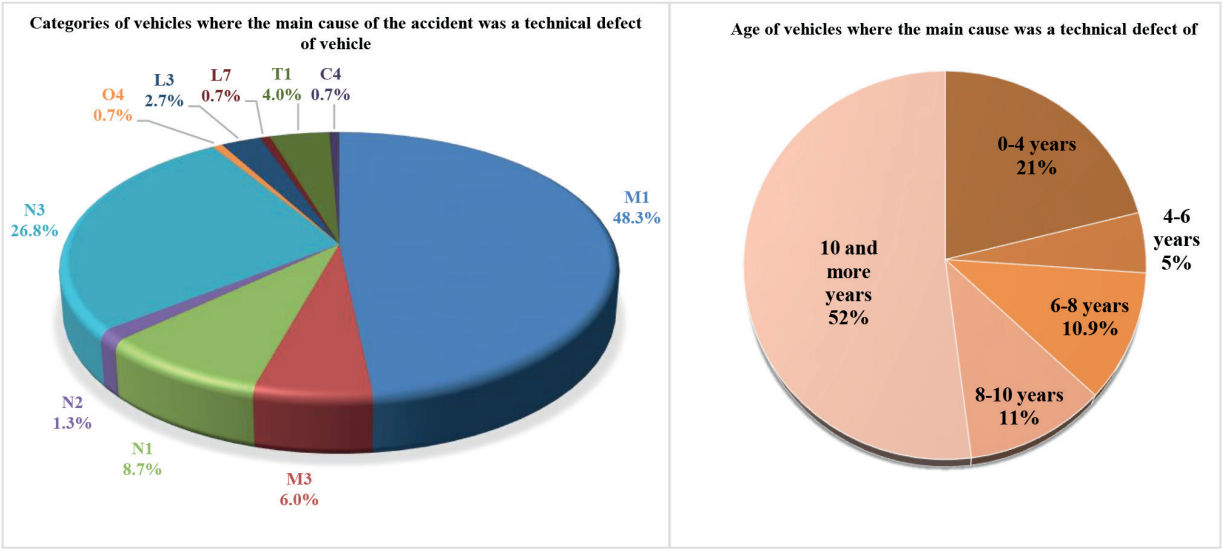

Figure 4 *Percentage of categories of vehicles and age of vehicles, which were involved in traffic accidents due to vehicle technical defects*

and lighting systems, while in the USA it was tires, the so-called other causes, lights (main, brake), steering, brakes and direction indicator lamps. In comparison to the results of PTI, in the Slovak Republic the most frequently detected vehicle defects were in the category of the braking system (almost half of all the detected defects), lighting and reflective electrical equipment, as well as vehicle chassis and its accessories. Defects of axels, wheels, tires and axle suspensions were found in the fifth place only (just 5 % of all detected defects).

As regards the categories of vehicles involved in the traffic accidents due to a technical defect, their breakdown is shown in Figure 4.

It is clear from the first graph that majority of the accidents due to vehicle technical defects were caused by vehicles of categories M1 (passengers cars), N3 (commercial trucks) and N1 (light goods vehicles). Categories O4 (heavy goods trailers), C4 (tracked tractors) and L7 (heavy quadricycle) caused the least accidents. The above-mentioned distribution largely also replicates the distribution of the number of registered vehicles in the Slovak Republic and thus the rate of occurrence of the categories of vehicles in question in road traffic, as well. Regarding the age of vehicles involved in the traffic accidents due to technical defects, the second figure clearly shows that majority of such accidents were caused by vehicles older than 10 years (52 %). The second most numerous age category of vehicles that was involved in traffic accidents was surprisingly the category 0 to 4 years, i.e. new vehicles (21 %).

The distribution of age and odometer status of vehicles involved in traffic accidents due to a technical defect are illustrated in Figure 5.

The average age of all the vehicles that caused a traffic accident due to a technical defect was 11.01

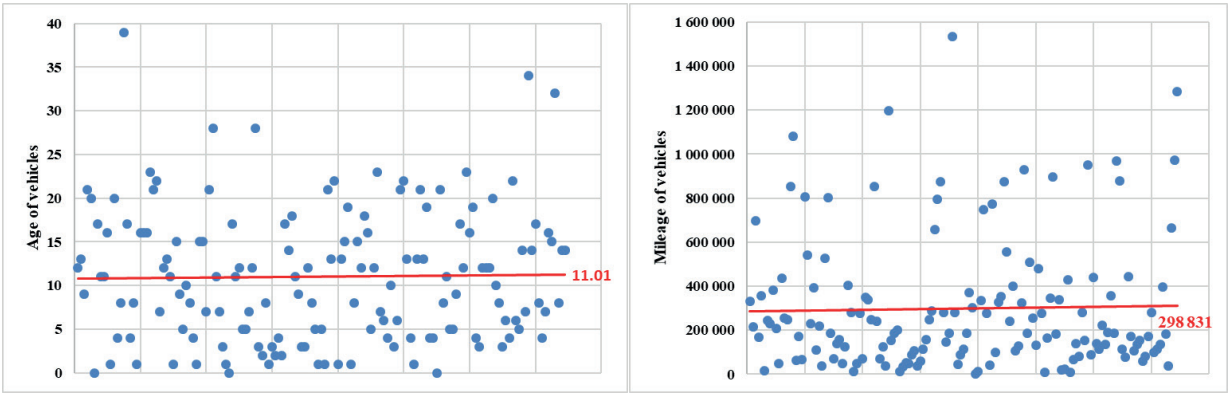

Figure 5 *Distribution of age and odometer status of vehicles involved in traffic accidents due to a technical defect*

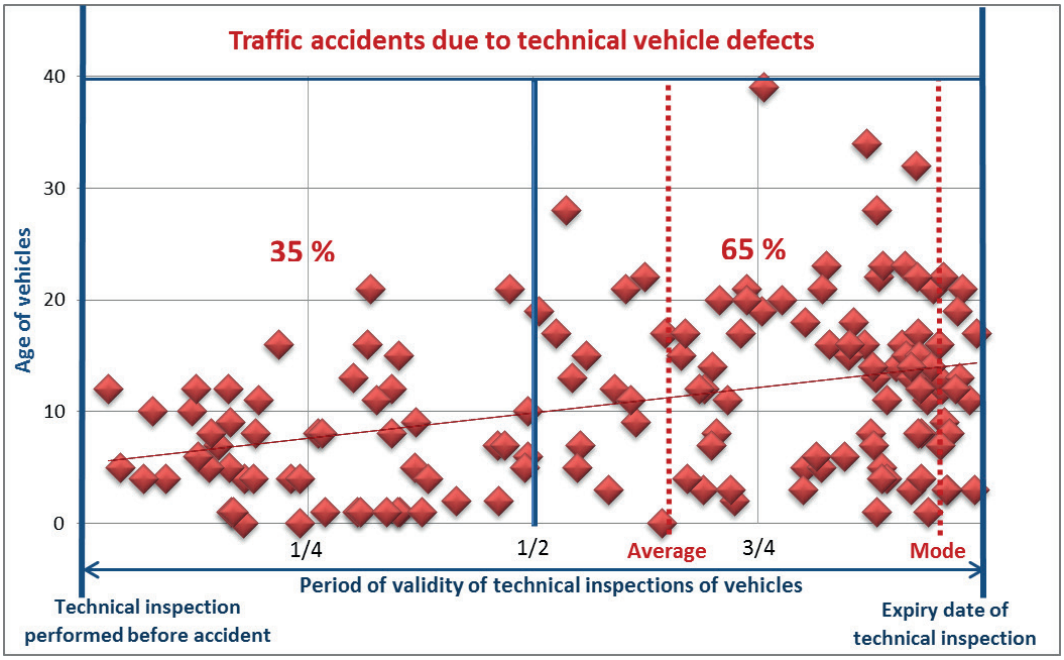

Figure 6 *Temporal distribution of all the accidents due to vehicle technical defects in the period from the performance of the technical inspection prior to the accident until the end of its validity*

years (10.5 years for vehicle categories M1 and N1), which is less than the average age of the vehicle fleet in Slovak Republic (13.03 years). However, the graph also shows that technical defect occurred in the new vehicles, as well and was the main cause of the accident when it comes to these vehicles.

In terms of the odometer status of vehicles, for which a technical defect was the main cause of the traffic accident, it is clear from the graph that the average mileage that all those vehicles had at the time of an accident was 298 831 (171 343 km for category M1 and N1). Here too, however, the graph shows that even the vehicles with low mileage in many cases had technical defects that caused the traffic accident.

In terms of the consequences of traffic accidents due to vehicle technical defects, the statistics for 2016-2020 showed that 73 people were slightly injured, 10 people were seriously injured, 3 people were killed and a total of EUR 2,529,690 of damage was quantified in these road accidents.

6 Examination of traffic accidents due to vehicle technical defects in terms of their temporal distribution during the period of validity of the technical inspection and the age of the vehicles

Based on the data on the exact dates of traffic accidents due to technical defects of the examined vehicles in the period 2016-2020, it was determined when the vehicles were last subjected to the periodic technical inspection prior to the date of the accident and what was the validity period of this inspections. In the case of new vehicles which, according to the legal regulations of the Slovak Republic, were not yet subject to periodic technical inspection, the date of the first registration was considered to be the date of the technical inspection before the traffic accident. Based on determination of the period of validity of technical inspection of examined vehicles at the time of traffic accidents due to technical defects of these vehicles,

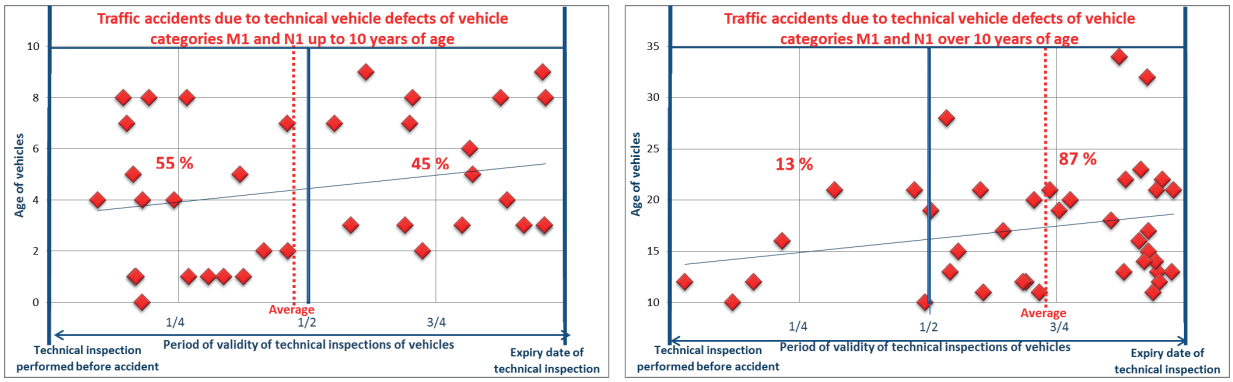

Figure 7 *Temporal distribution of traffic accidents due to technical defect of M1 and N1 category of vehicles aged up to 10 years and over 10 years in the period from the performance of technical inspection before the accident to the end of its validity*

the scatter graph (Figure 6) was subsequently created, into which data were transferred on the exact time of traffic accidents caused by technical defects of examined vehicles, which happened in the period from the latest technical inspection before the accident to its validity period.

The temporal distribution of all accidents due to vehicle technical defects in the period from the performance of the technical inspection before the accident until the end of its validity is illustrated in Figure 6.

The visual display of the data in the graph showed that vehicle accidents due to a technical defect occurred throughout the period of validity of their technical inspections, but the largest clusters were formed before the end of the validity of technical inspections. The calculated accident modus due to a vehicle technical defect is located in the graph approximately one month before the end of the validity of technical inspections. Thus, during that period happened majority of the traffic accidents due to vehicle technical defects. On average, however, traffic accidents due to vehicle technical defects occurred at the end of the second third of the period of validity of the technical inspection. Of all the traffic accidents caused by a vehicle technical defect, 35 % occurred in the first half of the period of validity of the technical inspection and 65 % of them occurred in the second half.

Subsequently, the same was done, but for vehicle categories M1 and N1. In fact, compared to other categories, most road accidents due to vehicle technical defects were recorded in the case of category M1 vehicles, which pose the greatest risk in terms of road safety. Moreover, the N1 vehicle category is similar to the M1 category. Therefore, special attention had to be paid to such vehicles. Those vehicle categories were therefore separately divided into two groups. The first group consisted of all the traffic accidents involving vehicles of categories M1 and N1, which were less than 10 years old at the time of the traffic accident. The second group consisted of all the accidents involving M1 and N1 vehicles, which were older than 10 years at the time of the accident. For these two groups, the two graphs were prepared (Figure 7), which depicted the temporal distribution of traffic accidents in the period from the performance of the technical inspection before the traffic accident to the end of its validity.

The temporal distribution of traffic accidents due to technical defect of M1 and N1 category of vehicles aged up to 10 years and over 10 years in the period from the performance of technical inspection before the accident to the end of its validity is illustrated in Figure 7.

The visual display of the data in the graph showed that traffic accidents due to technical defects of M1 and N1 vehicles with an age of less than 10 years usually occurred proportionally throughout the period of validity of their technical inspections, with a slight predominance in the first half of the period of validity of the periodic technical inspection, during which occurred 55 % of traffic accidents. In the second half, on the other hand, occurred 45 % of accidents. *Ratione temporis*, during the period of validity of the periodic technical inspection and age distribution, no anomalies or clumps occurred during traffic accidents. It could therefore be deduced from the above that newer vehicles have not yet been involved in traffic accidents due to technical defects, which would be affected by the technical inspection or its impending expiry date and the associated deterioration of the technical condition of the vehicles. Likewise, it is not possible to observe a clear dependence on vehicle age when it comes to occurrence of defects on vehicles. Only modest, as there is a slight increase in traffic accidents involving older vehicles in the second half of the period of validity of the periodic technical inspection. Traffic accidents due to vehicle technical defects of categories M1 and N1 aged up to 10 years are therefore probably due to other reasons, in particular, manufacturing defects found in certain vehicle components.

The situation was diametrically different in the case of vehicle categories M1 and N1 that are aged over 10 years. In this group, the traffic accidents due to vehicle technical defects were occurring to an incomparably greater extent only in the second half of the period of validity of their technical inspection. According to the

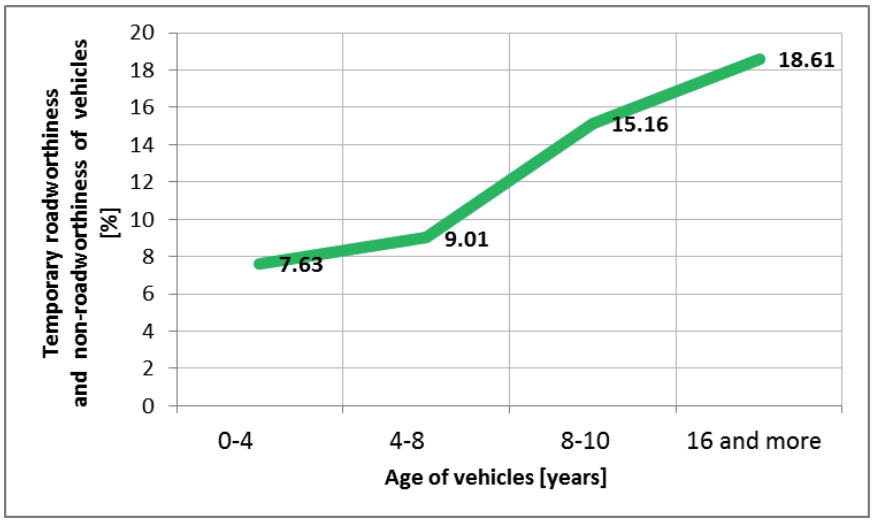

Figure 8 *Dependence of occurrence of the vehicle defects on the age of the vehicle in the Slovak Republic in the period 2019 - 2021*

legislation of the Slovak Republic, vehicle categories M1 and N1 are to be subjected to periodic technical inspections for the first time four years after the first registration and then at two-year intervals. The transformation of the period of validity of technical inspections of vehicles over 10 years of age into two-year periods showed that in the first year after the periodic technical inspections were carried out occurred only 13% of traffic accidents involving these vehicles. However, in the second year of validity of the technical inspection occurred up to 87% of traffic accidents due to technical defects on the vehicles cited.

Based on the above visual displays of the temporal distributions of traffic accidents due to technical defects in vehicles, it could be concluded that periodic technical inspections of vehicles have a demonstrable justification. With the approaching end of the period of validity of the periodic technical inspection, the incidence of traffic accidents due to vehicle technical defects and, consequently, the probability of their occurrence also increased rapidly. Moreover, since, according to Figure 4, the most traffic accidents due to vehicle technical defects involved vehicles of category M1 and at the same time the average age of vehicles of categories M1 and N1 that had a traffic accident due to a technical defect was 10.5 years, it could be deduced that by halving the validity of the periodic technical inspection for vehicles of categories M1 and N1 that are over 10 years of age, i.e. to one-year intervals, the number of traffic accidents due to technical defects of these vehicles could also fall by at least a half.

In this context, it should be noted that the age of vehicles constitutes a very strong factor that influences the incidence of vehicle defects. This can be empirically demonstrated. Data for the period 2019 – 2021, concerning the results of the assessment of the technical condition of vehicles at the PTI in the Slovak Republic, were selected from the information system of technical inspections of the Slovak Republic, namely the sum of percentages of temporary roadworthiness and non-roadworthiness of vehicles for the road traffic (i.e. the proportion of vehicles in which at least one serious or dangerous defect was detected) according to age bands. The above was selected from a total of all 3,554,432 periodic technical inspections and the related data are recorded in Figure 8.

From the graphic course of temporary roadworthiness and non-roadworthiness of vehicles, which was assessed on average by PTI in the Slovak Republic, it is visually clear that, in correlation with the increasing age of vehicles, the number of major and dangerous defects found on these vehicles during the technical inspections is also increasing. Thus, 7.63% of major and dangerous defects were found in vehicles aged 4 years and under and up to 18.61% of major and dangerous defects were found in vehicles over 16 years of age [37].

The above can also be verified through the correlation analysis. The value of the Pearson's correlation coefficient r(*X, Y*) of two variables *X*, *Y*, which is defined as the ratio of the covariance S_{XY} and the product of their standard deviations S_x S_y, is calculated according to:

$$r(X,Y) = \frac{S_{XY}}{S_X S_Y} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}((Y_i - \bar{Y}))^2}}. \quad (1)$$

The correlation coefficient of the dependence of the occurrence of vehicle defects (dependent variable) on the age of the vehicle (independent variable) in the Slovak Republic was calculated as r(*X, Y*) = 0.98, which is interpreted as a very strong correlation. The significance of this correlation coefficient was verified by the p-value test. Statistical P-value = 0.020346 < α (0.05), i.e. the null hypothesis H0 is rejected and the alternative

Table 6 *Assessment of the technical condition of vehicles by the PTI as temporarily roadworthy and not roadworthy and the number of traffic accidents caused by vehicle technical defects in each year in the period 2012 - 2020*

Year		2012	2013	2014	2015	2016	2017	2018	2019	2020
Temporarily roadworthy and not roadworthy vehicles	Quantity	30 757	40 835	58 130	98 689	97 114	70 627	84 711	162 836	165 629
	%	3.16	3.79	5.42	8.64	7.96	5.7	6.8	13.03	13.58
Accidents due to technical defects	Quantity	48	49	46	39	37	47	37	35	26

hypothesis H1 is accepted that there is a statistically significant linear relationship among y a x at the level of significance $\alpha = 0.05$.

This phenomenon is also evidenced by other studies conducted with a similar focus in other EU countries. In Finland, for example, over the period 2011-2015, on a sample of 13 million vehicles that underwent technical inspections, carried out research on the dependence of the number of major and dangerous defects found during technical inspections on vehicles on their age. It also follows from the above that as the age of vehicles increases, so does, quite significantly, the number of serious and dangerous defects found on vehicles during the technical inspections. In addition, in Germany, a survey was conducted in 2004 focusing on the effect of vehicle age on vehicle defect rate on a sample of 3 million vehicles during technical inspections and it was shown that 10% of major defects were found in vehicles around 4 years of age. In the case of vehicles older than 9 years, the defect rate increased to more than 31% [36]. However, this phenomenon is not accidental and does not concern only one year or one state. Studies from Sweden and Great Britain also prove it [36]. Passenger cars in Sweden and the so-called heavy vehicles from Great Britain show very similar trends.

It is therefore clear from the above that the factor that most influences the occurrence and number of technical defects found on vehicles during the technical inspection is the age of the vehicles and therefore shortening the interval of periodic technical inspections for older vehicles and categories, which suffered the most traffic accidents due to vehicle technical defect, would be highly justified. The PTI exclude from traffic a number of old vehicles with major and dangerous defects that pose a threat to road safety. These one-year periods of periodic technical inspections of M1 and N1 vehicles also apply in other EU countries, such as Finland, Latvia, the Netherlands, Spain, Estonia, Belgium, Bulgaria, Austria, etc.

7 Correlation of results of vehicles' technical inspections with traffic accidents due to vehicle technical defects

The purpose of periodic technical inspections of vehicles is to identify defects in vehicles, their parts, systems, components, or separate technical units in order to exclude from the road traffic technically non-roadworthy vehicles that pose a risk to health, lives, property and the environment. This leads to the hypothesis that the operation of PTI prevents the incidence of traffic accidents and thus has a positive effect on the road safety. However, this assumption cannot be unambiguously quantified. It is very difficult to identify and measure the direct causal link between the operation of PTI and the number of accidents caused by vehicle technical defects. Especially when technical inspections of vehicles have been carried out on the territory of the Slovak Republic for more than 70 years and therefore it is not possible to compare the state of accident rate before and after the introduction of these PTI. Similarly, statistics on traffic accidents due to vehicle technical defects do not create an objective picture of reality.

For this reason, a simple pairwise correlation and regression analysis was used to identify and measure the effect of periodic technical inspections of vehicles on accident rate due to vehicle technical defects. Within this framework, the correlation of the results of technical inspections of vehicles with the number of traffic accidents caused by vehicle technical defects in the period 2012 - 2021 was examined. The results of technical inspections of vehicles are represented by the number and percentage of temporary roadworthiness and non-roadworthiness of vehicles, which were assessed on average by the PTI in each year of the monitored period. Given that in the Slovak Republic the methodology for assessing traffic accidents due to vehicle technical defects did not change during the period under examination and therefore the data examined were not influenced by unknown variables. The monitored data (temporarily roadworthy and not roadworthy vehicles and traffic accidents due to technical defects) are recorded in Table 6.

The Pearson correlation coefficient was used to calculate the correlation rate between the temporarily roadworthy and not roadworthy vehicles (independent variable X) and the number of accidents due to vehicle technical defects (dependent variable Y). In order to eliminate doubts about the data of the independent variable, two correlation coefficients were calculated. The first was based on the number of temporarily roadworthy and not roadworthy vehicles and the second on the percentage rate of temporarily roadworthy and not roadworthy vehicles.

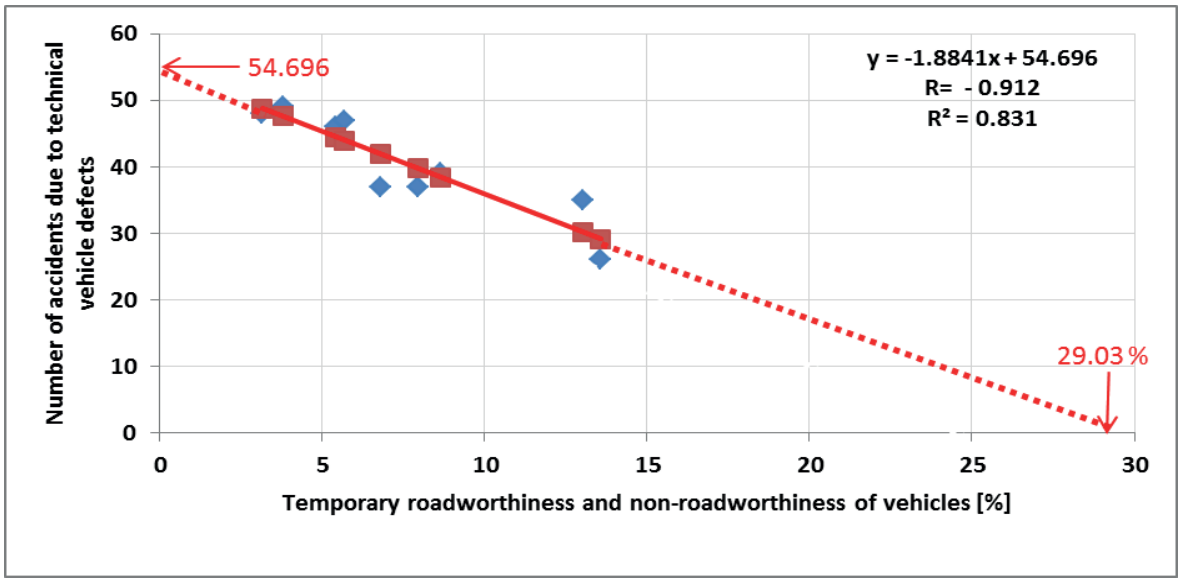

Figure 9 *Regression line and function*

The first correlation coefficient was calculated as r(*X, Y*) = -0.91, when the independent variable was the number of temporarily roadworthy and not roadworthy vehicles and the second correlation coefficient was calculated as r(*X, Y*) = - 0.912, when the independent variable was the percentage rate of temporarily roadworthy and not roadworthy vehicles. In both cases, this is interpreted as a very strong negative correlation. The significance of these correlation coefficients was verified by the p-value test. Statistical p-value = 0.000641 <α (0.05) if the independent variable was the number of temporarily roadworthy and not roadworthy vehicles and p-value = 0.000614 <α (0.05) if the independent variable was the percentage rate of temporarily roadworthy and not roadworthy vehicles. In both cases, therefore, the null hypothesis H0 was rejected and the alternative hypothesis H1 was accepted, i.e. there is a statistically significant linear relationship between *X* and *Y* (between the number of temporarily roadworthy and not roadworthy vehicles and the number of accidents due to vehicle technical defects) at the level of significance α = 0.05. This means that with the increasing number of vehicles assessed at the PTI as temporarily roadworthy and not roadworthy, the number of traffic accidents due to vehicle technical defects decreases. In view of the almost identical values of the calculated correlation coefficients, in order to simplify the interpretation of the results, only the correlation coefficient calculated from the percentage rate of temporary roadworthiness and non-worthiness was used for further mathematical modeling.

As a very high degree of correlation between the results of technical inspections given by the percentage rate of temporary roadworthiness and non-worthiness of vehicles and the number of traffic accidents due to vehicle technical errors with a statistically significant linear relationship was demonstrated, it was possible to determine a regression function.

The linear regression function is represented by a straight line that describes the linear relationship between the dependent variable Y and the independent variable X. The regression model of this line is estimated by the least-squares method, which minimizes the sum of squares of the residual deviations. The line estimated by the least-squares method is as close as possible to all actual values. The result is graphically recorded in Figure 9.

The regression function was determined in the form y = -1.8841x + 54.696. The value of R^2 (R Square) is the value of the coefficient of determination and in this case, it has a value of 0.831. This value, after multiplying by 100, indicates that the selected regression function explains the variability of the number of road accidents due to vehicle technical defects to approximately 83.1 %. The other part presents unexplained variability, the influence of random factors and other unspecified influences.

The null hypothesis H0 was tested in ANOVA, which states that the regression model chosen to explain the dependence (in this case a linear regression line) is not suitable. The alternative hypothesis H1 claims the opposite. An F test was used to evaluate this claim. Significance F = 0.000614 <0.05 (α - significance level), i.e. H0 is rejected and H1 is selected, which means that the regression model was selected correctly.

Based on the regression function, it was subsequently calculated by what rate of temporary roadworthiness and non-worthiness of vehicles would have to PTI in the Slovak Republic assess on average vehicles so that the number of road accidents due to technical defect would fall to zero. The value of this locating constant is 29.03 %. In the graph, this is expressed by extending the regression line shown by the dashed line to the

intersection with the X-axis. Value of the second locating constant is 54.696 (the number of road accidents due to technical defect, if the rate of temporary roadworthiness and non-worthiness of vehicles would by zero).

8 Conclusion and discussion

In connection with the elaboration of the topic, research of world literature was carried out, consisting of articles and studies that dealt with the issue of vehicle technical defects as the cause of traffic accidents and the effect of periodic technical inspections on the reduction of traffic accidents due to a vehicle technical defect. At the same time, some of these studies sought answers to questions about the justification for periodic technical inspection systems. Publications concerned showed that the proportion of traffic accidents caused by a direct causal link with vehicle technical defects to all the traffic accidents ranged from 1% to 24% and by an indirect causal link from 0.6% to 28%. Furthermore, the studies examining the effect of periodic technical inspections on traffic accidents showed that the effect of the system of technical inspection on accident rate ranged from no effect to a reduction in accident rate from 16% to 21%, or up to 50% and therefore periodic technical inspections are justified. However, some studies have argued the exact opposite [38].

The problem of the publications dealing with the technical defects of vehicles was that they covered a long period from 1967 to 2021 and the period, in which the older studies were created, which were the most numerous, were based on the period conditions (level of a vehicle fleet, roads, technical inspections, etc.), which were different from the current ones. These publications are therefore not entirely up to date as regards the empirical nature of the data and their direct use, but are definitely worth noting. Another problem was that just a few studies dealt purely with the mentioned topic, the sources of the data used in publication suffered from heterogeneity and were methodically differently processed. However, none of the publications examined the incidence of the traffic accidents in the period between the performance of technical inspections and the end of their validity, as well as the link between the results of the PTI of vehicles given by the temporary roadworthiness and non-roadworthiness of vehicles and the number of traffic accidents, what was examined in this article.

Regarding the publications, it should also be noted that, in particular, recent US studies (but also the older ones), differ significantly from European ones in that they increasingly call into question the system of mandatory periodic technical inspections of vehicles, which are gradually being abolished in individual US states [31]. This phenomenon largely reflects the social setting in the US, where there has long been controversy over whether the periodic technical inspections of vehicles are a cost-effective way to increase the road safety [25]. In particular, the analysis of changes in technical control procedures (in the US called security inspections), carried out in the US in 2017, raised many doubts about the effectiveness of these controls. According to the above analysis, the number of fatal accidents due to vehicle technical defects has been steadily decreasing over the last two decades, as well as due to the safer technology of newer vehicles [25]. However, the economic dimension plays a major role in this, because periodic technical inspections and subsequent repairs of vehicles represent financial costs for the inhabitants of the given states and thus their abolition, i.e. their absence is a politically popular topic.

As regards the traffic accidents due to vehicle technical defects in the Slovak Republic, it is clear that from the statistics that their rate is reported very low, as in other EU countries. The reason for that is the strict methodology of their assessment, according to which only a vehicle technical defect, which occurred suddenly and which the driver of the vehicle could not influence in any way, is to be considered the main cause of the traffic accident. Moreover, this must also be established by a court expert. The main goal of the police in investigating the cause of the traffic accident is to try to assign responsibility for the traffic accident due to a specific person and not to the technical condition of the vehicle, because if the vehicle is to be blamed, no penalty is imposed. In the event of a failure to comply with a person's obligations, a fine is imposed on that person. Therefore, it is assumed that the actual number of traffic accidents due to vehicle technical defects is higher than the one in reported statistics. Moreover, each country has its own methodology for assessing the technical defects as the main cause of accidents. For this reason, statistics on the number of traffic accidents due to vehicle technical defects suffer from heterogeneity, do not reflect reality and therefore it is not possible to marginalize the importance of the periodic technical inspection only based on their reported low rate.

Despite the low amount of information, data on traffic accidents due to vehicle technical defects in the Slovak Republic in the period of five years (2016-2021) were comprehensively processed. Their analysis showed that more than a half of the accidents due to vehicle technical defects were caused by tires (sudden air leakage and wheel failure), especially in terms of older vehicles with high mileage and vehicles of the M1 category. The above also corresponds to the most common vehicle technical defects that caused accidents abroad. Conversely, according to the statistical results of the assessment of the technical condition of vehicles at PTI in the Slovak Republic, the most frequent defects on vehicles were found on brake systems (almost half of all detected defects), lighting, reflective electrical equipment and chassis and its accessories. Defects of axels, wheels, tires and axle suspensions were found in the fifth place

only (just 5% of all the detected defects). This may also be since inspection operations during which the tires are being checked at the PTI (inspection items of group no. 5 axles, wheels, tires and suspension [2]) cannot be objectively inspected at the level of inspection bodies [39]. Although cameras are installed at the PTI in the Slovak Republic, for the purposes of supervision by the inspection bodies, through their use, however, it is not possible to check mainly essential inspection operations, for example how a technician of a PTI assesses braking systems. This then has a significant effect on the operation of the PTI, where in inspection items of group no. 1 (braking systems) technicians detect the most serious and dangerous defects on vehicles.

Furthermore, the article examined traffic accidents due to vehicle technical defects in terms of their temporal distribution during the period of validity of the technical inspection and the age of the vehicle. The purpose of that examination was to seek evidence confirming or refuting the justification for periodic technical inspections of vehicles. As a part of this, graphs were drawn up in which data on traffic accidents due to vehicle technical defects were set into the period of validity of the technical inspection, which was limited along the x-axis by the date of the technical inspection before the accident. At the same time, these accident data were also distributed in terms of the vehicle's age along the y-axis. Three of these graphs were constructed. The first graph (Figure 6) covers all the traffic accidents and all the categories of vehicles for the period 2016 - 2021, the other two graphs (Figure 7) show data on traffic accidents of only categories M1 and N1 on the grounds that category M1 had the largest share of these traffic accidents and vehicle category N1 is similar to category M1. With regard to vehicle categories M1 and N1 up to 10 years of age, according to Figure 7, accidents generally occurred proportionally throughout the period of validity of their technical inspections, with a slight predominance in the first half of the period of validity of the periodic technical inspection. Here, 55% of traffic accidents occurred, compared to 45% in the second half. Newer vehicles have therefore not yet been subject to traffic accidents due to vehicle technical defects that would be affected by technical inspection, i.e. its approaching expiry date and the associated deterioration of the technical condition of the vehicles, but for other reason, such as manufacturing defects in different vehicle components. According to Figure 7, the proportion of the traffic accidents due to technical defects of M1 and N1 vehicles over 10 years of age was only 13% in the first year since the performance of the technical inspection and in the second year of the validity of the technical inspection that share was up to 87%. On average, traffic accidents were occurring in this category no more than half a year before the end of the validity of the periodic technical inspection. It follows from the above that with the approaching end of the period of validity of periodic technical inspection, the occurrence of traffic accidents due to vehicle technical defects was rapidly increasing and thus also the probability of their occurrence. By reducing the mandatory two-year periods of periodic technical inspections of M1 and N1 vehicles that are older than 10 years by half, could hypothetically also reduce by more than half the number of traffic accidents due to technical defects of this group of vehicles. It is, however, debatable in this case whether the actual occurrence of defects in the vehicles, which cause the accidents at most in the period before the end of the validity of technical inspection was affected by the expiring period of the validity of the technical inspection or was that a random phenomenon. However, in this case, it should be noted that this phenomenon has a rational justification, as after a successful technical inspection, an owner of a vehicle is no longer motivated to have the vehicle inspected and defects fixed since he does not have to. For this reason, over time, within the period limited by the previous and the following periodic technical inspection, dangerous technical defects may occur (especially in the older ones), which are not known to the vehicle owner and which cause a traffic accident.

In the last part of the present article, an empirical identification and measurement of the effect of periodic technical inspection of vehicles on accident rate due to vehicle technical defects were carried out by means of a simple pairwise correlation and regression analysis. In particular, the links between the results of technical inspections of vehicles and traffic accidents due to technical defects were examined. The Pearson correlation coefficient was used to calculate the correlation rate between temporarily roadworthy and not roadworthy vehicles and the number of accidents due to vehicle technical defects in the period 2012-2021. The above correlation coefficient was calculated as $r(X, Y) = - 0.912$. This is interpreted as a very strong negative correlation and its significance was confirmed by a statistical test by means of a p-value. It follows from the above that as the number of vehicles assessed as temporarily roadworthy and not roadworthy by PTI increases, the number of traffic accidents due to vehicle technical defects decreases. Subsequently, the regression function in the form $y = -1.8841x + 54.696$ was determined and graphically portrayed together with the regression line (Figure 9). Based on the cited function, it was calculated that with an 83.1% probability, if vehicles in the Slovak Republic are to be assessed at PTI by an average of 29.03% rate of temporary roadworthiness and not roadworthiness, the number of traffic accidents due to vehicle technical defects will drop to zero. However, the question, in this case, could be whether the strong correlation found between the percentage of temporarily roadworthy and not roadworthy vehicles and the number of accidents due to vehicle technical defects is in fact the result of causal links, or only causality. The temporal link of phenomena does not always mean that there is a causal link between them. Many correlations are purely random and contain other

hidden or intervening variables. However, in the case of the calculated correlation between the results of the assessment of vehicles at PTI and the number of traffic accidents, there are logical causal links that militate against the time coincidences in trends.

The results formulated in this paper show that periodic technical inspections of vehicles have a measurable effect on traffic accidents due to vehicle technical defects and therefore have demonstrable justification. As the consequences of traffic accidents due to technical defects tend to be fatal, it is not appropriate to perceive mandatory technical inspections as just a financial burden for citizens, but as one of the effective tools for improving road safety. At the same time, periodic technical inspections of vehicles fulfil their purpose indirectly through the psychological effect that they have on vehicle operators. Awareness of the obligation to undergo a periodic technical inspection of a vehicle causes that certain defect on vehicles are being preventively fixed by the vehicle owners even before the performance of such inspection, thereby contributing in this manner to their safety as well as others [40]. Without this, they probably would not have any incentive to behave like this.

However, a prerequisite for an effective system of periodic technical inspection is that PTI will carry out their duty with better quality and realistically identify all the serious and dangerous defects on vehicles during the periodic technical inspections, which could endanger road safety. In this way, they could prevent traffic accidents that occur due to vehicle technical defects. Therefore, instead of calling the systems of periodic technical inspections into question, national authorities should rather take more stringent measures to improve the performance of PTI (especially at the EU level), such as the introduction at PTI of compulsory accreditation under ISO 17020 [41], which has a demonstrably positive effect on the quality of the PTI activity [42], as well as pay attention to inspections of PTI. As an example may serve the Slovak Republic, where inspection bodies effectively control the activities of technicians through cameras, thanks to which, after the introduction of this control system, the rate of temporary roadworthiness and non-worthiness in the assessment of vehicles at PTIs increased significantly and, in correlation with this, decreased the number of traffic accidents due to vehicle technical defects.

Acknowledgment

This research was funded by the project of institutional research of the Faculty of Operation and Economics of Transport and Communications, University of Zilina no. 2/KCMD/2021 Research on the impact of urban logistics on the environment.

This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

References

[1] Roadworthiness package. Regulation of the European Parliament and of the Council on periodic roadworthiness tests for motor vehicles and their trailers and repealing. Directive 2009/40/EC and Regulation of the European Parliament and of the Council on the technical roadside inspections of the roadworthiness of commercial vehicles circulating in the Union and repealing Directive 2000/30/EC and Regulation of the European Parliament and of the Council amending Council Directive 1999/37/EC on the registration documents for vehicles. Brussels: European Commission, 2012. SWD(2012) 206 final.

[2] Directive 2014/45/EU of the European Parliament and of the Council on periodic roadworthiness tests for motor vehicles and their trailers and repealing Directive 2009/40/EC.

[3] FAZZALARO, J. Periodic motor vehicle safety inspections. Connecticut General Assembly Office of Legislative Research, 2007. 2007-R-0591.

[4] ASANDER, S. Vehicle safety inspection systems. In: Conference and Workshop Wheels '92: proceedings. 1992.

[5] RACQ submission to travelsafe committee. Does Queensland need compulsory periodic inspections of passenger vehicles? Queensland: RACQ, 1990.

[6] ROMPE, K., SEUL, E. Advantages and disadvantages of conducting roadworthiness tests to monitor the mechanical condition for private cars, the impact of such tests on road safety, environmental protection and the renewal of the vehicle fleet and the scope for introducing roadworthiness testing throughout the European community. Final report commissioned by the Directorate-General for Transport, VII/G-2 of the Commission of the European Communities, Drawn up by the TUV Rheinland, 1985.

[7] GRANDEL, J. Investigation of the technical defects causing motor vehicle accidents. *SAE International Congress and Exposition* [online]. 1985, 850434. ISSN 0148-7191, e-ISSN 2688-3627. Available from: https://doi.org/10.4271/850434

[8] MCLEAN, A. J., AUST, H. S., BREWER, N. D., SANDOW, B. L. Adelaide in-depth accident study. Part 6: Car accidents. Adelaide: The University of Adelaide, 1979. ISBN 0-908204-02-7.

[9] TREAT, J. R. Tri-level study of the causes of traffic accidents: an overview of final results. In American Association for Automotive Medicine Annual Conference 1997: proceedings. Vol. 21. 1997. p. 391-403.
[10] HAWORTH, N., SMITH, R., BRUMEN, I., PRONK, N. Case-control study of motorcycle crashes. Australia: Federal Office of Road Safety, 1997. Report CR 174.
[11] HAWORTH, N., VULCAN, P., BOWLAND, L., PRONK, N. Estimation of risk factors for fatal single vehicle crashes. Victoria, Australia: Monash University Accident Research Centre, 1997. Reports No. 121.
[12] CASE, M., DE FOREST, R., YOUNGMAN, J. H. R. Compulsory periodic vehicle inspections. Technical Paper SAE. 1991. No. 912587.
[13] RECHNITZER, G., HAWORTH, N., KOWADLO, N. the effect of vehicle roadworthiness on crash incidence and severity. Victoria, Australia: Monash University, Accident Research Centre, 2000.
[14] FILIPCZYK, J., MAKAROVA, I., BELYAEV, E. Analysis of periodical technical inspection systems in automotive transport. The experiences of Poland and Russia. *Transport Problems* [online]. 2015, **10**(4), p. 121-128. eISSN 2300-861X. Available from: https://doi.org/10.21307/tp-2015-053
[15] WOLFE, A. C., O'DAY, J. Cost-effectiveness of periodic motor vehicle inspection (PMVI): a review of the literature. Washington, DC: National Highway Traffic Safety Administration [online]. Available from: http://deepblue.lib.umich.edu/bitstream/2027.42/158/2/71884.0001.001.pdf
[16] NHTSA. Study of the effectiveness of state motor vehicle inspection programs. Final report. USA: US Department of Transportation, 1989.
[17] WHITE, W. T. A theory of how the period of vehicle inspection affects the evolution of defects and the probability of accidents. In: Road Traffic Safety Seminar: proceedings. Vol. 1. 1988. p. 14-16
[18] LOEB, P. D., GILAD, B. The efficacy and cost-effectiveness of vehicle inspection. A state specific analysis using time series data 1984. *Journal of Transport Economics and Policy*. 1984, **18**(2), p. 145-164. ISSN 0022-5258.
[19] SCHROER, B. J., PEYTON, W. F. The effects of automobile inspections on accident rates. *Accident Analysis and Prevention* [online]. 1979, **11**(1), p. 61-68. ISSN 0001-4575. Available from: https://doi.org/10.1016/0001-4575(79)90040-X
[20] SCHULZ, W. H., FRANCK, O. An empirical study to estimate the economic effects of the introduction of a periodical technical inspection (PTI) for motor vehicles in Punjab (Pakistan). *The Open Transportation Journal* [online]. 2021, **15**(1), p. 182-193. ISSN 2667-1212, eISSN 1874-4478. Available from: http://doi.org/10.2174/1874447802115010182
[21] WHITE, W. T. Relaxation of PMVI: scenario selection. Wellington, New Zealand: Traffic Research Branch, Ministry of Transport, 1986.
[22] BUYVOL, P. A,. GABSALIKHOVA, L. M., MAKAROVA, I. V., MUKHAMETDINOV, E.M. Increase in the efficiency of the operation of vehicle inspection companies (in Spanish). *Contemporary Dilemmas - Politacal Education and Values / Dilemas Contemporaneos - Education Politica y Valores*. 2018, **6**(90), p. 1-13. eISSN 2007-7890.
[23] Study on the inclusion of light trailers and two- or three- wheel vehicles in the scope of the periodic roadworthiness testing. Final report - Publications Office of the European Union [online]. 2019. Available from: https://op.europa.eu/en/publication-detail/-/publication/366a32b6-34c2-11e9-8d04-01aa75ed71a1
[24] SCHULZ, W. H., SCHELER, S. Reducing the death toll of road accidents in Costa Rica through the introduction of roadworthiness inspections by the government. *SSRNElectronic Journal* [online]. 2019, p. 1-27. ISSN 1556-5068, eISSN 1556-5068. Available from: http://dx.doi.org/10.2139/ssrn.3420341
[25] HOAGLAND, A., WOOLLEY, T. It's no accident: evaluating the effectiveness of vehicle safety inspections. *Contemporary Economic Policy* [online]. 2018, **36**(2), p. 607-628. eISSN 1465-7287. Available from: https://doi.org/10.1111/coep.12284
[26] SCHULZ, W. H., SCHELER, S. Getting ready for Europe: an empirical assessment for the introduction of periodical technical inspections of road vehicles in Turkey. *SSRN Electronic Journal* [online]. 2020, p. 1-26. ISSN 1556-5068, eISSN 1556-5068. Available from: http://dx.doi.org/10.2139/ssrn.3420341
[27] KEALL, M. D., NEWSTEAD, S. An evaluation of costs and benefits of a vehicle periodic inspection scheme with six-monthly inspections compared to annual inspections. *Accident Analysis and Prevention* [online]. 2013, **58**, p. 81-87. ISSN 0001-4575. Available from: https://doi.org/10.1016/j.aap.2013.04.036
[28] FOSSER, S. An experimental evaluation of the effects of periodic motor vehicle inspection on accident rates. *Accident Analysis and Prevention* [online]. 1992, **24**(6), p. 599-612. ISSN 0001-4575. Available from: https://doi.org/10.1016/0001-4575(92)90012-8
[29] WHITE, W. T. Does periodic vehicle inspection prevent accidents? *Accident Analysis and Prevention*. 1986, **18**(1), p. 51-62. ISSN 0001-4575.
[30] BERG, G., DANIELSSON, S., JUNGHARD, O. Traffic safety and periodic vehicle inspections / Trafiksakerhet och periodisk fordonskontroll (in Swedish). VTI rapport 281. 1984. ISSN 0347-6030.

[31] CRAIN, W. M. *Vehicle safety inspection systems. How effective?* Washington DC: American Enterprise Institute for Public Policy Research, 1980. ISBN 0-8447-3361-X.

[32] LITTLE, J. W. Uncertainties in evaluating periodic motor vehicle inspection by death rates. *Accident Analysis and Prevention* [online]. 1971, **2**(4), p. 301-313. ISSN 0001-4575. Available from: https://doi.org/10.1016/0001-4575(71)90043-1

[33] GARCIA-CORDONIE, J., IZQUIERDO, P., VILAN, J. A., SEGADE, A., CASAREJOS, E., LAGO, M. L. Definition and implementation of an integrated management plan (IMP) applied to the equipment at periodical technical inspection (PTI) stations. In: 6th International Conference of Integrity-Reliability-Failure IRF2018: proceedings. 2018. p. 785-794.

[34] GARCIA, S. R., BABE, G. A., LOPEZ, D. V. Contribution of the technical inspection of vehicles to road safety / Contribucion de la inspeccion tecnica de vehiculos a la seguridad vial (in Spanish). Madrid: Fundacion Instituto Tecnologico para la Seguridad del Automovil (FITSA), Instituto de Seguridad de los Vehiculos Automoviles (ISVA), Universidad Carlos III, 2007.

[35] GARCIA, S. R., BABE, G. A., LOPEZ, D. V. Contribution of periodic motor vehicle inspection (PMVI) to vehicle safety. Madrid: Fundacion Instituto Tecnologico para la Seguridad del Automovil (FITSA), Instituto de Seguridad de los Vehiculos Automoviles (ISVA), Universidad Carlos III, 2012.

[36] Autofore: Study on the future options for vehicle roadworthiness enforcement in the European Union - International Motor Vehicle Inspection Committee (CITA) [online]. Available from: http://citainsp.org/wp-content/uploads/2016/01/PressReleaseEN.pdf

[37] HUDEC, J., ŠARKAN, B., CZODOROVÁ, R. Examination of the results of the vehicles technical inspections in relation to the average age of vehicles in selected EU states. *Transportation Research Procedia* [online]. 2021, **55**(6), p. 2-9. ISSN 2352-1465. Available from: https://doi.org/10.1016/j.trpro.2021.07.063

[38] JAROSINSKI, W. Periodic technical inspections of vehicles and road traffic safety with the number of road accidents involving fatalities. *Eksploatacija i Niezawodnosc - Maitenance and Reliability* [online]. 2014, **16**(1), p. 105-111. ISSN 1507-2711. Available from: https://doi.org/10.17531/ein.2014

[39] DUBRETA, N., MIKULIC, I. Subjectivity and technology in work of technicians in periodical technical inspection stations. *Interdisciplinary Description of Complex Systems* [online]. 2019, **17**(3), p. 640-658. ISSN 1334-4684, eISSN 1334-4676. Available from: https://doi.org/10.7906/indecs.17.3.18

[40] MIKULIC, I., BOSKOVIC, I., ZOVAK, G. Effects of driving style and vehicle maintenance on vehicle roadworthiness. *Promet - Traffic and Transportation* [online]. 2020, **32**(5), p. 667-667. ISSN 0353-5320. Available from: https://doi.org/10.7307/ptt.v32i5.3443

[41] ZOVAK, G., CALA, I., SISKO, I. Applilacion of standards in auditing of stations for technical inspection of vehicles. *Promet - Traffic and Transportation* [online]. 2009, **21**(3), p. 191-198. ISSN 0353-5320, eISSN 1848-4069. Available from: https://doi.org/10.7307/ptt.v21i3.225

[42] HUDEC, J., SARKAN, B., CZODOROVA, R., CABAN, J. The influence of quality management system on the operation of periodical technical inspection stations. *Applied Sciences* [online]. 2021, **11**(11), 4854. eISSN 2076-3417. Available from: https://doi.org/10.3390/app1111485