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Vehicle Technical Inspection Results in Relation to EU Directives and Selected EU Countries

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Although road accidents caused by defective vehicles are relatively rare, the roadworthiness of vehicles is important for road safety. In the European Union, the technical conditions that need to be fulfilled by the vehicles using public roads are regulated by EU directives. According to these directives, technical inspections are organized in every EU country. Our study analyzed the vehicle technical inspections in Slovenia over four consecutive years. The statistics for passenger cars and commercial vehicles are compared with two other EU countries: Germany and Finland. From this comparison, it follows that certain differences exist between the countries, although vehicle technical inspections are regulated by the same EU directives. Finally, multivariate regression models were built to predict probabilities of various vehicle defects detected during regular technical supervision as a function of the vehicle's age. It was found that the probability of fault detection can be effectively modelled as a function of vehicle age.

Keywords: passenger vehicles, commercial vehicles, technical supervision, fault statistics, statistical modelling

Highlights

- *A statistical analysis on technical supervisions was made for Slovenia.*
- *Linkage between the technical state of vehicles and vehicle participating in road traffic accidents was evaluated for Slovenia.*
- *Technical state of vehicles and typical detected defects were compared for Slovenia, Germany and Finland.*
- *Uniformity of considering the EU directives that regulate the technical safety and roadworthiness was discussed.*

0 INTRODUCTION

Every year, many serious traffic accidents occur, causing serious injuries or death to the people involved. There are many reasons for traffic accidents: human factor, inadequate infrastructure, technical defects of vehicles, and various combinations of the previously mentioned factors. Statistics from different countries around the world vary. In more developed countries, more traffic accidents are caused by human factors than by inadequate infrastructure or vehicle defects. In the USA, for example, vehicle defects are the main cause of accidents in 1.3 % to 2.7 % of cases [1], whereas this percentage is between 3 % and 6 % in the EU, according to Thomas et al. [2]. Rolison et al. [3] report that vehicle defects cause up to 12 % of accidents in the UK, but this information may be somewhat unreliable because it was obtained through a survey of police officers. In South Africa, the reported percentage of defect-related accidents varies between values of 2 % for direct causes and 6 % for indirect causes [4]. The most recent report for that country is 14.1 % for direct and indirect causes [5]. According to Van Schoore et al. [4], this percentage in less-developed African countries is higher and reaches 16 %. In India, vehicle defects are responsible for 9 % to 32 % of road traffic accidents, depending on the region [6]. Hudec and Sarkan [7] report that less than 1 % of traffic accidents are caused by vehicle defects in Slovakia. For Slovenia, it was rather difficult to find this data, but Brcar [8] reports that vehicle defects are responsible for only 0.2 % of road traffic accidents. This figure is also questionable because in most non-serious accidents the true cause of the accident is often not determined. Moreover, according to the non-public data available for our study, the causes of traffic accidents are not reported in the police database. In a very recent systematic overview Martin-delosReyes et al. [9] stated that road crashed, which can be attributed to vehicle defects vary between 3 % and 19 % in developed countries and up to 27 % in developing countries.

Others investigated the causes of accidents in a narrower range; for example, Newman and Goode [10] report various influences on road accidents in Australia related to fleet management, maintenance, and use of commercial vehicles. Uchida et al. [11] investigated a relationship between the active safety components of the car and the main types of accidents in Japan. Garnowski and Manner [12] investigated the influence of the parameters of the connecting road to the highway on traffic accidents.

From the above-mentioned studies, it can be concluded that many different parameters, variables, and circumstances cause road accidents. However, when the main cause of accidents is a vehicle defect,

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the following components have been identified as responsible in some selected countries:

- USA: poor condition or inadequate inflation of tyres (35 %), braking system defects (22 %), and steering system defects (3 %) [1], [13] and [14];
- UK: braking system defects, poor condition or inadequate inflation of tyres, steering-system defects, and poor lighting equipment [15];
- South Africa: poor condition or inadequate inflation of tyres (80 %), braking system defects (4 %), and steering system defects (3 %) [5].

Despite the small percentage of road accidents caused by defective vehicles, most of them could be prevented if all technical defects were detected during regular technical inspections. These inspections are required and enforced by the individual member states. In the EU, there are several directives that regulate the technical safety and roadworthiness of road vehicles:

- Council Directive 1999/37/EC on the registration documents for vehicles (document 01999L0037-20180520) [16] and Directive 2014/46/EU amending the Council Directive 1999/37/EC on the registration documents for vehicles (document 32014L0046) [17].
- Directive 2007/46/EC [18], a framework for the approval of motor vehicles and their trailers, and of systems, components, and separate technical units intended for such vehicles (document 02007L0046-20200902).
- Regulation (EC) No 661/2009 [19] concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components, and separate technical units intended therefor (document 02009R0661-20190424).
- Directive 2014/45/EU [20] on periodic roadworthiness tests for motor vehicles and their trailers and repealing Directive 2009/40/EC (document 02014L0045-20140429).

Since the national regulations in the EU member states for road vehicle technical inspections are subordinate to the EU directives, it can be assumed that in the various member states with comparable vehicle populations, approximately the same statistics exist on the defects found during roadworthiness testing. Having obtained these statistical data for Slovenia, the data for passenger cars were compared with those of Finland and Germany. In addition, the data for commercial vehicles were compared with Germany. The reason for this is that reliable data sources in publicly available forms were found for these two EU countries.

Then, multivariate regression models were established to predict the probability of defect detection at technical inspections. Different static and dynamic regression models were tested for nine defect groups (lighting and electrical equipment, braking system, steering, vehicle identification, axles, chassis and suspension, visibility, emissions, and other equipment) for the Slovenian fleet of passenger cars, commercial vehicles, and motorcycles and ATVs. Finally, a correlation between the technical condition of vehicles and road accidents in Slovenia was investigated for the same three types of motor vehicles.

The article is organized as follows. After the introductory section, the basic statistical analyses and data models are explained. The third section presents the results and discussion. In this section, first, the process of data preparation is described. Then, the statistical data for Slovenia are presented and discussed, followed by a comparison with Germany and Finland. The section ends with regression models for predicting the probability of fault detection during technical inspections and a discussion of the relationship between the technical condition of vehicles and traffic accidents. The article ends with a concluding section, a list of references, and an acknowledgement.

1 METHODS

1.1 Data Cleaning and Pre-Processing

The following databases were obtained from the Slovenian Traffic Safety Agency and the Ministry of Internal Affairs:

- Databases of the vehicles' roadworthiness that follow from the technical inspections for the years 2016 to 2022.
- Databases of defects detected during technical inspections for 2016 to 2022.
- Traffic accident databases for the years 2016, 2017, and 2018.

The individual databases were composed of the following data:

- vehicle roadworthiness database (23 factors): vehicle ID, car brand, factory mark, commercial mark, commercial type, VIN number, designation of vehicle category, description of vehicle category, vehicle upgrade (label and description), additional equipment, type of fuel (label and description), date of the first vehicle registration, date of the first registration in Republic of Slovenia (RS), kilometres driven, vehicle owner

code, vehicle user code, technical inspection (TI) date, the outcome of the technical inspection (roadworthiness), the start of TI validity, end of TI validity, implementing contractor;
- vehicle defect database (16 factors): vehicle ID, VIN number, designation of vehicle category, description of vehicle category, vehicle upgrade (label and description), additional equipment, type of fuel (label and description), fault label, detailed fault description, item description (up to four items), vehicle condition assessment;
- traffic accident database (8 factors): vehicle ID, VIN number, licencing plate, car brand, commercial mark, vehicle mass, the maximum technical allowed mass of the vehicle, and date of the traffic accident.

For the statistical analyses, all three bases were linked via the VIN number of the vehicle. This was done using MS Access software by creating various queries that we used to facilitate data review, processing, and cleaning. For data processing and analysis, the vehicles from the databases were divided into five categories:
- passenger cars: categories M1 and M1G;
- buses: categories M2, M2G, M3, and M3G;
- commercial vehicles: categories N1, N1G, N2, N2G, N3, and N3G;
- motorcycles and ATVs: all categories with the designation L*;
- tractors: all categories with the designation T*.

For the most part, the vehicle roadworthiness database and the vehicle defects database clearly recorded the data, although there were some problems related to the letters with a canopy being written with different characters, indicating a mismatch in the text code tables. However, the problem was easily resolved by replacing these letters, as they were the same in all databases.

In addition to this deficiency, the following problems were the most common and troublesome in the individual records:
- Inconsistency of vehicle brand entries for older cars, trucks, and tractors (e.g., the numeral “0” is used instead of the letter “O”).
- The same vehicle models have different commercial marks (e.g., a “space” character is used where there should be no space numeral “0” is used instead of the letter “O”). Some commercial marks also contain the manufacturer’s name and/or more detailed information about the vehicle (e.g., engine description as 1.9 TDi).
- In some records, there is incorrect information about the commercial mark, or there is no such information at all. The inconsistency of commercial marks is high for motorcycles and tractors. Especially in the case of motorcycles, the number of brands is very large (>300) for two reasons: i.) inconsistent brand names and ii.) brands of which there is only one motorcycle in Slovenia (e.g., various niche manufacturers or local craftsmen). In addition, commercial-mark inconsistency is extremely high for commercial vehicles and tractors. The inconsistency of commercial marks for vehicles extends across all four years.
- The mileage (kilometres driven) is missing or incorrect (e.g., 0, 1, pure multiples of 10). The missing kilometres appear for vehicles that were not registered for the first time in the Republic of Slovenia and only for the first entry in the database. In later years, the kilometre data for these vehicles are entered.
- Duplicate records in the database for the same technical inspection result.

These problems and data inconsistencies were solved as follows:
- Additional data pre-processing with special macros in MS Access. In this way, most of the problems with passenger cars could be solved, but far fewer problems with the other four types of vehicles can.
- Manual correction of vehicle brands and commercial marks for some commercial vehicles, motorcycles, and tractors, which was very time-consuming. Indeed, almost twice as much time was spent correcting the commercial marks of tractors and commercial vehicles for each year than for correcting the names of all passenger cars, even though the databases contained about ten times fewer records for tractors and commercial vehicles than for passenger cars.
- Regression of mileage based on vehicle age and statistical region. The main problem related to this inconsistency was a very large mileage spread. Therefore, this option was applied only to a limited extent so as not to affect the summary statistics too much.
- When processing statistical data on motorcycles, all brands for which only one technical inspection was carried out in the current year were excluded.

Table 1 shows the number of records for the performed technical inspections after the data cleaning was carried out for the individual years and individual types of motor vehicles. It can be concluded from Table 1 that the number of individual technical inspections of vehicles is consistent between

Table 1. *Number of considered records for technical inspections of motor vehicles*

Vehicle type	Year						
	2016	2017	2018	2019	2020	2021	2022
Passenger cars	99821	1029319	1040114	1062620	1052913	1069943	1077562
Commercial vehicles	118584	126839	135776	143332	145706	151155	153565
Motorcycles and ATVs	81382	103494	96187	99396	99747	105387	116107
Buses	5643	5876	6039	6105	5454	5514	5888
Tractors	103520	106124	107801	110001	105892	105387	111034

years, with a slight, but consistant, positive trend for passenger cars and commercial vehicles.

1.2 Basic Statistical Analyses

For the five vehicle categories, the following statistical data were calculated:

- vehicle roadworthiness (share of acceptable, conditionally acceptable, or not acceptable vehicles and not acceptable vehicles with critical fault) as a function of the vehicle age summarized at the levels of regions and the whole of Slovenia;
- average mileage as a function of vehicle age summarized at the level of regions and Slovenia as a whole;
- absolute and relative numbers of the nine detected fault groups (according to the nine fault categories: lighting and electrical equipment, braking system, steering, vehicle identification, axles, chassis and suspension, visibility, emissions, and other equipment) as a function of the vehicle age summarized at the levels of regions and the whole of Slovenia;
- ranking of vehicle commercial marks according to their roadworthiness as a function of the vehicle age for passenger cars, commercial vehicles, and motorcycles;
- statistical distribution of the critical vehicle defects as a function of the vehicle age for commercial marks of passenger cars, commercial vehicles, and motorcycles.

In the last two cases, the statistical data for buses and tractors were not processed because the number of buses is too small, and the data on the roadworthiness of tractors are not reliable. In Slovenia, old tractors make up a significant part of the fleet. In the case of tractors, technical inspections do not have to be carried out at the site of the implementing contractors but can be done at an agreed-upon location in the farm's field. However, the control of such technical inspection points is more difficult and complicated.

2.3 Multivariate Regression Models

In various fields, the linear regression method is one of the most widely used methods for modelling the dependence between independent and dependent variables. Let Y represent the dependent variable and $\mathbf{X}=\left(X_1, X_2, \ldots, X_p\right)$ vector of p independent variables. Then a multivariate linear regression model has the following form [21] and [22]:

$$Y = a_0 + \sum_{i=1}^{p} a_i \cdot X_i, \tag{1}$$

a_0 represents the constant term, and a_i represent the i^{th} regression coefficient. For the application of the multivariate linear regression models, the following conditions must be fulfilled [19]:

- a linear dependence exists between the Y and X_i variables;
- variables X_i are mutually independent;
- prediction errors $\varepsilon_j = \hat{y}_j - y_j$ are mutually independent and normally distributed with a mean value equal to zero and a constant variance.

$\hat{y}_j$ represent a predicted value of the dependent variable for the j^{th} sample in the set. The constant term and regression coefficients are free parameters of the multivariate linear regression model estimated by the least square method based on pairs of the independent and dependent variables $\left\{\left(\mathbf{x}_j, y_j\right)\ ;\ j=1,\ldots,n\right\}$. If the dependent and independent variables are standardized before building a multivariate linear regression model, then the regression coefficients of the standardized model represent the relative importance of the corresponding independent variables.

By using different transformations of the basic independent variables X_i, multivariate regression can also be used to model non-linear dependencies between the independent and dependent variables. In this case, the condition of linear independence between each variable X_i is neglected. In our research, such a transformation was used to square some independent variables, which significantly improved the quality of the regression models for predicting the probability of defect detection.

Since we had at our disposal databases on vehicle technical inspections for seven consecutive years (2016 to 2022), the dynamic model of the dependence between the dependent (Y) and the independent variables (X_i) was also built. They were set up either as simple regression models:

$$Y = a_0 + \sum_{i=1}^{p} a_i \cdot X_i + a_{p+1} \cdot t, \qquad (2)$$

or as a decoupled time-space models with b_0 and b_1 being the time-related regression coefficients:

$$Y = \left(a_0 + \sum_{i=1}^{p} a_i \cdot X_i\right) \cdot \left(b_0 + b_1 \cdot t\right). \qquad (3)$$

Eq. (3) can be rewritten into the following form:

$$Y = a_0 + \sum_{i=1}^{p} a_i \cdot X_i + a_{p+1} \cdot t + \sum_{i=p+2}^{2\cdot p+1} a_i \cdot X_i \cdot t. \qquad (4)$$

For all regression models, a coefficient of determination R^2 was used to assess the quality of the regression model, because it represents a proportion of the data variance that is described by the regression model. The regression model is good if the value of R^2 is close to one. IBM SPSS 26 and Microsoft Excel software were used to build the regression models.

Regression models for predicting the probability of defect detection in each of the consecutive four years are presented in Table 2. A total of 135 regression models were built for each year: (3 vehicle categories) × (5 different models) × (9 fault groups). Dynamic regression models for predicting the defect detection probability are presented in Table 3. Altogether, 54 dynamic regression models were built: (3 vehicle categories) × (2 functional models) × (9 fault groups).

2 RESULTS AND DISCUSSION

2.1 Statistical Data for Slovenia

In Slovenia, different inspection periods are prescribed for different vehicles. For passenger cars, motorcycles,

Table 2. *Basic regression models for individual years from 2016 to 2022*

Model	Independent variables*		
	Passenger cars	Commercial vehicles	Motorcycles and ATVs
Model #1	X_1 = vehicle age	X_1 = vehicle age	X_1 = vehicle age
Model #2	X_1 = vehicle age X_2 = fraction of TI per age class	X_1 = vehicle age X_2 = fraction of TI per age class	X_1 = vehicle age X_2 = fraction of TI per age class
Model #3	X_1 = vehicle age $X_2 = X_1 \cdot X_1$	X_1 = vehicle age X_2 = X1 $\cdot X_1$	X_1 = vehicle age $X_2 = X_1 \cdot X_1$
Model #4	X_1 = average mileage per age class	X1 = average mileage per age class $X_2 = X_1 \cdot X_1$	X1 = average mileage per age class $X_2 = X_1 \cdot X_1$
Model #5	X_1 = average mileage per age class X_2 = fraction of TI per age class	X_1 = average mileage per age class X_2 = fraction of TI per age class	X1 = average mileage per age class X_2 = fraction of TI per age class

* The dependent variable *Y* in each regression model represents the defect detection probability at the technical inspection (TI). Therefore, each regression model has 9 variations for 9 defect groups that are detected at TIs.

Table 3. *Dynamic regression models*

Model	Independent variables*,**		
	Passenger cars	Commercial vehicles	Motorcycles and ATVs
Basic dynamic model	X_1 = *vehicle age* $X_2 = X_1 \cdot X_1$ X_3 = *t* = *year*	X_1 = *vehicle age* $X_2 = X_1 \cdot X_1$ X_3 = *t* = *year*	X_1 = *vehicle age* $X_2 = X_1 \cdot X_1$ X_3 = *t* = *year*
Decoupled dynamic model	X_1 = *vehicle age* $X_2 = X_1 \cdot X_1$ X_3 = *t* = *year* X_4 = *vehicle age · year* $X_5 = X_2$ · *year*	X_1 = *vehicle age* $X_2 = X_1 \cdot X_1$ X_3 = *t* = *year* X_4 = *vehicle age · year* $X_5 = X_2$ · *year*	X_1 = *vehicle age* $X_2 = X_1 \cdot X_1$ X_3 = *t* = *year* X_4 = *vehicle age · year* $X_5 = X_2$ · *year*

* The dependent variable *Y* in each regression model represents the defect detection probability at the technical inspection (TI). Therefore, each regression model has 9 variations for 9 defect groups that are detected at TIs.
** The variable "year" represents the individual database, i.e., 2016 => X_3 = *1*; 2017 => X_3 = 2 etc.

and ATVs, the first technical inspection takes place at the age of four years. After that, technical inspections take place at the ages of six and eight years. After the vehicle is nine years old, technical inspections are performed every year. For commercial vehicles, buses, and tractors, the technical inspections take place every year. In this article, only the results for the entire country of Slovenia are presented to facilitate comparison with Germany and Finland.

For reasons previously explained, this article presents only the statistical data for passenger cars, commercial vehicles, motorcycles, and ATVs. For

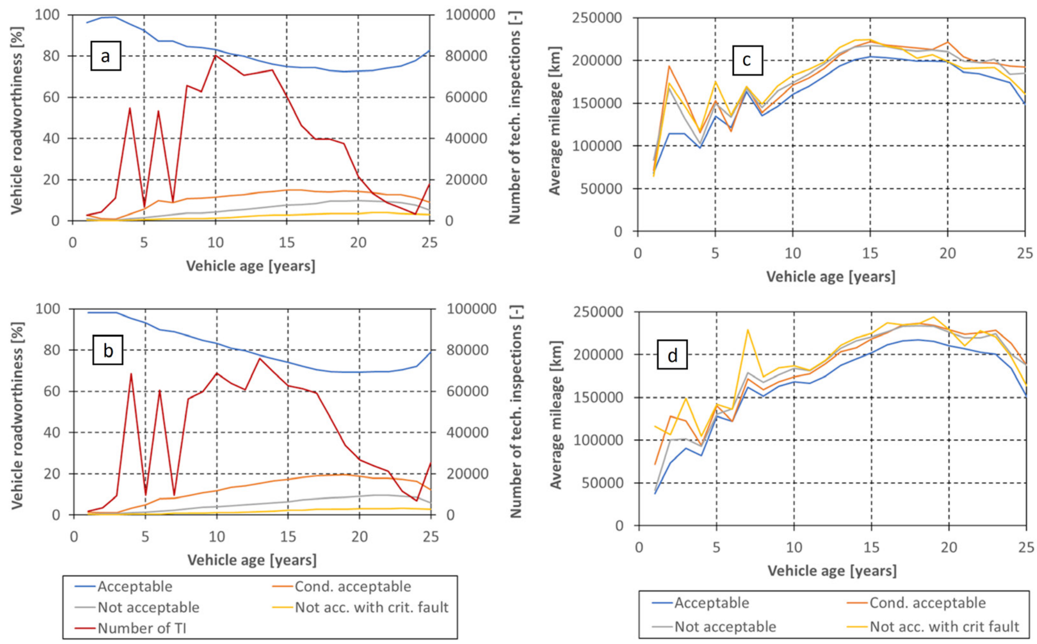

Fig. 1. *Results of the technical inspections: a) year 2018, b) year 2021; and average mileage: c) year 2018, d) year 2021; for passenger cars*

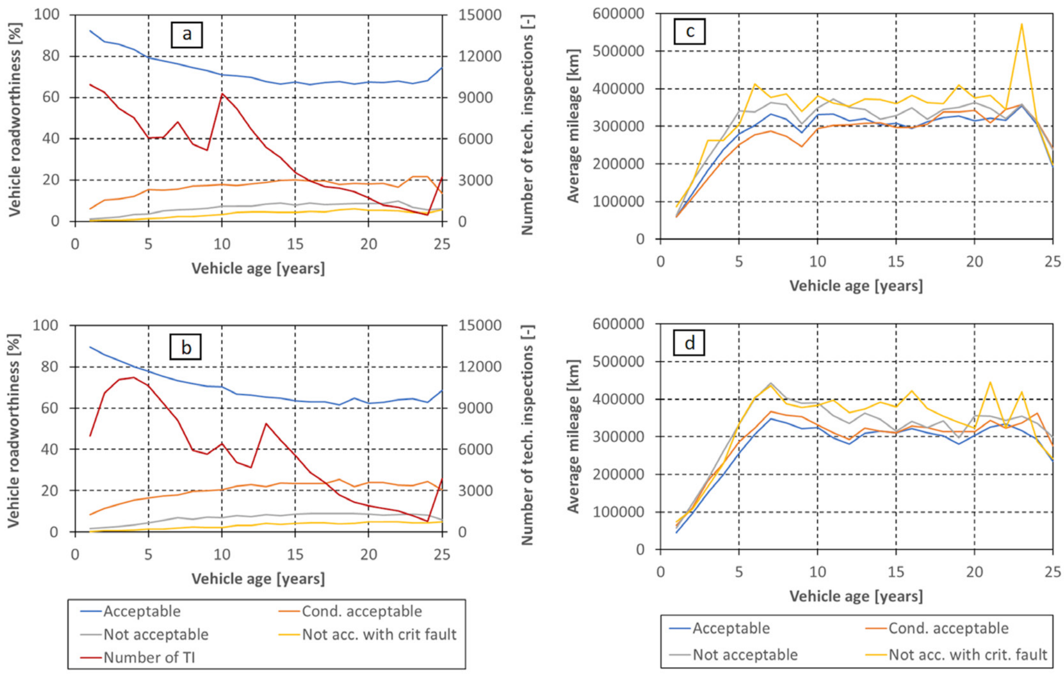

Fig. 2. *Results of the technical inspections: a) year 2018, b) year 2021; and average mileage: c) year 2018, d) year 2021; for commercial vehicles*

passenger cars, the average mileage and the results of technical inspections in 2018 and 2021 are presented in Fig. 1. The same statistics are presented in Fig. 2 for commercial vehicles and in Fig. 3 for motorcycles and ATVs. The statistics for the other five years are similar to these figures.

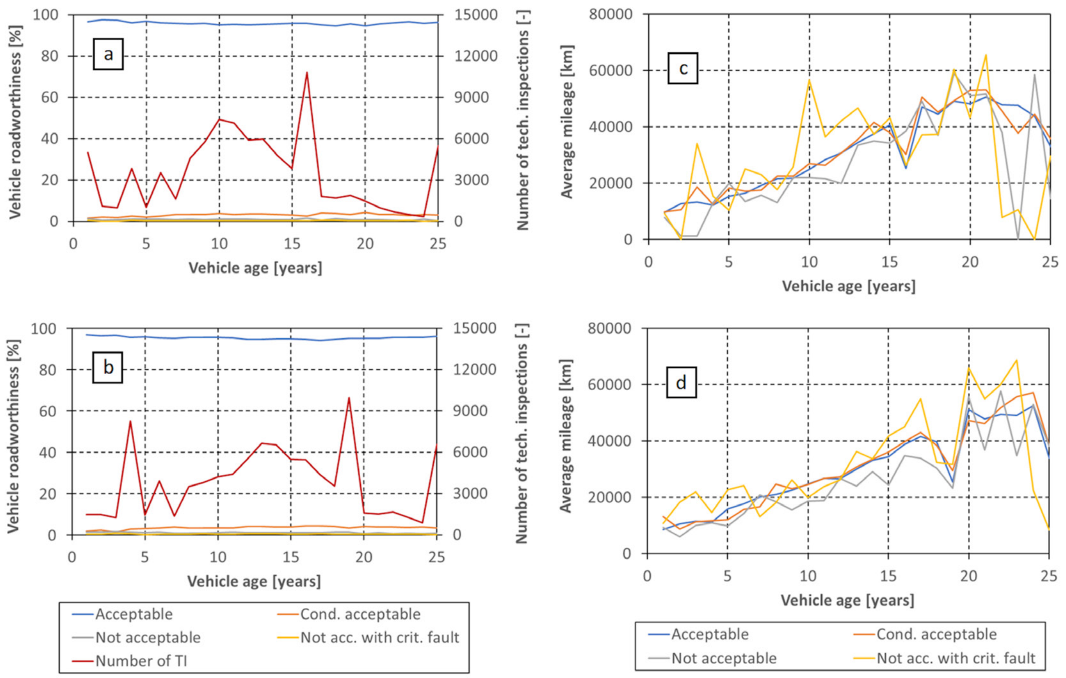

Fig. 3. *Results of the technical inspections: a) year 2018, b) year 2021; and average mileage: c) year 2018, d) year 2021; for motorcycles and ATVs*

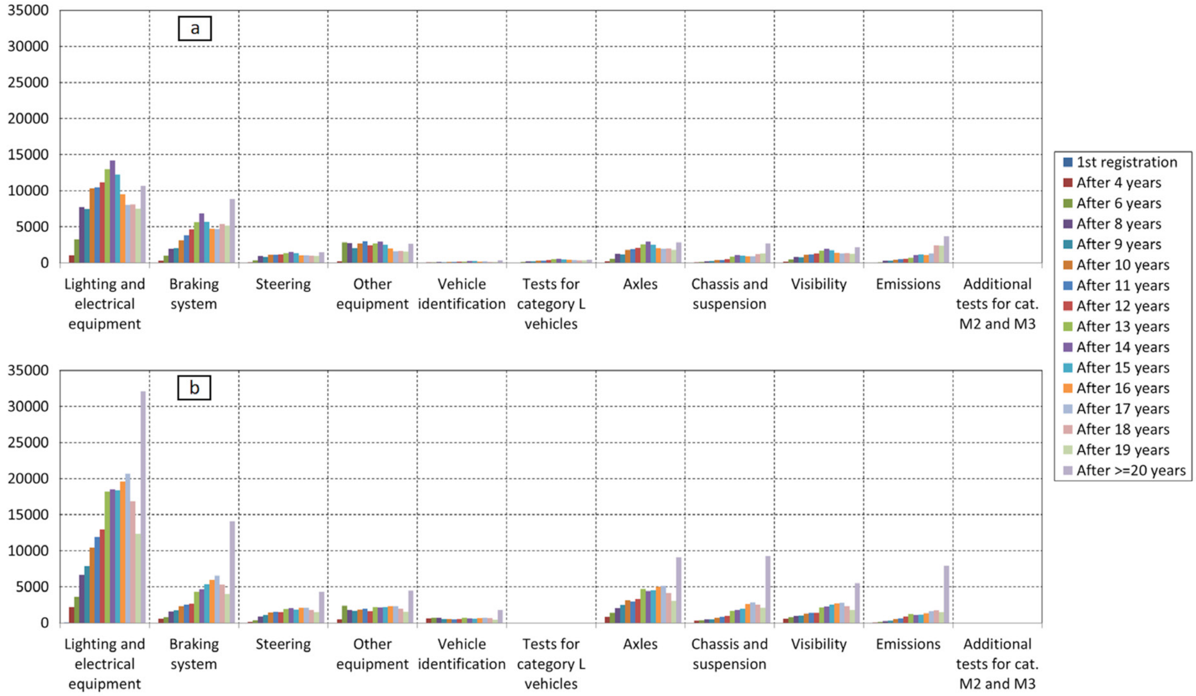

Fig. 4. *Detected defects as a function of the vehicle age – passenger cars: a) year 2018, b) year 2021*

Statistical data for 2016 to 2022 are consistent for the three vehicle categories. For passenger cars and commercial vehicles, the average mileage for technical inspections increases slightly but steadily from 2016 to 2022. The older the vehicle, the worse its technical inspection success and the higher its mileage.

After the age of 15 years, the decreasing trend of technical inspection success becomes a fairly constant. The trend in mileage as a function of age is rather proportional for motorcycles and ATVs, but degressive for passenger cars and commercial vehicles. It can also be seen in Figs. 2 and 3 that the peaks of technical inspections are shifted for three years, indicating a rather low volatility of the fleet. Since the number of technical inspections for commercial vehicles is rather small after the vehicle age of twenty years, it can be concluded that owners usually dispose of the worn-out vehicles. Except for passenger cars, the average mileage at technical inspection is not a good indicator of the technical roadworthiness of the vehicle. However, on average, passenger cars with lower mileage have slightly better technical inspection results than cars with higher mileage.

In this part of the study, a comparison was also made between the roadworthiness of vehicles found during technical inspections and the proportion of technically acceptable and unacceptable vehicles involved in traffic accidents. This comparison was made for passenger cars, commercial vehicles, and motorcycles and ATVs for the years 2017, 2018, and 2019. It was found that the relative proportion of acceptable/unacceptable vehicles in technical inspections corresponds very well with the records in the traffic accident database. Specifically, the vehicles that failed the technical inspection for the first time did not cause more accidents than the technically acceptable vehicles, as measured by their relative proportion in the technical inspections. This means that technical faultlessness is really not a major cause of road accidents in Slovenia.

Figs. 4 to 6 show distribution of detected defects according to vehicle age for passenger cars, commercial vehicles, motorcycles and ATVs for 2016 and 2018. For the commercial vehicles, the statistics are shown for every two years.

In Figs. 4 to 6, it can be seen that the detected defects are consistent between the two years, which is also true for the other five years with an exception of the oldest vehicles. After the year 2020 the technical inspections became more strict for this age group, which results in an increased number of detected defects. The same is also true for the first regular technical inspection for motorcycles and ATVs (i.e.

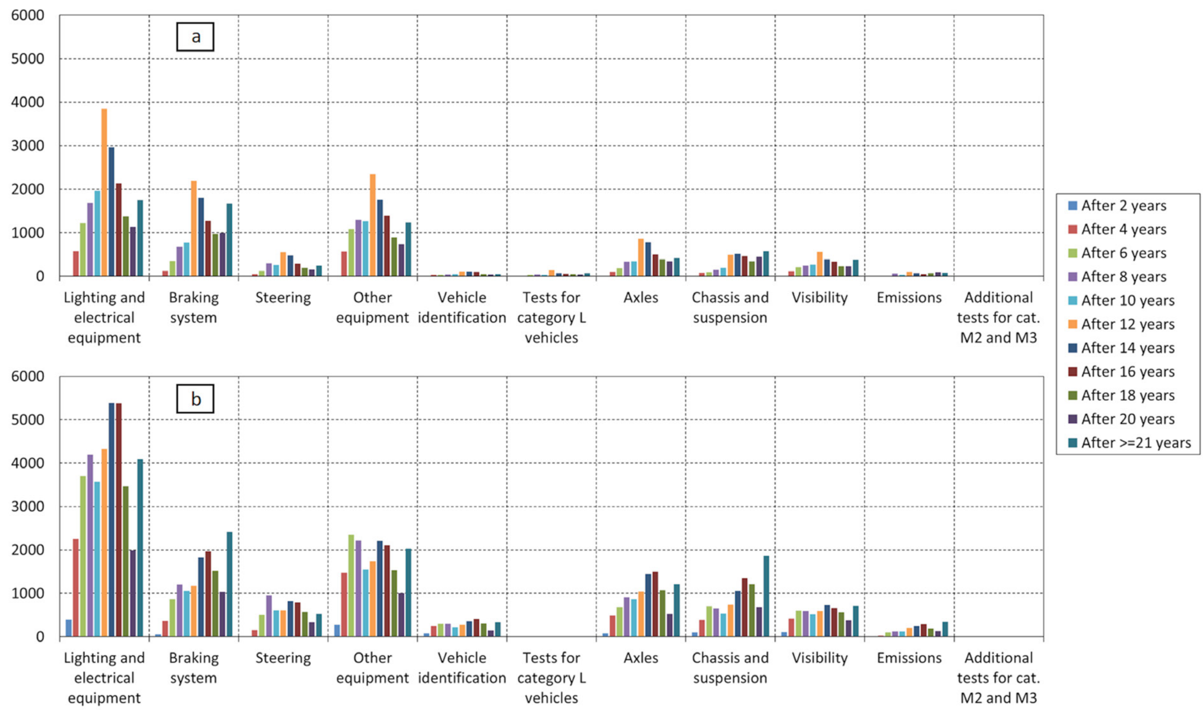

Fig. 5. *Detected defects as a function of the vehicle age – commercial vehicles: a) year 2018, b) year 2021*

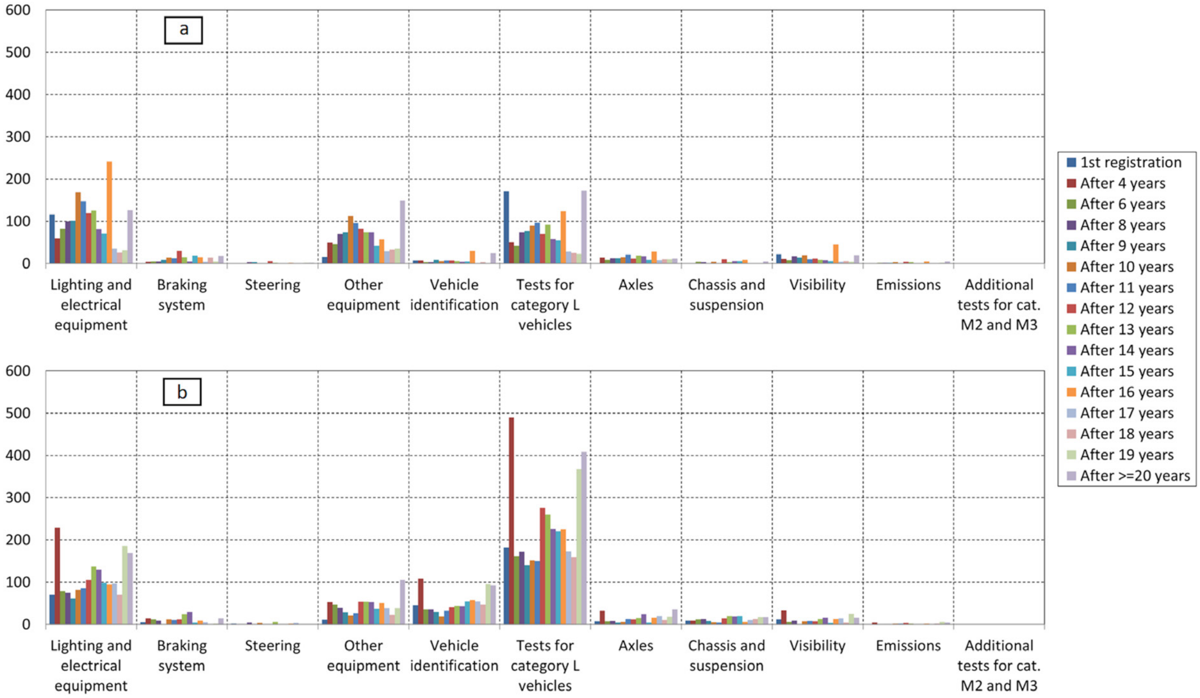

Fig. 6. *Detected defects as a function of the vehicle age – motorcycles and ATVs: a) year 2018, b) year 2021*

at the age of four years). For passenger cars and commercial vehicles, the most likely deficiencies are lighting and electrical equipment, braking system, and other equipment (missing first aid kit for passenger cars and fire extinguisher for commercial vehicles). Motorcycles and ATVs are most likely to have deficiencies in lighting, electrical, and other equipment or fail the tests for Class L vehicles.

2.2 Comparison with Germany and Finland

For comparison with the other countries, only publicly available data on the Internet were used. Despite the fact that some recently research results on the vehicle technical inspections for different EU countries are published (e.g. see Hudec et al. [23] for all vehicles or Tapak et al. [24] for vehicles with smart technologies) it is difficult to find more detailed statistical data on age-dependent different types of vehicle failures. In most of the published literature a summarized statistical data on the vehicle defects can only be found. For this reason, the statistical data on individual defect types for Slovenia are compared only to the equivalent statistical data for Germany and Finland. For the three countries the available statistical data did not contain detailed information on the generic vehicle's propulsion system (ICE, BEV or PHEV).

For passenger cars, a Traficon database [24] was used for Finland and summarized TUeV reports [26] to [29] were used for Germany. For commercial vehicles, data from Verkehrs Rundschau [30] and [31] journal were used. Although the country-specific regulations for technical vehicle inspections are subordinate to the same EU directives, the main defect groups are subdivided differently into subgroups. For this reason, it was difficult to compare the statistical data between EU countries. To make the comparison possible, the statistical data from the defect subgroups of Finland and Germany were combined so that the data corresponded to the Slovenian defect groups.

Table 4 compares the roadworthiness of passenger cars in Germany and Slovenia. Table 5 compares the probabilities of detecting typical defects in passenger cars in Germany and Slovenia. Fig. 7 compares the probabilities of defect detections for passenger cars in Finland and Slovenia. A comparison between Finland and Slovenia is made only for 2017 to 2019, since data on the technical inspections of passenger cars were not available for Finland for 2016. Fig. 8 shows the roadworthiness of commercial vehicles in Germany. Finally, Fig. 9 compares the probabilities of defect detections for typical commercial vehicle defects between Germany and Slovenia. This comparison for is made only for five years due to data availability for Germany.

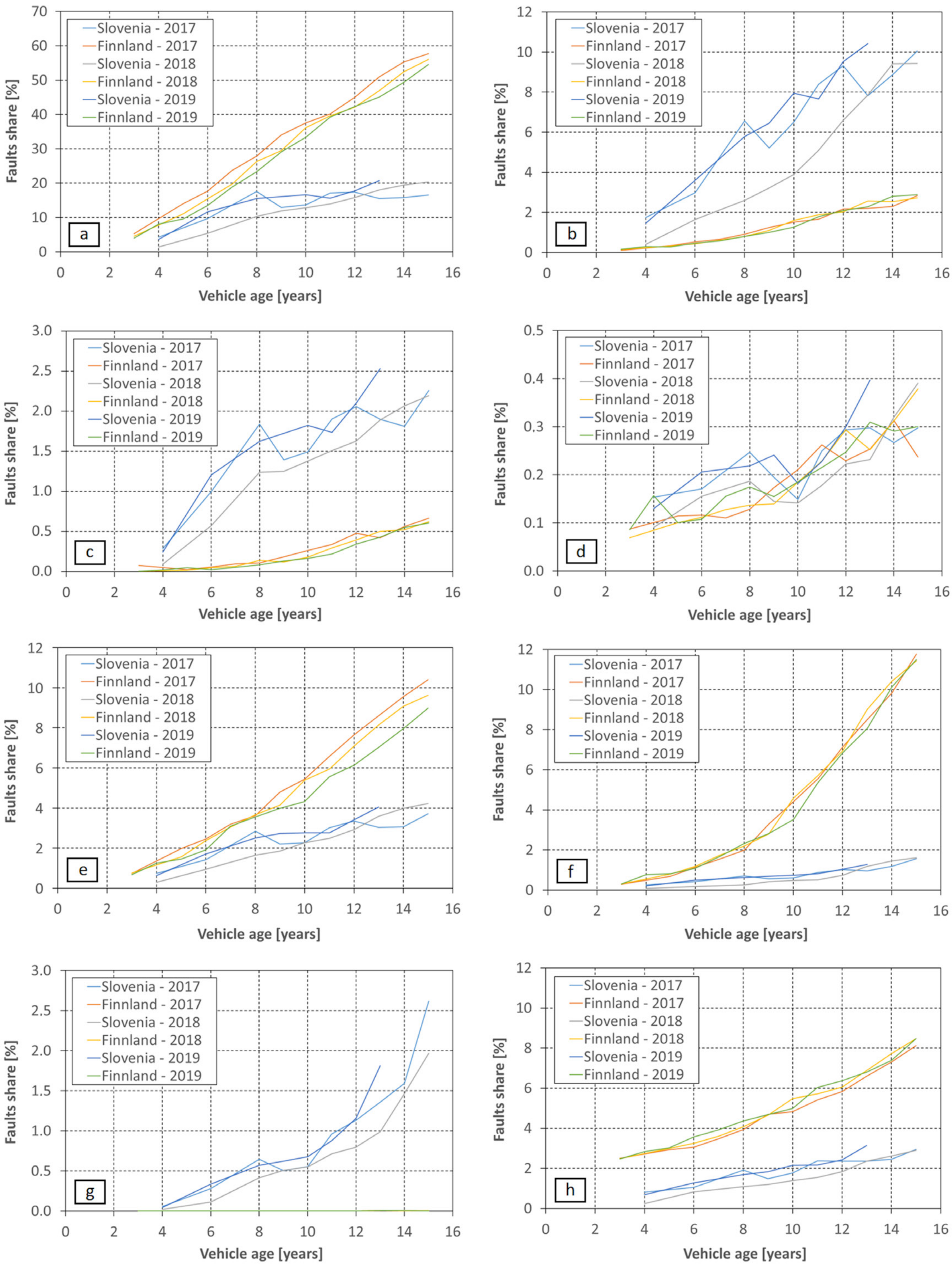

Fig. 7. *Defect detection probabilities for passenger cars in Finland and Slovenia: a) lighting and electrical equipment, b) braking system, c) steering equipment, d) vehicle identification, e) axles, wheels and suspension, f) chassis and body, g) emissions, h) visibility*

From Tables 4 and 5, and Fig. 7, the following can be concluded for passenger cars:

- The stringency of technical inspections is higher in Germany for all age classes of passenger cars than in Slovenia, where far fewer vehicles are considered to be in perfect condition. A direct comparison of the defects detected during technical inspections is only possible to a limited extent due to the different specifications of the defects in Germany and Slovenia. Nevertheless, it can be stated that the proportions of the most common defects (i.e., lighting system and brake system) are similar in Slovenia and Germany.

- In contrast to Germany, it is difficult to claim that technical inspections in Finland are stricter than in Slovenia. For four defect groups (lighting and electrical equipment; axles, wheels and suspension; chassis and body; visibility), more defects are found in Finland than in Slovenia, while for three defect groups (braking system; steering; emissions), more defects are found in Slovenia. No significant differences were found in vehicle identification. In both countries, the most frequent defects are found in the braking system and in lighting and electrical equipment.

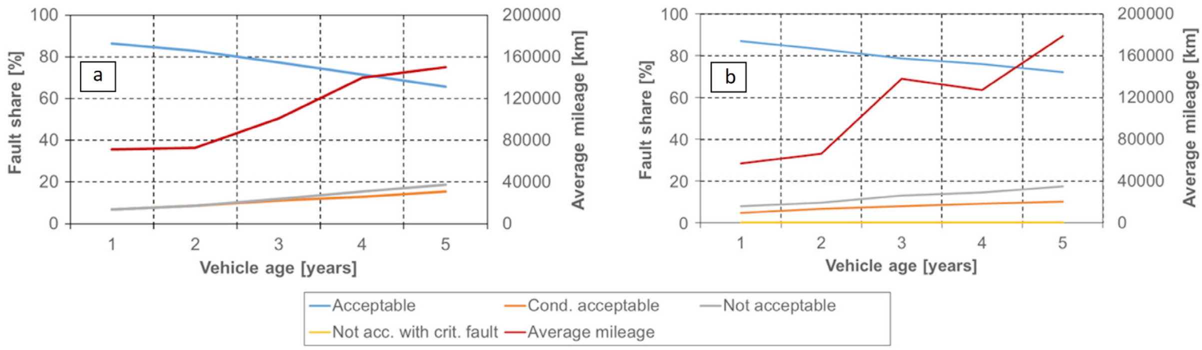

Fig. 8. Roadworthiness of commercial vehicles in Germany at technical inspections: a) years 2016/2017, b) years 2019/2020

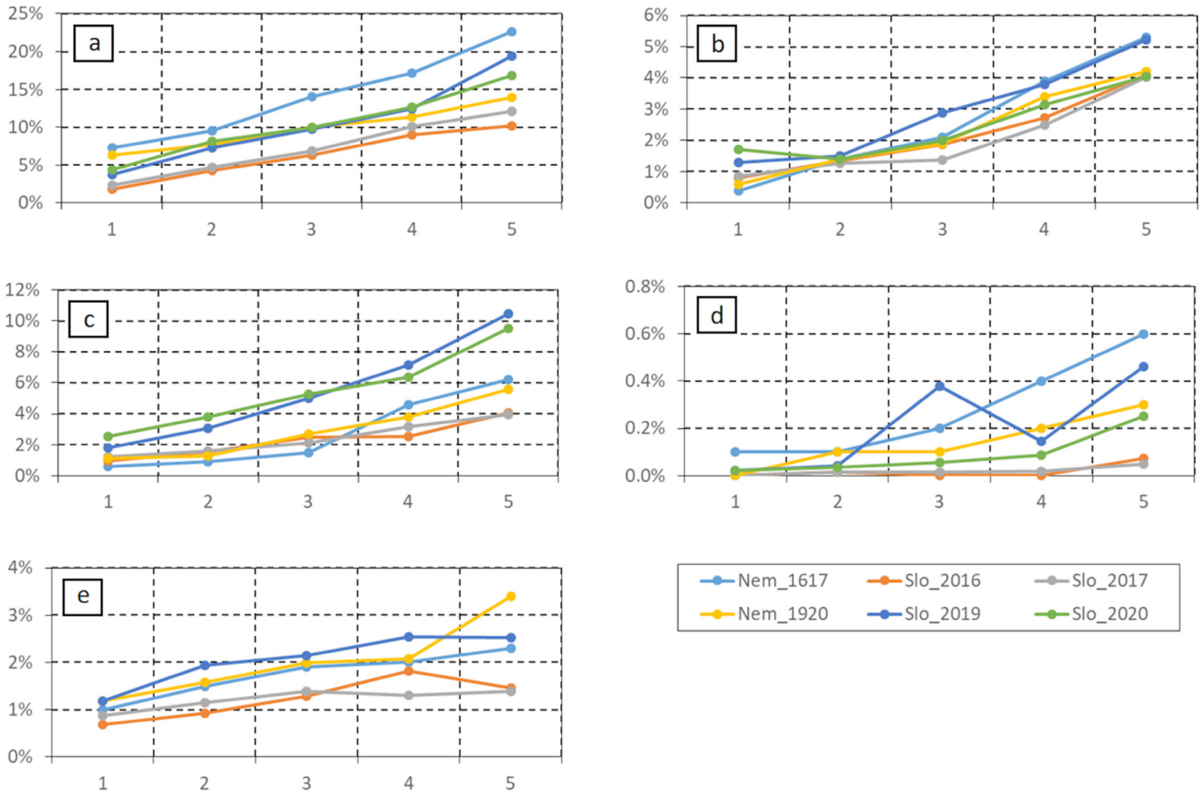

Fig. 9. *Defect detection probabilities for 1 to 5 years old commercial vehicles in Germany and Slovenia: a) lighting equipment, b) braking system, c) chassis and suspension, d) emissions, e) visibility*

Table 4. *Roadworthiness of passenger cars in Germany and Slovenia at technical inspections*

Age of the technically unacceptable vehicles	Germany [%]	Slovenia – all technically unacceptable vehicles* [%]			
		2016	2017	2018	2019
4 to 5	10.3	1.9	1.7	1.7	1.7
6 to 7	16.3	3.4	3.7	3.4	3.3
8 to 9	22.2	4.6	4.8	4.8	4.6
10 to 11	28.0	6.3	6.4	6.0	6.4

* The first technical inspection for passenger cars is carried out at the age of four years in Slovenia

Table 5. *Probabilities of fault detections for passenger cars in Germany and Slovenia*

Fault type	Germany	Slovenia			
		2016	2017	2018	2019
Lighting equipment	7.3 %	10.7 %	11.9 %	11.4 %	10.5 %
Suspension elements	4.5 %	0.3 %	0.3 %	0.3 %	0.4 %
Braking system	2.8 %	3.3 %	3.3 %	2.9 %	2.1 %

From Figs. 2, 8, and 9, the following conclusions can be drawn for commercial vehicles:

- The average mileage of commercial vehicles up to five years old is comparable in Slovenia and Germany, but the percentage of defect-free vehicles (including critical defects) is lower in Slovenia than in Germany for the same vehicle age.
- The relative frequency of detected defects is not the same in Slovenia and Germany, although it is difficult to compare these data because of the different specifications of the defects. Never the less, no significant differences were found for the lighting equipment, brake system, visibility, or chassis and suspension. In both countries, the most common defects are with the lighting system.

From the comparisons presented, it can be concluded that technical inspections in the three countries place a different emphasis on individual defect groups. As a result, the roadworthy condition of vehicles may be assessed differently in these countries. Nevertheless, the most common defects found in these countries are the same, which means that the prescribed technical inspection procedures do not differ to an unacceptable extent.

2.3 Regression Models for Predicting the Probability of Fault Detection

Figs. 10 and 11 show the defect detection probabilities at technical inspections in the years 2018 and 2021 for commercial vehicles, motorcycles and ATVs. The statistics for the other five years are similar and will not be presented here. For the passenger cars, these probabilities are shown in Fig. 7 for the years 2017, 2019 and 2021. The statistics for the other years are also similar. When these figures are compared to Fig. 4 to 6 the same trend can be noticed, i.e., that after the year 2020 the technical inspections became more strict. Since more faults were detected at approximately the same number of technical inspections per year the probability of fault detection rose in the years 2020 to 2022.

From Figs. 7, 10, and 11, it can be seen that the probability of defect detection during technical inspections did not increase proportionally with vehicle age. It was also found that vehicle age predicted the probability of defect detection much better than average mileage. Consequently, the basic regression model #3 from Table 2 was consistently found to be the best for the three vehicle categories and defect groups studied. The regression coefficients and the values of the deterministic coefficient R^2 for

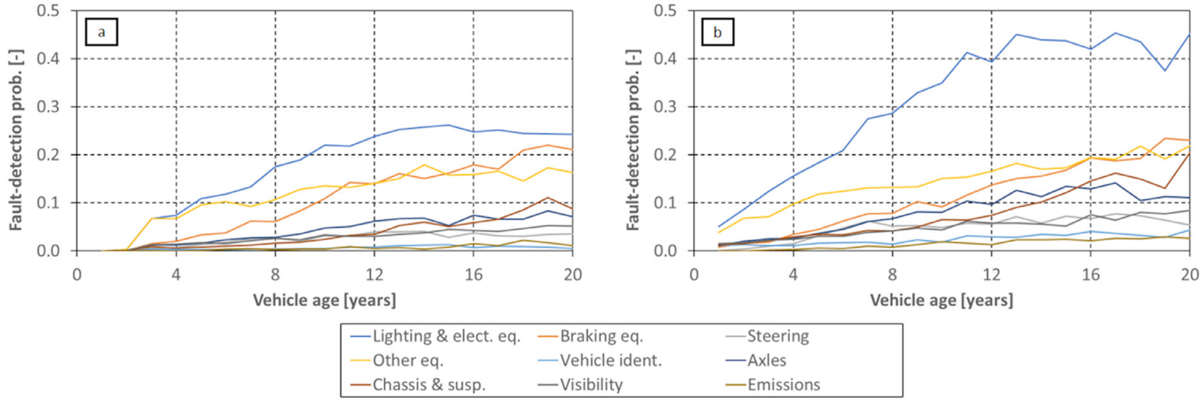

Fig. 10. *Defect detection probabilities for commercial vehicles in Slovenia: a) year 2018, b) year 2021*

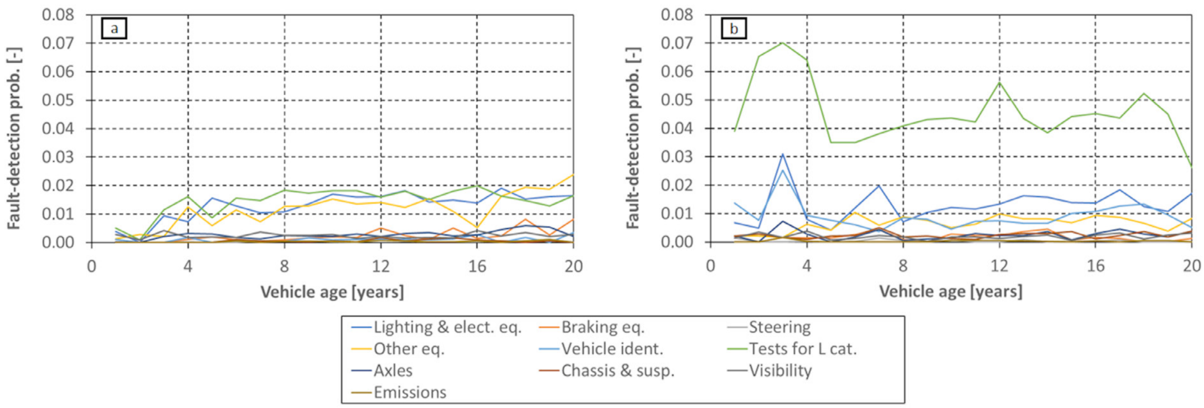

Fig. 11. *Defect detection probabilities for motorcycles and ATVs in Slovenia: a) year 2018, b) year 2021*

the basic regression model #3 are shown in Table A1 in Appendix for the relevant fault groups and the year 2018. Since the coefficients for the other six years are very similar, they are not shown here. Both dynamic regression models from Table 3 were also successful in predicting the probability of defect detection, but the decoupled model was consistently better than the basic dynamic model. For this reason, Table A2 in Appendix presents the regression coefficients and the values of the deterministic coefficient R^2 for only the decoupled dynamic regression models for the relevant defect groups.

From Table A1, we can conclude that the regression models for passenger cars and commercial vehicles are good, as reflected in high values ($R^2 > 0.7$) of the R^2 value for all error groups except emissions and vehicle identification. In contrast, the regression models for motorcycles and ATVs are poor. This results from the following facts: i) the probabilities of fault detection are much lower compared to passenger cars and commercial vehicles, and ii) the probabilities of fault detection vary significantly between different vehicle ages.

Comparing Table A2 with Table A1, we see that the dynamic regression models are comparable the base regression model #3 according to their R^2 values remain relatively high (R^2>0.7) for passenger cars and commercial vehicles. The dynamic regression models for the motorcycles and ATVs are poor for the same reason explained earlier. Never the less, it is advantageous to model the probability of fault detection separately for each year, because it can be concluded from the results, which were presented before, that there are relatively more faults detected at technical inspections after the year 2020.

3 CONCLUSIONS

In the EU, several directives regulate the technical safety and roadworthiness of road vehicles. Moreover, national regulations are subordinate to these directives. In our study, the roadworthiness of vehicles found during regular technical inspections was statistically analysed and compared with the road accident database. In this part of the study, it was found that the technically unsound vehicles (i.e., vehicles that did not pass the technical inspection for the first time) do not contribute more to road accidents than the technically roadworthy vehicles, as measured by their relative share determined during the technical inspections.

Then, the statistics for passenger cars and commercial vehicles were compared with those of the other two EU countries (i.e., Germany and Finland). From this comparison, it can be concluded that the individual defect groups are weighted differently in the different countries. This could lead to some differences in roadworthiness ratings across EU countries. Nevertheless, the most frequently identified defects were the same in the countries compared, which means that the prescribed technical inspection procedures do not differ to an unacceptable extent.

To complement this, year-specific and dynamic regression models were also constructed to predict the probability of defect detection for Slovenian passenger cars, commercial vehicles, motorcycles, and ATVs. It was found that the probability of defect identification during technical inspection can be predicted well for almost all defect groups for passenger cars and commercial vehicles. However, due to data variation and inconsistency, this cannot be reliably done for motorcycles and ATVs. Dynamic regression models were also found to have somewhat lower modelling power than the year-specific base regression models.

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5 NOMENCLATURES

a_0	constant term of a linear regression model, [-]
a_i	linear regression coefficient of the i^{th} term, [-]
b_0	time-related constant term in the dynamic regression model, [-]
b_1	time-related linear coefficient in the dynamic regression model, [-]
n	number of sample points, [-]
p	number of independent random variables, [-]
t	time [s]
x_i	realization of the i^{th} independent random variable X_i, [-]
$\mathbf{x}$	realization of the independent vector $\mathbf{X}$, [-]
X_i	i^{th} independent random variable, [-]
$\mathbf{X}$	vector of independent random variables, [-]
y	realization of the dependent random variable Y, [-]
Y	dependent random variable, [-]
ε	prediction error, [-]
j	running index, [-]

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7 APPENDIX

Table A1. *Regression coefficients and determination coefficients for the basic regression model #3 for the year 2018*

Coeffi-cients	Light. & elect.	Brake system	Steering	Other equip.	Vehicle ident.	Cat. L tests	Axles	Chassis & susp.	Visibility	Emissions
					Passenger cars					
a_0	-0.0793	-0.0336	-0.0085	-0.0078	0.0000	n/a	-0.0170	-0.0040	-0.0091	-0.0091
a_1	0.0319	0.0106	0.0033	0.0062	0.0002	n/a	0.0061	0.0007	0.0034	0.0017
a_2	-0.0010	-0.0002	-0.0001	-0.0002	0.0000	n/a	-0.0002	0.0001	-0.0001	0.0000
R^2	0.9245	0.9079	0.9064	0.7764	0.8657	n/a	0.8772	0.8520	0.8868	0.6826
					Commercial vehicles					
a_0	-0.0487	-0.0516	-0.0098	-0.0059	-0.0032	n/a	-0.0225	-0.0204	-0.0042	-0.0039
a_1	0.0362	0.0213	0.0059	0.0188	0.0016	n/a	0.0103	0.0069	0.0043	0.0014
a_2	-0.0011	-0.0005	-0.0002	-0.0005	-0.0001	n/a	-0.0003	-0.0001	-0.0001	0.0000
R^2	0.9662	0.9218	0.8258	0.8854	0.6144	n/a	0.8879	0.7942	0.8873	0.5675
					Motorcycles and ATVs					
a_0	0.0012	-0.0018	-0.0002	0.0014	0.0005	0.0174	-0.0004	0.0000	0.0022	-0.0002
a_1	0.0021	0.0007	0.0001	0.0014	0.0000	-0.0002	0.0006	0.0001	0.0000	0.0001
a_2	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R^2	0.5816	0.2884	0.2038	0.5436	0.1875	0.0048	0.3602	0.1377	0.0787	0.1805

Table A2. *Regression coefficients and determination coefficients for the two dynamic regression models*

Coeffi-cients	Light. & elect.	Brak. system	Steering	Other equip.	Vehicle ident.	Cat. L tests	Axles	Chassis & susp.	Visibility	Emissions
					Passenger cars					
a_0	-0.0352	-0.0368	-0.0071	0.0039	-0.0015	n/a	-0.0100	-0.0057	-0.0073	-0.0205
a_1	0.0235	0.0123	0.0031	0.0052	0.0002	n/a	0.0040	0.0011	0.0031	0.0050
a_2	-0.0008	-0.0002	-0.0001	-0.0002	0.0000	n/a	-0.0001	0.0000	-0.0001	-0.0001
a_3	-0.0112	0.0028	-0.0006	-0.0012	0.0008	n/a	-0.0019	0.0009	0.0003	0.0036
a_4	0.0028	-0.0008	0.0002	0.0000	0.0000	n/a	0.0010	-0.0002	0.0001	-0.0010
a_5	0.0000	0.0000	0.0000	0.0000	0.0000	n/a	0.0000	0.0000	0.0000	0.0000
R^2	0.9305	0.9412	0.9214	0.8295	0.8313	n/a	0.9185	0.9497	0.9194	0.8710
					Commercial vehicles					
a_0	-0.0138	-0.0191	-0.0066	0.0377	-0.0027	n/a	-0.0144	-0.0133	-0.0012	-0.0045
a_1	0.0227	0.0137	0.0043	0.0150	0.0004	n/a	0.0070	0.0039	0.0029	0.0013
a_2	-0.0007	-0.0001	-0.0001	-0.0004	0.0000	n/a	-0.0002	-0.0001	0.0000	0.0000
a_3	-0.0035	-0.0022	-0.0010	-0.0015	0.0005	n/a	-0.0009	-0.0002	0.0004	-0.0002
a_4	0.0053	0.0009	0.0010	0.0006	0.0005	n/a	0.0014	0.0009	0.0006	0.0002
a_5	-0.0002	0.0000	0.0000	0.0000	0.0000	n/a	0.0000	0.0000	0.0000	0.0000
R^2	0.9570	0.9149	0.8673	0.8534	0.8447	n/a	0.8932	0.9213	0.9129	0.8722
					Motorcycles and ATVs					
a_0	0.0076	-0.0016	0.0001	0.0060	0.0001	0.0101	0.0015	0.0001	0.0044	-0.0003
a_1	0.0011	0.0008	0.0000	0.0016	-0.0002	-0.0007	0.0004	0.0001	-0.0002	0.0001
a_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
a_3	0.0002	0.0004	0.0001	-0.0004	0.0014	0.0077	-0.0001	0.0003	-0.0001	0.0001
a_4	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000
a_5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R^2	0.1514	0.1234	0.0961	0.1299	0.1710	0.3591	0.1128	0.1243	0.1102	0.0916