TRENDS IN TRAFFIC ACCIDENTS OF FIREFIGHTING VEHICLES AND THEIR EVALUATION

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Resume

The Fire Rescue Service of the Czech Republic is a security force whose primary task is to protect the lives and health of the population from fire and other emergency and critical situations. Members of the Fire Rescue Service of the Czech Republic need special firefighting appliances for performing these public services. The first-response firefighting vehicles are professionally denominated as firefighting vehicles. These vehicles are used to transport units of firefighters, fire extinguishers and a technical equipment to a scene of an intervention. Traffic accidents occur occasionally while an emergency drive. Traffic accidents always have a negative economic impact on a fire protection unit and can endanger its operational capacity in the short term. This paper summarizes results of a traffic accidents analysis of a major group of emergency firefighting vehicles - water tenders.

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1 Introduction

Authors of this paper have been monitoring and evaluating traffic accidents of firefighting vehicles type water tenders (hereinafter referred to as WT) for a long time. Those vehicles usually go as the first to a site of an intervention in the Czech Republic. First analysis of traffic accidents, conducted by the authors, focused on a period from 2011 to 2016. Results of this analysis were published in 2018 [1]. During 2017 - 2019, the trend of a total number of traffic accidents involving firefighters was increasing, unfortunately. Results of the second follow-up analysis were published in 2020 [2]. Selected aspects of traffic accidents of firefighting water tenders during years 2020, 2021 and 2022 were analysed and described in this paper, with an aim to highlight main trends and economic consequences of traffic accidents of firefighting vehicles. The paper focuses on an evaluation of causes and effects of the traffic accidents using a Generic Error-Modelling System.

2 Problem formulation

Two previous analyses [1-2] were based on an evaluation of traffic accidents (hereinafter referred to as TAs) published annually by the Police of the Czech Republic [3]. Lately published assessment was summarised in a document "Road Accident Yearbook 2020" [4]. In 2020, there were 94,794 of investigated accidents, 460 people had died and a material damage amounted to 6,016 mil. CZK (245.6 mil. EUR according to the CNB exchange rate from February 23, 2022, 1 EUR = 24.50 CZK). While studying this document, the authors focused on TAs caused by truck drivers. This group included trucks with and/or without a trailer and with a semi-trailer. Drivers of these trucks caused 10,052 Tas, within them 66 people died. The analysis [4] highlights that the highest number of TAs was in the lightest weight vehicle class up to 3.5 t, i.e., 4,368 TAs and 28 persons killed, and then in the weight class above 12 t, where it was 3,462 TAs and 25 persons killed.

Furthermore, following characteristics have been found in the overall statistics of TAs, which were used as a starting point for the analysis.

Main causes of traffic accidents caused by truck drivers. Situations when a driver did not fully pay attention to driving (2,427 TAs), an incorrect turning or reversing (1,385 TAs) and an avoidance without a sufficient lateral distance (911 TAs) were the major causes of truck drivers' TAs.

The length of driving experience of drivers of all motor vehicles. Regardless of the length of driving experience, the most frequent cause of TAs was an incorrect driving that means the driver was not fully engaged in driving. For the driving practice up to 1 year there were 5,283 TAs, of which 2,692 TAs caused by the incorrect driving. In a group of driving experience from 1 to 2 years there were 3,040 TAs, of which 1,658 caused with the same reason as above mentioned. Drivers with the practice from 3 to 5 years caused 5,318 TAs in total, of which 2,899 appeared again due to the incorrect way of driving. In a group of drivers experienced from 6 to 10 years there were 8,136 TAs, of which 4,762 arose for the same reason - the incorrect driving. In the group with a longer than 10 years practice there were 25,363 TAs in total, in which 15,603 accidents occurred due to the incorrect driving.

The age of the driver responsible for the TA. There, the following numbers were recorded in the statistics: 11,523 TAs happened in the age group 21 to 29 years, drivers aged 30 to 39 years caused 11,114 TAs, drivers aged 40 to 49 years caused 11,881 TAs and 8,417 TAs happened in the age group 50 to 59 years.

Based on detected results, three hypotheses have been laid down and then verified.

- Hypothesis No. 1: The incorrect driving is the most frequent cause of all TAs.
- Hypothesis No. 2: Drivers with the driving experience of 6 to 10 years cause most TAs.
- Hypothesis No. 3: Drivers younger than 29 years cause most TAs.

These hypotheses formed a direction of the study of firefighting trucks' TAs. The study focused both on the cause of the accidents, and the age of the drivers responsible for the accident. None of these hypotheses was confirmed by results of previous analyses [1-2]. The most common cause of culpable accidents of water tenders was the incorrect avoidance (36%) in years 2011 - 2022. In terms of economic consequences, however, the greatest material damage occurred in TAs caused by an excessive speed (75 %). Most of TAs involving units of the Fire Rescue Service of the Czech Republic (hereinafter referred to as FRS CR) were caused by drivers in the age from 30 to 39 years, next age group was from 40 to 49 years. Therefore, the analysis was extended with a study of an influence of a length of the driving experience.

The current analysis focused on causes, economic consequences, and trends in the TAs of firefighting water tenders. Trends in an accident rate, number of emergencies, a mileage of firefighting trucks and their changes were monitored in the period 2011 to 2022.

3 Methodology

A solution procedure and methods used were the same as in the previous analyses [1-2]. Sources of primary data have been taken from the so-called "Reports of Firefighting Vehicles Traffic Accident". These reports have been processed by machinery service technicians at regions, territorial departments, and individual fire stations according to the Code of Mechanical Service [5]. The analysis was based on following criteria for selecting the TAs:

- A traffic accident character - an accident caused by firemen.
- A purpose of a ride - an emergency.
- A type of a firefighting vehicle - a water tender.

Filled forms "Reports of Firefighting Vehicles Traffic Accident" (hereinafter referred to as RTA) have been centrally collected at the Directorate General of the Fire Rescue Service of the Czech Republic (hereinafter referred to as DG FRS CR). They have been processed by the MS Excel software. Data from these reports were then analysed by the authors of the paper. Elementary filtering functions in MS Excel software were used to sort records according to the above criteria. A total of 394 records of TAs were assessed for the period 2011 - 2022. Statistical yearbooks issued annually by DG FRS CR [6] were used for comparing the trend of the number of incidents in relation to the mileage of firefighting vehicles.

4 Evaluation of the traffic accident statistics

Results of the TAs analysis, carried out according to the criteria mentioned above and trends in the number of emergencies relative to the mileage of firefighting vehicles, are shown in Tables 1 and 2, and Figures 1 to 5 [6].

4.1 Causes of traffic accidents

The first steps in solving the task have been focused on filtering the TAs by the cause. An overview of water tenders TAs frequency, sorted by the cause, is summarized in Table 1. Figure 1 shows the share of individual causes for the referred period 2011 - 2022. 163 accidents (36% of all TAs) occurred due to the wrong bypassing - the incorrect overtaking of another vehicle.

***Table 1** Causes of traffic accidents*

Causes of traffic accidents	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
not keeping a safe distance	4	6	5	2	3	3	5	6	5	2	5	6
speeding	5	3	8	9	6	4	10	5	4	2	6	6
wrong bypassing	5	6	11	13	10	10	20	17	23	13	20	15
not giving way	1	0	0	1	1	2	3	0	4	4	1	0
dangerous reversing and turning	9	8	11	6	6	8	9	10	7	8	8	19
other	2	0	3	5	3	1	1	2	7	4	3	11

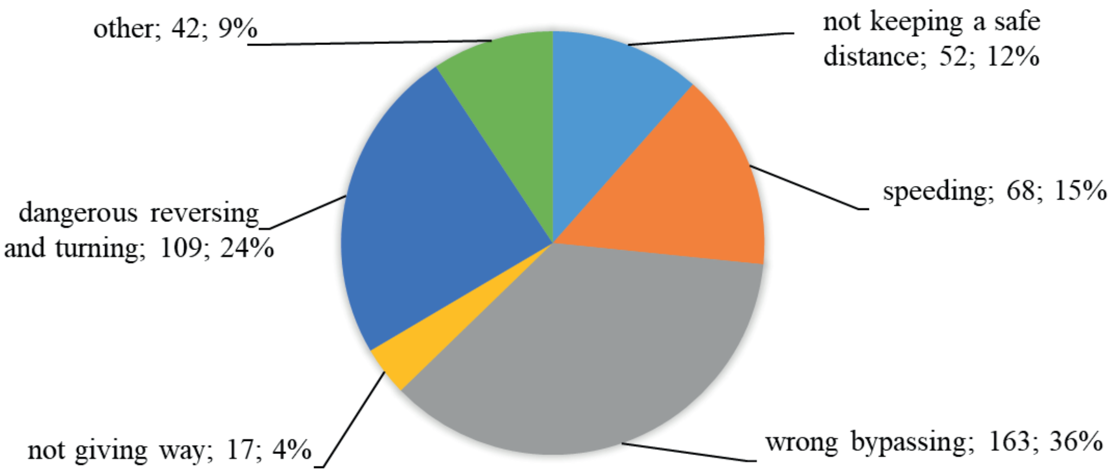

***Figure 1** Shares of traffic accident causes, years 2011 - 2022*

***Table 2** Damage to firefighting water tenders by the cause of traffic accident*

Damage in thousands of EUR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
not keeping a safe distance	1.6	11.4	12.9	0.0	0.2	0.4	5.1	5.0	51.0	0.0	2.9	5.4
speeding	45.3	183.7	174.1	518.5	549.3	1.4	219.3	329.5	94.7	177.8	696.0	300.5
wrong bypassing	2.0	1.1	26.5	0.8	1.4	11.9	299.5	152.8	17.5	39.8	9.7	5.6
not giving way	4.1	0.0	0.0	2.9	4.9	4.1	4.3	0.0	20.4	66.9	2.0	0.0
dangerous reversing and turning	6.9	2.4	2.0	1.0	3.2	15.5	5.0	11.3	1.6	2.7	2.8	16.6
other	1.4	0.0	0.8	1.8	2.4	1.6	1.2	1.6	2.2	6.9	0.3	11.3

4.2 Value of damage in traffic accidents

Another part of the analysis was the evaluation of the amount of damage to firefighting vehicles during accidents caused by the driver-firefighter. Table 2 summarizes the damage to firefighting vehicles, sorted by the cause of the Tas, during 2011 - 2022. Amounts of the damage were converted from CZK into EUR according to the Czech National Bank exchange rate from February 23, 2022 (1 EUR = 24.50 CZK).

In 2021, previous peaks of damage from 2014 and 2015 were surpassed. That was due to three serious accidents of firefighting vehicles in November and December 2021, which resulted in the total damage of 16.5 million CZK (673.5 thousand EUR). Those accidents were caused by speeding. Excluding these three TAs, the year 2021 would have been very successful from the perspective of the financial damage. Figure 2 shows different causes of traffic accidents, the amount of damage in thousands of EUR and in percent during the monitored period.

The most serious cause of accidents in terms of the amount of damage was speeding. Accidents occurred due to speeding reached 78% of the total amount of

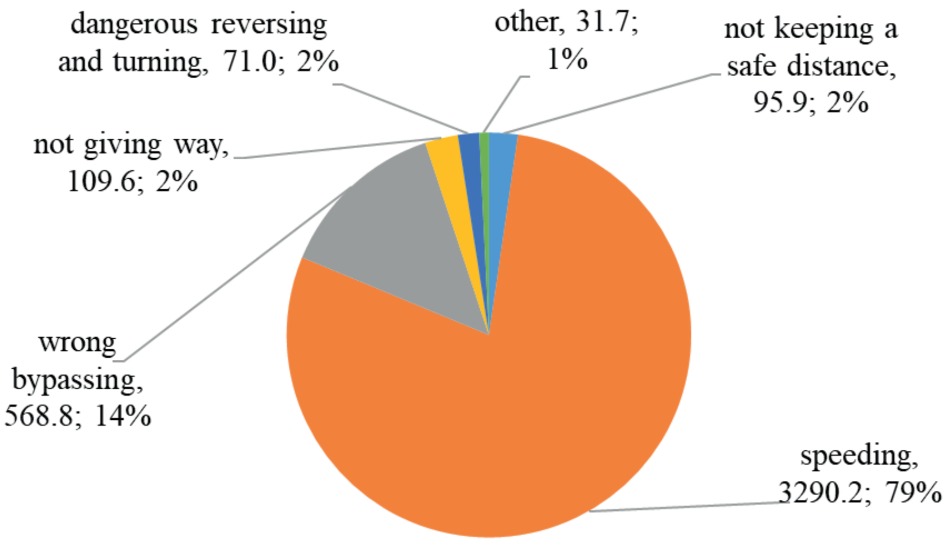

***Figure** 2 Damage to firefighting vehicles by the cause of traffic accident in 2011 - 2022*

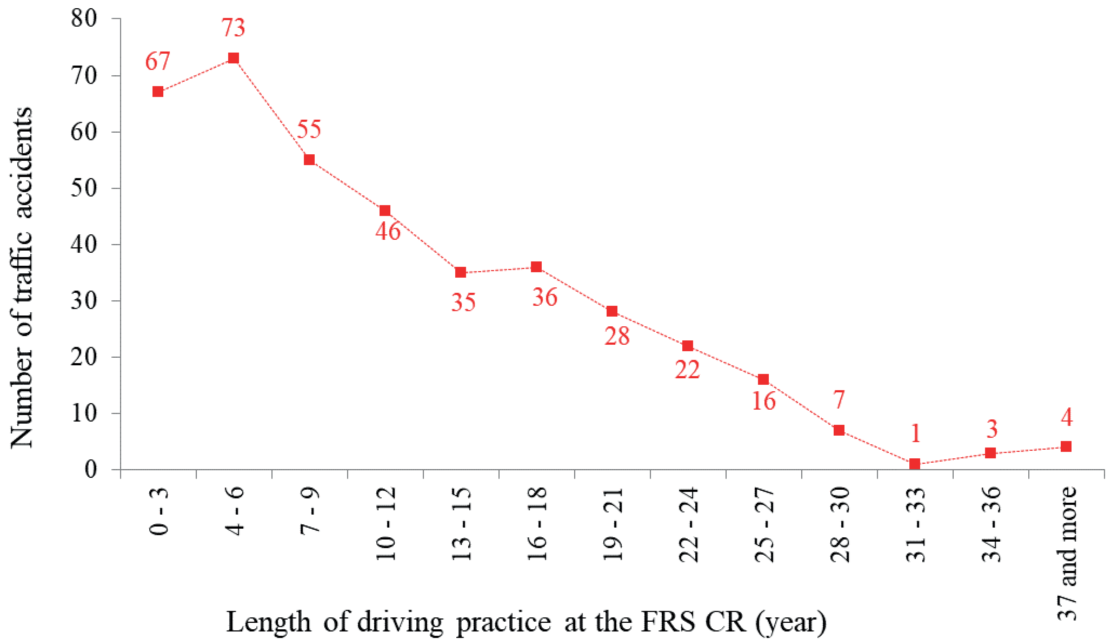

***Figure 3** Number of traffic accidents in relation to the truck driver's practice*

damage, but only 16% of the total number of accidents. Speeding, as the only cause from the whole spectrum of 6 categories of causes, significantly influenced the overall result. That fact could confirm the Pareto rule 80/20 [7].

4.3 The length of drivers' experience

Third part of the analysis was focused on the TAs with respect to the length of a truck drivers experience. The driving experience was evaluated in two categories:

- the experience in driving firefighting vehicles at the FRS CR.
- overall experience in driving trucks (i.e., the driving practice before joining the FRS CR plus the driving experience at the FRS CR).

To picture the trends, and to illustrate the relationship between the duration of the driving practice and the number of TAs, 3-year intervals of the practice length have been set. Relations between the number of TAs and the duration of the driving practice are shown in Figure 3, for the referred period 2011 - 2021.

Drivers with the experience at the FRS CR up to 6 years belong to the most critical group with the greatest numbers of accidents. For drivers with the experience of

7 years or more there can be seen a significant decrease in the number of road accidents. Drivers with the length of driving practice at the FRS CR from 0 to 9 years caused 50 % of the TAs in the monitored period. In intervals 13 - 15 and 16 - 18 years of experience in driving at the FRS CR, the number of accidents was almost equal. For drivers with more than 19 years experience, there is a second positive break - there can be seen a permanent decrease in the number of road accidents. The lowest numbers of TAs (1 - 4) have been found in each 3-year interval after exceeding outreaching 31 years of driving practice at the FRS CR.

Unfortunately, our findings have confirmed the data from the previous analysis. Most accidents were registered for drivers with the driving experience at the FRS CR between 4 and 6 years.

4.4 Number of emergencies and a mileage of firefighting water tenders

In the next part of the analysis, the annual statistics of emergencies [6] and evaluated TAs were compared. Figure 4 shows both the total numbers of emergencies, and numbers of culpable TAs of water tenders (in total 394) for each year of the monitored period. To complete the information, the number of all the registered TAs without distinguishing the type of vehicle was 712 for the monitored period. For the referred period, there was, on average, one TA per 3,435 emergencies. That part of the analysis was followed by an analysis of the number of emergencies and the distance covered by firefighting vehicles. In statistical yearbooks [6] mileages were reported only for fires and technical accidents. These two types of emergencies reached 69 % of all emergencies in 2011 to 2021. Resulting trends are summarised in Figure 5. The average mileage per one emergency was 7.76 km. In relation to the total number of emergencies, the average mileage per an accident was approximately 26,659 km. Both variables were higher between 2019 and 2021 compared to the results of previous analyses for the years 2011 - 2018.

Finally, one sad finding emerged from the analysis of TA statistics in 2020 - 2021: four fire fighters and one civil person were killed in analysed TAs and three water tender vehicles were destroyed in 2021. The damage to these three firefighting trucks was estimated at 16.5 million CZK (673.5 thousand EUR). Speeding was identified as the cause of all the three serious road accidents. The road surface was wet in two cases, one TA occurred while driving on an icy road. The crashed vehicles were driven by fire fighters with the driving experience at the FRS CR in the length of 5, 23 and 29 years.

Furthermore, the analysis resulted in a requirement to include an actual speed before the moment of the accident to the “Report of a traffic accident” forms for improving the analysis of TAs at the Fire Rescue Service of the Czech Republic. That information has been permanently recorded in the navigation systems GINA from GINA software Ltd., Brno [8] and Rescue Navigator from Point.X Ltd., Prague [9], which have been installed in fire vehicles of the Fire Rescue Service of the Czech Republic. Their disadvantage is the real-time recording of the vehicle position with a frequency of 1 record per 5 seconds (0.2 Hz). The second type of devices, which were

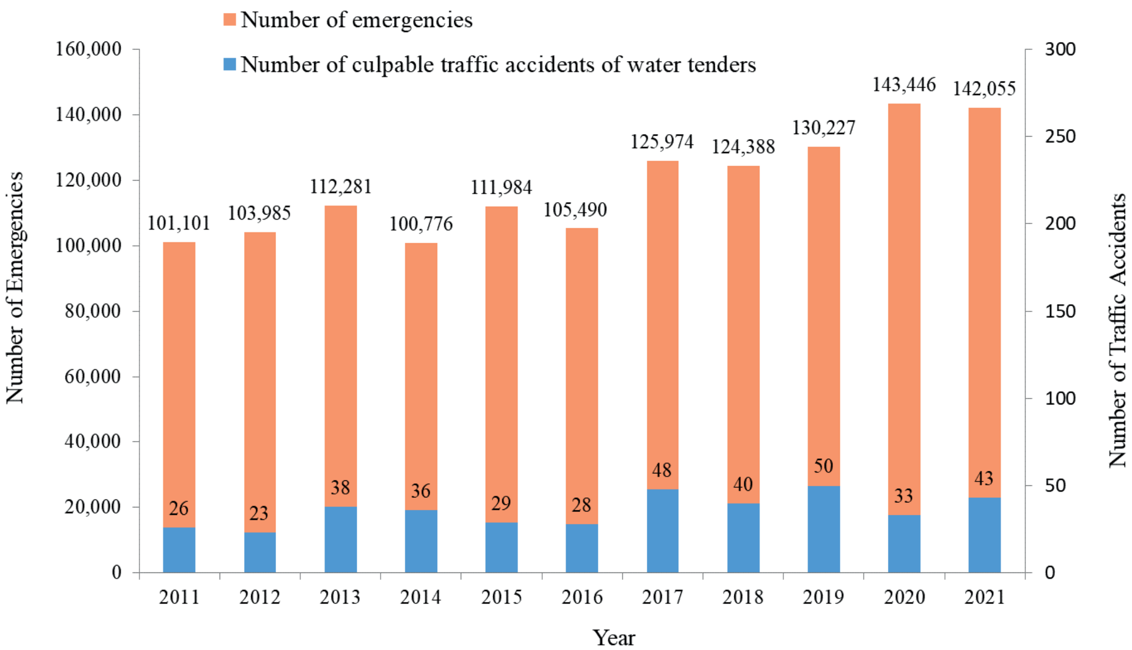

Figure 4 *Trends of emergencies and traffic accidents in 2011 - 2021*

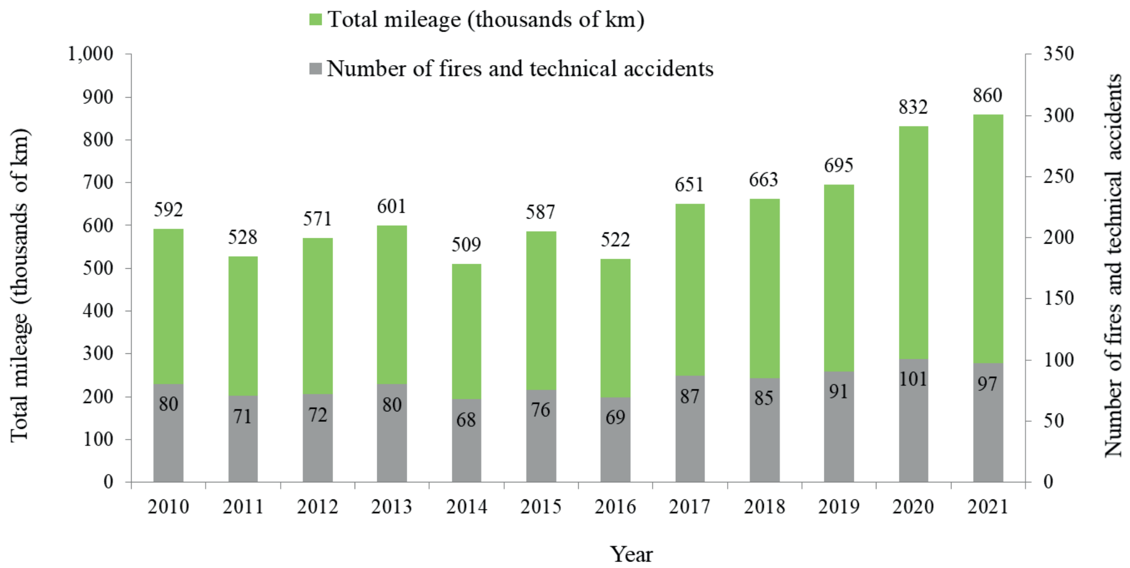

Figure 5 *Number of fires and technical types of emergencies and the mileage in 2011 - 2021*

installed in most of fire vehicles in the last 5 years, were on-board cameras, which recorded the journey in front of the vehicle. In the case of types equipped with a GPS module, a record of the vehicle's position is made at a frequency of 1 Hz (1 record per a second). If a dual set of cameras is used in the vehicle, then the second camera is placed in the cab of the vehicle and records the driver's driving activity. This real-time vehicle position data, including the audio and video footage of the journey before the TA occurred, could already be used to analyse the cause of the TA more in detail.

5 Cause and effect analysis of traffic accidents using the generic error-modelling system

Causes of Tas, involving firefighting vehicles, were investigated in the framework of the specific research projects "Verification of the Driving Characteristics of Water Tender Type Vehicles" No. SP2021/58 [10] and "Stress Load of Drivers" No. SP2022/49 [11]. In both projects, one of the defined sub-objectives always was the analysis of TAs of fire protection units of the FRS CR with a focus on a fire-fighting vehicle of the type of water tender. The TAs analysis was always focused on accidents caused while emergency driving. Here, the firefighter-driver of a vehicle was exposed to an increased mental and physical stress, compared to normal work activities at the fire station. From the RTA forms [5], information on individual TAs incurred on fire vehicles was listed with the level of culpability: culpable TA and TA with complicity. The information was entered into MS Excel. Then, the data not reported by the FRS CR in the statistical document "Analysis of traffic accidents in fire protection units" were filtered out. As a part of a previous specific research project "Verification of driving characteristics of water tender type vehicles", it was demonstrated that vehicles drive faster in a left-hand curve than in a right-hand curve of the same radius. Based on the findings of the second specific research project "Stress load of drivers", TAs were evaluated with a focus on the damaged side of the vehicles.

5.1 Questions for the analytical survey

To evaluate the TAs of WT vehicles in detail, the researchers outlaid several following questions.

- What are the most common locations for TAs?
- At what times?
- In what driving mode?
- At what speed?
- In what weather conditions?
- What is the frequency of financial damage by amount?
- What is the most common type of error?

Individual TAs sites were divided into on-road and off-road with a further division into left and right turn, straight section and downhill.

The TAs time was divided by a daytime into day (sunrise to sunset), day/night (sunset to civil twilight), night (civil twilight to civil dawn), and night/day (civil dawn to sunrise) parts, as in the day/night and night/day parts of the daytime an optical spatial perception change [12-13].

The driving mode was divided according to the purpose of driving into emergency and other, and further into start, finish, steady state, parking, rest.

The speed of the vehicle at the time of the accident could not be assessed, this information was not included in the RTA form in most cases.

In terms of meteorological conditions, the road surface was divided into dry, wet, and low adhesion (this term includes ice and snow on the road). It was also indicated what the visibility was when the TA occurred. To assess the road surface, temperatures above and below 0 °C were given. For the accident assessment, most frequent financial damages during each TA were filtered in MS Excel.

Most common errors were evaluated according to the Generic Error-Modelling System (hereinafter referred to as GEMS) [14], to classify human errors. This model is divided into three performance levels:

- Skill-based errors, usually errors of inattention or misplaced attention;
- Rule-based errors, for instance choosing an inappropriate rule, incorrect view on the state, overzealous pattern matching, frequency gambling, and/or insufficient rules;
- Knowledge-based errors. These are incomplete and/or inaccurate understanding of the system, bias, overconfidence, and cognitive load.

5.2 Evaluation of the accident rate of water tenders from reports of firefighting vehicles traffic accident

Firefighters - drivers of firefighting vehicles at FRS CR caused or partially caused 368 TAs for the assessed period 2012-2021. Of that, it was possible to trace only 268 TAs for which the complete RTA forms with all the necessary data were provided.

The data evaluated showed that 93.3% of the TAs were culpable and 6.7% were with complicity (hereafter referred to as culpable TAs). While emergency driving, 56.3% of TAs were caused by the drivers, as shown in Table 3. 15.3% of TAs occurred while arriving at the scene of an incident, while crossing at the intervention site or departing from the intervention site. On the return journey from the intervention, 7.1% of TAs occurred.

Table 4 shows a magnitude of the total damage incurred with a distribution:

- small TAs - the damage up to 100,000 CZK (up to 4,082 EUR), with no injuries,
- large TAs - the damage above 100,000 CZK and up to 1 million CZK (from 4,082 to 40,816 EUR), with a slight injury.
- serious TA - a severe or fatal injury, the damage over 1 mil. CZK (above 40,816 EUR).

In the evaluated period, 30 people were slightly injured, 8 people were seriously injured and 2 people were killed in culpable TAs, including accidents with a complicity.

Table 5 shows the number of culpable Tas, according to their severity, depending on the type of driving. Most large and serious culpable accidents occurred during the emergency drives.

***Table 3** Number of culpable traffic accidents by a driving mode*

Driving mode		Number of TAs	Percentage (%)
Emergency driving		151	56.3
At the intervention site	Arrival at the site of an intervention, stopping the vehicle, crossing at the scene	29	10.8
	Reversing, departing from the intervention site	12	4.5
Return journey from the intervention site		19	7.1
Other rides		57	21.3

***Table 4** Severity of the traffic accident*

Size of the total damage at the TA	Number of TAs	Percentage (%)
Small	207	77.2
Large	40	14.9
Serious	21	7.8

***Table 5** Number of culpable TAs by the driving mode and the severity of the TA*

Driving mode		Severity of the TA		
		Small	Large	Serious
Driving to an intervention		105	26	20
At the intervention	Arrival at the site of an intervention, stopping the vehicle, crossing at the scene	25	4	0
	Reversing, departing from the intervention site	12	0	0
Return journey from the intervention site		18	1	0
Other rides		47	9	1

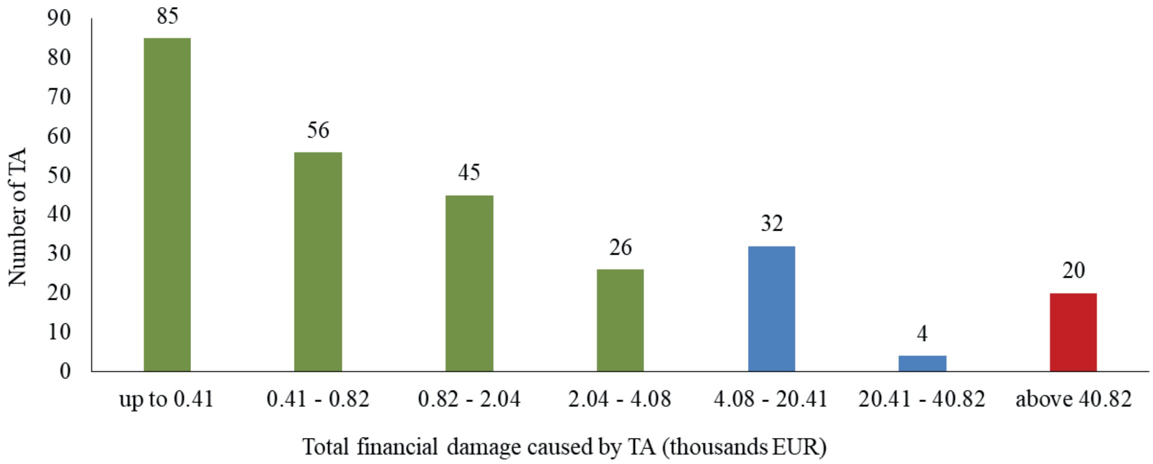

Figure 6 *Total financial damage caused by traffic accidents*

Table 6 *Generic Error-Modelling System*

Errors:	Number of TAs	Percentage (%)
Skill based	231	86.19
Rule based	24	8.96
Knowledge based	13	4.85

Table 7 *Number of traffic accidents of FRS CR vehicles depending on the road type*

Type of the road surface	Number of TAs	Percentage (%)
Roadways - asphalt	251	93.7
Paved surface - outside the road (parking lot, company complex)	7	2.6
Terrain - off the road	10	3.7

Table 8 *Number of traffic accidents depending on the manoeuvre and the communication section*

Communication section	Manoeuvre	Number of TAs
Direct section	Driving forward	114
	Overtaking	2
	Reversing	53
	Avoidance manoeuvre	38
	Turning	2
Right-hand turn	Turning right	15
	Reversing	2
Left-hand turn	Turning left	14
	Avoidance manoeuvre	2
Left-hand turn, Descent	Left turn, descent	3
Crossroads	Passing through the crossroads	4
	Avoidance manoeuvre	2
	Turning	1
	Driving forward	1
Decline	Driving forward	5
	Rest	2
Rugged terrain	Driving forward	2
	Reversing	2
	Turning	2
Rest	Rest	2

Figure 6 shows the total financial damage converted into thousands of EUR distinguished by colour (green - small damage, blue - large damage, red - serious damage).

Table 6 identifies the most common probable error types according to the GEMS, based on the available data.

Table 7 shows numbers of TAs generated in the period under review. From the available data, a following distribution of TAs by type of communication was made:

- 93.7% of TAs happened on roads,
- 3.7% of TAs occurred on an off-road on unpaved terrain.

Here it should be added that less than 1% of all evaluated emergencies occurred on the off-road terrain according to the route characteristics at Fire station Znojmo in August 2018 [15].

Table 8 shows numbers of accidents, depending on the road section and the manoeuvre, during the TA. Most of the TAs were caused by the WT drivers on the straight road in forward driving, reversing, and evasive manoeuvres. The next frequent group of TAs was the passage through right-hand and left-hand curves.

From the characteristics of the routes of the evaluated emergencies at Fire stations Brno - Lidicka, Znojmo, Zlin, Valasske Mezirici, Ostrava - Fifejdy and Novy Jicin within the analysis in the period 2018 and 2019 [15], the share of vehicle movements in curved road sections as potential critical points was identified. The average distance driven through the curved sections to the intervention site was 4%.

5.2.1 Road surface affecting the limit speed of the vehicle

Using Meteoblue climate diagrams [12] which are available for all the locations on Earth, and are based on hourly weather model simulations over a 30-year period, a summation of precipitation amounts was performed. On average, there were 208 dry days per year in the Czech Republic, 157 days with precipitation, 17 of which are snow days.

The condition of the road affecting the speed limit of the vehicle is shown in Table 9. 45.9% of the accidents caused during the study period occurred on low adhesion road surfaces. Drivers caused 12.3% of TAs on wet surfaces and 41.8% of TAs on dry surfaces.

5.2.2 Temperature effect on the adhesion between the tyre and the road surface

The Czech Republic had 101 frost days per year on average [12]. Table 10 shows that in 22.4% of TA cases,

Table 9 *Road surface affecting the limit speed of the vehicle*

Condition of the roadway	Number of TAs	Percentage (%)
Dry	112	41.8
Wet	33	12.3
Low-adhesion	123	45.9

Table 10 *Temperature effect on the adhesion between the tyre and the road surface*

Outer temperature	Number of TAs	Percentage (%)
above 0 °C	208	77.6
under 0 °C	60	22.4

Table 11 *Lighting conditions*

<table>
<tr><th colspan="2">Lighting conditions</th><th>Number of TAs</th><th>Percentage (%)</th></tr>
<tr><td>Good visibility</td><td>Day</td><td>180</td><td>67.2</td></tr>
<tr><td rowspan="4">Reduced visibility</td><td>Day/Night</td><td>6</td><td>2.2</td></tr>
<tr><td>Night/Day</td><td>5</td><td>1.9</td></tr>
<tr><td>Night</td><td>46</td><td>17.2</td></tr>
<tr><td>Adverse conditions</td><td>31</td><td>11.6</td></tr>
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Table 12 *Traffic accidents depending on the daytime and the traffic density*

Time of the day	Number of TAs	Percentage (%)
Day, from 7:00 a.m. to 6:00 p.m.	192	71.64
Night, from 6:00 p.m. to 7:00 a.m.	76	28.36

***Table 13** Causes of traffic accidents*

Cause of TA	Number of TAs	Percentage (%)
Incorrect estimation of the lateral distance	101	37.69
Speeding	53	19.78
Incorrect estimation of the distance behind the vehicle	47	17.54
Incorrect estimation of the distance in front of the vehicle	19	7.09
Crossing the intersection at red lights	12	4.48
Inattention	11	4.10
Driving on an unpaved roadside	8	2.99
Errors of non-driving personnel	4	1.49
Incorrect approach to an elevated obstacle	3	1.12
Not using the anti-running wedge	3	1.12
Incorrect starting	2	0.75
Low visibility	2	0.75
Other	2	0.75
The technical factor	1	0.37

a low temperature could decrease a tyre adhesion on the road.

5.2.3 Lighting conditions

Table 11 shows lighting conditions when the road accidents occurred, according to the available data, divided into good and reduced visibility. Reduced visibility is a situation where the road users on the road cannot distinguish clearly enough other vehicles, persons, animals or objects on the road [16]. A good visibility means the time of day from sunrise to sunset. A reduced visibility means the period between day and night and night and day, as well as night, and adverse conditions:

- day/night: from sunset to civil twilight,
- night: from civil dusk to civil dawn,
- night/day: from civil dawn to sunrise,
- adverse conditions: fog, snow, heavy rain, smoke, heavy dust stirring.

Table 11 shows that 32.8% of accidents occurred in a low visibility and 67.2% of accidents occurred in a good visibility.

5.2.4 Traffic accidents depending on the daytime and the traffic density

According to the graph of daily variation of traffic intensities [17], the highest traffic density is from 7:00 a.m. to 6:00 p.m. (marked as the day), while in the early evening, evening, night, and early morning hours, i.e., from 6:00 p.m. to 7:00 a.m., the traffic intensity is low (marked as the night). Based on that, the TAs have been divided according to the daytime in Table 12. 66.32% of the analysed emergencies took place during the day and 33.68% at night [14]. In terms of a mileage [14], 66.81% emergencies took place per day and 33.19% per night. Depending on the daytime, more TAs occur during the day (71.64%) than at night (28.36 %).

***Table 14** Recommendations for education and training based on the most common traffic accidents*

Recommended training and precautions	Number of TAs	Percentage (%)
Estimation of a lateral distance	89	38.5
Estimating the distance behind the vehicle	49	21.2
Estimating the distance in front of the vehicle	27	11.7
Driving on low adhesion road surfaces	20	8.7
Avoidance manoeuvre	16	6.9
Safe speed training for cornering on different surfaces and practical training	14	6.1
Emphasis on increasing attention	7	3.0
Off-road driving	6	2.6
Starting and approaching an elevated obstacle	3	1.3

5.2.5 Causes of traffic accidents

From the analysis of the available data, Table 13 summarises the number of accidents based on their probable cause.

5.3 Evaluation of the findings using the generic error-modelling system

Evaluated data show that the firefighter-drivers caused or were complicit in 67% of TAs while driving to the intervention, arriving at the intervention site and moving to the next intervention (see Table 3).

Most of the large and serious TAs were connected with the emergencies. According to the distribution of TAs by daytime, 72% of TAs occur in heavy traffic during the day between 7:00 a.m. and 6:00 p.m. (see Table 12).

When evaluating the accidents depending on the type of manoeuvre, it was found that most TAs occurred on the straight road section (almost 78 %), and 114 TAs (43%) in the forward direction (see Table 8).

21% of TAs occurred when reversing, 93% of which were on the straight section. During the evasive manoeuvres, drivers caused 16% of TAs, 91% of which were on the straight and often clear section of the road (see Table 8).

The analysis showed that, according to GEMS, most TAs were skill-based, up to 86% (see Table 6).

6 Conclusions

During the description of single parts of the analysis of culpable TAs of firefighting vehicles type water tenders during 2011 - 2021, partial conclusions were also presented. Total of 394 TAs were analysed with the total damage of 102.3 million CZK (4.18 mil. EUR). Results of the research can be summarised in following findings.

The most frequent cause of TAs was wrong bypassing - 148 TAs (37 %). That increased by 1% in 2020 - 2021.

The greatest deal of damage to firefighting vehicles was caused by speeding - 73.3 mil. CZK (3 mil. EUR) in 54 TAs (78 %). There was an increase of 3% in 2020 - 2021.

When assessing the impact of the length of experience in driving firefighting vehicles at FRS CR, the greatest number of road accidents was caused by drivers with less than 6 year experience. The number of TAs decreased with drivers who had more than 6 years driving experience.

From evaluation of the emergency statistics, it was calculated that there was one TA per 3.435 emergencies. In terms of the mileage, that was 26.7 thousand km per one TA. These figures had a slightly increasing trend in years 2020 -2021.

From evaluation of the available data, it appeared that the firefighter-drivers caused 67% of the TAs while emergency driving, arriving at, and crossing at the intervention site. Most of the large and serious TAs were related to emergency. When distributed accidents by the daytime, more TAs occurred in the heavy traffic during the day (72 %). Most of the TAs occurred on a straight segment of the road (78 %).

The analysis shows that, according to the Generic Error-Modelling System, most accidents were skill-based (86 %). For this reason, it would be advisable to deepen the current firefighters-drivers training with specific activities such as estimating a lateral distance, estimating the distance in front of, and behind the vehicle, evasive manoeuvres (see Table 14).

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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