COMPARISON OF BRAKING DYNAMICS AT HIGH SPEEDS OF FIREFIGHTING VEHICLES ON TATRA CHASSIS WITH DIFFERENT BRAKING SYSTEMS

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Resume

In this paper are summarized the results of measurements of the driving characteristics of fire-fighting vehicles during the braking from high speeds. Two water tender vehicles manufactured by TATRA, used by the Fire Rescue Service of the Czech Republic, were compared. The tested vehicles differ in their braking systems. In the study are monitored the braking distance and deceleration, which were compared with previous tests focusing on tire type, test track surface, and weather conditions. When braking from a speed of 80 km/h, the worst results of the braking distance were recorded for SCANIA of 64 m and TATRA TerrNo1 (9T5 2243), of 73 m. These vehicles were equipped with drum brakes. In the case of the SCANIA vehicle, the cause was the heating of the drum brakes. For the TATRA TerrNo1, the reduced braking efficiency was likely due to the brake wear and thermal effects on the drum brakes.

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1 Introduction

This paper builds upon previous research conducted by the authors [1-2], which presented results of braking distance measurements of firefighting vehicles at higher speeds. The experiments were performed for initial velocities of v_0 = 70, 80, and 90 km/h.

The first series of measurements was carried out on a dry concrete surface at the non-public Prerov-Bochor airfield [1]. The tested vehicles included two fire trucks with TATRA chassis - one equipped with drum brakes and the other with disc brakes, and one SCANIA 4x4 vehicle with drum brakes. The second series of tests was conducted on a wet asphalt road (following overnight rainfall) in the municipality of Hlucin [2]. This phase involved a TATRA vehicle with disc brakes and a SCANIA 4x2 vehicle with drum brakes.

The long-term focus on the fundamental dynamic driving characteristics of firefighting vehicles, specifically braking distances and longitudinal acceleration at higher initial speeds v_0 = 70, 80, and 90 km/h, is motivated by accident statistics, previously analysed by the authors [3] and subsequently updated [4]. Between 2011 and 2022, excessive speed was identified as the primary cause in only 68 at-fault traffic accidents (15%) involving firefighting vehicles responding to emergency calls. However, those incidents accounted for as much as 79% of the total material damage to firefighting vehicles during the analysed period, amounting to EUR 3,290,200.

2 Tested firefighting vehicles

The measurements were conducted on two TATRA firefighting vehicles with different braking systems and of different ages. These vehicles are designed for operation on paved roads with rear-wheel drive, with the option to engage front-wheel drive for off-road use on unpaved surfaces. This corresponds to the chassis design, which features a central load-bearing tube and swinging half-axles. An overview of the basic characteristics of the tested vehicles is provided in Table 1.

Table 1 Overview of the basic characteristics of the tested vehicles

Firefighting vehicle	TATRA TerrNo1 (9T5 2243)	TATRA Terra (1TH 0621)
Fire marking	CAS 20/4000/240-S2T	CAS 20/4000/240-S2T
Registration number	9T5 2243	1TH 0621
Location	HS Novy Jicin	HS Koprivnice
Extinguishing agent volume - Water (l)	4000	4000
- Foaming agent (l)	240	240
Crew during testing	1+3	1+5
Dimensions (L/W/H) (mm)	8070/2550/3150	8355/2550/3245
Operating weight (kg)	12600	13300
Maximum weight (kg)	18000	20000
Engine power (kW)	325	325
Tires - Front axle	Michelin XZY 3	Michelin XZY 3
- Rear axle	Michelin X Multi HD	Michelin X Multi HD
Date of manufacture of tires	Week 5, 2020	Week 35, 2022
Transmission	Semi-automatic Norgren	Automatic Allison
Brake system	Drum brakes	Disc brakes
Assistance systems	ABS	ABS
Date of purchase	28/05/2015	15/12/2020

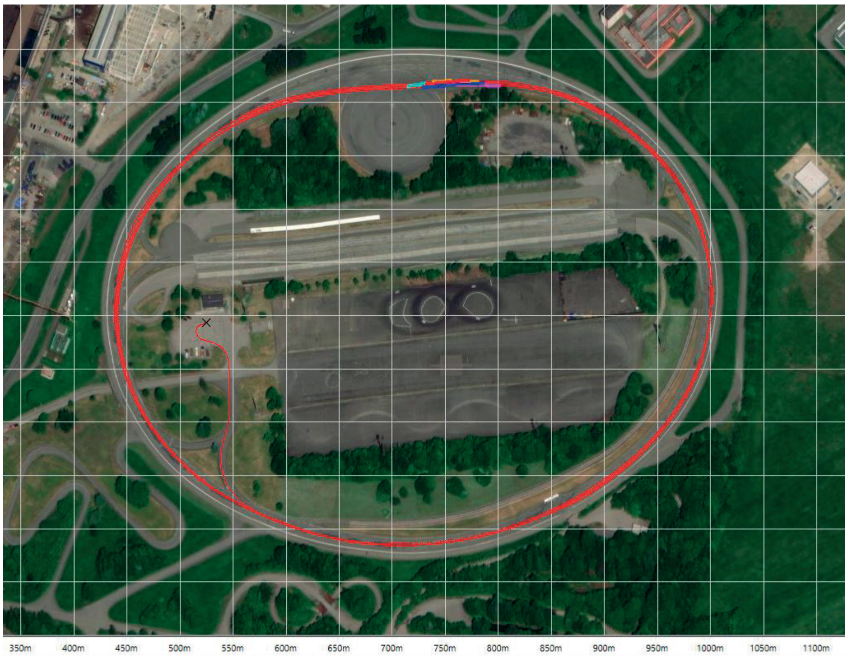

***Figure 1** Recording of the position of the TATRA TerrNo1 firefighting vehicle during testing from an initial speed of 70 km/h*

The first tested firefighting vehicle is the TATRA 815-231R55 4x4.2, commercially designated as TerrNo1 (hereinafter referred to as TATRA TerrNo1), registration number 9T5 2243. A detailed description is available on the website [5].

The second tested firefighting vehicle is the TATRA 815-2T5RA3 4x4.1, commercially designated as Terra (hereinafter referred to as TATRA Terra), registration number 1TH 0621. A detailed description is available on the website [6].

3 Measuring equipment

Two Performance Box devices, manufactured by Racelogic Ltd, Buckingham, United Kingdom, were used to measure the driving characteristics. A detailed specification of the devices is available on the manufacturer's website [7]. The measuring devices were mounted inside the cabin on the windshield along the longitudinal axis of the vehicle. The device determines the absolute position of the vehicle in real time using signals from the GPS and GLONASS systems. Based on position and time, it calculates the travelled distance, instantaneous speed, acceleration, and a range of other parameters. The recording frequency is 10 Hz. The device has been equipped with an SD card on which the recorded data were stored. These data were subsequently transferred to a computer and processed using the VBOX Test Suite software (hereinafter referred to as VTS), version 2.1.6.5877 [8].

The theoretical basis for evaluating the measured data was described in detail in previous studies by the authors [9]. It is based on general principles of physics [10] and relevant technical literature [11-12].

4 Test location

The experimental measurements were conducted at the TATRA TRUCKS company test track in Koprivnice on November 2, 2024. The testing began at 9:00 a.m., with an ambient temperature of 9 °C. The weather was overcast, and light drizzle occurred intermittently during the testing. The asphalt surface of the track remained wet throughout the entire measurement period. An example of the recorded driving path of the TATRA TerrNo1 vehicle (red trace) and its braking phases (multi-coloured traces) overlaid on a map background during evaluation in the VTS software is shown in Figure 1.

5 Measurement procedure

Braking and acceleration tests were conducted with fully loaded firefighting vehicles, including filled extinguishing agent tanks and complete operational equipment. It was determined that for each initial speed of 70, 80, and 90 km/h, seven experimental runs would be performed to eliminate the possibility of invalid trials, such as failure to reach the prescribed initial speed. The objective was to obtain at least five valid runs for further evaluation. Each test run began with departure from the parking area, followed by acceleration on the test track loop to the required initial speed for braking. The driver maintained this speed until reaching the designated braking zone, where the intensive braking was initiated using the service brake until the vehicle came to a complete stop. After stopping, the driver continued to apply pressure to the brake pedal for approximately three seconds to secure the vehicle in place following the rebound of the suspended cabin. No auxiliary braking systems were used during the measurements.

6 Evaluation of measured data

The primary evaluation of the measured data was carried out using the VTS software. Boundary conditions for each tested task were gradually configured within the software. The resulting evaluated values were exported in “csv“ format and subsequently processed further in the MS Excel environment. The evaluated data from the braking distance measurements of both tested vehicles are summarized in the graphs shown in Figures 2 to 4, according to the initial speed.

For evaluation of the longitudinal deceleration during braking, a correction based on Regulation ECE No. 13 [13] was applied. According to this regulation, longitudinal acceleration is evaluated within the interval from 80% to 10% of the initial braking speed. This approach eliminates nonlinearities at the beginning of the braking process, related to brake system engagement, and at the end, where vehicle oscillation may occur during complete stop. Due to the scope of the evaluated data, only the calculated average values are presented in Figure 5. Since the VTS software uses gravitational acceleration ($g = 9.81$ m/s^2) as the unit for acceleration, the reported values can be interpreted as the coefficient of adhesion.

Figure 2 *Braking distances of tested vehicles for initial speed v_0 = 70 km/h*

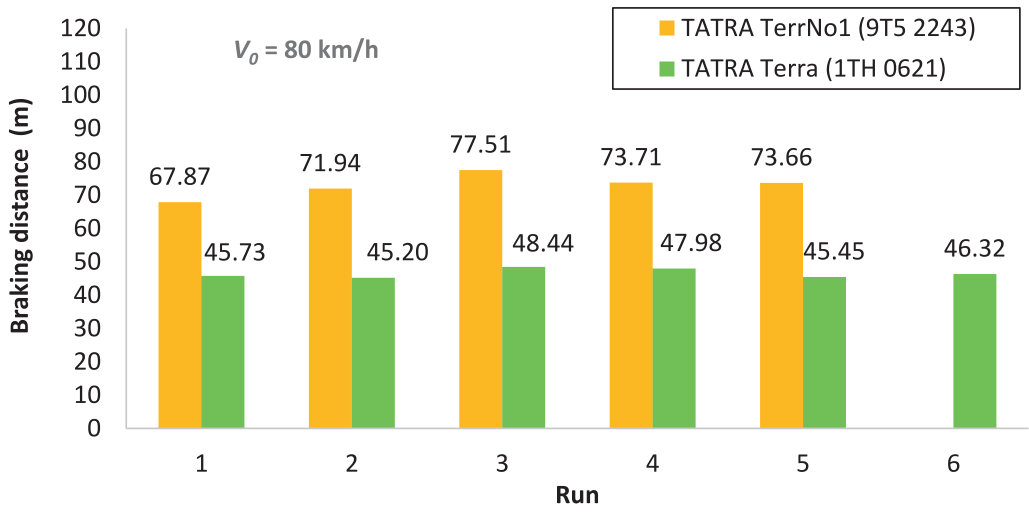

Figure 3 *Braking distances of tested vehicles for initial speed v_0 = 80 km/h*

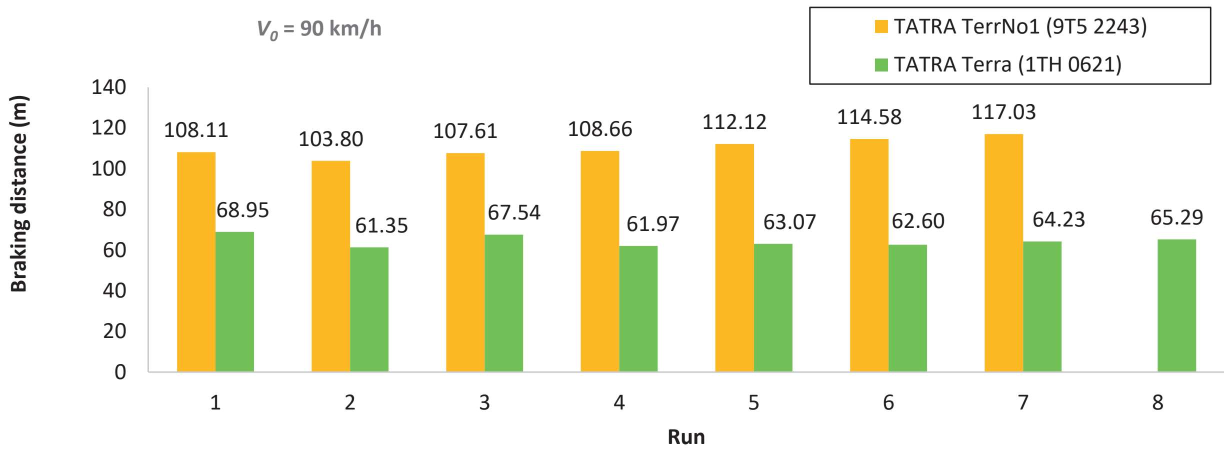

Figure 4 *Braking distances of tested vehicles for initial speed v_0 = 90 km/h*

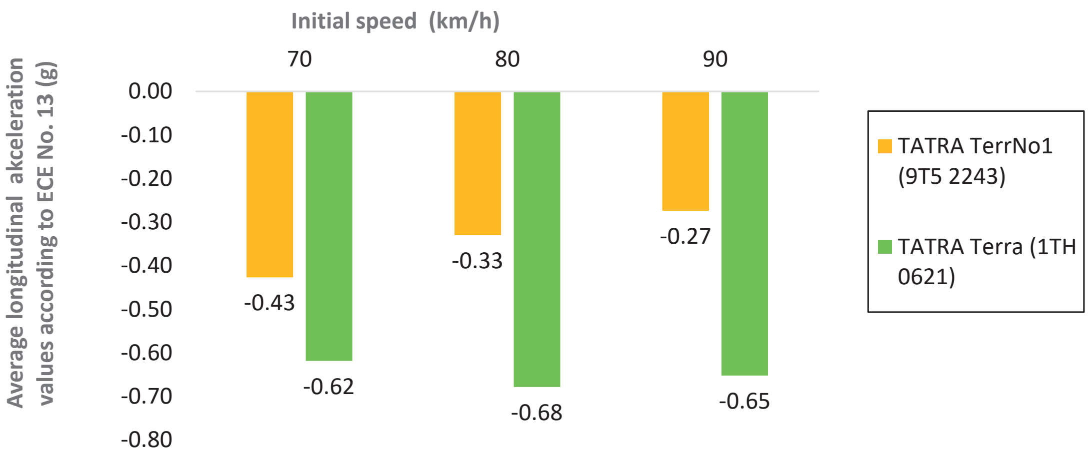

Figure 5 *Average longitudinal acceleration values according to ECE No. 13 during braking*

Table 2 *Wheel disc temperatures during testing*

Firefighting vehicle	TATRA TerrNo1 (9T5 2243)	TATRA Terra (1TH 0621)
Wheel disc temperature at the end of braking from v_0 = 80 km/h (°C)		
- left front wheel	250	310
- left rear wheel	190	140
Wheel disc temperature at the end of braking from v_0 = 90 km/h (°C)		
- left front wheel	295	321
- left rear wheel	240	180

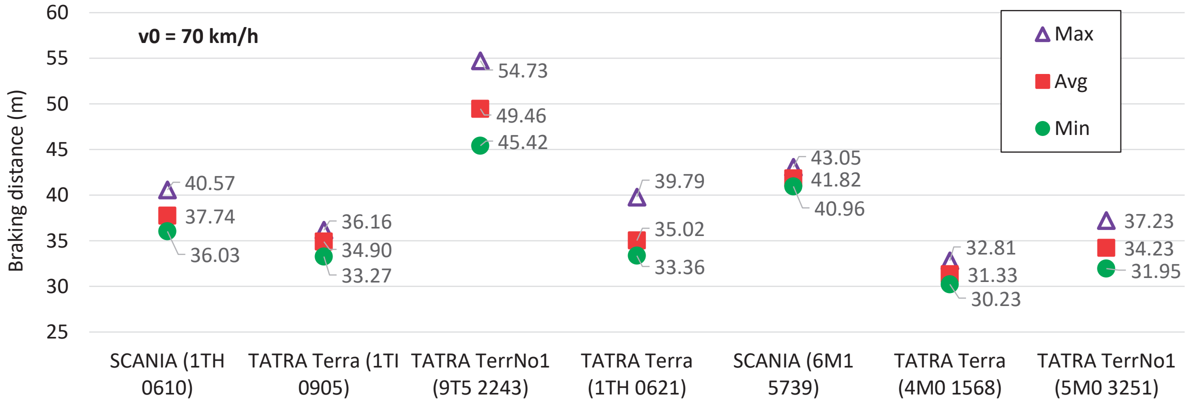

Figure 6 *Braking distance (m) for an initial speed of v_0 = 70 km/h*

The TATRA TerrNo1 vehicle (9T5 2243) equipped with drum brakes exhibited the poorest performance across all the tests. At the defined higher initial speeds, repeated test cycles led to gradual overheating of the drum brakes. This phenomenon had a noticeable impact on the braking distance results. A progressive increase in braking distance was recorded for this vehicle, with differences reaching nearly 10 meters even at speeds of 70 km/h. It was necessary to interrupt the testing several times and allow the brakes to cool down by driving around the test track with occasional light braking.

After completing the braking distance test cycles, from initial speeds of 80 and 90 km/h, an indicative temperature measurement of wheel discs was performed using a Dräger UCF 7000 thermal imaging camera. The measurement was conducted only on the left side of the vehicle, on both the front, and rear wheels. The recorded temperatures are presented in Table 2. The comparison showed that the disc brakes reached higher temperatures, yet their braking performance did not deteriorate.

7 Comparison to previous similar tests

One of the objectives of this paper was to summarize and compare the obtained results with previous tests [1-2]. The graphical representations in Figures 6 to 8 summarize the braking distance measurements' results of the tested vehicles from all three experimental campaigns. The graphs are categorized according to the initial braking speed. The average (Avg), maximum (Max), and minimum (Min) values of the measured braking distances are presented.

The first four tested vehicles shown on the graphs from the left were provided by the Fire Rescue Service of the Moravian-Silesian Region. Their license plates contain the letter "T". The remaining three vehicles were provided by the Fire Rescue Service of the Olomouc Region, with license plates containing the letter "M".

All four vehicles from the Moravian-Silesian Region were tested on a wet asphalt road surface. The three vehicles from the Olomouc Region were tested on a dry concrete surface at an airfield. During the testing of all vehicles, the ambient temperature ranged between 6 and 11 °C.

As the initial speed increased, the differences in braking distances between the worst-performing vehicles - TATRA TerrNo1 (9T5 2243) and SCANIA (6M1 5739) - and the other vehicles became more pronounced. It cannot be conclusively stated that this was solely due to their drum brakes, as three other vehicles in the group also had the drum brakes but performed better in braking.

Figure 9 summarizes the average braking distances depending on the initial speed of the tested vehicles, including the type of front axle tires. The data presented in Figure 9 suggest that the influence of the tires on the TATRA TerrNo1 (9T5 2243) vehicle can likely be excluded. The same tires on the TATRA Terra (1TH 0621) vehicle with disc brakes showed better braking performance on the same road surface.

Figure 10 presents the average values of longitudinal acceleration depending on the initial speed of the tested vehicles, also including the type of front axle tires. These values were obtained using the VTS software after applying the correction according to Regulation [13]. The best results were achieved by all three TATRA Terra vehicles with disc brakes and the SCANIA (1TH 0610) vehicle with drum brakes and a 4x2 road chassis.

8 Conclusion

The objective of the testing was to conduct and evaluate measurements of the basic driving dynamics of firefighting vehicles during braking from high speeds, and to compare the findings with previous tests. The resulting braking distance of a vehicle is influenced by a number of factors. The primary ones include climatic conditions, road surface condition and its type, tires, and the braking system.

All vehicles were tested under similar ambient temperatures. Therefore, the influence of this factor cannot be assessed in the context of this testing.

The conditions and type of road surface had an

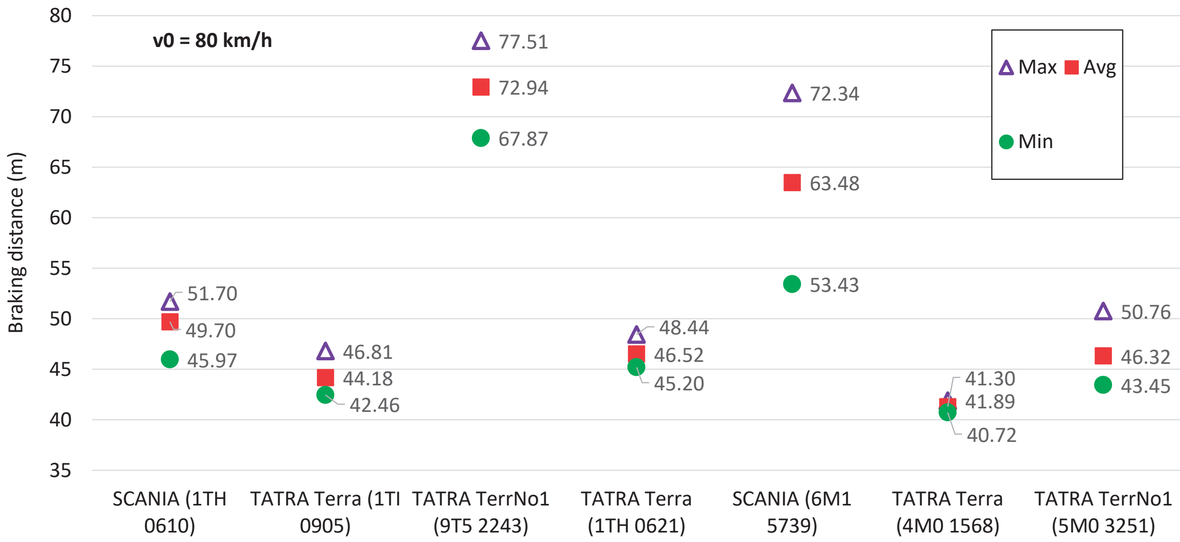

Figure 7 *Braking distance (m) for an initial speed of* v_0 *= 80 km/h*

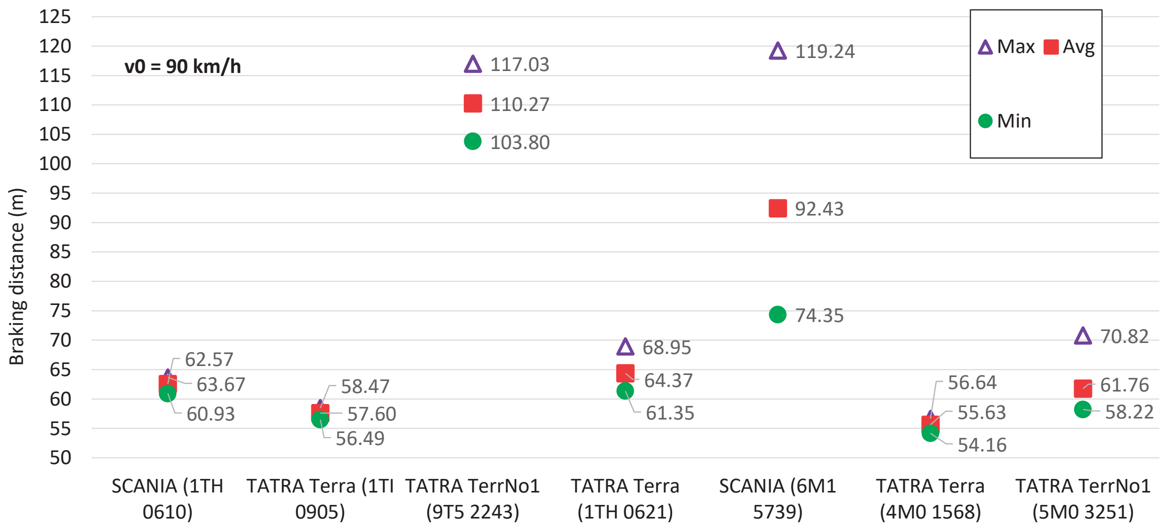

Figure 8 *Braking distance (m) for an initial speed of* v_0 *= 90 km/h*

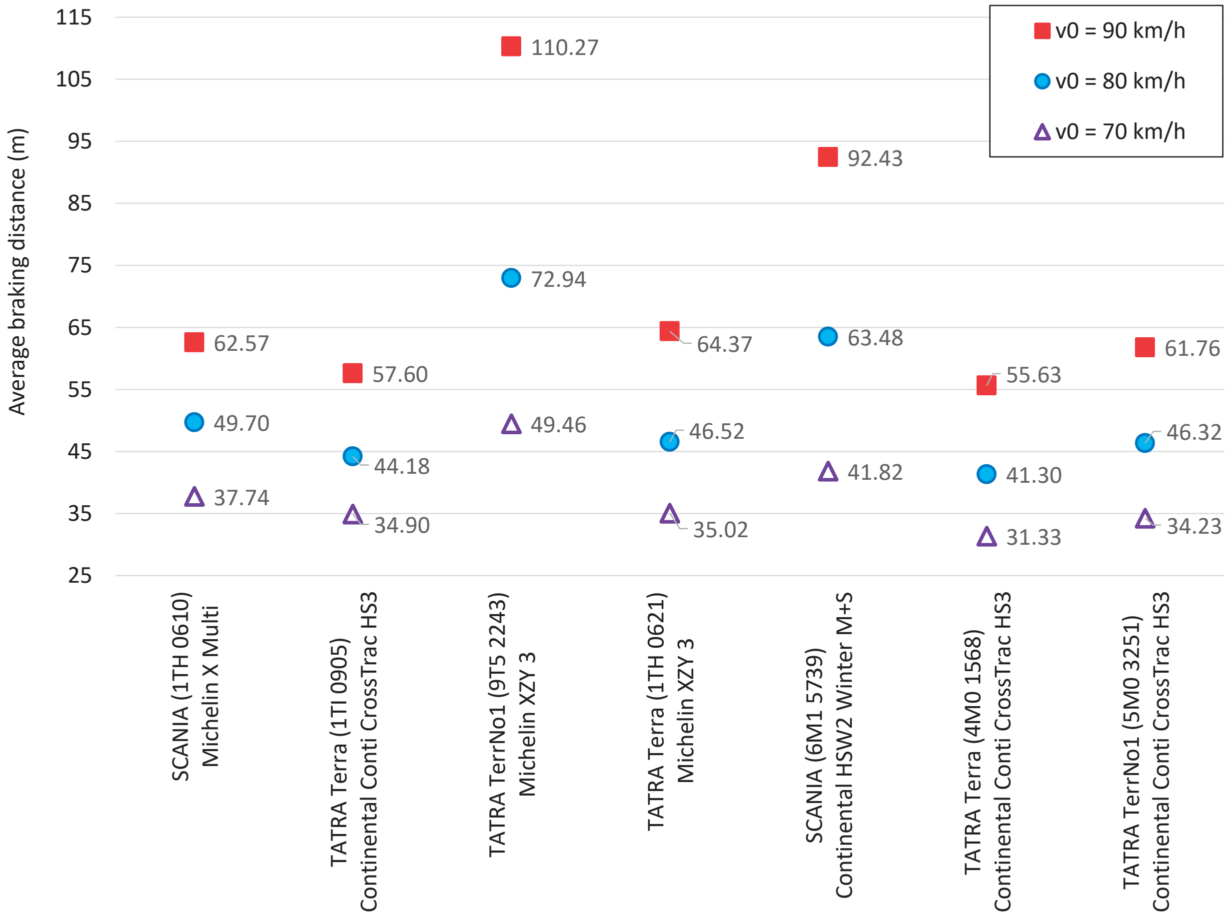

***Figure 9** Effect of tire type on average braking distance (m)*

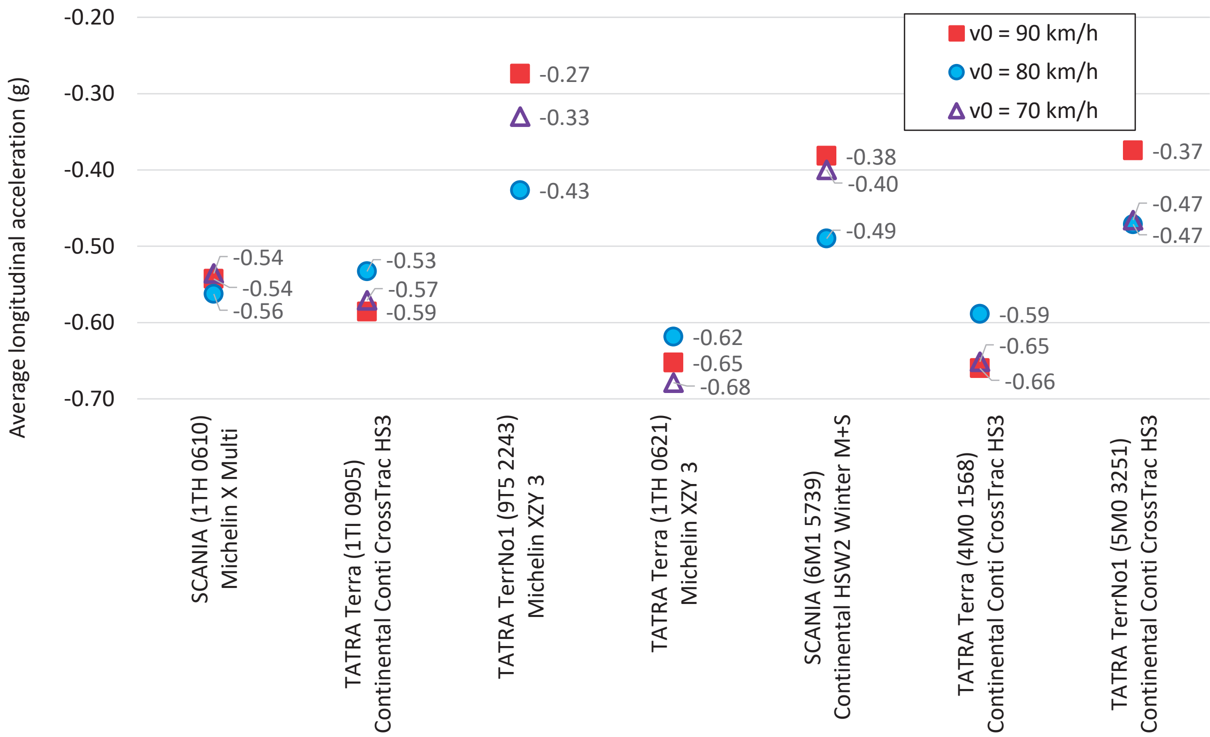

***Figure 10** Effect of tire type on average longitudinal acceleration during braking according to ECE No. 13 (g)*

impact only on both TATRA TerrNo1 vehicles. During testing on a wet asphalt surface, worse braking distances were recorded compared to a dry surface. At an initial speed of 70 km/h, the difference in average braking distance was 15 m; at 80 km/h, it increased to 27 meters; and at 90 km/h, it reached up to 48 m. These significant differences suggest a possible technical issue with the 10-year-old TATRA TerrNo1 (9T5 2243) vehicle equipped with drum brakes. The other vehicles performed comparably well regardless of the road surface. An exception was the SCANIA vehicle (6M1 5739), where the effect of drum brakes overheating became apparent due to frequent braking without regular cooling runs between braking cycles.

The TATRA vehicles were fitted with Continental Conti CrossTrac and Michelin XZY 3 tires. The SCANIA (6M1 5739) vehicle was equipped with Continental HSW2 Winter M+S tires. The influence of this factor cannot be reliably assessed here. TATRA vehicles with Continental Conti CrossTrac tires performed comparably well in braking. The TATRA vehicles with Michelin XZY 3 tires showed significantly different braking performance (see Figure 9). If, however, the cause of the discrepancy lies in the technical condition of the 10-year-old TATRA TerrNo1 (9T5 2243) vehicle, then the Michelin XYZ 3 tires demonstrated the best performance. We would therefore recommend equipping first-response fire vehicles with these tires.

Based on the above results, the best braking performance was achieved by the TATRA Terra vehicles with disc brakes. The worst braking performance was recorded for the TATRA TerrNo1 (9T5 2243) vehicle with drum brakes.

Given the increasing number of fire trucks being purchased on SCANIA chassis in the Czech Republic, authors recommend that the driver training for these vehicles include a focus on the issue of drum brake overheating at higher speeds during the frequent intensive braking. This phenomenon was particularly evident during the braking from an initial speed of 80 km/h. After the fifth braking cycle, it was necessary to cool the brakes by driving along the test track without braking [1].

The type of brake material used has a significant impact on the braking distance. During the testing the specific brake materials used on the tested vehicles were unknown. The issue of brake materials was addressed in a paper [14], which briefly presented the results of the project “Safe Response Driving of Firefighting Vehicles to Emergency Sites” (project number VH20182021035). Laboratory measurements of the friction coefficients of brake materials showed that the original brake material used in the SCANIA 4x4 vehicle performed the worst.

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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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