CETRA[2018]

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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CASE STUDY OF VEHICLE SIDE CRASHES WITH TRAMS

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Abstract

Side impacts belong to the most dangerous types of collisions. This type of collision is typical for accidents of vehicles at crossroads (intersections). In cases where the public city transport includes tramways, there is also a risk of collision between vehicles and tramways. Considering the stiffness of construction and mass of a tramway, depending also on the number of travelling passengers, even collision at relatively low crash speeds into side part of passenger vehicle may result in severe injuries of passengers. Ten accidents of tramways with personal vehicles according to the speed of collision, damage on vehicles and the effects to injuries of the vehicle´s crew have been analysed in this paper. The crash speed is analysed according to damage on the vehicle and verified with the support of the simulation programme calculation. The cause of the accident in connection to mutual visibility aspects at the crash scene has also been analysed. All the analysed accidents occurred in city Brno, Czech Republic and were documented as part of CzIDAS project (Czech In-Depth Accident Study based on GIDAS database) by Traffic Research Centre institution. Cases have been analysed in cooperation between Brno University of Technology and Traffic Research Centre, Czech Republic.

Keywords: tram, vehicle, crash, passenger injuries, accident analysis

1 Introduction

There are several specific characteristics that are typical of tramway transport systems. On the one hand they are similar to railways in that the vehicles move on rails and thus must deal with the same problems as trains with regard to low adhesion and lack of manoeuvrability when encountering obstacles. On the other hand, trams are lighter than trains and attain lower speeds. However, unlike trains, trams operate in mixed traffic alongside other types of transportation which often cross their lines. This means that tram drivers face greater demands on their vigilance and ability to predict events that may occur on the road, including collisions with pedestrians, which are a common occurrence, [1]. Traffic accidents involving trams, as well as the seriousness of their consequences, are influenced by a range of factors connected with the vehicles themselves, the road and individual drivers. One study [2] found that transport accidents which are statistically significant in terms of their seriousness are those featuring low-floor tramcars, older vehicles and higher collision speeds.
Research has been conducted into injuries to the drivers of personal vehicles during collisions with trains; such investigations have been presented in articles such as [3], whose authors used three models (OP, MNL and RPL) to evaluate injury intensity and determine which model was the most effective. They discovered 10 independent variables for evaluating injury intensity and concluded that the OP model was the most suitable for the task.
The largest network of tram lines in the world is in Melbourne. The authors of [4] investigated tram driver vigilance during various road traffic situations with the aim of evaluating risk factors and influences. They also wished to distinguish between tramway layouts that were more

DOI: https://doi.org/10.5592/CO/CETRA.2018.738

and less safe for the remainder of road users. They found that raised and differently coloured kerbs next to tram lines provide a considerable increase in safety at locations where tram lines are crossed by other vehicles.
Key aspects that influence variations in tram driver behaviour were presented and analysed in [5]. Other research [6] shows that the remainder of traffic participants consider the risk of colliding with a tram to be low, and in fact lower than their risk of collision with all other traffic participants.
The evaluation of collisions with trams is dealt with in [7], which describes an experiment that simulates the collision of a tram with the side of a vehicle at different speeds. During the tests, collisions were carried out with a special bumper used for tram collision testing as well as with a standard tram bumper.
Research works [8], [9] and [10] concerned issues involved in the performance of vehicle impact testing, including side impacts, the collection of dynamic parameters and the simulation-based computer modelling of such processes with the aid of the Virtual CRASH simulation programme. They also dealt with specific case studies related to these issues.
During tramway operations, accidents occur between trams and other traffic participants. The most common cases are dealt with in [11].
Internal statistics from the Brno Public Transport Authority (hereinafter DPMB, a.s.) show that the frequency of tram accidents per calendar year ranges from 400-500, i.e. an average of one to two accidents per day. The causes of these accidents can be grouped into several categories – see Table 1. It is clear that the most common accidents involving trams occur when a tram is moving on a parallel course to another means of transport and then their trajectories subsequently cross. Another frequent cause is failure to give way. With both types of accident, in most cases other road users, not tram drivers, are at fault. However, it is typically tram drivers that cause accidents connected with failure to estimate provided road-space. This term refers to collisions which occur as one traffic participant is stationary and the other is moving in its vicinity. The extent of damage to the vehicles involved is typically minimal.

Table 1 Overview of the numbers of accidents involving trams in the city of Brno, divided into categories [11]

Year	A – Parallel road use	B – Failure to give way	C – Failure to estimate provided road-space	Other types	Total
2016	207	59	79	82	427
2017	265	65	48	90	465

2 Methods and accident reconstruction

2.1 Data collection

The data used in this article were gained as part of the HADN project for the in-depth analysis of traffic accidents. This is currently being implemented within the Czech Republic via the CzIDAS (Czech In-depth Accident Study) project by the Transport Research Centre in cooperation with the company IDIADA CZ a.s. The methods utilised by the HADN project are primarily based on German research taking place within the GIDAS (German In-Depth Accident Study) project. The project involves the detailed documentation of traffic accidents and their consequences with the aim of analyzing the causes both of the accidents themselves and of the injuries that occur during them. Project outputs take the form of recommended measures aimed at reducing the seriousness of tram-related accidents, or preventing them altogether.
The evaluation of the consequences of the presented traffic accidents was carried out in cooperation with the Institute of Forensic Engineering at Brno University of Technology, whose academic staff have been investigating issues concerned with the analysis of traffic accidents

for many years. The materials used for the evaluation of collisions mainly included photo documentation acquired at the scene of the accident, records of trace evidence left by the colliding vehicles at the accident scene, recorded speeds taken from the tram's recording device, information from contracted medical facilities about the injuries of those involved in traffic accidents, and simulations of events occurring during accidents with the aid of computer simulation modelling.

2.2 Accident reconstructions

The analysis of events occurring during accidents was based on objective data gained from the scenes of accidents, i.e. photo documentation of damage to vehicles, the surrounding environment of the transportation route, and trace evidence arising as a result of traffic accidents (recorded in recent years via geodetic measurements). This was combined with tram speed and braking data provided by the DPMB, a.s. The simulation programme Virtual CRASH (version 3.0) was used for the simulations, in which not only the dimensions of the collision partners are taken into account, but also their weights. As it is not possible to determine the exact number of passengers present in a tram at the time of an accident, the simulated trams were considered to be half full. The weights of the simulated automobiles not only corresponded to the technical parameters of the real vehicles, but also incorporated the actual amount of people in each vehicle at the time of the accident. The pre-collision movement of the simulated trams was in accordance with data from on-board recording devices, and was also determined so that the simulated course of each accident corresponded to the logic of accident events and was acceptable from the technical perspective.

2.3 Example of a reconstructed traffic accident

The following example of a reconstructed traffic accident concerns accident No. 1 (Fig. 1 below). This involved a collision between a BMW X3 automobile with a ČKD Tatra T3R tram. The accident resulted in serious injuries to the driver of the BMW, who was in the vehicle alone. It happened on Veveří Street in the centre of Brno. The driver of the vehicle decided to conduct a U-turn into the opposite lane, but overlooked a tram that was simultaneously moving in parallel to the vehicle. This resulted in the collision of the tram with the left side of the car.

Figure 1 Damage to the BMW X3 vehicle and the Tatra T3R tram

From the reconstruction (Fig. 2 below) it is apparent that the tram struck the left side of the BMW with its frontal part at approx. 43 km/h while the BMW was moving at around 5 km/h. As a result of the collision, the BMW was pushed by the tram for around 16 m before both vehicles came to a halt. At a time of 2 seconds before the collision the driver of the BMW may have begun to turn left, at which point the vehicle was located approx. 8 m before the point of impact and was travelling at around 23 km/h. At that moment the tram driver could have identified the intentions of the BMW driver and may have started to react. After one second the tram could have started to slow down from a speed of 47 km/h.

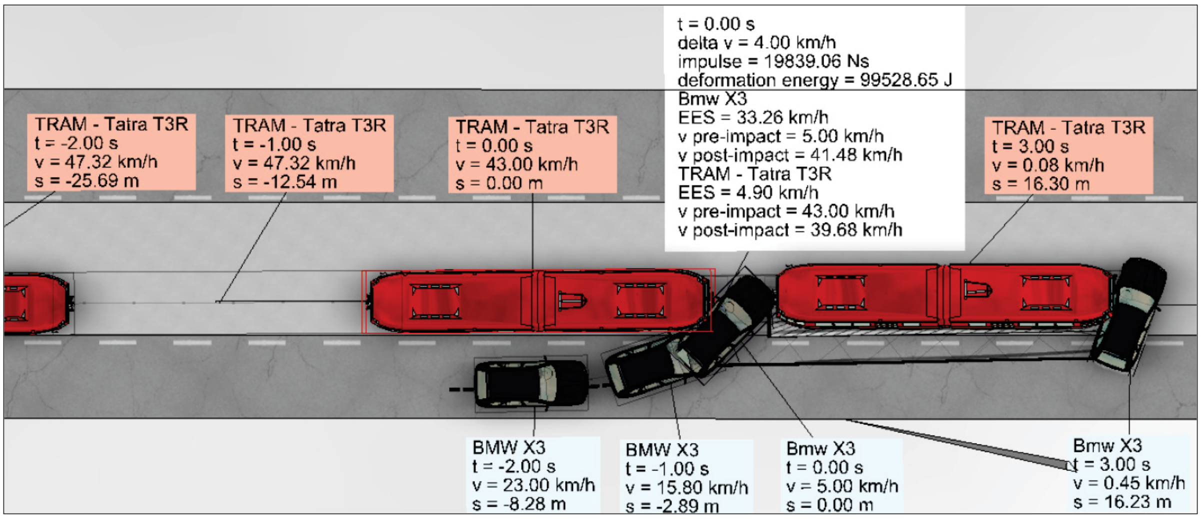

Figure 2 Reconstruction of the events of the accident using the Virtual CRASH simulation programme

3 Results

3.1 Summary of the results of performed accident reconstructions

In order to better compare individual incidents involving trams, the investigated traffic accidents were divided into 3 separate categories, A1, A2 and B, which correspond to the most common and most serious types of collision (Table 2).

Table 2 Results from the reconstruction of 10 cases where trams were involved in accidents with vehicles

Accident No.	Car / tram	Impact speed [km/h]	Initial speed [km/h]	Category
1	BMW X3	5	23	A1
	ČKD Tatra T3R	43	47	
2	Škoda Octavia I	11	25	A1
	ČKD Tatra K2P	30	41	
3	Škoda Felicia Combi	10	24	A1
	ČKD Tatra T3P	30	42	
4	Ford Mondeo Mk. 2	20	35	A1
	ČKD Tatra K2	27	47	
5	VW Touareg	19	33	A2
	ČKD Tatra KT8D5N	30	37	
6	Seat Cordoba	22	36	A2
	Vario LF2R	42	42	
7	Volvo V70	12	12	A2
	Vario LF2R	13	20	
8	Opel Vectra C	25	31	B
	ČKD Tatra KT8D5N	26	42	
9	Renault Thalia	12	8	B
	ČKD Tatra T3G	24	38	
10	Alfa Romeo 145	40	45	B
	Škoda 03T6 Anitra	25	30	

A1 – Both the tram and another vehicle are moving in parallel when the vehicle suddenly makes a U-turn in order to drive in the opposite direction. This type of accident is very problematic, as tram drivers often cannot predict the intention of the driver to perform a U-turn across the tram lines.
A2 – Both the tram and another vehicle are moving in parallel when the vehicle suddenly turns left across the tram lines. Just as in the previous category, such collisions are serious incidents in which the tram driver could theoretically predict the intention of the vehicle driver to turn left but for the fact that, in many cases, the behaviour of vehicle drivers is very surprising and unpredictable, meaning that tram drivers often do not have time to react.
B – Failure to give way at an intersection. This category of accident occurs when a driver fails to give way as a result of ignoring traffic signage (No. 9), or of ignoring traffic control signals where a road crosses tram lines (No. 8 car driver, No. 10 tram driver).

3.2 Car passenger injuries

During the documentation of accidents for the HADN project, reports are submitted concerning the injuries of individual participants. In the investigated cases of tram collisions with vehicles, injuries were only suffered by those travelling in the vehicle, and not by any individuals in the tram. This corresponds with the low braking deceleration values attained by rail-borne vehicles along with the relatively low ability to change speed and manoeuvre of trams in particular. Table 3 (below) presents an overview of injuries to individual vehicle passengers for the investigated accidents.

Table 3 Overview of injuries to vehicle passengers

Accident No.	Position in the car	Passenger injuries
1	driver	bruised lung, fractured ribs, fractured shoulder-blade, broken hip and pelvis
2	driver	bruised arm
3	driver	fractured ribs and collarbone
4	driver	injured thorax
5	driver	slight injury – treatment at sight
6	right backside	head injury, concussion
7	driver	thorax and abdomen injury
	left backside	head and neck injury
8	driver	slight injury – no further notes
9	driver	head laceration
10	driver	cervical spine injury, chest and knee injuries

4 Discussion

The results of collisions between trams and personal vehicles (i.e. the sides of such vehicles) are primarily influenced by the shape of the nose of the tram. The older types of trams involved in the investigated accidents were made by ČKD Tatra. These feature a firmly fixed coupler which protrudes from the frontal part of the coachwork. During collisions, vehicles often become impaled upon this coupler and then dragged by the tram. This form of post-collision movement subsequently leads to more serious injuries. The ingress of the coupler into the coachwork of the personal vehicle can also cause injuries to the lower limbs of vehicle passengers. The frontal parts of new trams are designed to pose a lower threat to other road users, i.e. they are more rounded and have no protruding couplers (Fig. 3).

Figure 3 Left: the nose of a tram with a coupler (accident No. 5); right: the nose of a modern tram without a coupler (accident No. 6)

The extent of injuries to vehicle passengers is of course influenced by the construction design and technical state of the individual vehicles involved. The seriousness of injuries to passengers resulting from collisions with trams moving at similar speeds can vary widely. During accident No. 3, a collision with a tram travelling at approx. 30 km/h, the driver of the vehicle suffered from fractures to the ribs and collarbone, while in the case of accident No. 5 the driver did not suffer any serious injuries and was simply given medical treatment at the scene of the accident (Fig. 4).

Figure 4 Left: a vehicle built to an older construction design (accident No. 3); right: a modern vehicle (acc. No. 5)

3 of the 10 investigated accidents occurred on Lidická Street at locations where the tramway tracks are raised above the level of the street (Fig. 5). This measure was taken in order to prevent collisions between vehicles and trams, as stated in [4]. It is clear from the analysis that it is necessary to make it still more obvious to drivers (through visual cues in particular) that they have driven onto tram lines, so that they may come to act in a more careful manner.

Figure 5 Tramway tracks raised above street level, Lidická Street, Brno (accidents No. 2, 3 and 4)

5 Conclusion

The case study presents typical accident situations involving the intersection of moving trams and personal vehicles which have occurred in the recent past within the city of Brno (Czech Republic). The main goal was to highlight the results of the collision of personal vehicles with trams, with the primary focus being on the marked discrepancy in weight and options for manoeuvring that exists between such accident participants. In particular, the dissimilar opportunities for each participant to avoid the accident were considered, along with the possible differing perception of critical situations by those involved.

Acknowledgements

This article was created with the financial support of the Ministry of Education, Youth and Sports under the National Sustainability Program I, the Transport R & D Center (LO1610) project on Research Infrastructure acquired from the Operational Program Research and Development for Innovation. 1.05 / 2.1.00 / 03.0064).

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