Identifying Selected Tram Transport Risks

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Identifying Selected Tram Transport Risks

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Abstract. In the area of transport infrastructure risks, infrastructure is inspected for safety. It is an element of transport safety management based on risk management and forms part of preventative activities and measures. As regards tram infrastructure which is a component of urban transport infrastructure, there are potential collisions with cars, cyclists and pedestrians. Data from Gdansk Buses and Trams (GAiT) shows that between 2012 and 2016 on average there were about 650 incidents involving trams (collisions and accidents). The objective of inspection will be to identify sources of hazards which may lead to tram accidents or indirectly when tram infrastructure may contribute to accidents not involving trams. The objective of the work is to identify the risks to urban public transport operation with a special focus on trams and to formulate recommendations on how to improve its quality and safety.

1. Introduction

When analysing transport management as part of urban public transport [1], analysts responsible for risk assessment should focus on transport infrastructure and organisation. Hazard identification should look at the resources that help to carry out transport and how that transport service is delivered. As a consequence, the risk analysis will cover five groups of incidents triggered by rolling stock, drivers (tram drivers), passenger behaviour, service delivery and transport infrastructure. In the area of transport infrastructure risks, infrastructure is inspected for safety. It is an element of transport safety management based on risk management and forms part of preventative activities and measures. As regards tram infrastructure which is a component of urban transport infrastructure, there are potential collisions with cars, cyclists and pedestrians. The objective of inspection will be to identify sources of hazards which may lead to tram accidents or indirectly when tram infrastructure may contribute to accidents not involving trams. The objective of the work is to identify the risks to urban public transport operation with a special focus on trams and to formulate recommendations on how to improve its quality and safety. Using Gdańsk as an example, an analysis was conducted of accidents involving trams between 2013 and 2017. The most frequent accidents were identified. Field work included a tram safety inspection on all of Gdańsk's tram lines (about 55 km) looking at tram and road safety. The inspections helped to identify recurring problems or problems that occur on longer line sections. Process analysis helped to define accidents that have had an organisational element to them. Once identified, the hazards were used to carry out operational risk assessment in connection with the daily operations of transport and maintenance companies. The article suggests a recommended method for operational risk assessment for tram transport. The results will be covered in research to come.

2. Literature study

There are much fewer tram accidents than there are accidents with other vehicles (cars, buses, motorcycles, bicycles). They are, however, much more severe especially where pedestrians and cyclists are involved and may involve multiple casualties if a tram derails [2]. Previous studies have identified several inherent road safety concerns for trams, since they are large and heavy vehicles often operating in a complex road environment with multiple other road users [3]. Road users frequently ignore the risks believing that trams are slow and that tram drivers drive carefully [4]. Examples of such behaviour are given in the work of Kruszyna and Rychlewski [5]. The authors showed the effect a tram approaching a public transport stop has on pedestrian compliance with the traffic rules. Obviously, the problem is not connected with the sole existence of such a stop, but with pedestrians' desire to board a certain public transport vehicle. The objective of the research was to identify if this desire had a visible effect on pedestrians' willingness to break the traffic rules and risk a traffic accident. It is also important to note that tram stop hazards are extensively covered in the literature. Several studies have identified safety concerns for tram systems specially at tram stops under mixed traffic operation as trams, cars, and pedestrians share the same roadway [6], [7], [8], [9]. At older type tram stops (e.g. curbside stops, safety zone stops) in mixed traffic conditions, passengers must cross curbside road traffic lanes to access and egress from trams and collisions between general traffic and passengers often take place as a result of such pedestrian movements [10], [11]. Platform tram stops are being constructed progressively to replace older design stops (e.g. safety zone stops) to improve disability access and safety for tram passengers in many countries [12], [13]. Work by Naznin et al. is noteworthy in this respect [14]. The aim of the study was to investigate the safety impacts of platform stops over older design stops (i.e. Melbourne safety zone tram stops) on pedestrians in the context of mixed traffic tram operation in Melbourne, using an advanced before–after crash analysis approach, the comparison group (CG) method. The same authors also studied another key aspect of urban tram transport. In [15] they studied how tram drivers' safety perceptions alter along various tram route sections, signal settings and stop configurations. The participating tram drivers perceived that the raised tram tracks and tramways with raised yellow curbing beside tracks are safer lane priority features on the Melbourne tram network compared to full-time, part-time and mixed traffic tram lanes. They regarded 'hook turns' as a safe form of tram signal priority treatment at intersections and platform tram stops as the safest tram stop design for all passengers among all other tram stop designs in Melbourne. Findings of this research could enhance the understanding of crash risk factors for different tram route features and thus can offer effective planning strategies for transit agencies to improve tram road safety. A considerable number of tram-involved crashes has been recorded in many countries all over the world, especially in mixed traffic [12], [16], [17], [18], [19].

The most tragic tram accident took place in Argentina in 1930 killing 56 of the 60 passengers when the tram fell into a river. In 1996 Ukraine suffered its tragic tram accident with 34 people killed of 150 passengers and more than 100 were injured. Poland's most tragic tram accident happened in Szczecin in 1962 brining the death toll to 15 of about 500 passengers and 150 injuries. The most common cause of tram catastrophes (significant numbers of deaths) includes too high speeds and tram derailment [20], [21]. Tram catastrophes are frequently caused by faulty brakes when trams go down steep gradients [21]. Some countries have set up special commissions to investigate tram accidents or use commissions responsible for studying rail accidents. Examples include the Finland's AIB [20], UK's RAIB [20], and KOMEDO in Sweden [22]. All serious train and tram accidents must be investigated. Faced with a growing number of transport systems, many cities started collecting data and comparing the safety of different public transport systems including tram systems. France, for example, developed and adopted legislation on the safety of infrastructure and transport systems in 2002. The law is based on risk assessment as part of safety management of transport infrastructure [23]. The following are the most common tram accidents [23], [24], [21], [25], [26]:

- involving a single tram,
- involving other trams,

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- involving other road users,
- others.

Dangerous incidents involving a single tram include: fires - explosions, tram derailments (with possibly the most severe consequences), involving a passenger, hitting an obstacle on the tracks or near the tracks. Incidents involving other trams occur when the tram driver enters the wrong route and hits another tram which is moving in the same or the opposite direction, hitting the rear of another tram as it is coming to a stop or is standing at a stop or junction. Incidents involving other road users include: hitting a pedestrian at a stop or pedestrian crossing, hitting a cyclist, hitting a motor vehicle at a junction when crossing the tracks. Other incidents include e.g. vehicles hitting a pedestrian when near tram stops. The biggest risk is when tram stops are part of pavements with pedestrians having to cross the road as the tram approaches the stop [27] or when tram stops are at signalised junction exits [28].

The human factor as a cause of tram accidents a lot of times involves driving across the tracks above the speed limit. As a consequence, infrastructure deteriorates faster in an uncontrolled way. Excessive speed may also cause trams to derail [29], [30].

3. Study method

3.1. Overall risk analysis

A transport system assessment for a specific area includes operational risk involved in the day-to-day operations of haulage and maintenance firms. The risk is present during the process of tram operations which are recurring, known and well understood and delivered cyclically. In general sense operational risk means the consequences of having the wrong or unreliable processes (tram traffic), people (road users) and systems (infrastructure, trams and organisational systems) and external events (weather, vandalism, terrorism, etc.). The analysis and assessment were conducted for three types of risk: individual, group and societal [31], [32].

Individual risk refers to the behaviour of a single road user or a single vehicle on an element of transport infrastructure. It is the probability that a consequence of specific severity is experienced during one trip or within a selected time interval when a road user is exposed to risk from transport infrastructure and other road users. Individual behaviour in this sense may result in vehicle rollover or derailment and hitting another vehicle or running off the transport infrastructure. Once identified, the risk helps transport infrastructure authorities to maintain a specific risk level depending on the class of the line and traffic. Individual risk can be controlled and its level can be effectively lowered. The mathematical model of individual risk in this case has this form (1):

$$RI = P * SI \tag{1}$$

where: RI – individual risk, P- probability of a dangerous incident, SI- consequences for the individual resulting from a dangerous incident.

Group risk refers to a group of people who are in a place of risk or near that place. In the operational sense, it is defined as the probability of fatalities exceeding N in a single dangerous incident. As a result, it is the probability of a consequence (number of tram driver, passenger and bystander victims) occurring in a single dangerous incident. Group risk provides road authorities with a basis for taking decisions to improve those elements of transport network that are most at risk and ensure that the budget is spent effectively. The general model of group risk can be formulated as follows (2):

$$RG = F_{(N)} \cdot N^{a} \tag{2}$$

where: RG – group risk, $F_{(N)}$– probability of fatalities of number N in a dangerous incident, N – forecasted number of fatalities in a dangerous incident, a – risk aversion.

Societal risk is a consequence (victims and damage suffered as a result of road accidents) over a given period (usually per year), in a given area which may occur as a result of dangerous incidents caused by malfunctioning of the tram transport system. Societal risk provides transport and city authorities and bodies responsible for safety (police, rescue services, health service) with a basis for taking decisions to improve those elements of tram safety system that are most at risk and ensure that the budget is spent effectively. The model of societal risk has this form (3):

$$RS = E \cdot P \cdot S \tag{3}$$

where: RS – societal risk, E – exposure – representing a quantitative measure of road user exposure to a potential hazard (such as miles travelled), S – consequence of dangerous incidents.

3.2. Method of tram derailment risk analysis.

The risk of tram derailment can be assessed just as the risk of train derailment [33]. It is defined as a function of the probability of a breakdown of the wheel-track system and the probability of consequences or damage caused by system malfunctioning. In this context the risk of tram derailment is estimated as the product of tram derailment frequency, exposure to the risk of derailment and average consequences of derailment. The consequences of tram derailments depend primarily on the speed when derailing and the cause of derailment. The model of derailment risk has this form (4):

$$R = Z \cdot M \cdot D \tag{4}$$

where: R = risk of tram derailment, Z = frequency of tram derailment, M = exposure to the risk of tram derailment, D = average consequences of tram derailment.

3.3 Hazard identification

The hazards to tram infrastructure safety are identified by assessing the technical condition of infrastructure (not a subject of this work) and assessing road and tram safety using road safety inspection procedures. The inspection is also designed to identify hazards and sources of hazards on tram networks which will help with implementing effective safety treatments and improve infrastructure standards. As regards tram infrastructure which is part of urban transport infrastructure, potential collisions with cars, bicycles and pedestrians are possible. The job of a road safety inspection will be to identify sources of hazards which may contribute to tram accidents or indirectly tram infrastructure may cause accidents without the involvement of trams (e.g. pedestrians crossing the road illegally to get to a tram stop – risk of being hit by a car). Table 1 shows the scope of tram infrastructure inspection and the hazards it looks at.

4. Results

4.1. Safety assessment

Data from Gdansk Buses and Trams (GAiT) shows that between 2012 and 2016 on average there were about 650 incidents involving trams (collisions and accidents). The majority of the incidents are handled without involving the police. Underreporting means that the police database does not represent the real number of incidents. The advantage of the police database (SEWIK) is that it carries a lot more information about causes and circumstances. To illustrate the scale of underreporting the figures below show police data (Figure 1) and GAiT data (Figure 2) [33]. Tram collisions have been on a steady rise since 2012 (from 141 collisions in 2013 to 187 in 2016). The number of accidents is constant at about 20 per year. The trend clearly shows that treatments are necessary.

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Table 1. Scope of road traffic inspection in relation to tram infrastructure

Group of items	Group of elements or road users
Technical condition and parameters of tram line	route stops terminal stop and access routes to depots
Vertical and horizontal marking	for trams for other road users
Safety devices	on route at stops
Lighting	on route at stops
Road user behaviour	tram drivers driver pedestrians (non-passengers) and cyclists passengers

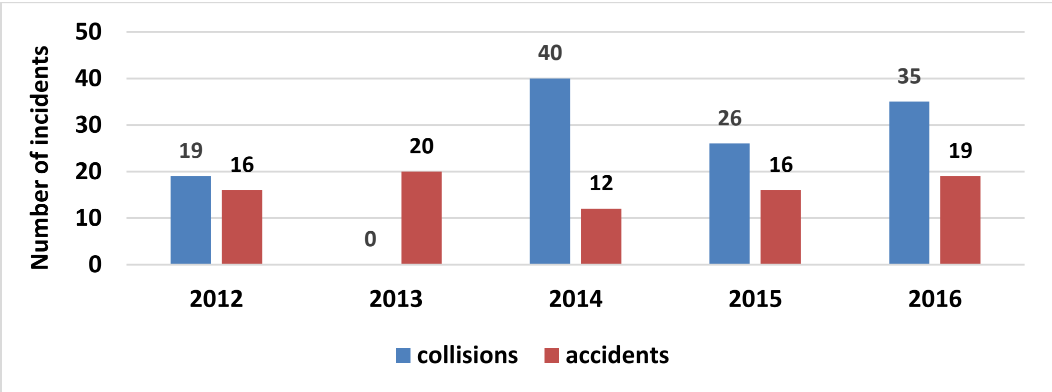

Figure 1. Collisions and accidents 2012-2016 (source: SEWiK) [33]

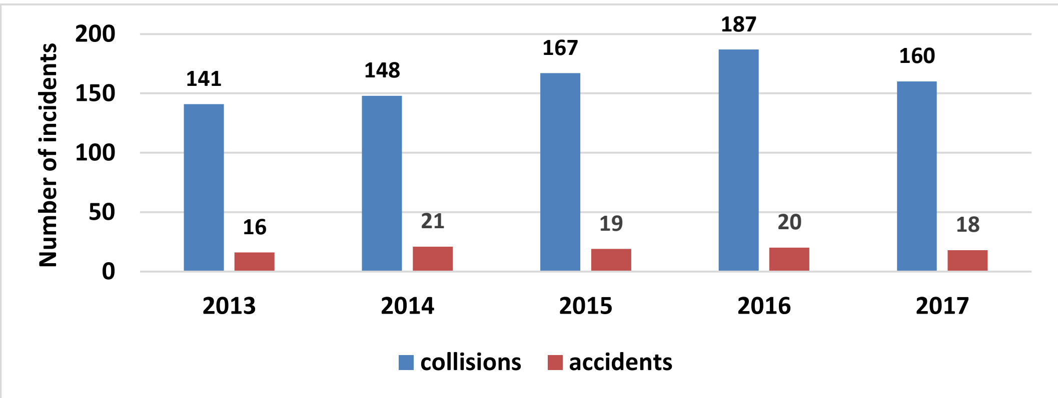

Figure 2. Collisions and accidents 2013-2017 (source: GAiT) [33]

Junction incidents are the most frequent which is probably because more than 85% of the tracks are separated from other traffic which makes junctions the most common point of collision [34]. Accidents and collisions are usually caused by: failure to give way, speed not adjusted to the conditions, pedestrians stepping onto tracks on a red light, vehicles driving onto tracks on a red light, wrong manoeuvres. The types of incidents which qualify as collisions and accidents include side crashes, followed by hitting a pedestrian and hitting a preceding vehicle. Car drivers are clearly at fault in most collisions with as much as 77% of the cases attributed to drivers. Other road users are responsible for a similar number of incidents: pedestrians – 6%, tram driver – 9%, other – 7%. One percent of all incidents is caused by passengers. Figure 3 shows the location of road accidents on the tram network in the years 2012 – 2016 [33].

Figure 3. Location of tram incidents 2012-2016 [33]

4.2 Hazard assessment

The study included a tram traffic safety inspection. Conducted in the field, the inspection examined all of Gdansk's tram lines (about 55 km) focussing on tram and road traffic. The work has helped to identify recurring problems or ones that occur on longer line sections which are a source of hazard or a hazard to other road users. Fifteen principal hazards and sources of hazards to tram infrastructure have been identified (figure 4):

- places of potential collisions between car and tram traffic at and around signalised junctions, a result of signalisation phases, vehicles waiting on tracks, driving on a red light (photo 1),
- places of potential collisions between car and tram traffic at and around unsignalized junctions or track crossings, a result of cars waiting on tracks, especially if no accommodation area is provided (photo 2),
- no visibility in places where streams of different road users intersect – junctions, track crossings, pedestrian crossings, exits (photo 3),
- no light signals for pedestrians crossing tracks, especially for 2x2 cross-sections with the tracks in the central reservation (photo 4),
- poor technical condition of tram infrastructure markings (photo 5),
- pedestrian crossings over tram tracks have no facilities for the blind and visually impaired people (photo 6),

- tram lines are part of the roadway with no separation which means pedestrians use the roadway when boarding or alighting (photo 7),
- no safeguards to prevent cars from driving onto tram stop platforms (photo 8),
- no safeguards to prevent pedestrians from crossing tram tracks and roads where it is illegal (photo 9),
- no safeguards to prevent people from stepping off the tram stop platform where it is illegal (photo 10),
- hazards should a tram derail where grades are present (photo 11),
- presence of fixed obstacles in junction and tram track crossing areas posing an additional hazard in the case of tram-car collision (photo 12),
- no clearance zone, tram lines too close to the road (photo 13),
- very bad technical condition of tram and accompanying infrastructure (photo 14),
- pedestrians crossing the road on a red light when trams wait at tram stops on exits.


Photo 1


Photo 2


Photo 3


Photo 4


Photo 5


Photo 6

Figure 4. Hazards and sources of hazards to tram infrastructure

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Photo 7

Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

Photo 13

Photo 14

Figure 4 (continue). Hazards and sources of hazards to tram infrastructure

The examples above illustrate direct hazards to road users and have mainly to do with the parameters of geometry, markings and functional features of the entire transport infrastructure, i.e. the tram infrastructure in this case.

5. Conclusions and recommendations

Analysis of Gdansk's tram network statistics shows that incidents are very frequent (about 200 a year). Most incidents involve collisions and accidents which affects not only the efficiency and reliability of the tram system, but primarily road safety. In addition, many of the incidents are caused by power breakdowns or damage to traction lines. The inspection of tram tracks has helped to identify a significant number of hazards that are part of the tram and road infrastructure. As a result, actions are recommended to improve the safety of tram transport users. The measures include:

- a detailed analysis of road safety at collision points between trams, other vehicles and pedestrians to assess how well the measures meet the requirements (visibility, markings, traffic layout, etc.) and identify the risk level of an incident (accident, collision),
- implementing ad hoc measures where collisions and accidents are most frequent to improve road safety such as additional horizontal and vertical marking, including warning signals,
- train tram drivers on road safety,
- launch educational campaigns for drivers and pedestrians to raise awareness of trams and their parameters,
- verify the effectiveness of traction network maintenance and power supply and use special marking to highlight places that are most at risk of damage by trucks,
- take steps to improve infrastructure standards to: improve visibility for trams and other road users (drivers, pedestrians and cyclists), improve the perception of the system and better inform other road users (to enhance tram traffic zone recognition, vertical and horizontal marking, light signalization) and provide safeguards (through fencing off, barriers, removing obstacles).
- a detail risk assessment on sections with higher grades (app. 5%).

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