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Summary:

Traffic safety of tram transport

During the eighties and nineties tram transport has experienced sort of a renaissance in many cities both in Europe and overseas. Large transport capacity as well as little local pollution are prominent qualities giving tram transport an advantage to alternative street-running means of urban transport, especially bus. On the other hand, arguments have been raised against tram transport from traffic safety considerations, with reference to poor manoeuvrability and long braking distance.

In Oslo the traffic safety aspect of tram transport has been increasingly focused in recent years. Oslo Sporveier, the municipal public transport company in Oslo, commissioned the present research in order to get an updated assessment of the tram accident risk, and an elucidation of possible measures to increase the safety of tram transport.

Method

The research utilized several different methodological approaches, including:

- A literature study, summarizing available international articles and reports about traffic safety and tram transport.
- Collecting information from other cities with a tram system, including a visit to Gothenburg to see some examples of physical measures to improve the safety in streets with tram traffic.
- Analysis of a representative sample of tram accident reports, to assess probable causal factors.
- Interviews with tram drivers, and observations of their working situation during driving in different traffic environments.
- Risk analyses showing accident development during the last years as well as differences between track types varying in degree of segregation from other traffic.
- Comparison of accident risk between trams and buses running in the same streets.
- Comparison of accident risk between different types of trams.
- Videotape recording of the complete tram network, with camera positioned close to the driver's viewpoint.

To get risk estimates taking into consideration the *exposure*, accident rates for collisions between tram and car and between tram and pedestrian were expressed as accidents per million vehicle-km. Risk of accidents on board

the tram was expressed as accidents per million passenger-km, and risk of accidents during boarding or leaving was expressed as accidents per million trips. For comparisons between tram and bus both vehicle-km and passenger-km were used as measures of exposure.

The tram transport in Oslo amounts to about 3 million vehicle-km per year, or about 80 million passenger-km. The average trip length is 2.6 km.

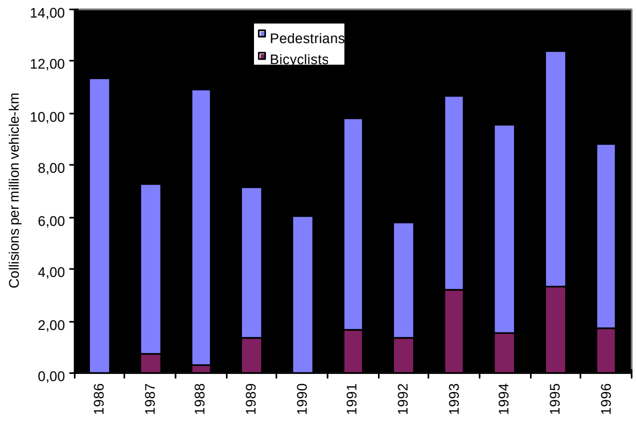
Types of accidents

For the assessment of causal factors as well as for consideration of safety measures it is useful to draw a distinction between accident involving other road users on the one hand, and the tram occupants on the other hand.

The accidents involving other road users, where the tram is directly involved, comprise mainly collisions with cars and with pedestrians, the former being the most frequent, whereas the latter generally are more severe.

Pedestrians and bicyclists

During the years 1986-96 collisions between trams and pedestrians or bicyclists averaged 27.1 per year, about 85% of these involve pedestrians and 15% bicyclists. There seems to have been a slightly increased risk of bicycle accidents over these years, whereas there has been no notable change in the risk of pedestrian accidents.



Collisions 1986-96 between tram and pedestrians/bicyclists, per million vehicle-km.

Concerning severity of tram accidents involving pedestrians, there were 10 fatalities during 1982-95. Killed and seriously injured persons constituted 21% of the pedestrians involved in tram accidents, compared to 9% of other road users in tram accidents.

In most pedestrian accidents, the pedestrian steps into the street without noticing the approaching tram, very often against red traffic light. Another common accident cause is a pedestrian crossing the street so close to the front of a stationary tram that he is not observed by the driver.

Accidents at tram stops

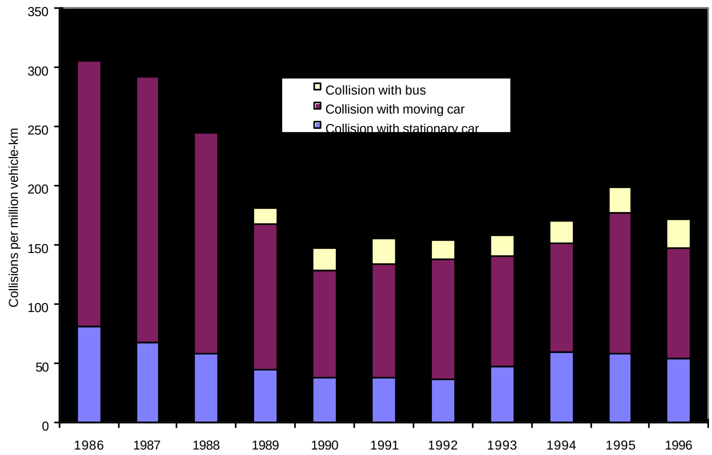
Previous research has shown that the accident risk is high at tram stops. Accidents involving pedestrian is the main problem at these sites, and these accidents include both pedestrians being hit by trams, and pedestrians being hit by a car while on their way to or from the tram.

Analyses of personal injury accidents in Oslo during the period 1982-95 show that the number of accidents per tram stop is about ten times higher for stops with a refuge (safety zone) in the street, as compared to stops where passengers board the tram directly from the street or from the pedestrian pavement. This difference is of about the same order when correction is made for differences in the frequency of tram departures between the different kind of stops. However, to draw a firm conclusion regarding accident risk at tram stops with different layouts it would be necessary to collect additional information about the traffic volume of pedestrians as well as motorized traffic, which has not been possible within the scope of the present project. Thorough investigations of each accident would also be useful to get information about the course of events leading to an accident, as a basis for suggesting accident-reducing measures.

Experience from other cities than Oslo suggest that the design of safety zones is important for the safety. The safest design seems to be stops where safety zones for the two directions of travel are shifted longitudinally, with a pedestrian crossing zone between the two safety zones, implying that pedestrians always cross in front of the stopped tram. It is also suggested that the stopping lines for the trams be retracted some 5 to 10 metres from the pedestrian crossing, to improve the driver's possibility to observe crossing pedestrians. In addition, the safety can be increased by fences between the safety zones and the roadway, between the pedestrian pavement and the roadway, and between the tracks, in order to prevent pedestrians from crossing outside crossing zones.

Collisions between trams and motor vehicles

Collisions between trams and motor vehicles occur much more frequently than accidents with pedestrians or cyclists, but mostly these accidents entail property damage only. During 1986-96 there were on the average 590 collisions annually. About 30% are collisions with stationary cars, which have stopped or parked too close to the tram tracks, and where the tram driver misjudges the lateral clearance during passing. About 10% are collisions between trams and buses. The remaining 60% are almost exclusively collisions with moving cars. The number of collisions with motor vehicles was considerably reduced during the last half of the eighties, but the decreasing trend has stopped, and during the nineties the risk has been rather stable, possibly with a slightly increasing trend.



Collisions 1986-96 between trams and cars/buses, per million vehicle-km (before 1989 the figures for cars include collisions with buses).

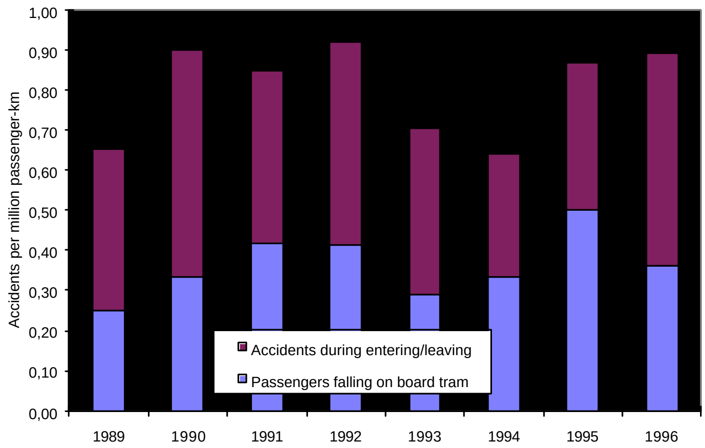
The most frequent tram accident category is collision with a car coming from the tram's right at an unsignalized intersection without a yield sign. The most likely explanation is that car drivers pay less attention to traffic from the left, since in most intersections there is no crossing tram traffic, and one therefore has to yield only to traffic from the right. Such collisions could probably be prevented to a large extent by warning signs in streets which crossing tram lines, preferably with warning lights activated by approaching trams.

Other frequent accidents include collisions with cars making a U-turn in front of the tram and trams running into the rear of a braking car.

Accidents on board the tram and when getting on or off

Accidents incurred by passengers include primarily falls during the trip or during entering or leaving the tram. Each year there are about 60 accidents with passengers. In both accident categories elderly people and women are over-represented. There has been no notable change in the risk of such accidents during the last ten years.

A previous study showed that 70% of the accidents on board happen during acceleration or deceleration at stops. Our results confirm that most accidents occur in such situations, and also when the tram has to stop for other road users that unexpectedly get into the track. There are also some cases of passengers falling in curves due to the lateral acceleration.



Falls on board the tram, and accidents during boarding and leaving, per million passenger-km (1989-96).

Information about the cause of events, and background factors, for accidents on board the tram is very limited. It is therefore not possible to present a comprehensive account of typical factors contributing to such accidents. Better knowledge about such factors may give some clues regarding choice of measures to prevent accidents. To what extent do the accidents occur with passengers standing at the ticket machine to validate their ticket, with passengers on their way to the exit or to find a seat, or with passengers who are standing during the trip?

Many accidents with passengers getting on or off are triggered by automatic doors starting to close when a passenger is on his way in or out. Some passengers seem to get scared in such situations, and may stumble when they try to move quickly away from the closing doors. Possibly, many passengers do not know, or do not trust, that the doors automatically will open if anything gets stuck between them, and that there is no danger of getting jammed.

Although more detailed knowledge about circumstances is lacking, there is reason to believe that this kind of accidents can be prevented by improving the automatic door closing system, to prevent the doors from starting to close while passengers are on their way out or in. Most trams are equipped with a button to disengage the automatic closing of doors, for use by passengers with baby strollers or prams. Passengers should be better informed (by symbols or text) that this button is supposed to be used by anyone who needs extra time to get off the tram.

Causal factors

On the basis of an analysis of representative sample of 200 accident reports likely causal factors were classified according to the following categories: *tram driver, other road user (or passenger), the tram itself, or the traffic environment.*

It was concluded that more than half of the *collisions between tram and car* were caused by errors by the car driver only. Tram driver error was considered main causal factors in about ¼ of the accidents; these comprised mainly collisions with stationary cars due to misjudgment of lateral distance. The remaining ¼ were made up of accidents with more complex causal patterns. Among *pedestrian accidents* about 2/3 are caused by errors of the pedestrian only, whereas tram driver error very seldom was the main cause. The *accidents on board the tram and during boarding and leaving* have less clear causal patterns, although it seems reasonable to consider the automatic door closing systems as causal factors for many of the accidents incurred by passengers getting on or off. Errors by other road users, necessitating heavy braking by the tram, is an important causal factor for passengers falling in the tram.

The tram park comprises several different types of trams, differing considerably in the design of the driver cabin, braking and speed controls, and/or door opening/closing systems. The risk analyses revealed no large differences in average accident risk between different tram types. There seemed to be, however, an inverse relationship between annual vehicle kilometres and risk for the different tram types. Since the drivers rotate between all tram types, this difference in risk is most likely explained by varying driver experience and proficiency in driving different tram types. This may possibly explain why the risk of the oldest tram type in use (SM53) has increased during the last years, paralleling a phasing out of this tram type. Similarly, lack of experience among the drivers may explain why another old tram type bought from Gothenburg some years ago (SM91) had a very high risk during the first two years of operation in Oslo, an explanation supported by interviews with drivers. These results underscore the importance of standardizing certain aspects of the driver cabin of trams, so that drivers do not have to change between trams with quite different control systems, e.g., braking controls by hand vs. foot.

Driver age seems to be related to accident risk. Among drivers having incurred one or more accidents, the young drivers on the average had more accidents than older drivers. Drivers below 34 years of age, having had accidents during 1989-96, were involved in 5.3 accidents on the average, compared to 2.3 among drivers aged 54 and over.

Accident risk on track types with differing degrees of segregation

It has previously been shown that the risk of tram accidents is lower for trams on completely segregated track compared to trams in mixed city traffic. Between these extremes there are varying degrees of segregation, such as physically separated track in a street median or alongside a street, transit malls reserved for trams, buses and taxis, and separate transit lanes in streets with other additional traffic. In this study accident risk for the different types of accidents was computed separately by track type.

Not surprisingly, the risk for all accident types was lowest for trams on completely segregated tracks, with crossings controlled by signals and gates. For collisions between trams and cars there is a monotonic inverse relationship between risk and segregation. The risk of accidents with pedestrians or bicyclists, however, is curvilinearly related to segregation, with the highest risk in transit malls. This may possibly be explained by transit malls being located in areas with a much pedestrian and bicycle traffic. Further investigation including traffic counts of pedestrians and bicyclists are necessary to disentangle the effect of segregation from traffic volume effects. The same inverse U- relationship is found also for tram vs. bus, and also in this case the explanation may be differences in traffic volume.

Tram accidents per million vehicle-km 1994-96, by accident group and type of track.

Track type	Collision with moving car	Collision when passing stationary car	Collision with pedestrian/ cyclist	Collision with bus/tram	Total
Segregated track	12,4	1,1	1,1	3,3	17,9
Physically reserved track	87,4	24,2	4,2	29,5	145,4
Transit mall	105,4	36,7	27,2	65,1	234,5
Reserved transit lane	102,4	75,7	13,3	46,1	237,5
Mixed traffic	122,6	72,9	7,4	13,5	216,3

The risk of accidents among tram passengers varies less between track types than accidents involving other road users. A higher risk of falling on board the tram in transit malls and physically segregated tracks may possibly be related to a higher variability in the tram's speed on these track types. Naturally, since there is no interfering traffic, the speed is high between intersections; and this may necessitate heavy braking at intersections. This possible explanation can only be verified by more detailed accident investigations.

The risk of accidents with passengers getting on or off increases with decreased segregation. However, since these risk estimates have not been corrected for differences between track types regarding number of passengers boarding and leaving, this relationship may possibly be explained by differences in exposure.

Accidents on board the tram and during entering and leaving, per million passenger-km 1994-96, by type of track.

Track type	Falling on board tram	Accidents during entering or leaving tram
Segregated track	0,13	0,19
Physically reserved track	0,34	0,09
Transit mall	0,46	0,43
Reserved transit lane	0,45	0,43
Mixed traffic	0,29	0,63

High-risk locations (blackspots)

Some locations on the tram network seem to be characterized by an accumulation of accidents. To identify such blackspots all tram accidents in the years 1995 and 1996 involving cars, pedestrians or bicyclists were classified according to location. Carl Berners Plass was the location with the highest number of accidents, 20 in total. Next follow the intersections Gustav Vigelands Gate/Drammensveien (Thune roundabout), Frognerveien/ Løvenskiolds Gate and Inkognitogata/Colbjørnsens Gate, with 13, 12 and 10 accidents respectively during the two-year period.

Some longer track sections also seemed to have a particularly high accident rate, e.g., Cort Adelers Gate from Drammensveien to Aker Brygge (the Vika Line). On this 600 metres section 27 accidents were reported in less than 1.5 years.

Accidents with pedestrians and bicyclists make up only a small proportion of these accidents, and it is difficult to identify many blackspots. The intersection Hausmannsgata /Storgata, however, seems to stand out, with 5 accidents during the two-year period.

There are good reasons for more thorough analyses of the identified high-risk locations, since it will be particularly beneficial to concentrate traffic safety efforts in these areas.

Comparing accident risk between tram and bus

The accident risks for tram and bus were compared on the basis of accidents and exposure in streets trafficked by both tram and bus. This eliminated the need to make corrections for other traffic. Comparing these two modes of transport on the basis of passenger-km shows that the total risk of accidents for the tram is 3 times higher than for the bus. Using vehicle-km as exposure measure, the risk is 3.4 times higher for the tram.

About 20% of the accident risk of the tram is made up of collisions during passing of stationary cars, whereas the proportion of such accidents for the bus is negligible.

For collision with cars (except the passing of stationary cars), the risk per vehicle-km is 3.5 times higher for tram than for bus, and for collision with pedestrian/bicyclist it is 4 times higher.

The difference in risk between tram and bus is less for accidents involving passengers, compared to accidents with other road users. The risk of falling during the travel is about the same for both modes, whereas accidents during entering or leaving is slightly higher for the tram.

Accident reporting and registration

The possibility of efficient use of accident information as a basis of implementing safety measures depends heavily on the quality of the accident data. It is important to get as much relevant information as possible about the cause of events and circumstances regarding each single accident.

The analyses of tram accidents in this project build mainly on data from Oslo Sporveier's accident data base OSKAR, which has as its primary data source accident reports filled out by the tram drivers. During our work with the analyses the desirability of better quality of the data has become apparent.

The reporting form which is supposed to be filled out by the driver, makes a good basis for recording the most relevant information about the accidents. Certain additional information would be desirable, though; for example information about weather and road friction, and use of the various braking systems. The latter information was included in the previous version of the form, but the form has been changed, in order to harmonize with the standard European form for reporting of motor vehicle accidents. Delays and other driver stress factors possibly contributing to accidents would also be useful to include. It should also be noted that the form is primarily suited for reporting accidents involving motor vehicles, and less adapted to pedestrian accidents.

The filling in of the form can be improved by having the form checked by a person with particular responsibility for accident reporting, if necessary reviewing the form together with the driver, to secure that all relevant information is included.

When data are entered into the data base, it is important that names of locations are coded in an unambiguous way, and it should be noted whether the accident happened at a tram stop.

With the object of a running assessment of the risk situation, as well as evaluations of implemented safety measures, it is important to establish good procedures for continuous recording of passenger-km and vehicle-km for the various network sections, tram-lines, and tram types, with easy access to information for specific time intervals.

Measures to improve traffic safety

Establishing efficient procedures for accident reporting and registration is an important prerequisite to the development and implementation of traffic safety measures. Concerning the specific measures, they can be grouped into different categories according to the kind of measure (road and traffic engineering measures, improvements of trams, information, education and training) and to road user group (tram driver, passengers, other road users) which the measures are supposed to influence.

Summary table of suggested tram traffic safety measures. The Xs indicate which accident types the measures are expected to prevent.

	Collisions with cars	Collisions with pe-destrians	Falling on board the tram	Accidents during entering or leaving
Road markings showing area subtended by tram	X	X		
More efficient enforcement of parking regulations	X			
More intersections controlled by traffic signals	X	X	X	
Better information to road users about priority rules	X			
Signs to warn other road-users of crossing trams	X	X		
Improved visibility of the tram	X	X		
Tram tracks in street median rather than alongside pedestrian pavement	X	X		
Separate signal phases for cars and trams	X		X	
Prohibition of turns across tram tracks	X		X	
More defensive tram driving (e.g. longer headways)	X		X	
Better segregation between trams and other traffic	X		X	
Traffic signals controlled by trams (publid transit priority)	X	X	X	
Increased field of vision from driver cabin		X		X
Fences between tram track and pedestrian area		X		
Special safety measures at tram stops		X		
Use of audible signal when approaching stop or crosswalk		X		
Separate signal phases for trams and pedestrians		X		
Ticket purchase and validation before entering tram			X	
Better grab handles on board the tram			X	
Increased seating capacity (fewer standing passengers)			X	
Reserved seats near doors for the elderly and disabled			X	
Improved systems for automatic closing of doors				X
Low-floor trams, and platform-height adjusted to these				X

Some of the measures listed in this report have been tried out and evaluated elsewhere. Most of the measures, however, have been suggested on the basis of risk analyses or more general traffic safety considerations, and therefore are expected to be beneficial, even though they have not been systematically evaluated with respect to effects on accident risk.

Some measures are tailored to a specific type of accidents, whereas others are more general and are supposed to reduce the risk of different kinds of accidents. The table above shows a summary of some suggested measures, with indications of the type(s) of accidents they are expected to influence.

It is difficult to estimate the magnitude of the various measures' expected effects on accident risk. More detailed information about the accidents, e.g., by in-depth investigations of a large number of accidents, would give a better basis for such estimates.

For further improvement of the knowledge base regarding the efficiency of various tram safety measures it would be desirable to carry out systematic evaluations of any measures decided to be implemented. If possible, a measure should be tried out experimentally in a limited setting, before a decision is made regarding full-scale implementation. For example, a measure can first be implemented at a random sample of locations, and the risk at these locations before and after implementation can be compared to similar locations without these measures.