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Operation and safety of tramways in interaction with public space

Analysis and Outcomes
Detailed Report

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Operation and safety of tramways in interaction with public space

Analysis and Outcomes
Detailed Report

Colophon

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COST Foreword

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Chair's foreword on TU1103 Action – Operation and safety of tramways in interaction with public space

Tramway and Light Rail Transit systems were reduced in the 1950s, but since 1990 they have been reintroduced or extended in many cities all over Europe. And therefore, the multiplication of lines has multiplied their interaction with other public space users.

However in spite of this great spread, and even though accidents involving tramways usually have a big impact on the public's emotions, the International Association of Public Transport (UITP) has demonstrated[1] that statistics indisputably show that the tram is safer than private cars. A large proportion of accidents with trams are caused by third parties ignoring or overlooking rules and recommendations. Tramway/LRT urban insertion is the key interaction with third parties. Bad or non-adapted layouts can be reasons for bad understanding or disrespect. Common problems are encountered all over Europe and all tram networks are facing difficulties, having bad or good experiences, trying successful solutions, and all looking for improving more and more their safety level. Their experience could be useful for others, in order to get best practices and adapt them to their local context, thanks to access to the knowledge and experience.

It is a pioneering work: it brings together for the first time in a study of this scale experts from across Europe and from across the spectrum of tramway involvement: operators, designers, researchers and national authorities, to share their experience on tram safety issues.

The sharing of information, feedback, and experience is one of the best ways to improve tram safety in urban spaces. Urban insertion of tramways and LRTs is not an exact science but the sharing of ideas and practical solutions is a good way to give the best clues to a tram network to find the best layouts for one dangerous interaction place or a new insertion. This is what the TU1103 group has achieved here: to share with you our experiences.

This is the aim of this final document: not guidance as such, but the sharing of suggestions, good experiences and best practices which TU1103 members can give to the profession on safe tram urban insertion.

Laetitia FONTAINE,

Chair of the COST Action TU1103

Service Technique des Remontées Mécaniques et des Transports Guidés (STRMTG – France)

[1] UITP 2009 Core Brief "Light Rail Transit – a safe mean of transport" UITP information sheet

Availability of deliverables of the Action

This Report is the deliverable for final Working Phases 2 and 3 of the TU1103 Action. It is a Public Report, and is available on the public part of the Action's website www.tram-urban-safety.eu. The Report includes summaries of working group outcomes and general outcomes of the Action.

The Memorandum of Understanding of the Action presents our methodology, aims and deliverables: all details in Appendix A.

The report of Working Phase 1 is available at: http://www.tram-urban-safety.eu/spip.php?article329 and in Appendix B.

Detailed information about each topic and the entities involved in the Action will be covered in the Working Group reports (for each Working Phase). These will be restricted to the members` part of the Action website, but specified parts of this detailed information can be made available on demand, which will be expressed by request to the Action webmaster Mr. Dominique BERTRAND (webmaster@tram-urban-safety.eu).

Executive Summary

The insertion of tramways and Light Rail Transit into an urban area so that they can operate safely and efficiently while interacting with other public space users is one the most important challenges to the planning principles on urban rail infrastructure design. To find the best adapted and safest infrastructure design for optimising interactions between tramways and other users of urban space, is for public transport operators and authorities one of the means to improve the level of service, and thus help to grow the modal shift in favour of Public Transport.

Dealing with this issue, this Action enhances this strategy by examining how operators and city authorities can collect, process and analyse accident data and assess safety management improvements, and it gives the opportunity to hold a debate about some main safety experiences in several European countries and cities.

Rather than providing conclusive guidance, the report of COST Action TU1103 seeks to share suggestions, successful experiences and good practices, which can contribute to enhancing a safer insertion of trams into urban areas.

While the tram is generally a safe mode of transport, all tram networks are facing the task of maintaining and improving safety, and similar issues are encountered all over Europe. Then, there are both good and sometimes bad experiences, successful stories, appropriate solutions and efficient practices. Various countries' feedback and knowledge could be useful for others, if sharing them leads actors to adapt best practices to local settings.

This Action is quite a pioneering work: it brings together for the first time in a study of this scale, experts from across Europe and from across the spectrum of tramway involvement: operators, designers, researchers and national authorities, to share their experience on tramway safety issues.

The work of the partners began with the collection of regulations, methods of analysis and practices regarding tramway safety monitoring and layout design; this was done for all involved countries and the field of investigation was limited to interactions with urban space.

Then the various participating actors went into debates to share experiences and analysis of all these materials, from safety data collection and use of indicators to layout configurations and tramway running conditions. This was organised among specific technical themes and carried out through a qualitative approach, in order to achieve analysis based and realistic conclusions.

The results of this process then are summaries of good practices and experiences for a safer insertion of tramways in urban spaces. Advice given in the report aims at a better interaction of trams with public space, for new tramway systems as well as for existing networks.

The methodological approach led to separate discussions in two parts, with the first one dealing with data collection, processing and evaluation tools, and accident scenarios, and the second one dedicated to tramway infrastructure design and running conditions.

These two parts are presented in the report after an introductory chapter. It is expected that the reader may seek and find sustainable solutions to tramway layout issues for proceeding with a new tramline project as well as aiming at improving an existing one.

This document provides conclusions and possible solutions for a safety management system and monitoring as well as to upgrade the safety levels of infrastructure in urban space, both aimed at making the tram an even safer means of transport than it already is.

Starting with existing issues and good practices implemented in local contexts to solve or avoid such kinds of problems, the method, based on lessons learned, consists in identification of the list of hazards and of possible solutions, leading to provide good examples and advise about less satisfactory ones. This is done for each interaction point along the tramline with which a designer, researcher or planner may be confronted.

In Chapter 2 on safety data collection and monitoring tools, the idea is to propose examples of good practices and suggestions about tools and ways to collect and efficiently use relevant data. This advice should be useful mainly for operators, transport authorities and national or regional safety regulation bodies dealing with new networks as well as seeking improvements on existing systems. Researchers have not been forgotten as the report lists some data which can be used for in-depth analysis.

In this chapter a template of an “ideal accident report” is proposed (see §2.1), which should be considered as a check-list of information to be collected rather than the exact model to comply with. The collection of data on accidents, which should be done as soon as possible once the collision has occurred, is essential and may usefully be complemented with other sources such as CCTV images or automated event recorders (black boxes). These can also be used to identify near-misses, as a complement to drivers’ reports of emergency braking; this can bring more information to help in understanding street users’ behaviour and issues linked with some configurations of alignments and station areas (see §2.2).

In addition, the collection of a number of accidents in a database at a local level, and where possible also at a national one (see §2.3), can help to monitor and assess the safety level through the usage of some indicators. The location of accidents and near misses enhances the identification of hotspots in a tramway network (see §2.5).

Regarding indicators, some relevant indicators which are the most commonly used are suggested (see §2.6). They are classified in several types (global, geographical and typological), with indications about their advantages and limitations in practical use.

Accident data collection and analysis are complementary solutions implemented in the field: identified hotspots may require layout improvements, and data collection allows to monitor new or improved layouts during the operation of existing networks, as well as implementing new projects (see §2.7 and 2.8).

Infrastructure design and operating methods are the topic of Chapter 3. Regarding these issues, the main achievement is the compilation and analysis of good and bad safety-related practices about the interaction of trams with other street users (pedestrians, cyclists, and road vehicles) (see §3.2 and 3.3). Starting from rather similar types of hazardous situations which tramways face in every country (see §3.4), the study has identified specific design solutions that may be generally considered as safe or potentially dangerous (see §3.5).

It is important to consider that no system is 100% safe and that there always will be people walking, cycling, and driving around tramways; the objective is to agree on some measures which will protect those Interaction Points in as natural a way as possible (see §3.6). Using the existing examples and know-how, analysis has been made of good and bad configurations. Objectives have been identified and a classification made. Specific problems have been investigated for each type of interaction point and hazards have been identified.

As for the occurrence of accidents and the involvement of third parties, a questionnaire survey carried out within the scope of the action showed that out of 89 hotspots identified by operators, the majority were located on intersections (85%). A smaller proportion (12%) were associated with running sections, including pedestrian crossings, or with stations (2%). Regarding intersections, 72% of all intersection hotspots were located at junctions, while the rest occurred in roundabouts. In 88% of the cases, a vehicle was involved in the accident; another 10% of accidents involved pedestrians, and only 2% motorcycles (see §3.5). As the sample of this survey is small and not representative of all existing networks, these figures must obviously not be considered as statistically valid, but the results give an indication of where the majority of accidents occur.

In §3.6, the main interaction points between trams and other road users are categorised. The first main conclusion from this categorisation identified the need to study stations and stops separately from the rest of the infrastructure ("running sections"). This distinction is drawn because of the important differences between those two types of zones, both in relation to the operation of the system and the behaviour of street users (see §3.6.3). In all, five types of interaction points were identified for study: road intersections, divided into junctions and roundabouts as described above, pedestrian crossings, stops and stations (see §3.6.4), and running sections (general interactions not at stations, junctions, and pedestrian crossings). For each type of interaction point, possible solutions are suggested using the following structure: configuration, hazard, objective, measure, and example (see §3.6.5).

For both vehicles and pedestrians, unawareness of the presence of a tram is a relevant cause of collisions. The main causes of accidents are linked to misbehaviour and disrespect for road rules by third parties. An important lesson learned is that cooperation between the public space manager (the municipality) and the planner and designer of a tram line is essential to avoid such misbehaviour and disrespect.

Generally, four types of approaches can be used: engineering solutions, police or enforcement authority measures, operational solutions, and educational campaigns, besides a long and permanent dialogue with the public space manager. In order to address the major cause of accidents at hotspots, tram operators advocate improving traffic light design and efficiency for a better priority for trams, and stricter enforcement. Other favoured engineering solutions include clearer carriageway markings and modifications to traffic light programming.

Finally, the report deals with lessons learnt and success stories on data collection and analysis and on infrastructure design (see §4.1 and 4.2). Regarding the first topic, some examples are presented, such as the analysis using a bow-tie approach (the case study from Brussels), the near-miss analysis (the case study from Stuttgart) and the French experience with a tram accident database. In relation to the second topic, the report introduces success stories concerning infrastructure design from 19 networks. They are categorised as follows: intersections (left or right-turn, roundabouts, and junctions), pedestrian crossings, and general interaction points. For each entry, a brief description of the problem is followed by a description of the solution and the lessons that have been learnt. These success stories have a shared perspective on how it is possible to integrate traffic conditions and geographical context and increase safety for public transport users as well as to economise on resources.

During the four years of this Action, it was important for all actors to share with and learn from each others' safety experiences. As a final recommendation, one would say that safety on a light rail or tram network depends on all stakeholders being involved directly and indirectly, but that the most important factor for this success is a permanent dialogue between operator and municipality, sharing the important objective of having a commitment to reduce or eliminate accidents in order to contribute to creating liveable cities.

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Definitions

For the purpose of this report, the following definitions have been established:

- **Accident**: any event which has a physical impact on persons (inside or outside of the tram), vehicles (tram or others) or fixed equipment of the tram system. The level of severity is not considered for determining which occurrences qualify as accidents. Due to the scope of this report, only collisions involving tram and third party (car, pedestrian, bicycle...) are considered as accidents.
- **Accident severity:** Level of human and material consequences caused by an event.
- **ALARP – As Low As Reasonably Practicable:** the level to which risk should be reduced in a Safety Management System (SMS) when the ALARP objective is chosen. The ALARP objective should only be chosen when the complete elimination of risks is impossible or the costs of doing so are disproportionately high to the improvement gained.
- **Casualty**: is used in this report to denote anyone who is killed or injured in an accident. Casualty can be divided into fatalities, seriously injured persons or slightly injured persons. Normally accepted definitions are [Source: Commission Regulation (EC) No 1192/2003 of 3 July 2003 amending Regulation (EC) No 91/2003 of the European Parliament and of the Council on rail transport statistics]:
    - **Fatality**: a person who is immediately killed in an accident or who dies within 30 days of an accident as a result of an injury (except suicide).
    - **Seriously injured person**: any person who was hospitalised for more than 24 hours after injury (except suicide).
    - **Slightly injured person**: any person who suffered minor injuries which do not require medical assistance or, if admission to hospital, do not require to stay at the hospital.
- **Conflict zone**: in a junction, is the area shared by tram and cars and where collisions may occur. It also applies for bikes lanes and pedestrian paths crossing a tram line.

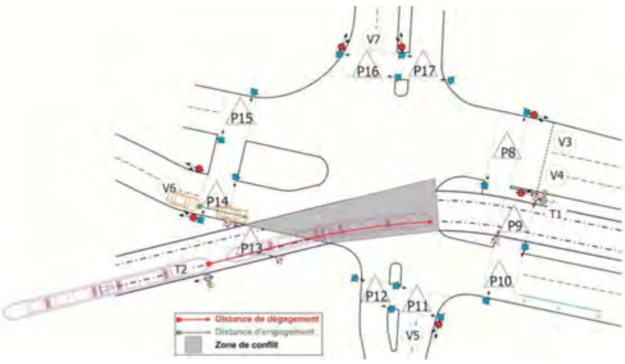


Figure 1 – Conflict zone

- **Data:** Collected information from different entities in a raw state.
- **Database:** A collection of information on one topic in order to describe specific items.
- **Event**[2]: any occurrence that has an impact on safety. Events can be divided into accidents or incidents. Due to the scope of this report, an event does not include collisions between trams,

[2] More precise definition and typology can vary between countries (see also chapter 2.6 and glossary WP1 report in Appendix D).

derailments or casualties inside the tram. Furthermore, occurrences which are related to security such as vandalism, are out of scope.

- **Hazard**: a physical situation with a potential for human injury (definition taken from EN50126 "Railway Applications"). Note: EN50126 is only relevant for the planning of technical systems and not for operations.
- **Hotspot:** a specific location on the tram network defined as a place in the urban area where the most accidents (collisions) occurred, in a fixed period. For more details see chapter 2.5.
- **Incident**: any event with no physical impact on persons, vehicles or fixed equipment; any event where no injuries or damages are produced. For example, a near-miss accident.
- **Indicator:** a tool to quantify the level of safety, to identify and to rank the states and to measure the trend about safety issues.
- **Interaction points**: the main points of the tramway and LRT infrastructure whose design has to be properly studied in order to guarantee the safety of the system in its interaction with public space. It should be pointed out that the meaning of "interaction point" in this case is wide, including interaction locations but other interaction elements as well, such as signalling and signage.
- **Junction:** intersection between tramway and one or several road(s).
- **Left turn**: a traffic movement in a junction where a vehicle (car, bicycle, bus, etc.) changes direction and crosses the tramway. In UK and Ireland, the equivalent is a right turn because of road traffic rules.
- **Light Rail Transit or Light Rapid Transit (LRT)**: in contrast to a tram system, it can have 100% exclusive lanes or a completely segregated track. There is no strict differentiation from tram-systems, though vehicles can normally be longer than trams. Streetcars and trams are subtypes of light rail transit.
- **Near-miss accident:** any event that was very close to becoming an accident but did not turn into an accident because one or more factors concurred to avoid it at the last minute. For example, when the tram driver uses the emergency brake to avoid an imminent collision. Near-miss accident is a type of incident and not an accident.
- **Passenger of the tramway**: people on board, getting in or out of the tram, or waiting at stations.
- **Passengers x kilometres run:** It is the total number of passengers multiplied by the average distance travelled.
- **Pedestrian area:** A space mainly used by pedestrians. The access to pedestrian areas is restricted for cars and in some countries there are restrictions on tram speed.
- **Pedestrian crossing:** Specifically designed point of the tramway line where pedestrians are authorised to cross.
- **Post-analysis:** All processes taken after an event in order to improve safety.
- **Predictive approach:** further profound safety analysis that can only be implemented after having established a consistent data acquisition and evaluation.
- **Proactive approach:** configuration analysis that can only be implemented after having established a consistent data acquisition and evaluation. Anticipating events by analysing incidents, precursors (numerous Emergency Brakes in a specific zone…) and proposing changes in the layout concerned and/or operational rules.
- **Public Space User**: any person who uses urban infrastructure, either in a vehicle (motorized or non-motorized vehicle such as bicycle) or as a pedestrian.

- **Reactive approach:** is based on the consistent evaluation of accident data. Its focus lies on structured and continuous data acquisition in order to derive preventive measures from their analysis. Proactive and reactive approaches are complementary. Both should be followed by an in-depth analysis to judge their efficiency on tram safety.
- **Risk:** the probable rate of occurrence of a hazard causing harm and the degree of severity of the harm (definition taken from EN50126 "Railway Applications"). Note: EN50126 is only relevant for the planning of technical systems and not for operations.
- **Running section**: any part of the network with no crossing interaction, generally these are intersections between stations, junctions and pedestrian crossings.
- **Safety**: deals with the risk and precautions taken to reduce the level of risk related to accidents and incidents, such as the urban design insertion and measures, which can be taken within the institutional framework.
- **Safety Management System (SMS)** (not the one from European Directive on Railways): a systematic, explicit and comprehensive process for managing measures to improve safety in public space. A SMS should be woven into the ethos of an organization and become part of the culture, the way people carry out their jobs.
- **Station / Stop:** a fixed location where passengers may board or alight from a tram. It may or may not include raised platforms. The terms 'stop' and 'station' have the same meaning and depend on operator's normal use.
- **Signage**: any traffic sign to inform road users of traffic rules or safety hazards (e.g. vertical "stop" sign). Signage can be used together with signalling.
- **Signalling**: any traffic control system that uses lights to help or inform road users of traffic rules or safety hazards (e.g. traffic lights). Signalling can be used together with signage.
- **Swept path**: is the maximum width at ground level at any location of the tram vehicle when in motion, including the effects of tilt, sway, the effects of curvature, including superelevation or cant of track, and end and centre throw of the tram, plus a safety margin. In order to establish realistically the necessary clearances from street furniture, facilities, cars,...

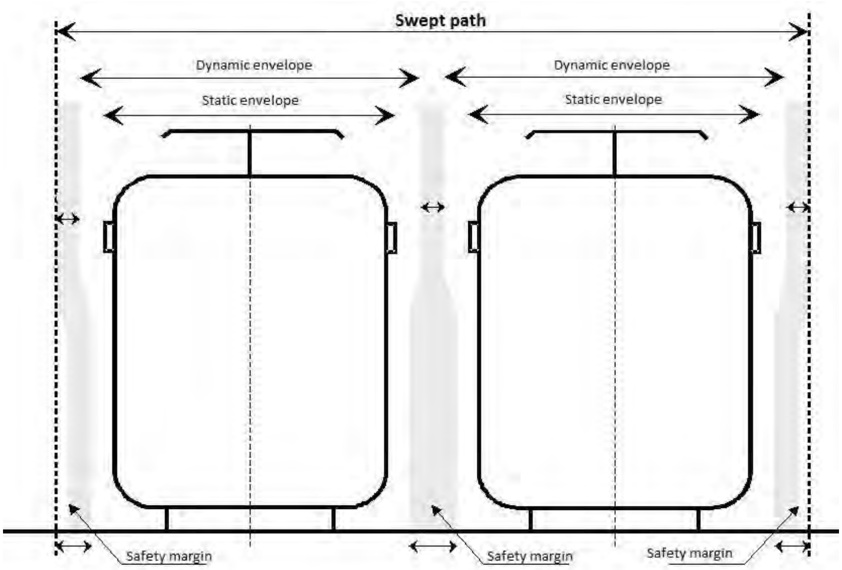


Figure 2 – Swept path illustration [Source: Metro do Porto, Critérios de Projecto – Traçado. MP-936657/09_V3.0 (Novembro 2010) translated in English]

- **Total km run**: the whole distance made by the complete fleet, sum of vehicle km.

- **Tramway**: is a public guided transport system in urban spaces, sharing its road with other users at least at crossings, driving on line-of-sight for all or part of its length. Tramway is considered as a system, comprising three main sub-systems: the infrastructure and the fixed installations, rolling stock and the operation. Tram is the vehicle and tramway is the system.

> During the report, tramway will be identified as a general term to refer to LRT and tramway. The word "LRT" will be specifically used for when they are included in the scope of the Action, see chapter 1.2.

- **Vehicle km**: distance made by one vehicle.
- **Vehicle x kilometres run:** It is the total number of kilometres run by the entire fleet in commercial operation.

1 Introduction

1.1 The Tramway and the city

Tramway systems follow a new philosophy for a public transit mode, where several advantages are combined such as operating in a specific public space corridor, having priority over all modes of traffic, and having the physical and psychological comfort of travelling at ground level, enjoying the urban landscape in all its fullness.

This philosophy for public transportation meets the policies of land use, mobility and the environment, which aims to make cities more sustainable by discouraging the use of private cars and by proposing quality public transport which assures comfortable trips with strict control of travel time.

To reach this aim, both the vehicles and the infrastructure that make up the new tramway networks were developed taking into account an acceptable integration with the city. The vehicles are electrically powered, clean, quiet, and usually are characterized by a very careful design with large windows to enable its users (driver and passengers) as much as possible a free visual relationship with the outside. The infrastructure, such as poles for the overhead line equipment and cabinets for switching and signalling gear etc, is carefully implemented taking into consideration the space where they will be installed. The surfacing of the tramway can be done with the materials commonly used on pavements and roads but also with grass, boosting the creation of new and true green corridors crossing the cities.

However, one must be conscious that tramway systems do not interact only with the cityscape. Once a tramway starts to operate, it will interact with and change the daily habits of the citizens, with bigger impact on the street users. Knowing this, an accurate and well-balanced integration of the Trams in the City will influence positively the performance, comfort and safety conditions of the system. On the other hand, tramway systems that put the focus only on the Transport System or on the Urban Design will suffer the stress of the traffic, boosting the number of dangerous events involving cars, motorbikes, pedestrians and cyclists.

So to merge Tramway performance and urban space, interactions have to be dealt with properly.

1.2 Who should be concerned to improve urban tram safety?

From the perspective of mobility, the city can be seen as a stage used by several actors in their trips. Likewise, on the city “stage”, the citizens can be considered as actors moving by different modes: walking, cycling, driving a car, etc; and they interact with various external factors: the size and shape of the streets, the traffic lights, the vertical and horizontal signs and street markings, the green spaces on the street, etc. And because each mode of transport has different features and performance, the average speed and the stopping distance being the main ones, it was decided first to analyse Tram interactions with other ‘actors’ separately and systematically.

This report has two main target groups: planners and engineers (for infrastructure) and operators (for running on it). Ideally, these two groups should be involved at all stages of the design, but mostly this does not happen due to the fragmented and non-integrated process of planning and due to split responsibilities. Nevertheless, planners and operators should consult each other. One of the main purposes of this report is to make the information available to actors involved all along the process from design to accidents to (re)design:

- supervisory authorities and monitoring organisations at different levels,
- transport agencies and operators,
- road network managers,
- designers, architects, engineering consulting firms,
- research bodies.

For more institutional and political suggestions on improving tram safety and safety management systems in Europe, see Appendix C.

> The main objective here is to bring tools and safety analysis to allow these actors to improve tram and Light Rail Transit safety, through a better management of their insertion in urban spaces and therefore to minimize as much as possible the number and the severity of accidents between Tram and public space users (pedestrians, car drivers, cyclists...) and their impacts on both transport system and society.

Faced with some accidents or some complicated design problems during projects or modifications, some transport authorities and operators try to solve the problems on their own, with greater or lesser success.

When producing this report, functioning in an organised network has favoured much more productive exchanges than independent and occasional bilateral contacts. Furthermore, it has allowed us to save time and efficiency by sharing useful contributions on existing knowledge and/or by sharing common problematics, getting away from a "national" point of view.

> There are three different parts of the tramway system that influence safety: the vehicle, the infrastructure and the operation management. The infrastructure is the basis of main issues but is also the most expensive part of the system and it is very hard to change once the system has been built. On the other hand, the operation management can solve some problems generated by a poor infrastructure design, but this ability is limited and not every infrastructure problem can be solved in this way.

> In this report, safety deals with the risk and precautions taken to reduce the level of risk related to accidents and injuries, such as urban design insertion and measures which can be taken within the institutional framework. This Action is not talking about security (counter terrorism, vandalism, etc), neither about health hazards due to pollution and similar.

A tramway is defined here as an urban fully guided method of public transportation which shares public space with road/bike/pedestrian traffic (but. not with heavy rail or trolleybuses). The Action has looked at accidents, and near-misses when they are recorded, and it has considered the whole tram system, including infrastructure design (within urban, suburban, and mixed zones) and equipment management, to be important.

All good ideas or bad experiences were available to be shared within these limits.

This report focuses on the interaction between trams and other street users (pedestrians, car drivers, cyclists...) in urban spaces, but it does not include collisions between tram vehicles or with trackside equipment, or derailments.

So, accidents which are a consequence of an urban insertion issue are only considered. And therefore, accidents caused by track or signalling or rolling stock problems were not included

1.3 Which benefits?

Keep in mind that improving tramway safety will play a part in improving road safety in general and for vulnerable users in particular. It will also decrease the decrease operation and maintenance costs, contribute to rationalising and optimising the investment in the tramway system, improve its insertion, its safety and its efficiency and reliability, and indirectly will go in the direction of moderating the place of the car in town.

Even though trams remain the safest mode, everywhere safety is a hot issue for tramway systems. Accidents are sometimes serious, often spectacular and overexposed in the media. Beyond the direct consequences for people hurt, safety also has a big impact on the productivity and reliability of transport systems and urban functioning, by affecting operation on a wider scale since tramways often form strategic lines of the transport network. The primary cause of tram accidents is the conflicts with other users of public space, in relation to their behaviour and their perception of risk.

Across most cities and countries, 80-90% of accidents involving trams within public space are caused by third parties (UITP, 2009). In most cases the accident is attributed to the traffic misbehaviour by third parties. Therefore, major safety improvements can be accomplished by reducing the chances of traffic misbehaviour by third parties. Operators can achieve this goal by individually cooperating with the responsible (local) authorities. Nevertheless, operators can achieve a reduction of accidents internally by measures such as accident data analysis, training of drivers, etc. (UITP, 2014).

Thus, keeping the tramway part of the urban space without fences and providing an efficient urban insertion of tramway through infrastructure design, good performance, improved safety and traffic handling, is a crucial challenge for both transport authorities and operators.

Before starting with the core subject of urban tram safety issues and solutions, it was aimed to bring to light and qualify the impact of an accident on the system's productivity and to verify if a more expensive investment allows economies to be made on the future operation. In order to do so, it is necessary to assess this productivity (the effect on the journey time, the regularity, the time loss due to operational disruptions, the repair costs and other financial consequences of accidents) and to analyse the accidents and their impacts on both the transport system and on the community.

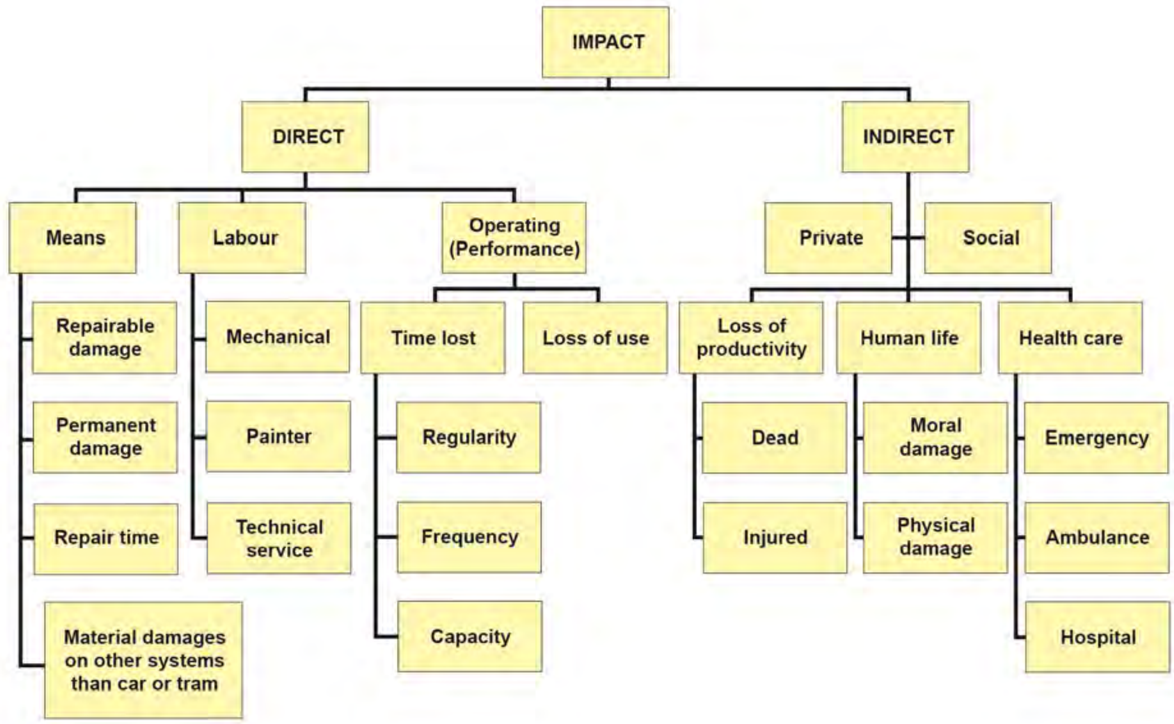


Figure 3 – Classification of accident impacts [Source: Rosario Barresi, STSM Report, Accidents' impacts on the system's productivity (2014) – Appendix N.2]

The "valuation of an accident can therefore be divided into direct economic costs, indirect economic costs and a value of safety per se. The direct cost is observable as expenditure today or in the future. The indirect cost is the lost production capacity to the economy that results from premature death or reduced working capability due to the accident" [Source: HEATCO, Developing Harmonised European Approaches for Transport Costing and Project Assessment (2006)].

To illustrate, if operators count only the cost of accidents with damage to the tram or specifically traffic accidents, an average cost is 3,102.27€. But the maximum cost declared by some tram operators can vary greatly from 5,500€ to 74,000€, and even to 1,000,000€ for another year. And the operators were asked if they have experienced the same or if derailment always leads to higher costs. The answer was that derailment and higher costs are "not necessarily linked and generally, there is no rule concerning the link between the type of a single accident and its consequences (and thus its cost)." The complete analysis report is available in Appendix N.2.

It could be useful to be able to justify actions on layout or operation, from an economic point of view. However, the cost of an accident is not predictable and the media impact of an accident and its impact in terms of image of the transport service is not measurable from an economic point of view. Still, it is possible to gain an idea of the range of material bought and man-hours needed. And of course, a complete economic assessment, of which the costs of accidents is part, is a complicated subject and would need economists to research it.

1.4 How the Action has been built

The first Working Phase (WP1) report has dealt with what exists in Europe (regulations, indicators, and layouts). It has been separately published and is available on: http://www.tram-urban-safety.eu/spip.php?article329 and in Appendix B.1. The WG1 report on definitions, national regulations and global views is available in Appendix D, the WG2 report on an overview of existing indicators is available in Appendix E, and the WG3 report on examples of interaction points is available in Appendix F.

The last Working Phases 2 and 3 of this Action deal with best practices and their analysis: particular attention has been paid to the causes of accidents and efforts have been made to identify the configurations that:

- pose recurrent problems in terms of operation or safety at intersections, stations and the running sections between them,
- correspond to sections of line that perform well and/or have no accidents,
- are innovative in terms of design.

The study then identified methods of analysis and best practices, and formed conclusions after analysis and debates. This was done through qualitative research and shared experience, and through debates between operators, researchers, designers and national safety authorities.

Finally, the results of the analysis - and of the Action as a whole - are best practices for the safest insertion of tramways in urban spaces, through suggestions presented in this report, with the identification of hazards, objectives and possible solutions, and design examples and additional measures aimed at a safe interaction of new and existing tramway systems with public space.

The report goes from accidents on a tram network to the whole process that leads to improvements in tram safety, and proposes some best solutions for each type of layout, in a future tramway project or an existing tramway line.

Warning: If you want to build a tramway or improve one - and keep it on surface, there is no magical recipe to apply to make it systematically safe. It depends on many parameters and some belong to geographical aspects, societal behaviours, global design choices, regulations, types of signs and how drivers respect them. All proposed measures have to be examined in detail for their compatibility with national rules.

It is supposed that the reader is looking for solutions to layout problems in probably one of two situations: creating a new tramline project or needing to improve an existing one. The aim of this document is to give good practices to make tram a safer means of transport than it already is, while facing some problems that still exist and to give good practice in a local context for solving or avoiding them. This is intended to be done in a simple way: if someone has or needs this configuration, the report proposes doing it this way (good examples) and to avoid doing it that way (bad examples). A list of hazards and of possible solutions for each interaction point along the tramline has been therefore provided.

> There are no generally good/safe or bad/dangerous solutions when tram layouts are concerned. Each case is unique and it should be designed or adapted according to its urban environment and traffic conditions. It is better to keep tramways integrated with the urban environment, not separated by fences or placed underground. Vonsequently, one should be alerted to the importance of making a sustainable choice of the type of junction, and once chosen one should be able to say how to design it and what should be avoided, giving some practical examples.

This report proposes here:

- Operational tools – to better manage accident data and safety (see chapter 2);
- Infrastructure design safety analysis – to know what advantages and disadvantages a type of layout can bring and which set of solutions can be proposed (see chapter 3);
- The risky places encountered most often– to learn from common problems and pay particular attention to such places (see chapter 3.5);
- Success stories – to show experience on improvements that worked (and still continue to be successful) (see chapter 4).

> The tram is already a very safe mode of transport – how can we make it still safer?!

1.5 How to read the report

In this report, the reader will find solutions to help with collecting and analysing accident data (one or several), assessing safety improvements, and solutions to help with finding the best adapted and safest infrastructure design for tram interactions with users of urban space.

It is separated into two main parts:

- A first chapter on data collection, evaluation tools (e.g. indicators, hotspots…) and accident scenarios – which is more appropriate to operators. It will discuss tools for collecting and analysing the best accident data.
- A second chapter on infrastructure design and operating methods – which is more appropriate to road network managers, designers, architects and engineering consulting firms. It will expose hazards and offer solutions for each type of tramway layout, through interaction between vehicles and the city, and operating conditions.

Research bodies and oversight/monitoring authorities are concerned at both stages.

The structure of the report is as follows:

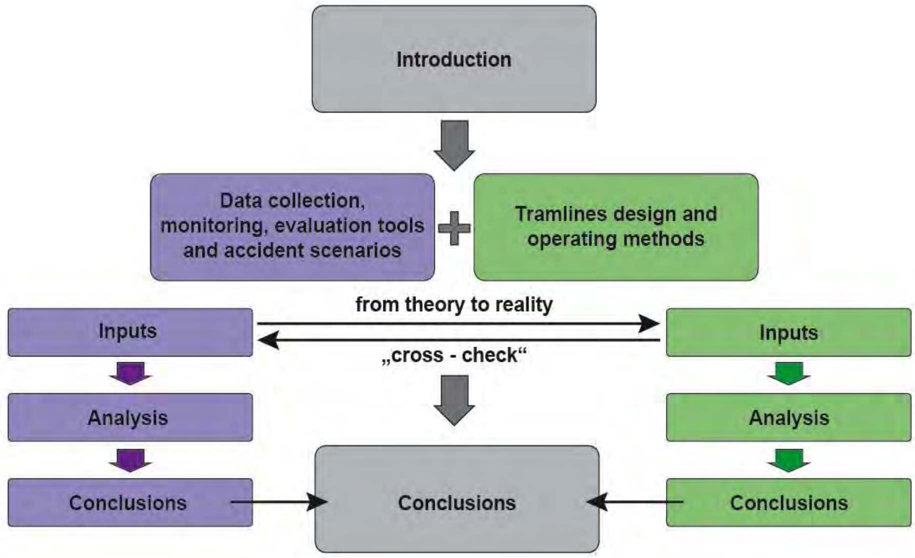


Figure 4 – Structure and logic of the report

Concerning content, data from WP1 have been used:

- To gather information on accident recording models that were identified during WP1, and analyse them in WP2 to build the “Ideal Accident Report” (see chapter 2.1).
- To propose other tools to analyse accident data (see chapters 2.2).
- To summarise views on the value of a national accident database, with pro and cons (see chapter 2.3).
- To list and analyse different possible indicators (see chapter 2.6).
- To list interaction points and describe examples (see chapter 3.6.1).

In the second Working Phase, participants in the Action interviewed tram operators all over Europe to get knowledge on and analyse their current hotspots and success stories (see chapter 3.5).

The results from these questionnaires and the most common accident situations observed were cross-checked with a large analysis which has been made of all the interaction points, based on examples collected in WP1 (see chapter 3.6 and Appendix F). These questionnaires have also allowed a check on the theoretical list of consequences and impacts of accidents and set their limits (see chapter 3.6.7).

Further, operators’ practices on safety management principles have been identified during our sessions and synthesized (see chapter 2.7).

Additionnally, several Short Term Scientific Missions (STSM) were conducted as part of the Action to research more specific topics, results of these have been incorporated in this document and their reports are joined in Appendix N.

2 From accident to data collection and analysis: tools and methods

This chapter is mainly aimed at operators in order to offer them good practice and suggestions on the best tools which can be suggested in order to collect more, and more accurate, data. This is not a criticism of what already exists: this chapter has been produced in order to offer experiences and suggestions to a new operator, to an operator seeking improvements in its Safety Management System, or to a national Safety Authority who requires operators to maintain and improve safety. Researchers have not been forgotten, and the report lists some data which can be used for in-depth analysis.

The main contents of the chapter are as follows:

- Tools for accident analysis, including operational ways of collecting data;
- Methods of data collection and their positive or negative impact on further analysis;
- Tools for an analysis of a single accident, a panel or all a network's events (or even larger);
- Suggestions on parameters and relevance of the most used indicators;
- Different organisational approaches.

Therefore, the objective of the chapter is to propose the best tools and potential methodologies to collect - including processing - and to analyse data.

2.1 First tool: accident report on the field

2.1.1 Overview of the contents of existing accident reports - approaches and limitations

Accident reports are different in many countries. They can be from one page to 10 pages. The Police report and operator report are different too (even for the same country) and they use different databases.

The group has gathered samples of the reports to get an overview of practices, and to get ideas of content and key points not to forget. Then, in a brainstorming, an Ideal Accident Report was proposed. Finally, it was checked by all operators and by UITP.

Table 5 presents examples of reports from a few countries (for details see Appendix G):

- UK (Metropolitan Police Road Traffic Collision/Accident Form);
- Poland (Police Road Accident Card and Operator Information Card);
- Austria (Austrian Guideline and Wiener Linien operator report);
- Czech Republic (Operator Accident report form and Emergency Report form);
- Norway (Police motor-vehicle accident report form);
- Germany (Police and operators' accident reports);
- France (Operator accident record).

Table 5 – Accident report samples for some countries

Principal content	UK Police Accident Form	Poland Police Accident Form	Norway Police Accident Form	Germany Operator Accident Form	Czech Rep. Operator Accident Form	Austria Operator Accident Form	Poland Operator Accident Form	France Operator Accident Form	Portugal Operator Accident Form
1. The occurrence:									
– date, exact time and location of the occurrence,	Y	Y	Y	Y	Y	Y	Y	Y	Y
– description of the events and the accident site including the efforts of the rescue and emergency services,	Y/N	Y/N	Y/N	Y	Y	Y	Y	Y	Y/N
– the decision to establish an investigation, the composition of the team of investigators and the conduct of the investigation.	N	N	N	N	N	N	Y/N	Y	N
2. The background to the occurrence:									
– staff and contractors involved and other parties and witnesses,	Y	Y	Y	Y	Y	Y	Y	Y	Y
– the trams and their composition including the registration numbers of the items of rolling stock involved,	N	N	N	Y	Y	Y	Y	Y	Y/N
– the description of the infrastructure and signalling system – track types, switches, interlocking, signals, train protection,	Y/N	Y/N	Y/N	Y	Y	Y	N	N	Y/N
– means of communication,	N	N	N	N	N	N	N	N	N
– works carried out at or in the vicinity of the site,	Y	Y	N	N	N	N	N	N	N
– trigger of the emergency plan and its chain of events,	N	N	N	N	N	N	N	N	N
– trigger of the emergency plan of the public rescue services, the police and the medical services and its chain of events.	Y	N	N	Y	Y	Y	Y	Y	N
3. Fatalities, injuries and material damage:									
– passengers and third parties, staff, including contractors,	Y	Y	Y	Y	Y	Y	Y	Y	Y/N
– goods, luggage and other property,	Y	Y	Y	Y	Y	Y	Y	Y	N
– rolling stock, infrastructure and the environment.	N	N	N	N	N	Y/N	N	Y	Y/N
4. External circumstances:									
– weather conditions and geographical references.	Y	Y	Y	Y	Y	Y	Y	Y	Y

Y - Yes; N - No; Y/N - information not complete

Several ways of collecting data after an accident between a tram and other street users were observed: different approaches and methods, as well as differences in content and extent. Half of the analysed reports are Police Road Accident forms, inspired by the European model. Others are forms used by the operators or national control authorities.

Concerning the inputs collected:

1. Date, exact time, location of the occurrence, description of the events and the accident site including the efforts of the rescue and emergency services are always given.

   But the decision to establish an investigation, the composition of the team of investigators and the conduct of the investigation is rarely mentioned.

2. Staff and contractors involved and other parties and witnesses are always identified. The trigger of the emergency plan of the public rescue services, the police and the medical services and its chain of events are included for almost all.

   But it is not systematic to record the vehicles and their composition including the registration numbers of the items of rolling stock involved, the description of the infrastructure and signalling system – track types, switches, interlocking, signals, train protection.

   Means of communication and trigger of the emergency plan and its chain of events are not mentioned.

   Works carried out at or in the vicinity of the site are rarely mentioned.

3. Passengers and third parties, staff, including contractors, and damage to goods, luggage and other property are always identified, but not damage to the rolling stock, infrastructure and the environment.

4. External circumstances – weather conditions and geographical references are described for each country.

2.1.2 Ideal Accident Report

The aim of this part is to present an Ideal Accident Report (IAR). This is not to criticize existing models nor to change current practices, but to propose the best and most useful practices for the collection of all necessary data when in the field after a tram or other street user accident: accident prevention starts with acquisition of accident data on site.

Even though the IAR does not focus on liability, the conservation of evidence builds the basis for any further legal claims concerning, for example, the clarification of liability and possible insurance claims. This task has to be executed with great accuracy. Every detail can have a crucial importance for subsequent investigations. An error during the acquisition can hardly be corrected at a later stage of data acquisition.

> The IAR model/template is a suggestion, adaptable for each operator's needs, internal and external data. It is based on WG4 work, on UITP work and on the comments on the template by the operators participating in the COST Action. But it is more than a suggestion, it is a detailed

list of pertinent data strongly suggested to tramways operators to collect in order to:

- Allow post-analysis and best understanding by operators but also researchers,
- Use data for evaluation for accident prevention.

For many operators the use of template checklists and accident report forms has been proved successful. Further additional documents include clear sketches of the accident scene, testimonies of the driving personnel and witnesses, black box recordings, pictures (survey of accident scenario, damage of vehicle and other details) and - if possible - video recordings etc. A homogeneous design of these documents within the operating company can assure consistent data acquisition and evaluation.

The IAR should:

- Show whether the acquired data is complete or not;
- Summarise essential information and keep it easy to understand;
- Be self-explanatory, with a clear picture of the accident, as well as the relevant parameters.

Summarizing, this template should allow the investigator to clearly describe one accident, to understand the event and to collect key data that facilitates further analyses by experts.

This template is intended for:

- Operators, infrastructure managers (on-site report and post-analysis).
- Possibly other entities (transport authorities, control authorities, national databases, governmental authorities).
- Research bodies, related research (further in-depth national/local analysis).
- Others: health and safety departments, mobility managers.

The intended use of the report can be for on-site investigation, post-analysis and/or statistics.

If time permits, someone from the tram company other than the driver should take information from tram driver and other sources about the accident, location, and circumstance in order to allow the driver to deal with passengers and to restart the operation. This person should reach the accident site as soon as possible.

Table 6 – The Ideal Accident report: our suggested check-list

Identification / location

- Line Number, stop, junction, time and date, vehicle number
- Precise address / house number / GPS / satellite map / network map / overhead pole

Type of location

- Multiple choice: Junction (roundabout, left turn, with/without traffic lights…) / pedestrian crossing / station / running section
- Type of alignment (pedestrian area / completely segregated track / mixed traffic / lane shared with bus) and segregation (physical or visual)

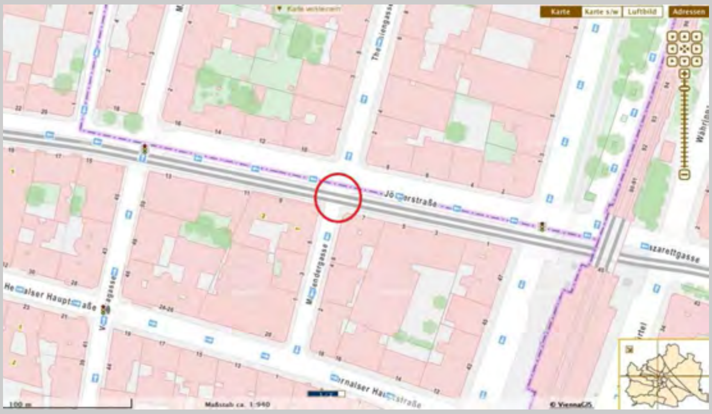


Figure 7 – Location, type of interaction and type of tracks position, example in Vienna

Figure 8 – Example in Barcelona – photo of location

Environment

- Fog, snow/ice, rain/storm, leaves on tracks
- Operational disturbances: degraded service, works, temporary speed limits, maintenance, manifestations

Involved persons

- Identification of tram vehicle, type of third party (if possible, category of age, gender...[3])
- Tram driver's name

[3] For adapting safety campaigns, making precise studies.

- Involved persons or vehicles (passengers, third parties)
- Witnesses (if possible)

Description of accident

- Drawing or sketch (of intersection, vehicle and person's movements, place of impact on vehicles, sign and signal type –dynamic/static- and location), pictures

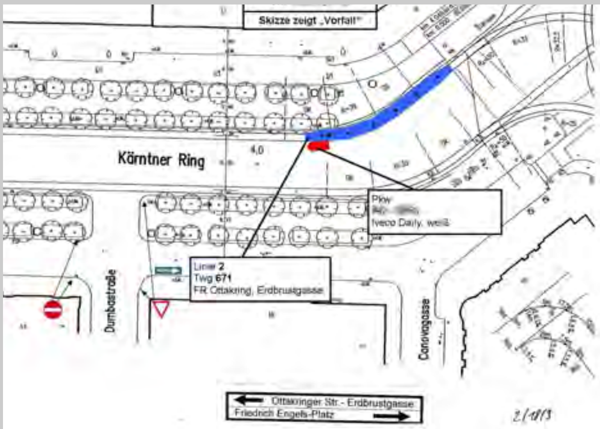


Figure 9 – Example from Vienna – accident sketch – end position of vehicles involved [Source: Wiener Linien]

Figure 10 – Example in Lyon – sketch over photo [Source: Kéolis Lyon]

- Direction of travel (track 1 or 2 for tram), road (for other involved party)
- Mark accurately on the ground the final position of the part of the tram involved

Figure 11 – Example in Vienna – marks made on the carriageway made by the operator [Source: Wiener Linien]

- Interview with tram driver, description of any unusual facts (consider collecting data for human factor post-analysis)
- Interview with car driver and witnesses (if possible), description
- Classification of accident. Use local scheme (if available)
- Causes: Left turn, distraction, red light crossing, forbidden manoeuvre, visibility (influenced by geometry, obstacles, traffic and/or weather, lightening conditions) etc.
- If risk management is in place - assign risk to incident

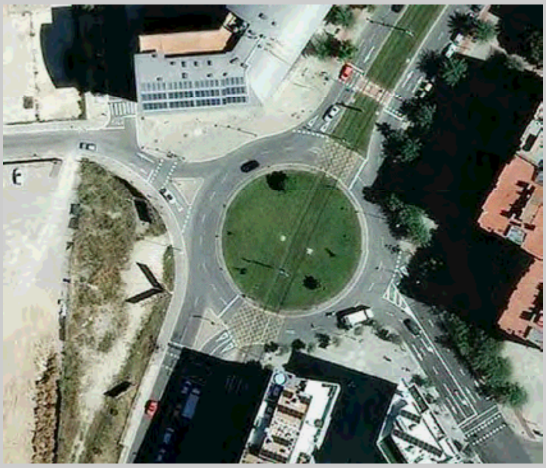


Figure 12 – Example in Barcelona – classification of accident [Source: www.icc.cat]

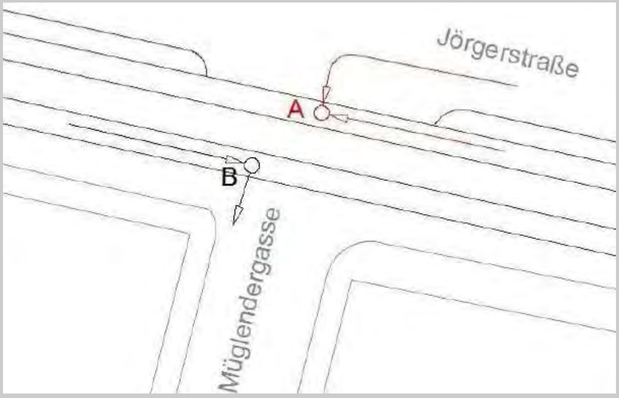


Figure 13 – Example in Vienna – classification of accident [Source: Wiener Linien]

Technical data

- Black box: Speed, emergency brakes, bell, turning signal,
- Radio exchange recordings
- CCTV
- Switches and trackside signalling systems
- Traffic light state (phases)

Consequences

- Personal (severity of the injuries (light, medium, severe, deceased)) for staff, passengers and third parties

- Material damage (to tram, to third party vehicle, or element) (severity of the damage (light, medium, severe) → technical report if available)
- Classification proposal of consequences:
    1. accidents with injuries or heavy material damage,
    2. (“regular”) accidents, no injuries
    3. Events with no further safety related relevance
- Infrastructure damage (severity of the damage (light, medium, severe))
- Operational effects (cancelled journeys, delays, overspills)

Bodies involved in response

- Police, fire brigade, ambulance, other resources needed to restore normal operation (internal maintenance, crane), inspector
- Trigger of the emergency plan (alert, information to passengers, measures for passengers and third party protection, coordination with responsible bodies)
- Expose immediate corrective measures taken by the operator (lower speed…) or other implicated authorities (the city...)

Apparent responsibility

- Internal, external

Special circumstances

- Internal fire, suicide, vandalism, terrorism threat, etc

Possible continuation

- Decision to establish a further investigation or not

Author and date of report

- Inspector’s name, date and signature

The IAR form should include the complete information about the incident, concerning every obligation of operation (information which is provided during further investigation by the regulatory authorities or other governmental institutions). The amount of detail and data provided will depend on the seriousness of the incident or accident.

It is necessary to ensure consistent professional execution of data acquisition and documentation by the operator. Appropriate commitment by the employees is required to avoid conflicts between data acquisition and other duties on site (e.g. passenger information, organizing replacement services, support for driver). Therefore, in theoretical and practical training, employees need to acquire the required abilities to take appropriate measures in case of an accident. Employees in charge have to exercise and practice their skills in data acquisition in order to ensure a high quality of permanent and structured internal data.

Minimum data to be tabularized:

- Data on date, time, characteristic of the location (junction, track characteristics, spatial situation), involved parties, accident cause, physical injury/fatality, material damage and question of apparent accident responsibility. Additionally, it can be useful to acquire further information, e.g. line, age and gender of the person(s) hurt and weather conditions.
- Place and time of accident should be described in detail to allow cross-referencing and completion of data.
- Report authority's official signature, date and stamp.
- Safe storage of the original accident report should be guaranteed for a given amount of time.

2.2 Other data collection tools

Data collection in the field is the main tool but others exist for improving the post-analysis. In this paragraph an overview is given of tools and information sources that fulfil two needs:

- Along with the standard accident report that is made soon after the event: sources that give supporting evidence about accidents.
- When standard or formal accident reports have not been made, or are confidential or otherwise unavailable: to find accident information via other routes.

The most important tools and sources for accidents are:

More objective tools	**More subjective tools**
Video images	Personal information of drivers, passengers and/or witnesses
Pictures	Occurrence books
Automatic recording ('black boxes')	Newspapers and other news channels
Voice recording	
Tracks and traces in the incident area	

For near-misses or risky situations:

More objective tools	**More subjective tools**
Emergency brake events	Driver's accounts
	Occurrence books

If one is looking at more than one specific accident, or at just one particular accident within an overview with others, several sources can also be available, such as for example operators' yearly reports, safety reports or analyses of federal/national agencies or inspectorates, chains of events with timing, traffic light phases, tram signal status at time of incident, detailed or additional interviews, control centre information (log files, interaction between driver and controller, emergency calls, reaction times), possible use of police reports, traffic volume at accident location, speed limits (cars / trams)…

2.2.1 Black boxes/logistic recordings

The 'black box' is a popular name which is commonly used, even when the box is actually coloured orange (as in aviation and often also in railway applications). Here it covers the technical systems in the vehicles that record the main characteristics such as speed and braking processes. Other names are in use, e.g. event recorders, on-tram data recorders and juridical recording units (JRU's). Several variations are included, e.g. tachographic or purely electronic systems.

Tramway rolling stock has been equipped in recent years with several digital recording systems. These systems range:

- from internal parameter measurements, like emergency braking actions, deceleration/acceleration and traction status
- to external recordings like front-view camera or even in-cab views.

For the internal parameters, most legal issues have long been taken care of, and other services like signalling or rolling stock maintenance use them extensively too. This is not the case for the camera recordings, although more and more networks are allowed to film the frontal view. In rare cases, internal cab images of driver behaviour are also recorded. In the case of accident analysis, this video data is considered very informative.

Figure 14 – Example of the commercially available black boxes - Black box type Teloc 1500 from Hasler Rail AG [Source: www.bernerzeitung.ch/region/bern/Dieser-Spion-faehrt-in-vielen-Zuegen-mit/story/24960723]

Advantages	Disadvantages	Legal issues
o Possibility to reconstruct an accident with details o High performance o High data protection	o Technical requirements o Difficult to analyse o Relatively small number of parameters	Sensitive data, privacy rules (if CCTV), can be requested by authorities.

Focus: Emergency brake monitoring

For the full safety management of tram and LRT operations it is not sufficient just to record, monitor and analyse incidents and accidents. Near misses can be addressed as well. Therefore other tools exist or can be applied to get a better insight of the risks in the network on the one hand, or about the driver's behaviour on the other hand.

Tram drivers are trained in defensive driving techniques and are constantly vigilant of pedestrians and cyclists, and brake to prevent a collision. Evidence suggests that these emergency brake applications are often made because of acts by third parties, e.g. the road vehicle driver, pedestrians and cyclists.

A useful indicator of a precursor to an incident (near miss) is the number of emergency brake applications tram drivers have to make. However, communication with the driver is needed to avoid the possible negative implications of recording emergency braking. If for example the driver is concerned that a sanction might be imposed on him, the number of emergency brake applications might decrease, compromising safety.

The numbers of Emergency Brake applications by Luas drivers below illustrates this important information:

Emergency brake origin	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
EB applications **by driver**	940	747	540	435	350	374	478	414	446

Table 15 – Annual statistics of emergency brake events at Luas, Dublin

In 2013, road vehicles were the cause of 38%, pedestrians 27%, and cyclists 4% of all emergency brake applications. For a further example, a success story of near-miss analysis in Stuttgart based on the amount of emergency braking is presented in chapter 4.1.2.

Advantages of EB analysis	**Disadvantages**	**Legal issues**
o Brings more data to supplement rare accident data, so providing better statistics o Precursor to an incident o Thus, allows identification of risky places – no accident yet but potential	o Difficult to collect data (black box gives no clear identification of location or drivers' declaration)	None.

2.2.2 Personal information from drivers, passengers and/or other witnesses

As noted previously, less objective tools are also worth collecting. Interviews with people involved in the incident or in the vicinity certainly can give valuable information. It is clear that people know a lot about what actually happened (e.g. the road was slippery) and that such information is not always available at a later time if no interviews were made. Therefore, even if a person is involved in the accident (and then might perhaps be a guilty party), his story is worth recording.

In certain cases important information could be obtained from noises such as (emergency) warning or (emergency) braking heard during the event, or noises due to the definite, dramatic conflict (physical contact) of vehicles involved.

In Brussels, an important source for hotspot identification and details is the drivers, their supervisors and the instructors. Ideally, one should establish a channel of communication to that audience, and make sure they receive feedback every time they report an issue. So, not only is there reactive hotspot identification from accidents which have happened, but also pro-active hotspot detection from people in the field identifying potential accidents before they happen.

Figure 16 – Authorities make notes shortly after the event

Summarizing, in many cases complementary evidence can be found on accident spots. Any investigator must always be aware of this possibility, which exists at the time of the accident, but often not in the days after it.

Advantages	Disadvantages	Legal issues
o Additional information to understand the event	o Lost or altered in witnesses' memories if collected a few days after o Not necessarily objective	Not always possible to get interview from people involved if police are present and retain recordings for legal procedures

2.2.3 Pictures of the accident

It seems unnecessary to give a long explanation and argument of the benefits of pictures as complements to accident reports. A photo is often useful to see what kind of interaction and what kind of damage has happened. Photos can be made from many positions and are therefore a clever tool to record the facts after a collision. Photos made just before and during the very moment of a collision itself are rare. If they are available, they can complete the accident dossier. The value of pictures next to written accident reports is often high because of the amount of detail they show.

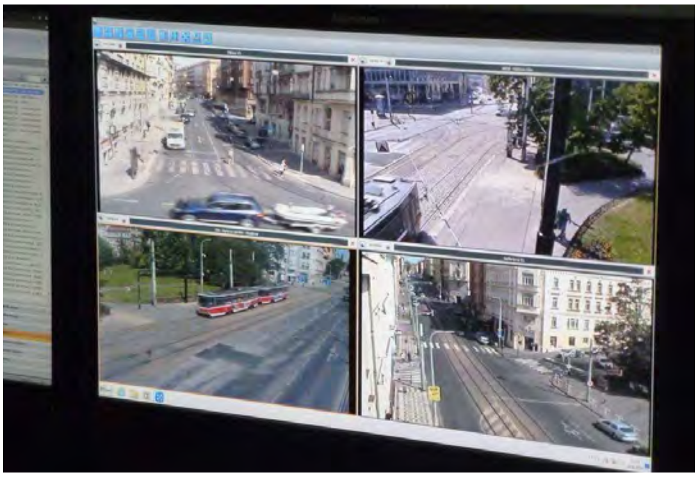
Figure 17 – Collision in France (2005) [Source: STRMTG, French guideline "Guide d'implantation des obstacles fixes à proximité des intersections tramways / voies routières'' (2012)]

However, two drawbacks must not be forgotten: pictures of severe incidents can be shocking or horrible and they also intrude into the privacy of the persons involved. Discreet use of pictures is therefore suggested, even if there is no national law on integrity and privacy to limit or to prevent photography.

Advantages	Disadvantages	Legal issues
o Replaces long descriptions, expressive o Objective	o May be shocking o Static	Privacy issues.

2.2.4 CCTV - Video images

In certain cases, a very welcome complement to personally written accident reports can be moving images that were made shortly before, during and directly after a collision type of accident. The best positions from which objective and significant videos can be recorded are the exterior front of the tram vehicle and outside on the road and/or the railway infrastructure. If they are placed in the best possible spots they make a recording of the accident that cannot be ignored because several objective facts are recorded exactly, just as they happened, no more and no less. The video contains overviews of the dynamic situation, including the collision itself. Such videos are of a key importance for investigators of the accident and in certain, but not all, cases they can help them make a sound judgment of the (correctness of) movements of those involved and the local circumstances that existed during the unhappy event.



External cameras looking in the forward direction are not common yet, but street cameras for tram safety purposes are surely not rare. However, these last are not always placed because of traffic safety; the reason is often for social security (prevention and/or observation of vandalism/brawls/misbehaviour etc.). Permanent monitoring at central offices can be found in many cities (for example the Milan or Prague facilities (

Figure 18)).

Figure 18 – Street camera views in Prague Traffic Control Center

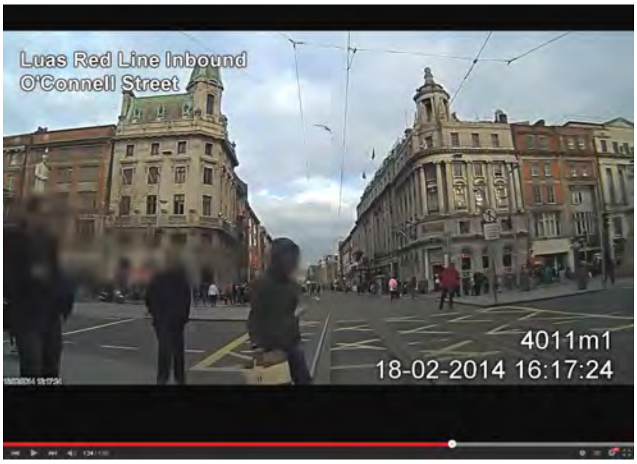
In general, video cameras for this use are called CCTV (Closed Circuit Television). Being part of a circuit and being watched online is not necessary however, stand-alone is also enough. In exceptional circumstances, it is also possible that a witness, just at the very moment, makes an occasional video with a personal hand camera because of touristic or other reasons.

Less useful for collisions, but not useless, are video images from internal tram cameras (again for social security). They record the situation of the passengers and/or of the driver and CCTV recordings can be used against legal claims in case of injuries inside the tram due to e. g. emergency braking.

CCTV is a growing development in the safety and security field of trams and light rail systems. Many operators already use them, e.g. in Barcelona and other Spanish cities, Dublin, Prague, Debrecen and The Hague. Both street cameras (on tram stops, on road crossings, turnarounds or elsewhere) and vehicle cameras (outside looking, preferably from the tram front or – for another reason – from the side position) are found in practice.

Figure 19 – Front cameras – LUAS tram

Debrecen in Hungary, the second largest city in the country, recently initiated a public transportation improvement plan that called for 18 tram vehicles with a newly designed on board internet protocol (IP) CCTV system including a camera inside the car for passenger security, a camera in front of the trams for operational safety, a network video recorder for video recording, and a wireless AP for remote live view from the control centre.



Another real application of CCTV is used by many operators, for example the Luas company in Dublin. On the Luas light rail fleet in Ireland the on-board CCTV system comprises 6 internal and 2 front facing IP cameras. CCTV-images from the front of the trams are sometimes used in campaigns that are impressive or even persuasive. They are used to show images of near-misses and conflicts with street users, and their dangerous behaviour in the traffic scene (Figure 20).

Figure 20 – Video-still of the Luas-campaign

For more details on CCTV uses around Europe and a link to the Luas safety campaign videos, see Appendix H.

Privacy

A question of importance is that of *privacy*. How far does the freedom and mandate of the organizations that make the videos go? Both governmental parties and operators do not usually have the automatic and full right to record civilians in video images. The national law can be the deciding factor, but there is still also an argument of culture and mentality. Several countries wrestle with the correct limit between acceptable and non-acceptable use of the cameras.

One of the main worries when using these kinds of systems is the legislation on Data Protection, which imposes some restrictions on the use of the images. Unions and other organisations concerned with privacy for most networks are examining the usage of such video streams or are openly against them. Internationally it was observed that the less blaming the internal company culture, the higher the probability that those video recordings of the internal cab are allowed. Generally, CCTV images can be viewed only by certain authorized people and can be used more widely only if a judge/police asks for it.

Advantages	Disadvantages	Legal issues
o Several facts are recorded exactly and objectively o Dynamic situation o Judgment of the correctness of movements of the individual collision partners and the local circumstances o Use for safety campaigns o Use against legal claims in case of injuries inside the tram, due to e.g. emergency brakes	o If not already installed at tram's front, it costs o Has to be easy to obtain the images, technically and legally	Generally, CCTV images can be used only by some authorized people and can be used more widely only if a judge/police asks for it.

2.2.5 Marks left by the event at the scene

Depending on the type of collision, track marks and traces at the scene of the accident can be of major importance in interpreting and understanding the course of an event. One can think of broken pieces from any of the transport vehicles involved, braking (skid) traces on the road, scratches on the rail track, other physical damage on the rail infrastructure, physical damage to street furniture, transferred soil, sand or stones, loss of fuel, and more subtly, the *temperature* of pieces of the tram or other transport vehicles, or *colour changes* wherever.

It is also conceivable that the quality of elements present on the spot is inferior, e.g. the visibility of a traffic mirror, the lamp of a signalling light, the light of a lamppost, the disappearance of a road sign behind a tree or a bush, etc.

Tracks and traces can be informative both in searching for the cause and the consequences. Examples of this can be the discovery of loose or broken bolts from sleeper-fastenings or other structures. It has to be judged whether they were loose before or after the accident. Of course, many tracks and traces are best recorded by pictures; however, broken pieces and parts can also be kept by themselves, as pieces of evidence.

Advantages	**Disadvantages**	**Legal issues**
o Evidence o Give additional clues on the causes and consequences of an event	o When collected, can be interfered with after the accident	None.

2.2.6 Occurrence books

Information about occurrences is kept in many ways. Here the term occurrence *books* is used, because of the original method of manual writing in 'logbooks' although nowadays it is common to use digital records to note occurrences of whatever kind, e.g. disruptions, problems and special circumstances. Usually the notes are made next to and independently of the accident reports and - when an occurrence has grown to an accident - they often give a further insight into the actions of the operator company.

Advantages	**Disadvantages**	**Legal issues**
o Additional information, mainly on circumstances, context	o Lack of accuracy o Non exhaustive of all what happened	None

2.2.7 Voice recorders and conversations

Complementary evidence for the investigation of accidents should in certain cases be obtained from conversations between drivers and the control centre or between one driver and another, if any audio tape system is built-in or if a telecom apparatus (mobile or not) is somehow involved in the accident process.

Advantages	**Disadvantages**	**Legal issues**
o Possibility to reconstruct an accident with details	o Has to be easy to obtain the records, technically and legally	Privacy.

o Reliable o No interpretation		

2.2.8 Street Information Systems

Different factors influencing road safety, such as traffic volume, density and structure, pedestrian organisation or visibility in the road corridor, when linked, give a comprehensive picture of the situation to be analysed. And analysing only one factor is often not sufficient, therefore all available data should be analysed. Dedicated software, which merges all that data, can make this process easier, faster, more efficient and more reliable. A detailed accident analysis helps road authorities understand the causes of accident occurrence and, based on that, find feasible solutions and develop a successful programme for road safety improvement.

To answer those needs, Road Information Systems were developed. Their main task is to integrate the services providing complex information on weather and traffic conditions on roads; to collect, store and share the road information; and to link with police information on accident data. Complete data give the broad view of the current situation and support the decision-making process. More details in Appendix I.

Advantages	**Disadvantages**	**Legal issues**
o Integrate complex information, different factors.	o Dedicated software.	None.

2.2.9 Newspapers and other media

In some cases, press releases can be used as a complementary data source. Both for recent incidents and for incidents in the past the information is often interesting. With a key word search a large source of data and reports can be found. In fact, with most severe incidents some information will surely be present, in text or in pictures.

Advantages	**Disadvantages**	**Legal issues**
o Can bring complementary data	o Non objective o Accuracy and sources to be checked o Relations between press and operators might not be good	None

2.3 National and European databases

A database is a collection of information on one topic (event, fact, object…), in order to describe it with specific items, gathered in a structured way and a defined location. It is more than a list, not a heterogeneous collection of data.

This allows:

- to search, sort or select some data per item or choose one/several parameters,
- to make some statistical exploitation.

Computer tools facilitate this use, regarding input, storage and use of data. The European statistics guideline (Commission Regulation (EC) No 1192/2003 of 3 July 2003 amending Regulation (EC) No 91/2003 of the European Parliament and of the Council on rail transport statistics) offers some basic structure.

> In any respect, accident data should first be recorded locally. As a second step, accidents might be evaluated on a broader basis, in a systematic manner in accordance with the Core Brief of UITP "Operational accident statistics – an essential element of accident prevention" (2014). However, it should be defined in advance which body takes over responsibility for running and operating such a database. On a local level, this often is done by the tram operator or the municipality. On a national or EU level, such a body would have to be defined. In any case, this body or authority should be independent.

2.3.1 The current situation in involved countries

From WG2 in WP1, we've learnt that only one country (France) has a specific tram accident database at the national scale (see success story in chapter 4.1.3 for details on French national tram accident database and its results). And no European one exists. However (see Table 21), in all participating countries, operators are gathering and exploiting data about tram accidents.

- For example, in Czech Republic, tram driver reports the place of the incident to the tram traffic controller. From there the authorized person (dispatcher) is sent to the place of the incident. Dispatcher secure all the information from the place of the incident and put it in the internal database of the tram traffic controller called MUNE, where it is possible to create output in the form of a Microsoft Excel document. Into this database completely all the data concerning the tram traffic and the place of the incident are written.

In some countries, people are interested in sharing things between operators (as in Spain) or building a common tool (like in Italy or Sweden).

In the meantime, we've learnt that other databases exist regarding road accidents:

- Germany has a road traffic accidents database which includes tram accidents.
- In Switzerland, the Federal Roads Office manages a road accident database that includes tram accidents, fed from local („cantonal") police data collections. The Federal Office of

Transport (FOT) manages a national database (NEDB) of public transport incidents fed with operators' entries.

- In France, there’s a road accidents database (BAAC File), filled in only when there are casualty(ies). This one is used both at the national level and at the local level by towns (at this scale a geographic interface called Concerto can be used to exploit data and produce accidents maps).
- In Poland, data and accident reporting from Police generally takes into account tram accidents, however, it does not take into account all the incidents occurring. Accidents’ reporting is harmonized on the national level, but not often sufficiently precise. Each operator executes his own accidents’ reporting, which includes more specific data.

From the investigated countries, only Germany established a coherent road accidents database, involving trams and other road users. This fact may be related to the number of tram networks (58) and kilometres run (245 millions in 2011) in Germany, compared with other countries (from 1 network in Ireland to 14 in Poland).

Police reports may be helpful for local studies, together with operators’ internal report systems. Insurance companies have their own databases, but these are generally only for internal use and not accessible. The following table shows an overview of which data are available.

Which data are available?	Portugal	France	Italy	Ireland	UK	Spain	Switzerland	Germany	Czech Republic	Poland
Statistical accident data:										
At national level:	No	Yes	No	Yes	No	No	Yes	No	No	Yes
Standardized (at national level):	No	Yes	No	Yes	No	No	Yes	No	No	Yes
At local level:	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Standardized (at local level):	No	No	No	No	No	No	No	No	No	Yes
At regional level	No	No	Yes: USTIF level	No	No	No	No	No	No	No
Standardized (at regional level)	No	No	Yes	No	No	No	No	No	No	No
Other sources:										
Police	?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospitals	?	No	Yes	No	No	Yes	Yes	No	No	No
Insurance companies	?	No	Yes	No	No	Yes	Yes	Yes	No	No
Other		Yes: BAAC = files are gathered in a national database, available to services of State and local organisations (town, departments, etc).	No	Yes: RSC - the Railway Safety Commission on the national level, TED the Operator´s Traffic Event Database. the RPA Luas Operation Annual Report	Yes: RAIB (Rail Accident Investigation Branch), from RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Ragulations), from HSE (Health and Safety Executive)	No	Yes: SAIB (Swiss Accident Investigation Board),	Yes: ITCS = Inermodal Transport Control SystemSystém; internal reporting system, technical supervisory authorities, statutory insurance firms	No	Annual reports of the Chamber of Public Transport

Table 21 - Overview of other accident data (levels and sources)

2.3.2 Advantages and difficulties of a national database (regarding tram accidents)

<table>
<tr><th>Advantages</th><th>Disadvantages / difficulties</th></tr>
<tr><td>
<u>General:</u>

Database can be a relevant tool to help people understand how accidents occur, through information about spatial and temporal location, context, circumstances, involved users, consequences and so on.
To get a precise description of accidents.
To make a larger analysis based on more than one network.
To make valuable statistics (more data to deal with).
At a national level, to exploite more valuable and representative data (due to the number of records) to improve regulations and technical guidelines concerning road and tram safety.
To facilitate standardisation and updating of data.

Database usually is a computer tool:

To enable quick answer to specific questions.
To facilitate cross-analysis (combined use of various parameters).

<u>For the operators:</u>

To get an operational tool without problems of maintenance.
To have a quality process on their own data (from the state level).
To get references (with national indicators) and to be warned/aware of any gap regarding their own indicators.
To compare the tendencies, and then to assess some modifications or corrective measures applied on their network.
To get quick answer on a possible specific question and to produce objective figures on the (supposed) risky points.
For some, it is a help for the (compulsory) annual report, a sort of “press-button” to give them the figures in the required format.

</td><td>
<u>General:</u>

Need to collect all the data (partial information can reduce drastically any analysis).
Common nomenclature (i.e.: light injured / seriously injured).
Setting up a codification is necessary to make things comparable (not just a list of incomparable information) and it is a heavy work.
To find the task forces to implement the database and to fill it in (at various scales: operators, state…?).
Since it is used by several actors, the tool must be managed by one entity, with rigorous organisation and methods of works (no various versions).
In case of small absolute numbers of events, data sets cannot be compared easily. This could prevent a statistical evaluation.

<u>For the operators:</u>

Identify someone involved in safety issues for collecting and filling in the database.
More resources: to update the accident data with new information. And time for training on codification and use of database.

</td></tr>
</table>

For the state:	For the state:
▪ To identify national trends/issues on tram safety. Results of database use bring relevant information for leading projects/modifications on tramlines. ▪ To enhance the control process (relevance and better credibility towards project managers and operators to impose measures, based on shared figures). ▪ To point out some interesting issues to be studied (complementary to other sources: operators' questions, national inquiry bureau's requirements…).	▪ Communication of the database is difficult because it is a heavy file. ▪ Communication may be sensible while some information are confidential (not to be let available to the general public or shared between competing actors).

General recommendations on accidents databases were set up by the UITP and were published in a Core Brief (Operational accidents statistics – an essential element of accident prevention - 2014) see Appendix J.1.

In conclusion, through the feedback, the knowledge and general view it enhances, a national database may improve the safety level.

2.3.3 Necessary criteria to make it successful

- Easy to fill in, accompanied by a guideline (clear, same sorts of inputs, same definitions);
- Easy to use;
- Collect high-quality, relevant, comparable and useful data on events;
- Effectiveness and efficiency of collecting methods, which have to be adapted to the nature of collected data and diversity of actors;
- Common way of collecting and reporting accident data;
- Well performed use of the collected data, followed with reliable analysis aimed at safety improvement;
- Management by an independent office (responsible for transmitting updated data from operators, ensuring confidentiality, performing analysis, quality checking, providing assistance for operators);
- Legal obligation for operators to report their data;
- Dedicated means (people, hardware, software); training of users.

2.3.4 Is a database relevant at a European scale?

Concerning the analysis of safety indicators (data collection and analysis), the group has answered two questions:

- Should a country have a means to harmonise its tram safety indicators? How to do it?
- Should it be done at a European level? If so, how?

A comparison has been done on what already exists in terms of harmonisation:

1. First, to railways: but trams are not railways. Trams are different since they operate in a street environment where the risks come from external actors (road traffic, pedestrians, road authorities) over which the tramway operator has little or no control. All an operator can do is make sure his drivers and traffic inspectors are prepared for the risks and take action to reduce them. Besides, in case of railways the EU regulation is based on interoperability. Urban tramway systems, however, are closed systems without network connection.
2. Second, to road: another comparison has been proposed since tramway companies are generally public transport companies and they have also public transport systems like buses. But trams are specific, with long braking distances, a constrained trajectory and various systems of priority.

None of them are satisfactory to the tramway systems. The core problem is to share the figures of the indicators within operators and outside - sensitive questions, possible quick but misleading comparisons... And the benefits of European wide harmonisation are difficult to determine and would probably be very difficult to achieve. There may, however, be some lessons to be learnt which could reduce hazards on new systems.

Indicators may be useful to assess evolution of safety level on a network or a line, but not to compare results of networks between them. They may help to identify some risky situations (i.e. roundabouts or "turn on" junctions) on a local basis, but are not relevant to explain why accidents occur.

The aim of the Action was not to build a European database, nor to compare tramway safety in various countries. However an analysis of advantages and difficulties to do so is proposed here.

<table>
<tr><th>Objectives / advantages</th><th>Disadvantages / difficulties</th></tr>
<tr><td colspan="2">The same (dis)advantages than at national level.
And additionally:</td></tr>
<tr><td>▪ More data, so statistics more valuable.
▪ European global view on tram accidents (no comparison between networks).</td><td>▪ Multiple operators.
▪ Language and definitions issues.
▪ To have the same codification.
▪ Different regulations.
▪ Each tram system has different configurations (from completely segregated to mixed areas).</td></tr>
</table>

2.4 Post-analysis through integration of all data

> The post-analysis based on accidents aims at understanding what happened on one single particular accident or a group of accidents (same location, same typology, same type of event) and how to avoid these accidents.

The objectives are to:

- Evaluate, register and minimize risk (risk/safety management system);
- Check if rules were adapted to the situation;
- Make a human behaviour analysis (driver's state at the accident and other parties behaviour);
- Bring complements to driver training;
- Search for improvements:
    - Organizational improvement (e.g. procedures, staff, processes, accountability);
    - Operational improvement (e.g. running times);
    - Infrastructure improvement (e.g. signage);
    - Rolling stock improvement (e.g. specifications, visibility, etc);
    - Environmental improvements (e.g. visibility by vegetation, etc);
- Make an economical evaluation;
- Make a conclusion and propose measures.

The post-analysis starts some time after accident resolution or closure, to look at it with a fresh mind, new angles and a global view, with accident reports and other sources.

Different methods are possible:

A. Treatment implemented at one location;
B. Treatment implemented at several locations in one tramway system;
C. Treatment implemented at several tramway systems.

2.5 What is a hotspot and why identifying them?

This word "hotspot" needs a particular attention to its definition. Indeed, we've experienced during meetings and in questionnaires that it was used with different meanings and illustrates different safety approaches.

A definition was given by the group, prior to the questionnaire (see chapter 3.5). But amongst operators safety managers, definitions have been more precisely specified before or within their answers:

- Warsaw operator said a hotspot is the point at which there is the greatest number of events over the last year.

- Some operators look at the first accidental locations for the last years (10 years analysis for Dublin, Barcelona or Manchester for example or last 3 years for Lisbon).
- Vienna operator explained that an accident accumulation point (=”hotspot”) is defined by 3 homogeneous accidents (with physical injury) within 3 years or 5 homogeneous accidents (with material damage) within 1 year (“*Guideline for safety and accident investigation”* FSV (2014): RVS 02.02.21 Verkehrssicherheitsuntersuchung. Richtlinien und Vorschriften für das Straßenwesen. Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr. Wien). In practice, hotspots are statistically monitored over a period of 5 years. The priority lies in systematically disarming the top hotspots in every period.
- Dublin assess the statistics of emergency brakes to identify Hotspots.
- The near-missed accidents (Dublin) or passengers accidents due to Emergency Brakes (Le Mans) are sometimes included in the accidents numbers.
- Some even mention being hotspots some places where there were minor collisions with vehicles and pedestrian falls.
- Bern tram operator admit that there are of course safety hotspots in their tram network. Until now, the accident numbers at these places remained on an absolutely acceptable low level, so there has been no necessity to implement any corrective measures regarding construction or traffic control. They trace this fact back – besides other factors they cannot influence themselves – to their internal training and prevention efforts. (e.g. hotspot n°1 has 6 collisions between trams and cars during the last 5 years).

Finally, there are several possibilities to identify network’s hotspots, some of which are given below:

- to count the number of accidents per location all along the line (for the last year or for the last x years) and to focus on the highest ones.

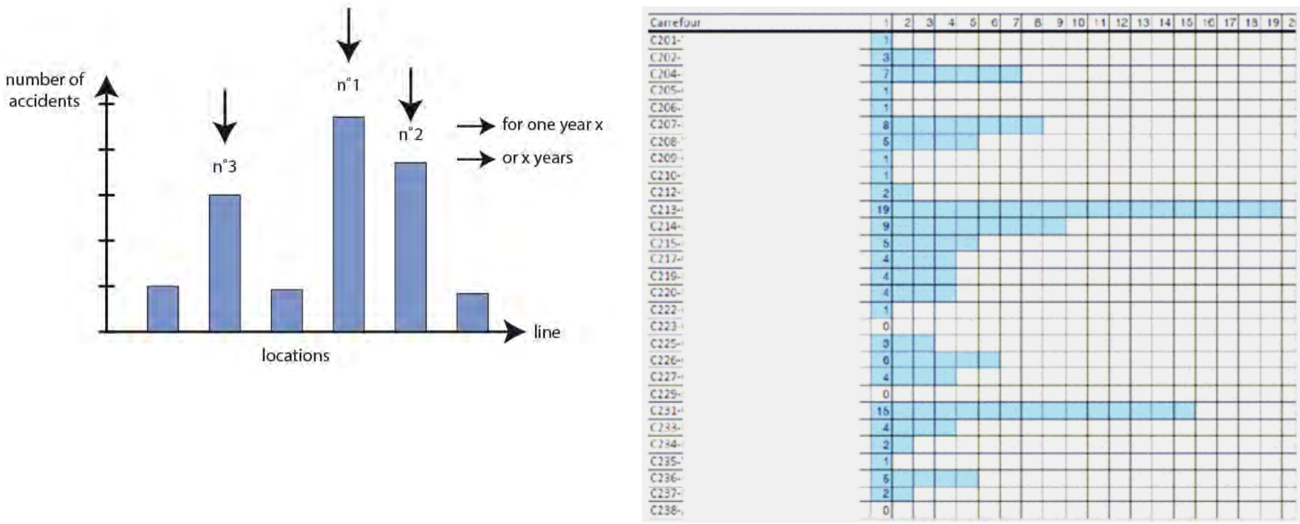
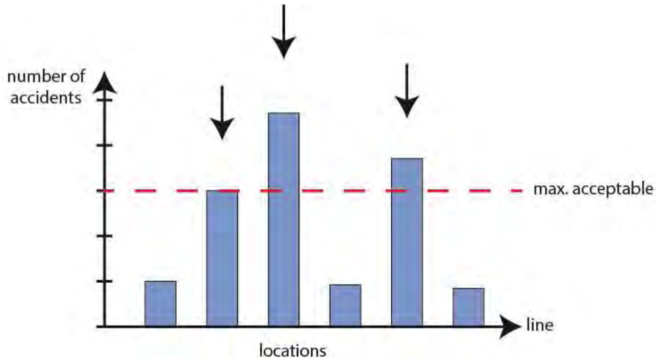
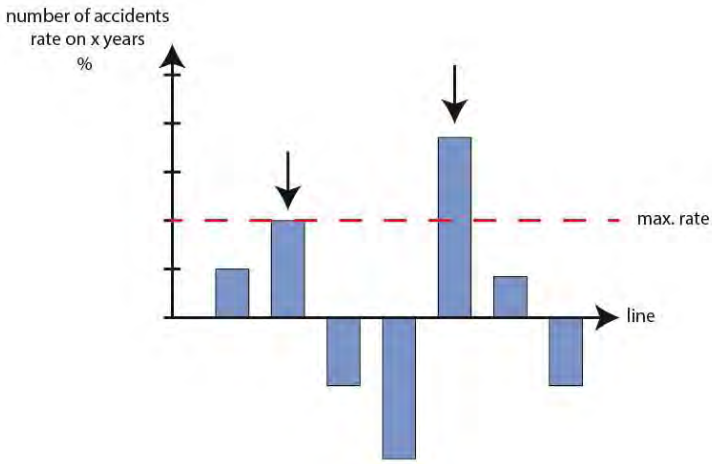


Figure 22 – One French network’s example of counting accidents in junctions [Source: STRMTG]

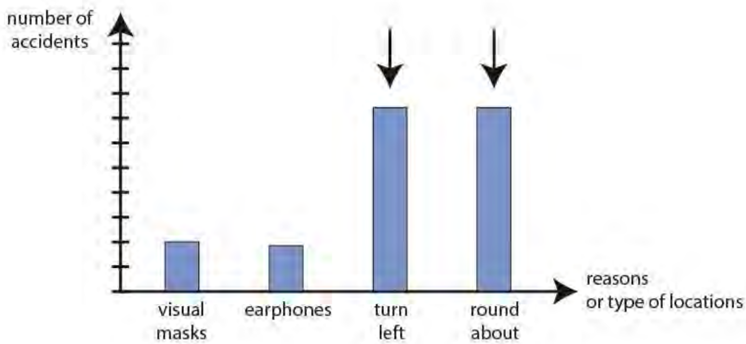
- to count the number of accidents per location all along the line (for the last year or for the last x years) and to focus on those which are above a minimum number (e.g. 3 per location during the period).



- to calculate the augmentation/diminution rate and focus on the locations with the highest increase of collisions.



- to count the number of accidents per type of causes all along the line (for the last year or for the last x years) and to focus on the highest ones.



- An important source for hotspot identification and details are the drivers, their line management and the instructors. One should foresee a channel of communication to that audience, and make sure they receive feedback every time they report an issue. So: not only because accidents have happened (reactive hotspot identification), but also pro-active hotspot detection (because the people on the field identify potential accidents somewhere before they happen).

These are not exhaustive ways of determining hotspots.

The identification of hotspots is the first step for in-depth post analysis and proposals of improvements (traffic signs and signals, road markings, tram driver trainings, safety street users campaigns...). This “classification” (n°1, n°2... or all spots above x accidents on x years...) is a way to know where to put main efforts (time to observe, to analyse, financial investments).

There are different possibilities to identify hotspots. The consequences of this identification are to know where to put most efforts. To count the number of accidents per location all along the line (for the last year or for the last x years) and to focus on the highest ones is the most frequent identification.

There is no management in particular to highlight, but all can be complementary. However, to identify hotsposts and have at least a view on a few years on all spots along the tram line is a good starting point.

Note that hotspots and indicators are complementary.

2.6 Indicators: major mean to follow urban tram safety

2.6.1 Definition and aims

Behind the general goal of indicators, there is the characteristic idea of comparing situations while using a set of data. Regarding tramway safety, indicators are a useful tool in order to assess final results such as:

- to show the trends in terms of safety, give general information through communication and media,
- to identify and rank the stakes, by highlighting critical points or situations on existing networks,
- to assess the strategy and efforts to improve safety, while looking at impacts of changes in operation or design of lines,
- to improve the knowledge for planning new lines based on bad or good experiences.

While using indicators, making comparisons between tramlines or layouts is not often relevant and needs to be very careful because of the different contexts. One should rather try to compare one system at two different points in time.

Moreover, indicators are useful for quantitative analysis and can provide general conclusions. A detailed and qualitative assessment of an individual incident is still of important and complementary value.

Here was distinguished three categories of indicators for tramway safety related to interaction with public space, that were called “global”, “geographical” and “typological”.

“Global” indicators

When observing trends in order to assess the safety, a comparison can be made:

- in time (i.e. from one year to another), and/or refer to defined goals (i.e. 0 casualty policy).
- with references, which may be figures regarding another transportation modes or road safety in general.

These are global indicators, gathering those related to:

- o the whole line or networks (without any reference to the location of accidents),
- o the whole period of operation (without any reference to date nor time),
- o the types of events (derailments, collisions, etc.), and severity (casualties, injuries…).

All of these indicators are determined without any reference made to causes, period, nor types of users involved...

When saying that urban insertion related events are making up the main safety issues for tramways, it is based on an indicator corresponding to the number of events.

	2005	2006	2007	2008	2009	2010	2011	2012	2013
SERVICE LEVEL									
Tram million kms	2.47	2.67	2.74	2.73	2.64	3	3.86	3.99	3.88
% change		+8%	+2.6%	-1.0%	-3.3%	+13.6%	+28.7%	+3.3%	-2.7%
INCIDENTS/ACCIDENTS									
Road traffic collisions (RTC) road vehicle/tram	36	24	28	32	23	30	30	24	38
Contact of person with tram	8	21	18	20	18	22	13	7	8
Collision between two trams	1	0	0	0	0	0	0	0	0
Derailment in depot	4	0	3	1	0	0	0	0	0
Derailment in service	1	1	0	0	1	2	0	0	0
SPADs	-	-	-	-	-	-	-	30	24
Emergency brake applications	940	747	540	435	350	374	478	414	446
Fire	0	0	0	0	0	0	0	0	3
Failure of a part of a Tram	0	0	0	0	0	0	0	0	2
Failure of OCS Support	0	0	0	0	0	0	0	0	1
Road vehicle striking an OCS support Pole	0	0	0	0	0	0	0	0	1
Emergency handle applications (incidents)	14	6	4	3	13	3	10	3	3
***Total Incidents/ Accidents**	**1004**	**799**	**593**	**491**	**405**	**431**	**531**	**478**	**526**
Incidents/Accidents per million km	**406.5**	**299.3**	**216.4**	**179.9**	**153.4**	**143.7**	**137.6**	**119.8**	**135.6**
CONSEQUENT INJURIES									
Fatality	0	0	0	1	0	0	1	1	0
First Aid	5	1	3	1	5	2	1	0	1
Medical Attention	10	9	11	4	20	15	9	7	12
Hospital Care	2	2	2	1	4	3	1	0	0
Total Injuries	**17**	**12**	**16**	**7**	**29**	**20**	**12**	**8**	**13**
Injuries per million km	**6.9**	**4.5**	**5.8**	**2.6**	**11.0**	**6.7**	**3.1**	**2.0**	**3.4**

Table 2 *Summary of all accidents and incidents by category*

Figure 23 – Numbers of accidents [Source: Railway Procurement Agency, Annual Report 2013 (2014]

“Geographical” indicators

When indicators are calculated and used in reference to localisation of accidents, they may be called geographical indicators. This second group is used to compare figures regarding:

- o different parts of networks,
- o various types of places (junctions, stops, etc.),

- the spatial localization of accidents.

Identification of “hotspots” (see chapter 2.5) is a good example of this use of indicators.

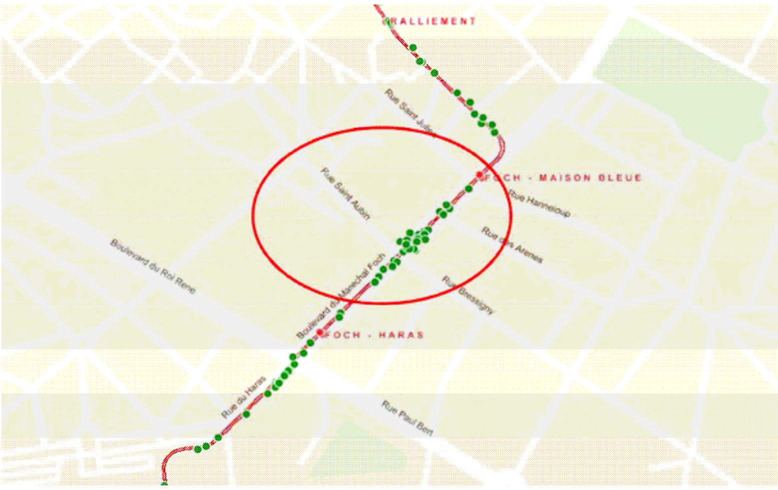


Figure 24 – Example - Map with accidents location

“Typological” indicators

A third group may be made up with indicators which are related to circumstances of accidents and involved parties:

- categories of involved persons,
- periods of time when accidents occur,
- causes of accidents,
- other contextual items.

Figures about severity of accidents were used to determine that pedestrian or cyclists are the most vulnerable casualties of accidents...

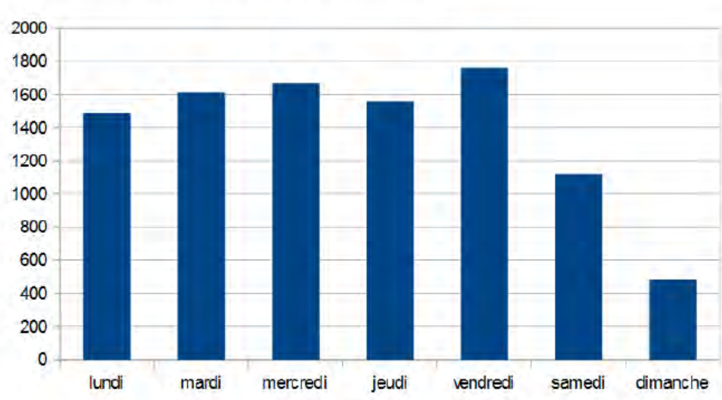


Figure 25 - Distribution of events along days of the week (all French networks, 2004-2012) [Source: ENTPE, TFE R.Leconte]

Besides these indicators dedicated to safety, some other indicators which may be related to impacts of accidents, with an economic or quality aspect can be identified, such as:

- operation disruption, through its duration or corresponding loss of income,

- o infrastructure and rolling stock repairing costs,
- o social costs.

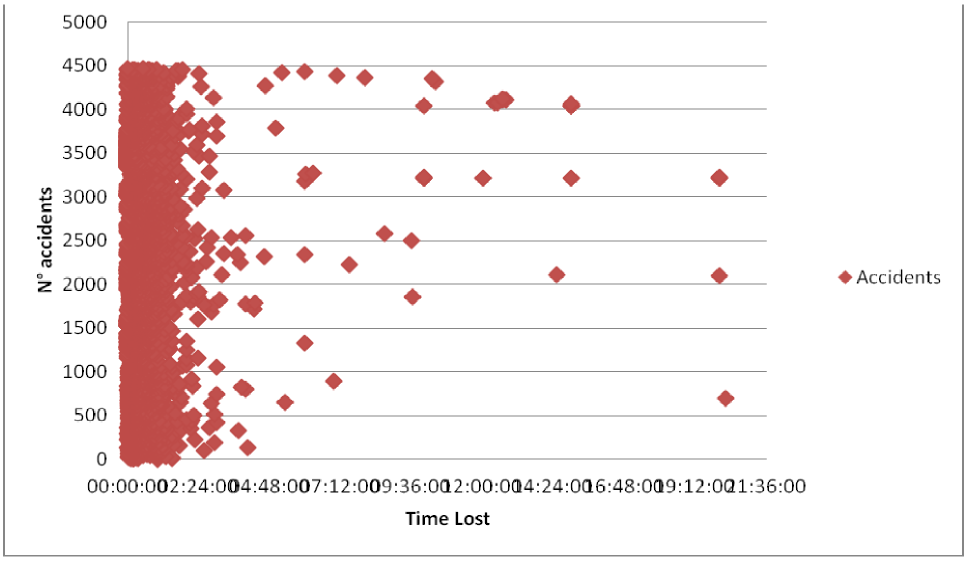


Figure 26 – Scatter plot of duration of disruption due to accidents from French accidents database [Source: Rosario Barresi, STSM Report, Accidents' impacts on the system's productivity (2014) – Appendix N.2]

2.6.2 Limits of use

During Working Phase 1, the Working Group 2 produced an overview of existing indicators in various countries involved in the Action. The detailed of all countries' practices are available in Appendix E.

From these outputs, it appears that the average number of indicators used by operators or at national level is about 20. However the situation looks very variable from one country to another:

- two countries record more indicators (Ireland with 40 indicators and Czech Republic with 45 indicators),
- the operator in Porto (Portugal) only uses 8 indicators.

Indicators are available at the national level in France, Ireland, Switzerland and Poland. For most of other countries, there are some examples from one or two operator(s). For France, Italy, Poland and Spain, the synthesis of group of operators was available.

Regarding indicators, no major difference appears between the national level and the individual operators. Beyond national contexts, operating companies (i.e. Keolis or Transdev) are trying to homogenize operators' practices in all their networks.

> As far as our aim is not to compare networks' performance about tramways safety at any level, there is no requirement for authorities, operators nor regulation bodies to produce and use exactly the same indicators. This leads to a first limit which is the availibility of data required to produce safety indicators. One must keep in mind that most of accidents data are collected by drivers, while they have to deal with the current situation (call for assistance, help the involved person, re-start operating ; etc.).

A second limit is the existing difference in definitions for collecting data.

For example, some countries do not separate collisions betweens trams and collisions with other vehicles, while fixed obstacles can be part of the rail systems). Moreover, some differences appear about casualties:

- not all countries use the OECD definitions of “injured”(in Czech Republic, the incapacity to work is used).
- regarding passengers: while a person travelling in the tram is obviously counted up as a passenger, it is not so clear for people staying on platforms at stations, or going out or in the tram: in some countries (i.e. France), they are considered as passengers, but may also be counted up as third parties.
- However, the main issue regarding passengers is the large diversity which may exist, even in one country, about the level from which a passenger is counted as a third party when he falls down or hit something inside the tram or on the platform.

A third limit is linked with different context of accidents and operation:

- frequencies of tramways,
- nature and level of traffics,
- layout (segregation of tracks, regulation and signalling,
- behaviours of users.

Moreover, regarding this information, an additional (and strong) limit may be the unavaibility of data regarding car traffic (especially to compare places).

2.6.3 Most useful indicators and their pro/cons

Setting up common definitions and same ways of calculating and using indicators would be a very good thing to enhance mutual comprehension, sharing and cooperation between these various actors. Figures are not directly comparable, even when methods, ways of doing and safety policies are similar. To have unique indicators every where would also be very useful for researchers and study bodies dealing with tramways safety and avoid potential misunderstanding in analysis and assessments.

On the other hand, collecting data and exploiting them to produce relevant figures and indicators is a heavy task, needing human and technological means and money.

That’s why are proposed here what was thought to be the most useful indicators for tramways safety monitoring, and highlight which of them could be the core for operators. This is mainly matching with the minimum already used. The choice and definition of these indicators is to be made while thinking to their relevance and potential use, but also by taking in account the fact that data are to be gathered by operators, and originally for most of them by the tram drivers. Whatever the definitions of data used are, the core thing is to explicit the context of data or indicators and not let it alone without any reference about it, nor definitions used.

- In case of several networks concerned (i.e. regional or national database): same definitions and ways of measures are necessary to make it efficient and coherent.
- Use of indicators to follow evolution of something requires maintaining same ways of doing in time.

Representativeness of indicators requires sufficient statistically meaningful data. However, it is difficult to fix a minimum of records in an absolute way. Fortunately, there are few accidents with trams. Anyway, it is important to give this information of the size of samples (number of events, or configurations, etc.) on which the indicator is based.

1 Number of accidents

Definition and nature	Raw data: counted accidents[4] during the period
Category	Global indicator
Representation	Tables
Spatial field of application	Line(s), network(s)
Period	Relevant to distribute it more than one time per year (monthly, ...)
Relevant for	Measuring the stakes, getting a general overview of safety on a network or a line Reporting to the authorities
Not relevant for	Comparing with other domains (road safety, heavy rail, etc.), due to the different operation conditions Comparing networks Not reflecting the safety level of the tram network (shows no evolution, no gravity, no type of accidents). A pure figure.

Tramway accidents by city			injured		death
City	**Period of reference**	**Number of accidents**	**slightly**	**seriously**	
Bergamo	2009-2011	9	4	0	0
Florence	2009-2011	9	10	1	0
Mestre (Venice)	2010-2012	6	3	1	0
Milan	1995-2012	161	436	36	21
Padua	2007-2011	6	0	1	0
Rome	1997-2011	107	314	38	10
Turin	2000-2011	33	113	6	6

Figure 27 – Tramway accidents by city – Italy [Source: Demetrio Sgrò, Università Mediterranea di Reggio Calabria, Sicurezza dei sistemi tranviari nel territorio italiano. Tesi di Laurea (BAC" (2012)]

Note: here, an analysis of such a table must be careful. Comparing networks based on raw data is not relevant since there is no data given on the size of the networks, neither the production of km runs or number of junctions. Besides, the period of collection is a parameter too to take into account.

[4] for definition of accident, see chapter on Definitions.

2 Number of fatalities, injured persons

This is a global indicator to give an overview and to highlight the stakes compared to other domains (road safety, heavy rail, etc.). It is subject to communication by media, so it seems interesting to manage it.

Definition and nature	Raw data: counted injured / fatalitities[5] during the period
Category	Global indicator
Representation	Tables
Spatial field of application	Line(s), network(s)
Period	Relevant to distribute it more than one time per year (monthly, ...)
Relevant for	Measuring the stakes, getting a general overview of safety on a network or a line Reporting to the authorities
Not relevant for	Comparing with other domains (road safety, heavy rail, etc.), due to the different operation conditions Comparing networks

Accidents							
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Fatal	1	1	2	1	0	0	3
Serious	7	10	4	6	8	3	2
Slight	30	15	19	16	25	21	18
Total	38	26	25	23	33	24	23

Casualties							
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Killed	1	1	2	1	0	0	3
Serious	7	11	4	12	8	3	2
Slight	37	21	33	30	32	25	25
Total	45	33	39	43	40	28	30

Figure 28 - Accidents and casualties involving trams on public highway (2005-2011) [Source: Department for Transport UK, STATS19 data]

[5] for definition of injured people and fatalities, see chapter on Definitions.

3 Accidents per km per year

Definition and nature	Ratio: number of accidents divided by number of kilometers run *better to count all km run on public streets – not only in commercial service*
Category	Global indicator
Representation	Diagram
Spatial field of application	Line(s), network(s) *The most relevant way is to do it line by line*
Period	Any (as far as enough events are concerned to be significant)
Relevant for	Assessment of policy, campaigns, operation methods (Evolution in time, ...), Identification of general safety stakes at a large scale (i.e. network, line) Comparison between lines (<u>only if they are similar</u>)
Not relevant for	Comparison between networks, countries with a ranking idea… Work on causes, localisation, types Looking for detailed stakes

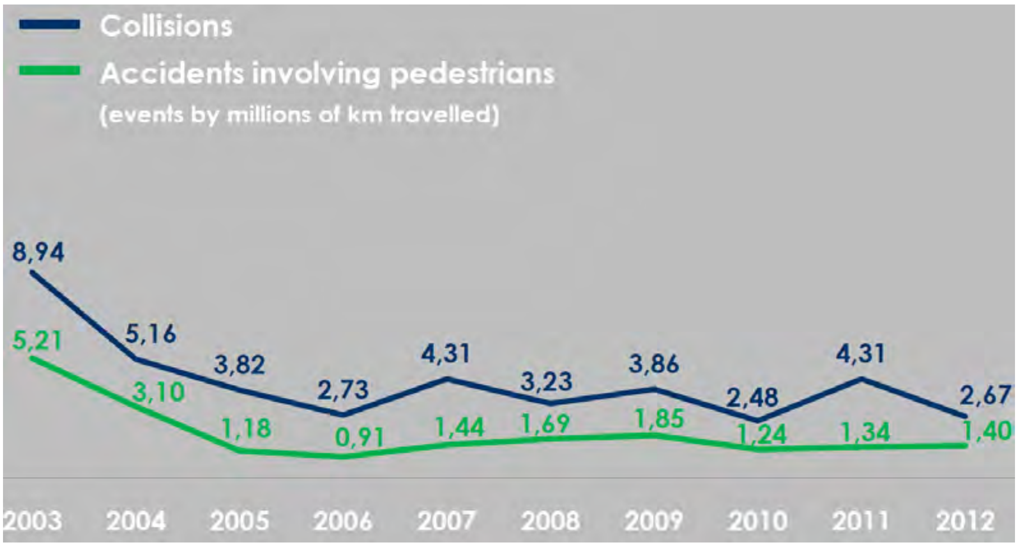


Figure 29 – Collisions per millions of kms travelled (and those including pedestrians) [Source: Metro do Porto]

4 Number of accidents per places

Definition and nature	Raw data: number of accidents[6] per places per period
Category	Geographic
Representation	Maps, linear scheme of lines
Spatial field of application	Network
Period	Minimum one year To be more significant a longer period (more than 3 years) is better, but needs no change in context or configuration
Relevant for	The most common tool to identify “hotspots” (places where you have to analyse safety issues) Communication about accidents location
Not relevant for	Getting any conclusion about causes of accidents (detailed analysis of accidents must be done after identification of hotspots Being used in a statistic way (too much depending on the context of places).

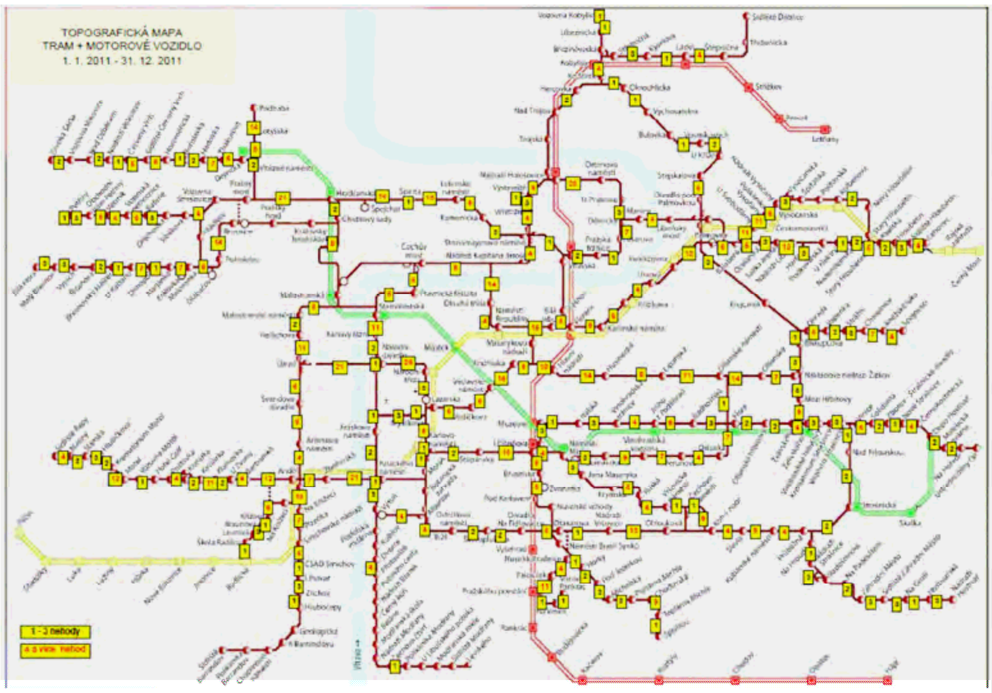


Figure 30 –Prague map with accidents location [Source: Dopravni podnik Praha, jednotka provoz tramvaje (Prague public transport operator, tramways unit) Accident report – 2011 Prague (2012)]

[6] It could be interesting to be done separately for collisions, passenger accidents… and also for near-missed accidents (through emergency braking, if possible to get precise enough information about location, causes).

5 Distribution of accidents by types of places (relative)

Definition and nature	Percentage of accidents for each type of lines section Types of places: stations, junctions, other sections[7]
Category	Geographic
Representation	Diagram, tables
Spatial field of application	Lines, network *This requires a codification of lines by elementary parts (which events localisation is made by reference to) or a precise information regarding type of section in events reporting*
Period	Minimum one year
Relevant for	To highlight safest types of layouts or conflicts management
Not relevant for	To compare in a detailed way places between themselves

GB (Total)	Accident Year						
Junction Detail	2005	2006	2007	2008	2009	2010	2011
Not At Junction or within 20 metres	9	3	8	6	9	9	12
Roundabout	1	0	1	0	1	0	0
T or Staggered Junc.	7	6	7	6	8	4	7
Crossroads	11	13	5	9	7	9	3
Junction - more than 4 arms (not roundabout)	2	1	0	0	2	0	1
Private Drive/Entrance	1	0	0	1	0	0	0
Other Junction	7	3	3	1	6	2	0
Total	38	26	24	23	33	24	23

Figure 31 – Reported Person injury road accidents involving Trams/light rail on public roads by junction type: 2005-2011 [Source: UK Department for Transport]

[7] Junctions should be distributed regarding main categories, such as roundabouts, with/without traffic lights, (simple) level crossings, bicycles lanes crossings, pedestrian crossings. For other sections, mixed traffic area, shared lanes, segregated tracks may be separated.

6 Distribution of casualties (fatalities, injured) by types of places (relative)

Definition and nature	Percentage of casualties (fatalities, injured) for each type of lines section Types of places: stations, junctions, other sections[8]
Category	Geographic
Representation	Diagram, tables
Spatial field of application	Lines, network *This requires a codification of lines by elementary parts (which events localisation is made by reference to) or a precise information regarding type of section in events reporting* Comment: should be made by road safety authorities (not only for trams) on road network
Period	Minimum one year
Relevant for	To highlight safest types of layouts or conflicts management To focus on most dangerous configurations (in terms of severity, and not in quantity as above)
Not relevant for	Percentage of accidents for each type of lines section Types of places: stations, junctions, other sections* Note that the consequences of an accident on people involved (safe or injured) is not linked to any mathematical logic so one has to be cautious with such small figures

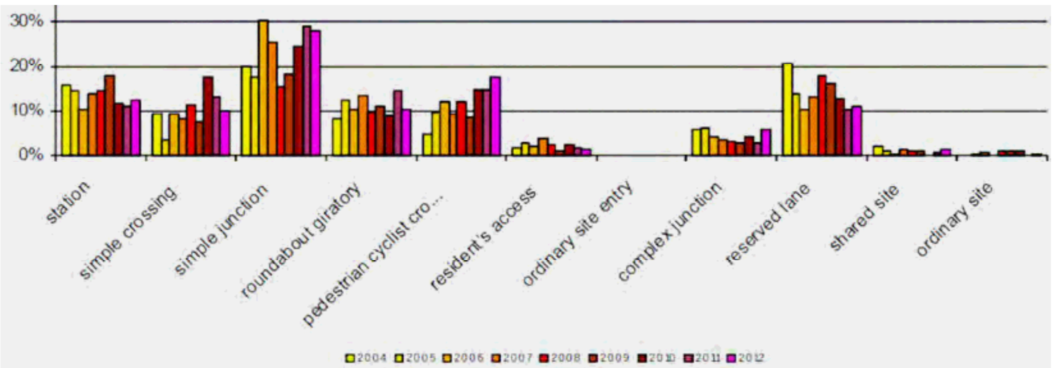


Figure 32 – Distribution of casualties of collisions per configuration [Source: STRMTG, French national Report on Accidentology of Tramways – 2004-2012 (2013)]

[8] Junctions should be distributed regarding main categories, such as roundabouts, with/without traffic lights, (simple) level crossings, bicycles lanes crossings, pedestrian crossings. For other sections, mixed traffic area, shared lanes, segregated tracks may be separated.

7 Number of accidents per number of type of places

Definition and nature	Ratio: number of accidents on each type of place divided per number of each type place (during a period/ each year) Types of places: stations, junctions, other sections[9]
Category	Geographic
Representation	Diagram
Spatial field of application	Lines, network *This requires a codification of lines by elementary parts (which events localisation is made by reference to) or a precise information regarding type of section in events reporting*
Period	Minimum one year (must be the same for all concerned sections)
Relevant for	To highlight most safe types of layouts or conflicts management (but need an analysis) It should be made separately for pedestrians and vehicles
Not relevant for	Not to compare places themselves In case of low number of configurations for each type

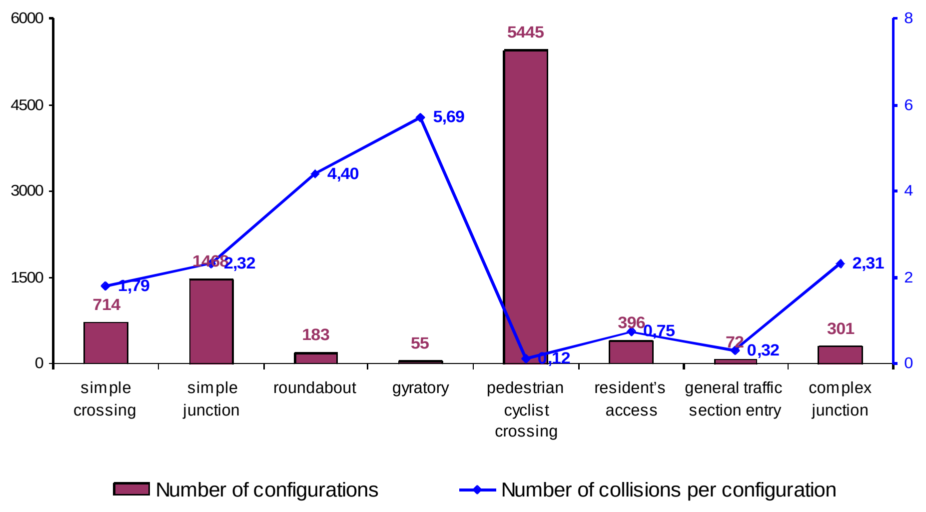


Figure 33 - Distribution of collisions with third parties per configurations 2004-2013 [Source: STRMTG, French national Report on Accidentology of Tramways – 2004-2013 (2015)]

[9] Junctions should be distributed regarding main categories, such as roundabouts, with/without traffic lights, (simple) level crossings, bicycles lanes crossings, pedestrian crossings. For other sections, mixed traffic area, shared lanes, segregated tracks may be separated.

8 Distribution of accidents by third parties (relative)

Types of third parties: pedestrians, cyclists, bikers; vehicles.

Vehicles might be distributed regarding main categories (cars, lorries at least)

Definition and nature	Percentage
Category	Typologic
Representation	Diagrams
Spatial field of application	Network
Period	Any but need enough data
Relevant for	A general overview of involved third parties To highlight the main stakes regarding third parties
Not relevant for	Settting up solutions to avoid accidents

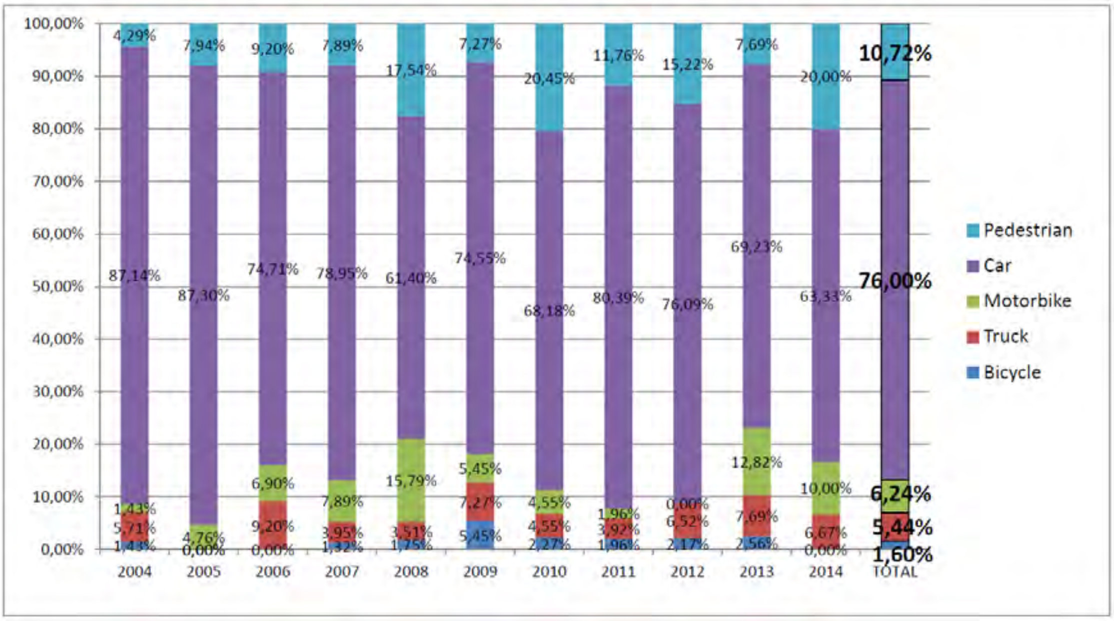


Figure 34 – Barcelona Trambaix distribution of accidents by third party types

9 Distribution of injured and fatalities by third parties (relative)

Types of third parties: pedestrians, cyclists, bikers; vehicles.

Vehicles might be distributed regarding main categories (cars, lorries at least)

Definition and nature	Percentage
Category	Typologic
Reprentation	Diagrams
Spatial field of application	Network
Period	Any but need enough data
Relevant for	A general overview of involved third parties To highlight the main stakes regarding third parties
Not relevant for	Settting up solutions to avoid accidents

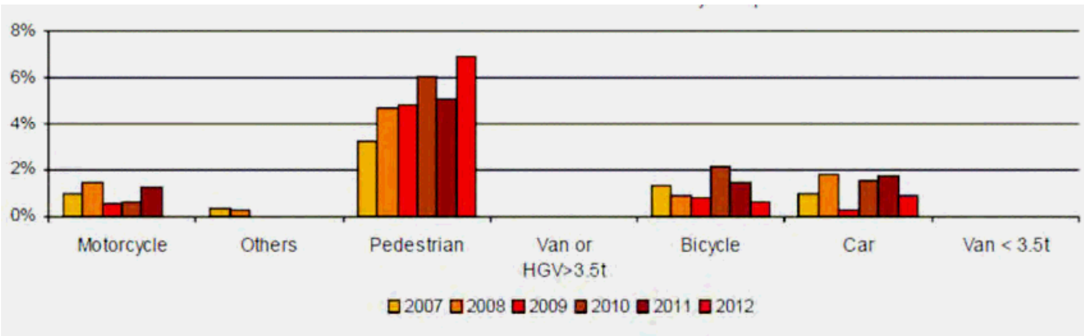


Figure 35 – Distribution of severely injured people after collisions ratio by third parties [Source: STRMTG, French national Report on Accidentology of Tramways – 2004-2012 (2013)]

10 Number of lost km / number of planned km

This is an indicator showing impact of incidents on quality of service (disruptions caused by accidents)

Definition and nature	Ratio number of lost[10] km divided per number of planned km
Category	Economic/quality
Representation	Figures, graphs
Spatial field of application	Network, lines
Period	Any (generally per year)
Relevant for	Showing influence of accidents on quality of service
Not relevant for	General measuring quality of service (many other factors)

Other indicators to be used in local or particular analysis:

- **Distribution of collisions with vehicles by causes (relative)**

i.e. : On a particular place

- **Number of events per period of the week (or hour of the day)**

It may be useful for specific studies on particular stakes, in relation with traffic conditions or car drivers' behaviour.

[10] due to disruption of operation caused by incidents (there may be others causes).

2.7 Safety Management - Issue treatment, evaluation and monitoring

In this paragraph, the processes will be elaborated on that operators typically organise to achieve safety evaluation and monitore using the data they collect reactively (after incidents or accidents), proactively (from configuration analysis) and predictively (safety analysis).

A Safety Management System is a systematic approach to limit the occurence of unwanted events, with their origins in four domains:

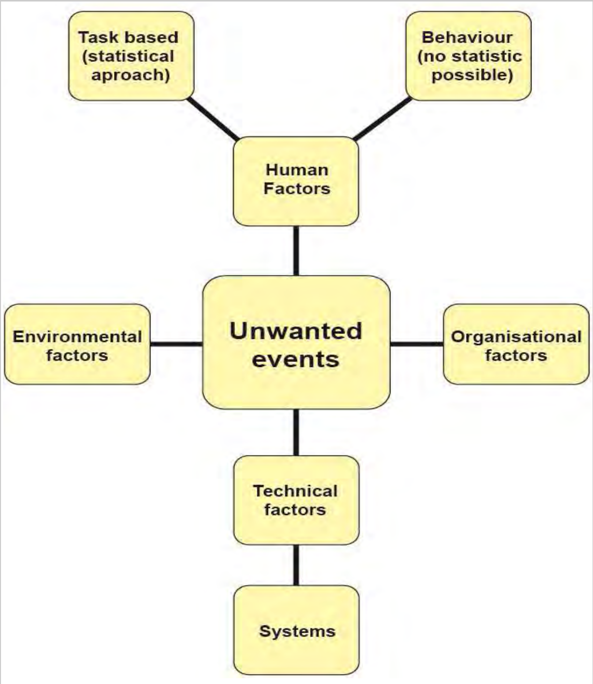


Figure 36 – The four factors of unwanted events' occurence

Several organisational models for operators exist where safety management is concerned, and in some countries a legal framework requires some such model. For instance, Ireland has developed a SMS for LRT which is available via the RSC website (Railway Safety Commission, Ireland). In other countries, the operator applies certain safety processes, formally or not, according to what seems useful and necessary, but without or with only a limited legal framework.

In the next paragraph, will be elaborate on safety management processes that appear in the most formal, extensive Safety Management Systems. Only a few operators have all of these processes formally running and in place, mostly due to legislation that prescribes them. Most operators are evolving towards the formal application of them. All operators have an individual organisational model in place that is aimed at managing safety by a selected collection of safety processes.

Contents of formal Safety Management Systems

Independent of the sector, four pillars can be identified in most Safety Management Systems found in literature and they typically contain:

1. The application and continuous improvement of a **Safety Policy**, and a periodic assessment of qualitative or quantitative **Safety Objectives**, including formal commitment and personal safety objectives of all management involved in safety processes and their periodic

improvement. The Safety Policy & Objectives also refer to detailed processes in case of emergencies and regulate the continuous improvement of the whole.

2. The application and continuous improvement of a **Risk Management** process for safety risks in projects and in the operational context, including the necessary roles, structures and governance frameworks to identify, analyse and maintain or reduce those risk levels to acceptable levels, even when the risks are shared.

3. The application and continuous improvement of **Safety Assurance/Monitoring** processes, including the core process "Management of Change", thereby making sure that when safety risks are being reduced, the effectiveness is being checked (for instance by audits or reviews), and that where necessary the organisation revisits specific and generic risks periodically.

4. The application and continuous improvement of **Safety Promotion** processes, that include all safety related training, in a technical, organisational or behavioural context, and the processes needed to compile, review and communicate Safety information to all relevant parties within and outside of the organisation, including continuous awareness campaigns towards safety critical personnel and the public using or near the transport system.

Figure 37 - The four pillars of a generic SMS (from ICAO)

In most countries, a subset of these four processes is active, due to some form of legal framework. The objectives of a SMS are most easily summarized by formally trying to answer the following questions, that each can be located in one of the four pillars above:

1. What the operator wants to achieve generically on safety for those he transports (A Safety Policy).

2. A Safety Governance, stating clearly who is responsible for what, who is verifying and who is validating. This document, known and understood by all managers, forms the basis for responsibilities and decision-making on safety.

3. Safety Risk Management practices, when to apply them, what for and when not, and to what alternatives exist for explicit risk estimation (Codes of Practice and Cross-validation).
4. Quantitative Safety Objectives: when a good statistical basis is available, what level of Fatalities and Weighted Serious Injuries (FWSI) does the organisation quantitatively accept (and under what assumptions)? What can the operator try to scientifically measure, or estimate at best the operayr can with all his expertise? What does he when no such statistical basis is available?
5. Safety Processes, like the one the organisation applies for changes in its systems, renewals etc, based or derived (where applicable) on existing, international safety norms and practices.
6. Safety Functions: who is explicitly doing the safety functions, and what does the oprator guarantee about these people's formation, training, feedback and guidance structures etc.? How does he manage knowledge related to safety aspects? How does he make sure people report near-misses, and how does he protect people having made mistakes without consequences? How does he train them against their own unconscious behaviour and strengthen their conscious defensive attitude?
7. How and what does the organisation document what has an impact on the safety of our collaborators and customers? How does it demonstrate that it governs its safety management?
8. How does the operator distribute safety related information and make sure everyone has the opportunity to know about it?
9. How does he manage accidents and how does he learn from them (documentation and handling process)?
    a. Internal safety promotion: how does the operator reach and continue to reach the safety personnel (in the context of accidents and near-misses)?
    b. External safety promotion: the impact of human behaviour in the environment of the transport systems and how does it reach out to the large numbers of people that (even unconsciously!) infer lower safety levels into their own system (mostly by putting themselves into a position they do not understand as dangerous for themselves or others).
10. How does the operator collaborate with internal audit, to make sure he annually ensures improvement possibilities? What kind of a revision process can be foreseen in each of the above chapters to improve them?
11. Safety Culture: how does one move from a blaming culture to a just culture? From reactiveness to predictiveness?

Important to note is that compliance (like ISO9001) strictly speaking is a prerequisite for any formal SMS: all underlying processes require formal procedures and the required qualitative elaboration to be effective and "valid". In other words: a formal SMS requires an active compliance management system, on which it "rests".

A Safety Policy is considered to play a central role in formal SMS. It is defined as *"A statement of the organisation's fundamental approach to achieve acceptable or tolerable safety"*. This policy is the "*first important milestone of SMS implementation that defines the value of safety in the overall business and performance framework of the organisation. Ideally, the safety policy should confirm the organisation's commitment to safety and clearly indicate that safety is afforded highest priority in the service provision*" [Source: http://www.skybrary.aero/index.php/Safety_Policy].

A vital complement to the safety policy is the operator's safety governance, which clearly defines the roles and responsibilities of all levels of management and individual safety functions.

A clear Safety Policy, known to all employees and linked with clear safety responsibilities, reinforces the operator's commitment to safety.

In general, one could state that a SMS formally leads to increased Safety Performance, and that this safety performance is objectified in Safety Targets (the quantified part of Safety Objectives). Safety Indicators serve to measure the performance at periodical moments in time. Examples of specific Safety indicators are given in chapter 2.6.

If there is no responsible manager like the CEO, accountable for Safety for the whole operator, and if no authority whatsoever "cares" about safety performance in a broadly measured way (and not only by quoting accident statistics), then Safety can be a very hollow, *legalistic* topic, that purely rests on paperpushing, pure lawfulness and barely anything else. A Policy materializing for every single employee what the company wants to achieve, driven by its top management, instead of just plainly quoting the law and blaming employees only on that basis, makes a lot of difference. And clearly illustrates to all levels of the organisation what it wants to stand for.

Safety Risk Management

The basis for Risk Management is the condition that certain threats to our system can be statistically estimated or calculated and that the impact of the resulting event can be assessed too. "Risk" is then defined as the combination of the foreseeable impact/severity of a consequence of a hazard and its foreseeable probability/likelihood. For any hazard in which human behaviour is the main component, explicit risk estimation is gradually being considered as to be avoided. For open systems like tramway systems, all interfaces with other road traffic for instance are to be considered inappropriate to be assessed as explicit risks.

> Accidents with pedestrians or other human factors illustrate the limits of risk management: in view of the potentially different outcome (miraculously surviving or dead pedestrian after a collision at almost same speeds), one cannot treat these accidents using risk management. In the contrary, the operator will demonstrate through the presence of training plans, internal education and the presence of a safety culture that he covers the hazards related to human factors. Single accidents will be evaluated with the affected employees. A reasonable employee training scheme in the context of follow-up care will increase effectiveness. During periodical driving instructions, accident situations can be discussed. Essential implications and measures have to be communicated. Identified hotspots and accumulations of similar accidents should be given special attention. Illustrating those localities on a map might be helpful to discuss daily safety issues more easily with the entire driving staff. Safety campaigns towards people around the tramway system will then cover the hazards – up to a certain limit – of the system boundaries.

Safety Promotion, Assurance processes and the Management of Change

Safety Promotion is the last pillar of an SMS, and constitutes the presence and the activation of internal training and education on Safety (like the awareness to Safety risks, the roles one has towards Safety, how to do Safety analysis, training on Safety procedures etc) and the presence of Safety communication Campaigns, both towards the employees and towards the general public that uses or is near to the tramway system.

A specific analysis has been led on safety campaigns involving trams and other street users: improvement of the safety level in the tram system can be obtained with the use of a communication campaign, defined as a number of communication actions, aiming to influence certain behaviours or attitudes of defined groups of people (recipients of the campaign). Campaigns implemented in various European cities were the subject of a Short Term Scientific Mission “Safety campaigns involving trams and other road users” performed during the Action. The survey was conducted in 24 cities in 11 countries and resulted with a database of 56 campaigns provided by 26 operators. Investigated actions consisted of internal measures, aimed at improving safety of the system and driver’s operational skills and external measures, such as educational and communicating campaigns.

Figure 38 - Flyer from the "Let's stay safe together" campaign [Source: Warsaw Trams]

Information was collected regarding planning, executing and evaluation of the campaigns, specifying aims and recipients of the campaign and channels used in the measure. 89% of studied campaigns had preventive character. Measures with defined causes of implementation were used due to unsatisfactory accident statistics. Collaboration with the municipality took place mainly in the case of the new tramline launching, when the risk of accident occurrence was relatively high. For example the city of Dijon implemented an educational campaign during the new tramline commissioning, to prevent risky situations; while the operator in Barcelona was requested by the city authorities to implement necessary safety improvement measures after several incidents during the trial period.

Specific aims of the campaigns were categorized on the basis of CAST Action (Campaigns And Awareness-Raising Strategies In Traffic Safety) recommendation, by following types:

1) To provide information about new or modified laws.

2) To improve knowledge and/or awareness of new in-vehicle systems, risks, etc., and the appropriate preventive behaviours.

3) To change underlying factors known to influence road-user behaviour.

4) To modify problem behaviour or maintain safety-conscious behaviour.

5) To decrease the frequency and severity of accidents.

Results of the research show that social campaigns towards safety improvement are frequently used in tramway systems. Information obtained resulted in general recommendations for implementing a safety campaign, considering planning, executing and evaluation of the measure as well as further dissemination of results.

Figure 39 - Flyer from the campaign "Sicher zu Fuβ" [Source: SSB Stuttgart, tram safety campaigns]

Best practices shown in the paper and interpretation of the survey results show that properly executed safety campaigns have an impact on the road safety; examples of performed campaigns imply the following general best practices for implementing a road safety campaign:

- To define the problem and to react as soon as possible;
- To prepare a broad situation analysis and review of previously implemented measures;
- To design a campaign as a long-range and systematic measure, dedicated to specify the problem and targeted on the defined groups of recipients;
- To collect data regarding specified risk before and after the campaign;
- To assess the impact, effectiveness of and social response to the campaign;
- To share information/experience among the other operators, the Police and other entities, on local/regional/national level;
- To maintain contacts with entities responsible for implementing necessary measures;

For further information refer to the report “safety campaigns involving trams and other road users” which is provided as an Appendix N.1 to this document.

Operator practices on Safety processes

The following paragraph describes one operator’s basic safety practices. Initial practices primarily concentrate on safety assurance, a reactive approach, which is based on the consistent evaluation of accident data. Its focus lays on a structured and continuous data acquisition in order to derive preventive measures from their analysis. Any further profound safety analysis (predictive) or configuration analysis (proactive) can only be implemented after having established a consistent data acquisition and evaluation.

Only with the appropriate structure of data acquisition and data preparation it is possible for an operating company to analyse accidents systematically. Normally, accident data is collected in an IT-supported database by the operator. The data has to be structured according to the operational needs for evaluation and reporting. The minimum information requirements, which have to be acquired consistently, are listed in chapter 2.1.2 “Ideal Accident Report”.

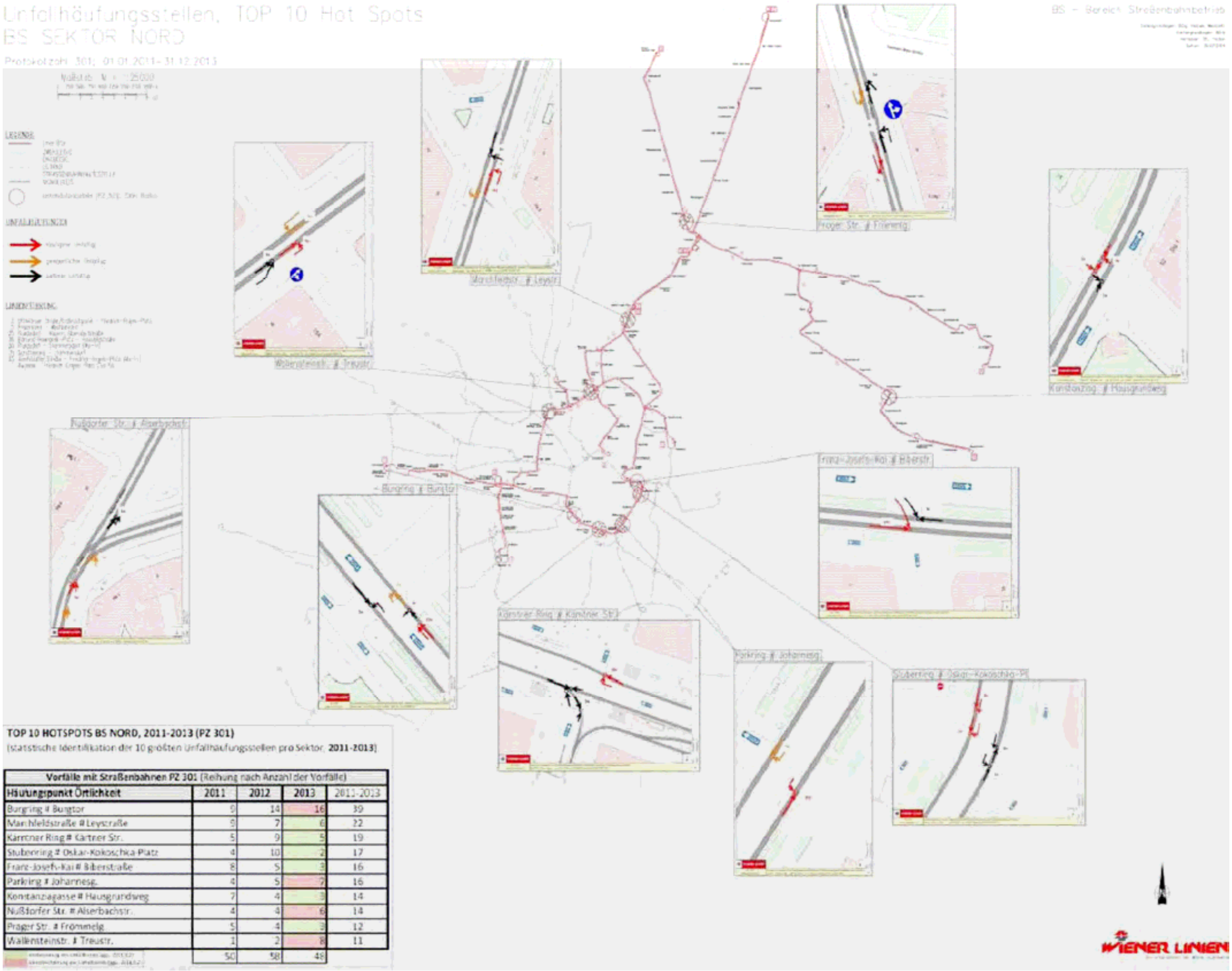


Figure 40 - Illustration of accident hotspot map [Source: Wiener Linien (2013)]

Concerning the (reactive) post-analysis of accident data, it is worthwhile to generate accident statistics periodically (monthly, quarterly, annually). Conclusions can be drawn directly from them. Maps of accident hotspots, which mark local points of frequent accidents in a city or network map, are well proved in practice. Additionally, diagrams which show the common accident types can be arranged clearly to further communicate certain information and aspects about specific focal points.

Compared to the actual accident sketch, which is part of the data acquisition for the individual accident report, these sketches show the most common traffic misbehaviours by third parties.

Prevention can also be derived from analysis of technical safety-related information collected even without the occurrence of an accident. For instance, occurrences of emergency braking can help identify hotspots of hazard or danger that should be particularly scrutinized. Tendencies in accident occurrences can already be illustrated with the help of only a few significant indicators. To some extent, certain aspects can be derived from the existing framework of internal evaluation (e.g. the frequency of accidents on different lines, locations, days of week and time of day can be observed).

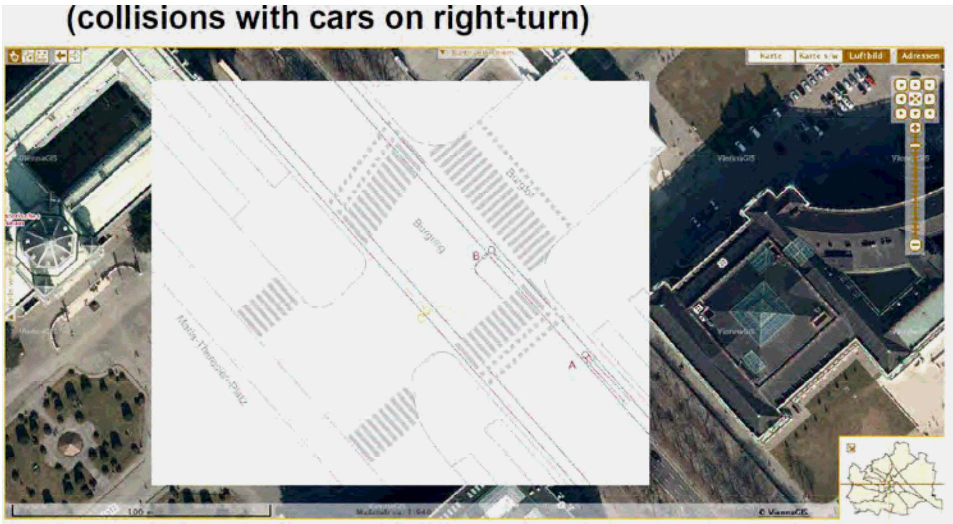


Figure 41 – Example of identification of collision type [Source: Wiener Linien]

A note on Safety certification

Safety requires an inherent verification and validation process, which is taken care of internally and to some extent also outside of the organisation. Safety verification within the transport organisation allows it to maintain and improve safety levels; it is the common solution. Safety verification outside the transport organisation will be done by designated bodies; they will monitor a required safety level in order to maintain this level. But, due to the separation of production and safety monitoring, they will not enhance a constant improvement process. Operators and infrastructure managers have an internal set of Safety Rules, and the validation and verification usually is done internally and sometimes demonstrated externally.

In France during operation, the Decree for Safety on Urban Guided Transports demands an internal control independent from operational production to make audits, check the respect of procedures, investigate accidents, make the annual report and propose actions to improve tram safety. For construction of a new line or extension, or for modifications to an existing system, this same Decree requires the owner to be responsible for safety and to include a second independent review, to check the whole tram project's safety (all sub-systems and interfaces, including the sub-system "urban insertion").

Safety Verification procedures with a high internal participation allow for a continuous safety improvement process; they are self-improving. Therefore, good practice in terms of safety certification is a mainly internal verification process with an external monitoring or cross-checking (for instance, by Supervisory Authorities).

2.8 Benefits of cooperation with municipalities

Tramways serve and operate in an urban environment. They are made to take part in street traffic and thus are interacting with traffic and urban space, leading to a demand for some coordination between tram operators and municipalities. In terms of traffic safety, this has several outcomes:

- Adjusting the respective design of street and tramway infrastructure,
- Coordinating traffic regulations, such as right of way, parking limits or speed restrictions, with the operational practice of tram operation,
- Evaluating incidents between trams and other traffic participants, and assessing possible consequences.

SSB, the operator of Stuttgart's Light Rail system, has been following a close cooperation with the municipality for many years. The key issue is to best adjust the tram service to the requirements of Stuttgart's citizens. Concerning traffic safety, the outline of the cooperation is as follows:

- Involved are representatives of the Street Traffic Authority, the Public Works Service, the Police, the Technical Supervisory Authority for trams, and of several departments of SSB (Operations Manager, system planning dept., signalling team, traffic inspectors).
- They meet on a regular basis (4 to 6 times annually) in the so-called "accident hotspot commission".
- The commission evaluates accidents and decides on possible means to avoid them in future. The commission also evaluates other indications on possible hotspots (e.g. observations by the police or complaints by citizens / "yellow cards"), thus it acts proactively as well.
- The solutions decided upon will be inserted into the budget planning processes of Stuttgart Municipality and SSB. Major projects will be approved by the municipal council, minor projects will be approved by the heads of the authorities and SSB. According to urgency and availability of finance, the measures will be implemented subsequently during the next fiscal years.
- Findings of general relevance will be communicated from the accident commission to the LRT planning group, which is formed by the Mayor of Stuttgart, SSB's CEO, SSB's Operations Manager, and the heads of the planning and construction departments of the City of Stuttgart and of SSB. This group will decide upon how to proceed with such findings accordingly.

This interactive procedure allows potential accident locations to be identified as soon as possible and to deal with safety issues in such an integrated manner as is demanded by an integrated public transport system.

Similar arrangements exist for tramways in other cities where the authorities responsible for town planning, highways and traffic management and tramway promotion, infrastructure and operation meet regularly to monitor tramway performance and safety issues. To identify optimum solutions must be a cooperative activity between all these agencies and in many situations implementing solutions will also need to be a joint activity.

2.9 What to keep in mind when collecting and analysing data?

From one accident on the street to the global analysis of a tramway network's safety, operators can use many different tools to collect and analyse accident data. Beyond those who are directly concerned, other authorities and researchers may also be interested in the analysis and its evaluation.

The first chapter proposed a template of an Ideal Accident Report as a check-list of data which must be collected as soon as an accident has happened. Data collection on accidents is essential and it can be usefully complemented with other sources such as CCTV, which were discussed to complete the primary data collection. Black boxes used in every accident can also be used to identify near-misses, as a complement to drivers' reports of emergency braking in order to bring more knowledge on behaviour and difficulties with some specific layouts.

Then the gathering of several accidents in a database, along with other methods such as the identification of hotspots in a tramway network, helps to identify and to assess safety evolution through indicators. This can be implemented at a local level and possibly at a national level. Some relevant indicators were suggested with their advantages and limitations of use. However, it is neither our ambition nor our mandate to impose a common data collection and usage methodology at a national or European level. Rather it is to draw on the experiences and practices of a large number of tramway operators to assist other operators to develop or improve sound safety policies.

Accident data collection and detailed analysis are complementary solutions implemented in the field: identified hotspots can require layout improvements, and data collection allows the monitoring of new/improved layouts during operation of existing networks as well as for the implementation of new projects.

3 Tram Infrastructure design: from safety experience to possible measures

3.1 Aim and method

Regarding infrastructure design and urban insertion, the main achievement is the compilation and analysis of good and bad practices in relation to safety when trams interact with other street users (pedestrians, cyclists and road vehicle users). Systems in every country face similar kinds of risky situations, and the Action has identified specific design solutions that may be generally considered as safe or dangerous.

Some countries have now opened brand new systems after the closure of their networks during the twentieth century while in others the old systems remain. The difference between those two approaches is reflected in the infrastructure as well as in the operational modes, and in the signalling and signage. So how can some good practices be established for a peaceful and safe tram interaction with the urban space and its citizens?

> It is important to consider that no system is 100% safe, and that there always will be people walking, cycling and driving around the tramway; the objective is to agree some measures that will protect those Interaction Points in a way as natural as possible.

In the following paragraphs and tables, the aim was to transform evaluation of tram design insertion safety into suggestions.

From existing examples and know-how, an analysis has been made of good and bad layouts. Then, objectives have been identified and classification made. Specific problems have been investigated for each type of interaction point and hazards have been identified. The suggestions and good practices in the local context are mainly to be found in the tables.

3.2 Users of Urban Space and field evaluation methods: how do people react to environment and traffic safety measures?

> When introducing particular safety measures (e.g. a barrier), it is likely that there will be adverse side effects.

Pedestrians and passengers are an integral part of the traffic system and will adapt their behaviour when necessary and possible. Any change within this system may lead to behaviour adaptation. The underlying notion is that people do not simply accept changes in the environment, but they respond to changes by changing and adjusting their behaviour. From a safety point of view this implies that the benefits of particular measures may not be as large as originally expected, or they might be even counter-effective.

So when introducing new safety measures or changes in the environment, it is crucial to look at the whole traffic system and consider which side effects are likely to occur. In some cases, there might be no safety benefits, but there may be other benefits, such as improved comfort or increased traffic flow. It is important to balance the pros and cons whenever a measure is introduced. It is important never to assume that there will be no behavioural changes associated with introducing new measures (Source: Theeuwes, J., Van der Horst, R., & Kuiken, M. Designing Safe Road Systems. A Human factors Perspective (2012)).

3.3 Operating conditions

Tramways are urban rail-bound transportation systems, which share the public road space with general road traffic, pedestrians and bicycles. Tramways are operated on the line of sight principle. Driving on line-of-sight is a tramway operating system imposing on the driver the need to be able to stop his vehicle at any time in the distance which he can see to be clear ahead. Similar to other road vehicles, it is the responsibility of the tramway driver to operate safely.

Tramways participate under the conditions of general road, bicycle and pedestrian traffic and are therefore subject to their relevant national road traffic legislation.

Spatial planning and the design of public space is the responsibility of the city authorities. Infrastructure elements such as intersections, crossings and stops are planned in coordination with the tramway operator.

The priority of tramways over other users of public space is normally (at so-called interaction points, e.g. intersections or pedestrian crossings) directed by the local transport authorities. Traffic control is arranged by traffic signs or traffic lights. Often, special traffic signals for tramways are additionally installed.

Speed limits for tramways correspond to the speed regulations of general traffic in shared areas and are determined by the design of the track. Tramways run either on tracks directly in the street or segregated from road traffic. The operating company carries the responsibility for safe operation and operational management.

The operating company selects, educates and controls its driving staff members. Furthermore it is responsible for continuously updated training.

3.4 Common types of safety events

Safety events, mainly accidents but also incidents relevant to safety, can be classified according to a variety of factors, such as location, modes involved or time of occurrence. This section deals with these factors, which should be used to classify safety events. However only the most common safety events identified by the Hotspots questionnaires submitted to operators (see chapter 3.5), will be dealt with in detail.

The table below summarizes the main factors which should be used to classify safety events by trying to answer the following questions:

- ➢ What are the possible incidents?
- ➢ Where do they occur?

- When do they occur?
- Who can be involved in incidents?
- How do they occur?
- Why do they occur?

In the following table the reader is invited to answer each of the above questions. Each column is independent so the table should not be read row by row. The arrows illustrate one posible combination of characteristics. The table is intended both for analysing specific safety events and for use during a broader analysis of a network.

The classification does not include all internal accidents that can happen to trams because the focus is on interactions between trams and other street users.

What?	Where?	When?	Who?	How?	Why? (direct cause)	Why? (root cause)
Near miss	Tram stop	Peak hour	Tram Vs. Bus	Parking manoeuvres	Infrastructure problem	Infrastructure design
Collision with other motor vehicle	Running sections (excluding junctions)	Off-peak hour on weekday (daytime)	Tram Vs. Private car	Prohibited or unexpected movement	Disregard for traffic rules or unsafe driving	Human factor (pedestrian)
Collision with pedestrian	Roundabouts	Weekend or holiday (daytime)	Tram Vs. Heavy road vehicle	Vehicles travelling same direction, same lane	Weather conditions	Human factor (private vehicle driver)
Collision with bike user	Signal controlled junction	Night-time	Tram Vs. Bike	Vehicles travelling same direction, different lane	Vehicle problem	Bad maintenance (vehicle, infrastructure)
Collision with object (inc. parked car)	Uncontrolled junctions	During a special event	Tram Vs. Pedestrian	Vehicles travelling different direction (no left turn)	Drugs or alcohol	Inadequate training of tram driver
No collision but injuries	Pedestrian or cycle crossing	Other	Other	Road vehicle turning left	Security issues (deliberately caused)	Unclear or unsafe operational procedures
Other	Depot or other reserved area	-	-	One vehicle stopped or parked	No apparent cause or other	Other
-	-	-	-	People waiting, entering or exiting tram	-	-
-	-	-	-	People crossing the tram line or walking over the tram line	-	-
-	-	-	-	Other	-	-

3.5 Main observed tram hotspots

Given that some of the participants in COST Action TU1103 were tram operators, or were people who had direct contact to tram operators in their home country, the idea of collecting information about tramway safety directly from the source came about. The main idea was to contact operators in all participating countries, and ask them to fill out a pre-established set of questions that aimed at identifying and describing the locations in the urban area where most accidents tend (or used) to happen: these were called "hotspots". More precision in chapter 2.5. The methodology is described in Appendix L.

The Hotspot Questionnaire was structured in three parts: 1) hotspots, 2) risky points, and 3) success stories. Parts 1) and 2) asked the operators to identify three locations, and describe them with some pictures, sketches, maps, etc. The information requested for 3) focused on previous risky points, and on the measures that reduced accidents and risk in that particular location, as well as their impact. The Hotspots Questionnaire included following questions:

1. What are the three safety hotspots in your network at the moment?

1bis. What are the measures that are implemented or planned/considered there and – if realized – what are the actual effects in practice?

2. What are other very risky points in the network, where happily no or only few accidents occurred?

3. What are the success stories about previous, former hotspots in your network?

Through the Hotspot Questionnaire, data has been collected from 24 operators and 13 countries, listed in table presented in Appendix L. A classification has been made, based only on the answers from tram operators. There are different possibilities for classifying the results: based on type of location, on accident causes or on applied solutions. All three are mentioned below.

First, it was observed that operators from different networks share common experiences on accident occurrences, but that the collection of data is different. This survey also has limitations in the fact that only a maximum of three networks per country were questioned. So it is partly representative of European tram safety issues (24 networks interviewed for 169 existing networks for TU1103 countries, as inventoried in WP1).

3.5.1 Where do accidents occur and who is the implicated third party?

On the total number of analysed hotspots (89 items), the majority of them are located on intersections (85.4%). A smaller portion take place on running sections – in this case including pedestrian crossings (12.4%) – or on stations (2.2%).

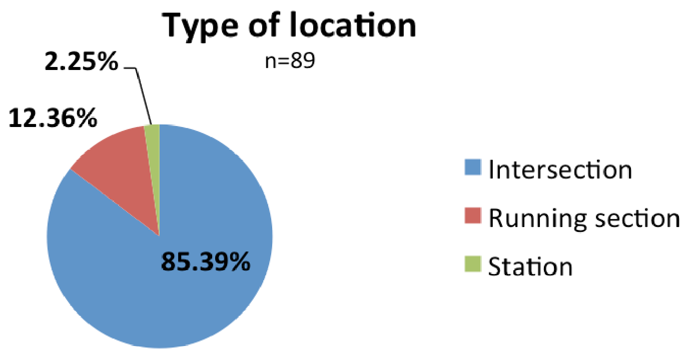


Figure 42 - Occurrences of hotspots on different infrastructure locations

The intersections for their part are divided into junctions and roundabouts. 72% of all intersection hotspots are located at junctions, the rest on roundabouts. However, these figures should be approached cautiously because they do not mean that junctions are more problematic than roundabouts since the global number of existing junctions and roundabouts on a specific network is not taken into account i.e. the figures are not normalised.

In 88% of the cases, a vehicle is involved in the accident. Another 10% of accidents involve pedestrians and only 2% motorcycles. The high figure for accidents involving third-party vehicles can be accounted for by the fact that these figures only refer to the hotspots identified by operators and not to the entire networks. A possible explanation would be that accidents involving pedestrians or cyclists are usually more dispersed through the network while accidents involving cars or buses tend to be concentrated on specific locations, the so-called hotspots.

3.5.2 What solutions are applied by tram operators?

In order to reduce the major cause of accidents at hotspots, a third of all operators propose first of all a traffic light reinforcement. Other favoured engineering solutions are carriageway marking reinforcement and modifications of traffic light programming. 16% of operators mention also operational solutions like tram speed reductions or training courses for drivers. The police and educational solutions are hardly commented on. All the details of the solutions can be consulted below.

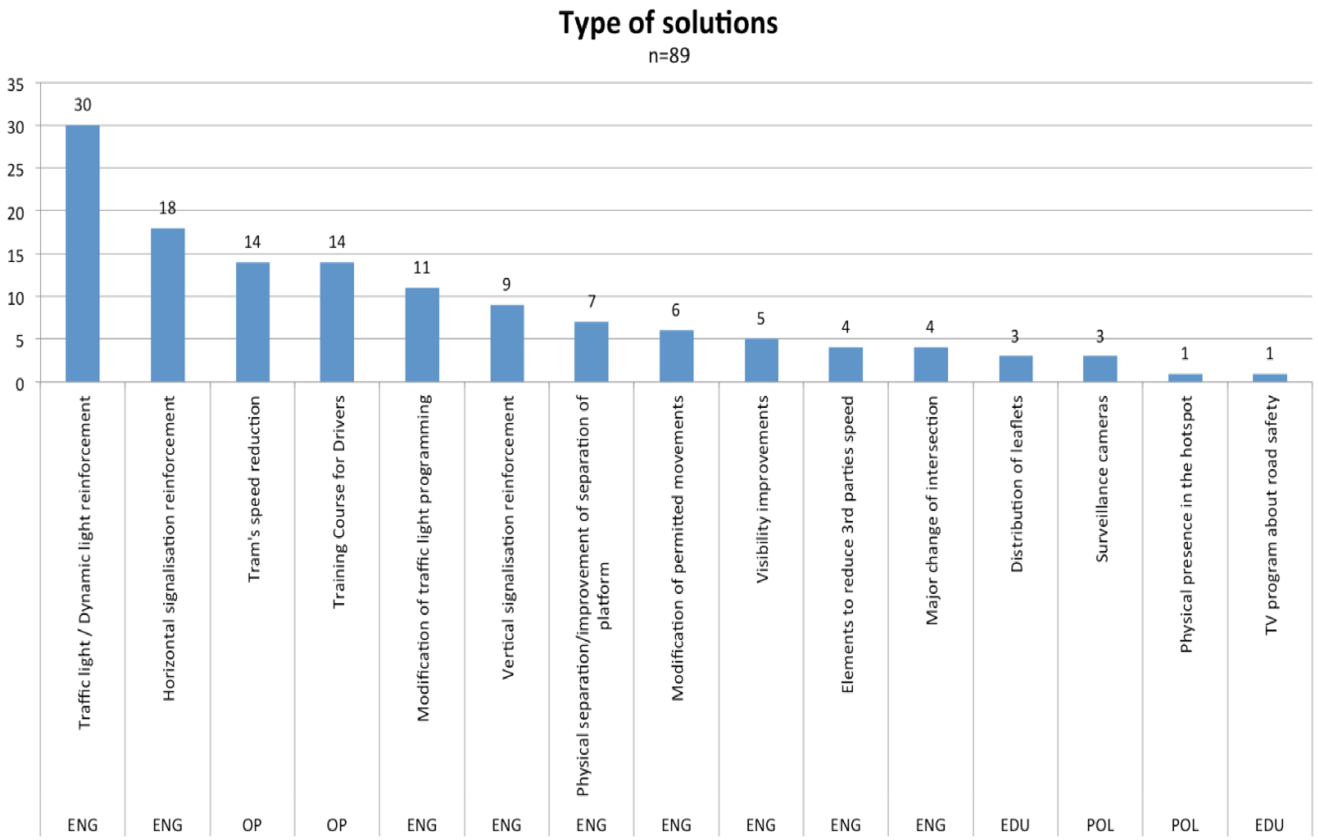


Figure 43 - Type of solutions mentioned by operators
(Key: ENG = Engineering; OP = Operational; EDU = Educational; POL = Police)

3.5.3 Analysis of situation

<u>Classification based on the type of location</u>

TYPIFICATION OF LOCATION

General Definition					
Type of location	Intersection	Station	Running section		
Type of traffic	Segregated	Mixed (with cars)	Mixed (with PT)		
Type of track	Single	Double			
Type of intersection	junction	Roundabout			
If Junction					
Location of platform in relation to car lanes	Central	Lateral	Boulevard	Changes side	Only tram
Inclination of intersection	Perpendicular	At an angle			
Movements crossing the platform	Permitted turn (WITH traffic lights)	Permitted turn (WITHOUT traffic lights)	Non permitted turn	Perpendicular crossing (WITHOUT traffic lights)	Perpendicular crossing (WITH traffic lights)
If Roundabout					
Inclination of entry lanes	Perpendicular	At an angle			
Location of tracks in relation to roundabout	Centered tracks	Non centered tracks	Lateral tracks not crossing roundabout		

Figure 44 - Classification of hotspots location based on responses from the Hotspots Questionnaire

The first level of division refers to the type of traffic in which the tramway operates (segregated or mixed with cars or with pedestrians/bikes). The second level includes the specific location in the network. Basically, locations of event occurrences can be divided in 3 types: intersections, stations or running sections – in this case including pedestrian crossings.

Intersections, because a significant number of accidents happen there, need a more specific classification into junctions and roundabouts. The latter have different properties referring to the track location in relation to car lanes, the inclination of intersection and the car movements crossing the tracks. Last but not least the type of track (single or double) is relevant.

<u>Classification based on the causes of accidents</u>

Another classification can be made by the causes of accidents where a third party was responsible. Based on this division, accidents can be divided into four main groups: including vehicles, cyclists, pedestrians or trams. Different street users imply various hazards; therefore in each of those groups different causes of road events can be considered.

Causes of accidents, where a vehicle which could include a tram in some cases, is the responsible party:

- Disrespect of traffic light;
- Non-permitted turn (left or right);
- Invasion of platform (parking manoeuvres, inadvertency…);
- Visibility problems;
- Non-awareness of tram presence;
- Traffic-light regulation problems.

Causes of accidents, where cyclists or pedestrians are the responsible party:

- Disrespect of traffic light;
- Crossing outside the pedestrian crossing;
- Non-awareness of tram presence.

Classification based on possible solutions

Due the fact that the last question in the Hotspots Questionnaire focuses on the solutions, a classification is also possible in this field. Generally there are 4 types of approaches used by the operators who responded to the questionnaire:

- **Engineering solutions** – based mostly on:
    - Signage or carriageway markings reinforcement;
    - Traffic light / dynamic light reinforcement;
    - Modification of traffic light programming;
    - Modification of permitted movements;
    - Visibility improvements;
    - Physical separation of platform;
    - Major change of intersection.·
- **Police implications** - focuses on physical presence near to the hotspots and on better camera surveillance·
- **Operational solutions** – such as tram speed reductions or training courses for drivers
- **Educational campaigns** - possible improvement using educational measures can involve a distribution of leaflets or a TV program about the road safety.

Of course combinations of various solutions also exist.

> To conclude, the major part of reported hotspots accidents are located at intersections (including one quarter on roundabouts). A smaller part take place on running sections and fewer in stations. But the figures are not normalised by the number of each type of location present. In the hotspots observed, the most mentioned cause of accident is linked to third parties and results from a disrespect of traffic lights by vehicles, intentionaly or not. Furthermore, the non-awareness of tram presence is a relevant cause of collisions, for vehicles as well as for pedestrians. Generally there are 4 types of approaches the operators could use: engineering solutions, Police implications, operational solutions, educational campaigns.

These sources from the field were later checked with the theoretical analysis made, see chapter 3.6.7.

These results from questionnaires were cross-checked with following theoretical analysis.

3.6 Safety analysis and proposals

3.6.1 Interaction Points Identification

Interaction points are the main points of the tramway's infrastructure whose design have to be properly studied in order to guarantee the safety of the system in its interaction with public space. It should be pointed out that the meaning of "interaction point" in this case is wide, including interaction locations but other interaction elements as well, as signalling and signage.

The first main conclusion made was the need to study separately the stations/stops and the rest of the infrastructure (called between stations). This distinction is made due to the important differences between those two kinds of zones, both in relation to the operation of the system and to the users/pedestrians behaviour.

In relation to tramway operation, the vehicles' speed when approaching stations/stops is usually low, as the vehicle needs to stop in the station for passengers to board and alight; the speed in between stations zones will be as high as it is allowed by the maximum speed of the infrastructure, by the operator or regulation, the vehicle acceleration capability, and the circumstances of the track (as the tramway usually runs on line of sight, where the tram driver adjusts the vehicle speed depending on the situation: existence of pedestrians in the vicinity, cars crossing the tracks, etc.).

In relation to users/pedestrian behaviour, some people around stations/stops are users of the systems, so they are aware of the approaching vehicles. So, it would seem that these zones would be safer because of this awareness. Nevertheless, others are not users of the systems and do not perceive the tram. So there are several circumstances that make the stops particularly troublesome points, which are the following:

- Users hurry to catch the vehicle coming, which can lead them to behave in a more risky way.
- The tendency to cross the tracks via inappropriate paths, in order to get the more direct route to their final destination.
- The accumulation of users during rush hour in the limited space of the platform, with some of them trying to pass each other in the unsafe zone of the platform.
- The possible existence of stopped tram vehicles which restricts the visibility of other approaching tram vehicles.
- When crossing the track pedestrians are not aware of approaching trams from both directions.

On the other hand, the other street users in between stations zones can be less aware of the existence of the tramway system, or, more commonly, of the approaching of a tram vehicle. This fact can lead to additional different hazards in these zones.

Once this distinction between different zones was made, then was considered which main users of the streets would conflict with the system. This was a pretty simple question, as obviously its answer is that every one of the other users of the street is a candidate to conflict with the systems, being them: road vehicles, pedestrians and cyclists.

Finally, a brainstorm was made by the Working Group Members in order to identify the interaction points, obtaining the following list of potential interaction points, as well as the potential conflicting users for every one of them:

Interaction point ID	selection		
	pedestrians	cars	cyclists
Road junctions (cars and cyclists) with tramway		x	x
Road junctions (cars and cyclists) with a left turn		x	x
Roundabouts		x	x
Tramway segregation along the street (lanes and sidewalks)	x	x	x
Tramway perception on mixed streets (cars and cyclists)		x	x
Tramway perception on pedestrians areas	x		
Pedestrians level crossings	x		x
Cyclists in segregated areas			x
Stops and its accesses	x	x	x
Interchange areas	x	x	x
Traffic (road & pedestrians) signals	x	x	x
Line signs and signals (for tram drivers)	x	x	x

Figure 45 - Interaction points

Safety objectives and measures will be presented directly in tables. To achieve this, the infrastructure was divided in different parts, in a classification. Tables present per configuration, the potential hazard, the objectives to be reached and possible measures to cover the hazard, with references and illustrations. It should be noted that the examples have not been examined scientifically to the effect whether and to which extent they reduce accidents in detail.

The interaction points have been gathered by:

- Road junctions and in particular roundabouts,
- Pedestrian crossings, cover issues that are common and need to be considered at all pedestrian crossing points – specific issues of pedestrian crossings related to junctions and stations are treated in the corresponding parts,
- Stops and stations,
- Running sections (general interactions between stations, junctions and pedestrian crossings).

Cyclists situations are dealt with in a dedicated paragraph but junctions, pedestrian crossings hazards analysis are also applicable to those public space users.

3.6.2 Road junctions and roundabouts with tramway

3.6.2.1 General considerations

While travelling at grade in an urban environment, a tramway system will need to traverse road junctions of various complexities. These at-grade intersections should be regarded as roadway junctions rather than railway level crossings.

Driving through a junction is a complicated matter and usually involves complex manoeuvres during which all street users (motorists, cyclists, pedestrians and tram drivers) must continuously assess the positions, speeds and intentions of other street users.

Junctions and roundabouts are locations of high accident frequency and have been identified as a major Hotspot on tram networks. The insertion of a tramway into a city requires careful consideration. Consequently, special attention should be given in determining the type and the efficient design of each junction that a tram needs to cross.

The design of the junction and the arrangements for controlling the tramway and other street users at a junction should be coordinated. The degree of signing or signalling will depend on the needs of other street users as much as upon those of the tramway.

> In any case, the tramway should be clearly identified in the urban context so that all street users are aware of it. Therefore, a junction or roundabout that has a tramway traversing it should be readily recognised as such by other road users. To prevent uncertainty, junctions where trams cross should be constructed and marked/signed/signalled to make obvious what sort of behaviour is expected from the road users.

Basic principles for improving safety in junctions and roundabouts with tramway

- Compliance with regulation about road signs:

Regulations require conditions of employment of different types of signals and set the minimum green duration, amber duration, maximum red duration and clearance duration according to the speeds.

- Operation as simple as possible:

The simplest operation is best understood and accepted by street users and improves the junction safety. Too many arms and complicated left turn movements decrease understanding.

- Fixed obstacles:

For every kind of junction, it is important to avoid the location of fixed obstacles near the intersection (along the tracks and adjacent to the tracks) (see Figure 46). Fixed obstacles that are close to the tramway should be located at least at the tram vehicle's stopping distance for its maximum speed at junction crossing. If that is not the case and there is a collision between a road vehicle and a tram vehicle, the tram may drag the road vehicle along for a certain distance. If a pole (or any other obstacle) is placed near the junction then the road vehicle may be caught between the tram vehicle and the pole. If the pole is located at least at the tram vehicle stopping distance from the junction this situation is avoided. Another solution is to use flexible objects that are designed to break close to the ground in case of an impact. The introduction of those elements should also consider drivers' visibility.

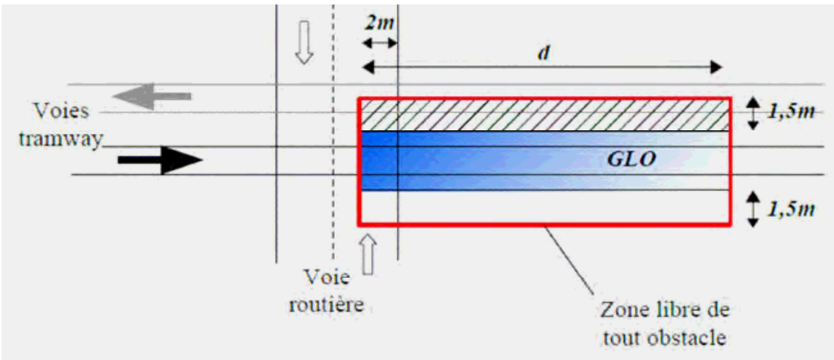


Figure 46 – Fixed Obstacles: free zones [Source: STRMTG, French guideline "Guide d'implantation des obstacles fixes à proximité des intersections tramways / voies routières " (2012)]

- Speeding:

Motor vehicles approaching a junction at inappropriate speed can increase the risk of accidents between trams and the motor vehicles. Measures such as to reduce the speed of road vehicles near a tramway junction, especially if it has proved to be a problematic one can be applied. Use of speed cameras, speed limits, rumble strips, speed humps and speed tables can be considered to reduce the speed of motor vehicles approaching the junction.

- Red light infringements by motorists:

They have been identified as a major cause of accidents at signalled controlled junctions. The incidence of motorists passing red lights can be attributed to unintentional or deliberate behaviour. In both cases, they can be reduced by, for example:

  - providing sufficient capacity (preventing vehicles from a queue cleared during 'green' period being 'left over');
  - enforcement by means of speed and 'red light' cameras;
  - making the traffic lights more visible, using LED lights instead of filament lights.
  - In a situation with two regulated junctions, one immediately after the other, the signal control at both junctions could be synchronised to minimise the hazard of a driver reacting to the signals from the wrong traffic lights. Louvres can be placed on the signal heads to reduce the hazard of see through.

Compliance with regulation about road signs, operation as simple as possible, fixed obstacles avoided, reduction of car speeds when approchaing junction with a tramway, red light infringements… are main basic principles for improving safety in junctions and roundabouts with tramway.

General design

Regardless of traffic management, a junction or a roundabout cannot have a good functioning without a geometric design suitable for this type of management. So first, the geometry of the junction must be appropriate to the traffic demand. It means that the use of two or more lanes for road traffic in the streets that form the junction or entry to the roundabout (instead of only one lane) must be justified by traffic demand.

The design of a junction which includes a tramway should consider the following:

A junction should be easily recognisable by all road users as a junction with a tramway traversing it.

Road users can be assisted by highlighting the tramway, road markings, signs, and appropriate junction layout.

Road users also need to be alerted to the presence of a tramway in the junction on approach.

Advance information and warning signs need to be installed in logical, clearly visible places in the field of vision. Signs on the approach to and at the junction are an important part of the overall junction design. However, the excessive use of signs should be avoided.

Reducing the size of the conflict zone increases safety because it reduces crossing distances.

However, there are two limits to the reduction of this area: the turning of large vehicles and, in the case of traffic lights, storage of vehicles turning left at the end of a green light phase inside the junction and the time needed for these vehicles to clear the intersection.

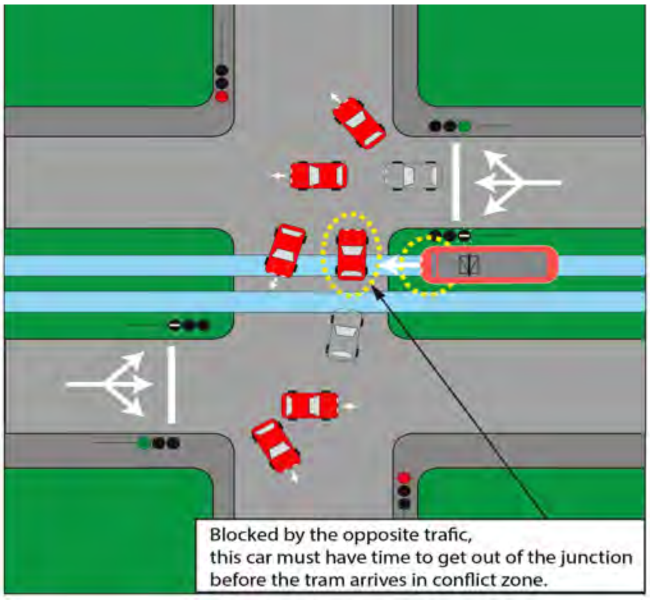


Figure 47 –Vehicle stopped on the track with no possibility to clear the conflict zone before the tram arrives, because of cars in the opposite direction having also their green phase

Preventing or discouraging illegal movements with road design, e.g., with kerbs, pillars, fences, bollards.
Tramway junctions should be designed to maximize visibility for tram drivers to clearly see the junction and for road users to clearly see approaching trams.

This includes that the axes of the two roads should be approximately at right angles. Appropriate sight distances, both while approaching the junction area and being at the junction are of major importance for the safe operation of the junction. Visibility splays are included at junctions to provide sight lines along the intersected street to ensure that both motorists and tram drivers have sufficient reaction time should a vehicle enter their path.

Road equipment and street furniture (signs, guard rails, crash barriers, overhead catenary system (OCS) and utility poles, shelters, lamp, posts, planting etc.) must not impair visibility.

- Sufficient lighting of junctions must be provided in order to reduce accident risk at night.
- The junction design should consist of easily recognisable elements in order to make layout and use of the junction simple and easy to recognise and understand for road users, particularly those who are not regular users of the junction.

Junctions and roundabouts with tramway changing direction

Special attention needs to be paid to junctions and roundabouts where the tramway changes direction or changes sides in the street.

For the case of junctions, if the tramway makes a turn or changes sides in the street, some straight or right-turn movements face the same kind of problems as left turns in regular junctions (lack of visibility of tram approaching from behind). In the following figure, movements that need special attention and control have been highlighted in red.

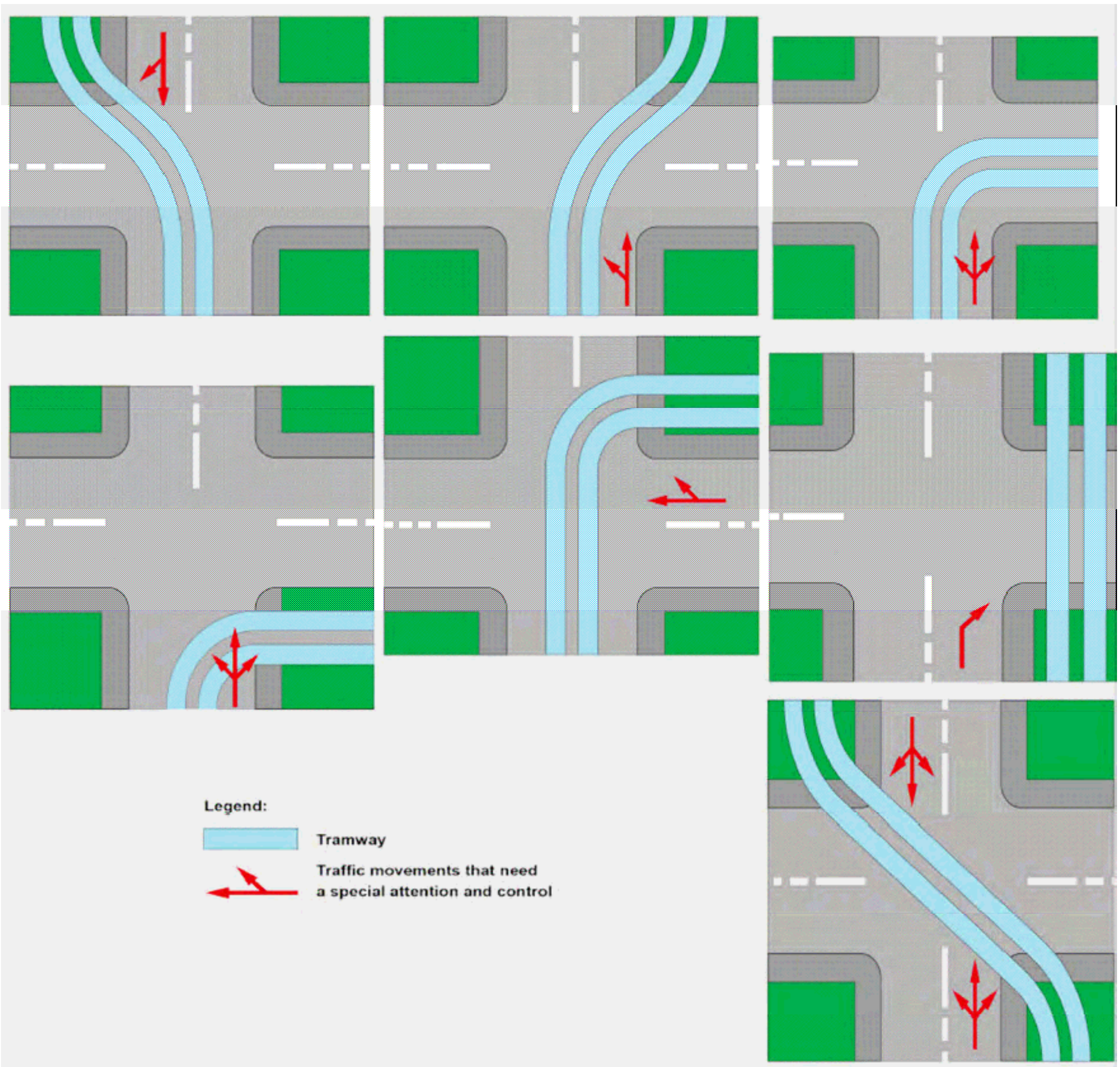


Figure 48 – Possible tramway and traffic movements in a junction

In the case of roundabouts, special care needs to be taken to avoid a roadway entrance to the ring road too close to the crossing of the tramway. On the other hand, as stated before, the crossing should be as close to a right angle as possible. Examples of good and problematic insertions are presented in the next figures.

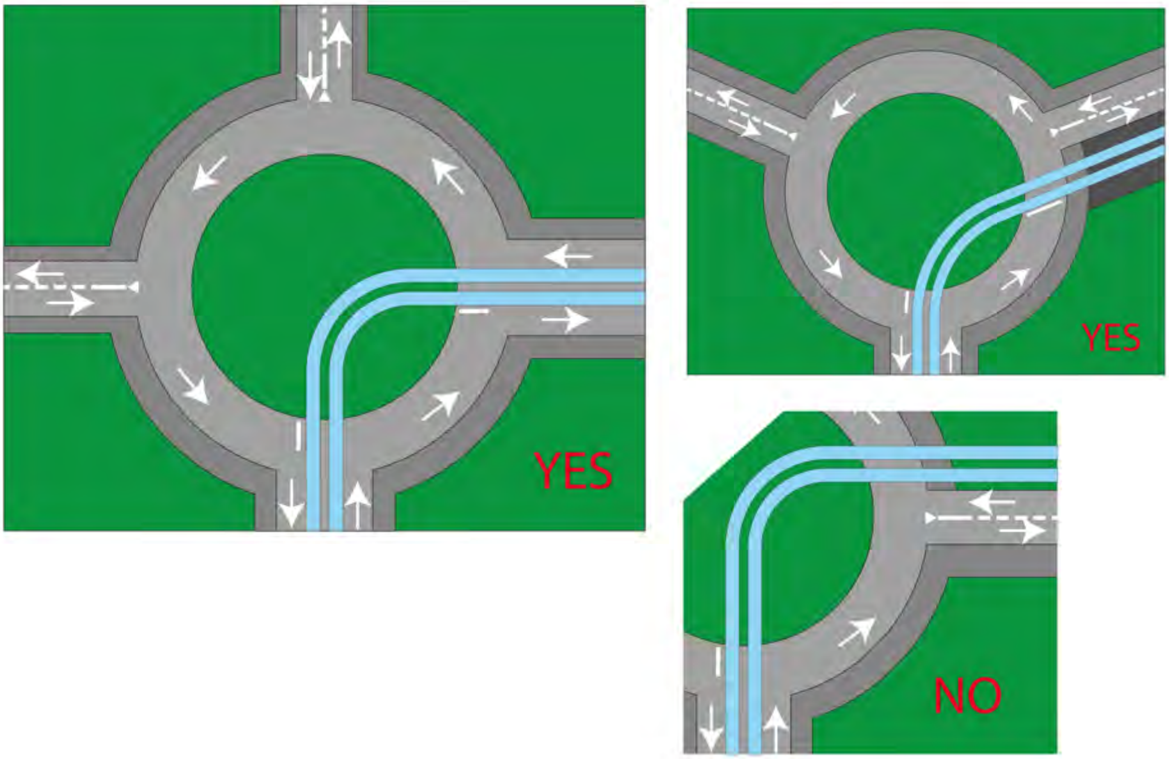


Figure 49 - Examples of good and problematic insertions

3.6.2.2 Road junctions

The two main types of junctions are:

- Priority Junctions (without traffic lights);
- Signalised Junctions (with traffic lights).

Priority Junctions (without traffic lights)

Priority junctions are junctions controlled by either stop or give-way lines or signs. This type of junction is appropriate where traffic flows on minor roads and the overall numbers of turning manoeuvres are relatively low and visibility is good, and should only be applied in secondary intersections, where conflicts between vehicles do not require special management. In most other cases, the use of traffic lights should be considered. However, in some cases, such as private access, other measures such as convex mirrors could also be considered.

At priority junctions, the tramway should be regarded as if it were the major road. The advantage of this is that through tram movements on the major road are not delayed. The design and signing should reflect the priority given to the tramway at these junctions. Before entering the junction, the traffic without right of way should be provided with sufficient visibility of the presence and speed of the tram. Where possible the axes of the junction should be approximately at right angles.

One of the most dangerous conflicts in a priority junction is where a roadway is parallel to the tramway and road vehicles are allowed to make a left turn (right turn in UK and IRL) across the tramway. At these types of junctions, the motorists on the parallel roadway may only look forward along the tramway and not look behind and be unaware of a tram approaching the junction from behind.

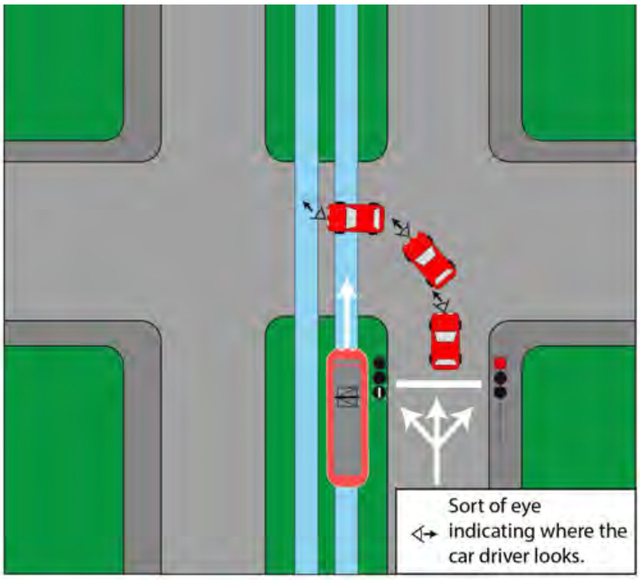


Figure 50 – Left turn movement and visibility issues

> This type of movement without traffic lights is risky. Instead, if the city structure allows, the routing of traffic should be reorganized, to avoid left turns across the tramway. This leads to physically prohibiting this dangerous turning movement. Where rerouting is not possible and warning signs are not effective, using traffic lights at the junction may be a better solution.

Signalised Junctions (with traffic lights)

Signal-controlled junctions depend on traffic signals, which indicate which traffic is allowed to proceed at a particular time. The primary purpose of traffic control by light signals is to separate conflicting traffic by the division of time and allow the movement of street users (motorists, trams, pedestrians, cyclists) in a strictly controlled manner. The sequence/phases of the traffic signals create time slots in traffic that allow street users to cross the junction safely.

The operation of signalled junctions is commonly used to increase reliability of tram service, e.g., with tram detection systems used to offer trams priority over other street users.

Taking account of the tramway in the operation of the light-signalling is via sensors (often magnetic detectors implanted in the ground) located upstream and in the junction (see Figure 51) and affecting the light cycle for:

- Adding a special phase for the tram;
- Or passing to a compatible phase with the movement of the tram;

- Or extending a compatible phase with the movement of the tram.

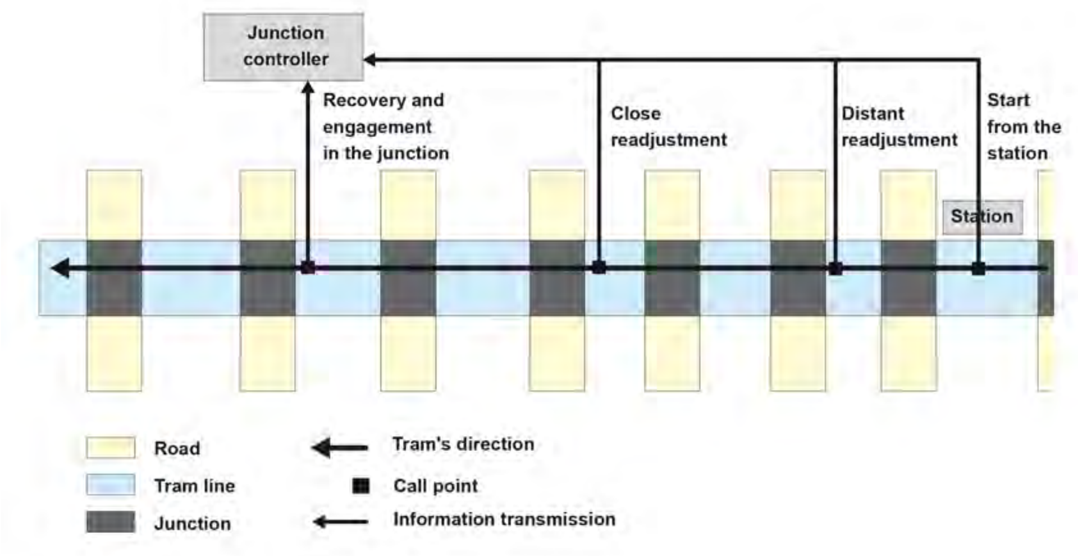


Figure 51 – Possible method for detecting tramways and including their phase and priority in the junction's phases

When two road vehicle movements in the same entry arm are allowed in different phases, each should have a specific lane and separate signals.

<u>Pedestrian crossing in tramway junctions</u>

Pedestrian crossings are an important element of junction design and should be considered carefully. For more information about pedestrian crossings, refer to chapter 3.6.3.

3.6.2.3 Roundabouts

A roundabout is a circular junction in which road traffic flows in one direction around a central island. Normally, it does not include traffic lights and the entering traffic gives way to traffic already on the roundabout.

Roundabouts are a very common solution for junctions without tramways in some European countries. Their main advantage is seen as providing a safe and almost continuous traffic flow. Furthermore, they are versatile points in the road network that offer, for example, the following possibilities:

1. They transform left turns into right turns, avoiding interference with opposite and side traffic;
2. They are U turning points on the streets;
3. They can avoid the need for traffic lights at a junction, eliminating dead-times in that junction and reducing the operation and maintenance costs;
4. They can force road vehicle drivers to reduce their speed when approaching.

Nevertheless, the roundabout operation changes when a tramway system is implemented.

The usual way of implementing a modern tramway in the roundabout is with the tracks running through its centre and protected with traffic lights. The roundabout works conventionally when the tram is not present or approaching (priority for road vehicles that are on the roundabout), but traffic lights are used to give priority to approaching or present trams. This means that road vehicle drivers will have the priority while running on the roundabout only when the tram is not present, but have to yield if a tram is approaching.

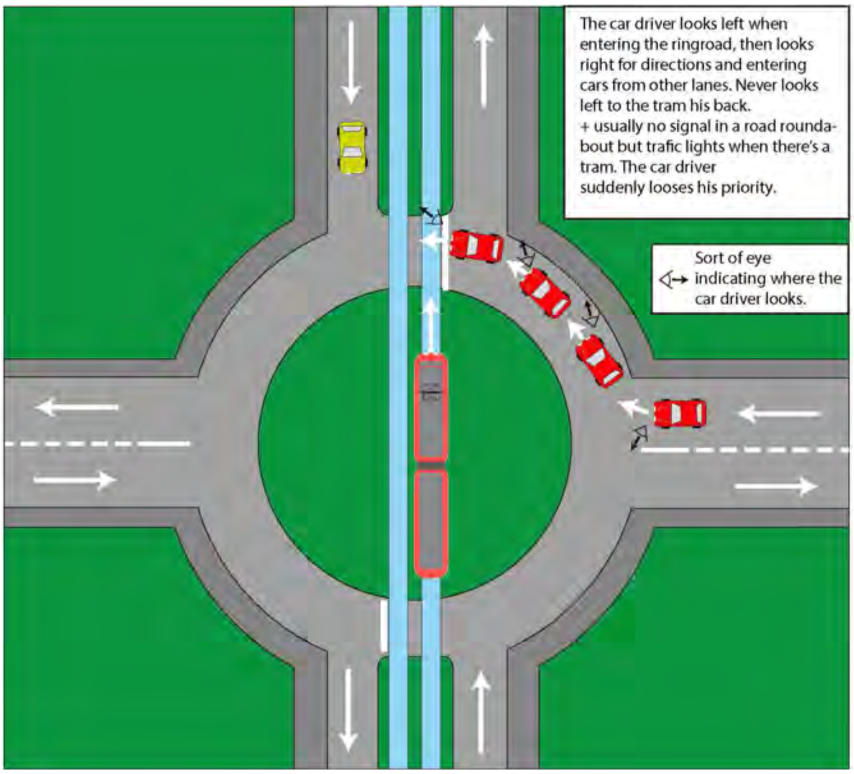


Figure 52 –Decomposition of different directions where the car driver looks when using a roundabout and difficulties about percieving tram inside

An example of problems this can cause is that, in France for example, the accident rate per roundabout is much higher than for general junctions (see Figure 53). Therefore, in some countries, roundabouts are regarded as unsafe. In some other countries, these problems are not as evident and roundabouts are regarded as a viable option for specific cases.

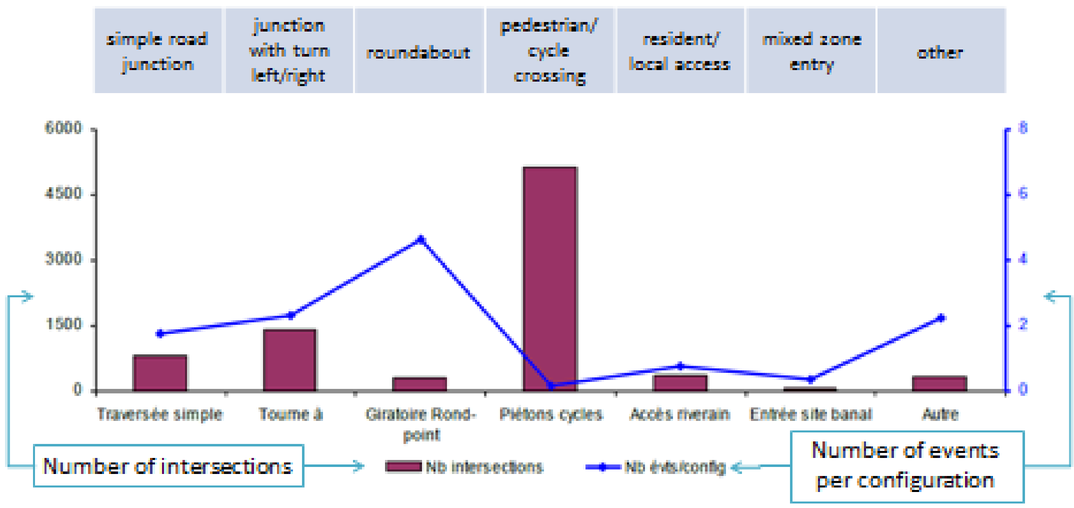


Figure 53 - Number of events per type of intersection [Source: STRMTG, French national Report on Accidentology of Tramways – 2004-2012 (2013)]

Therefore, it is crucial for the safety of a tramway-roundabout that the road vehicle drivers perceive at the right time what kind of situation they are facing (with or without priority for them on the roundabout). For this purpose, the design of the tramway in the roundabout must force the road vehicle drivers to reduce their speed, must be readable and understandable, especially by means of an adequate geometry, and must be completely unambiguous in relation to the mode of operation. [STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d'un giratoire par une ligne de tramway. Guide de conception (2008)]

Besides potential problems with lack of visibility, perception and information, the main problems in roundabouts are related to insufficent insertion of tramway in the roundabout, and to a short distance between the place where cars enter the roundabout and the crossing of roundabout and tramway, forcing vehicle drivers to focus their attention in two directions within a very short period of time.

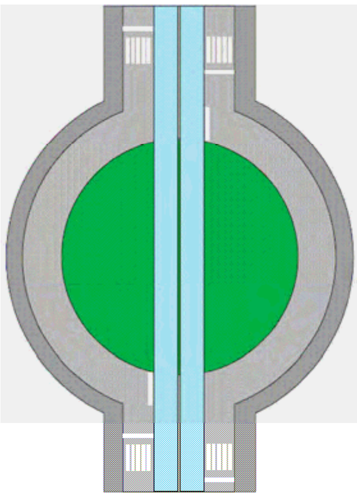
The **main recommendation** in relation to roundabouts is: **do not use roundabouts as a general solution, but only when there are strong reasons that make this configuration more advisable than a conventional signal controlled junction**.

<u>Particular cases when to use a roundabout in tramway crossings</u>

Possible reasons to use a roundabout in a tramway crossing are related to the kind of movements in the junction, and are stated in the following sections.

Nevertheless, when thinking about the movements that need to be addressed in a specific junction, a study of the surrounding area should be made in order to analyse the possibility of avoiding a specific movement in one point and allowing it more easily and safely nearby (for example, allow left turn at another intersection, or by circumventing the blocks and making a perpendicular junction with the tramway).

Roundabouts with two arms:



In a street without tramway, this solution is only used for reducing the speed of road vehicles or for providing the possibility of making U-turns at this particular point.

In the case of a street with tramway, if there is no other option for allowing this movement, and it is absolutely necessary to provide it at this point, the roundabout and U-turn solution over the tracks should be compared and a decision should be made considering the volume of road traffic that intends to make this movement.

Figure 54 - Roundabouts with two arms

Roundabouts with three arms (T junction):

In the case of a T junction, a roundabout layout is not advisable if the movements allowed in the junction are the ones in black in the figure. These movements can be accommodated by means of a two-phase cycle in the traffic lights, which is more efficient and safer.

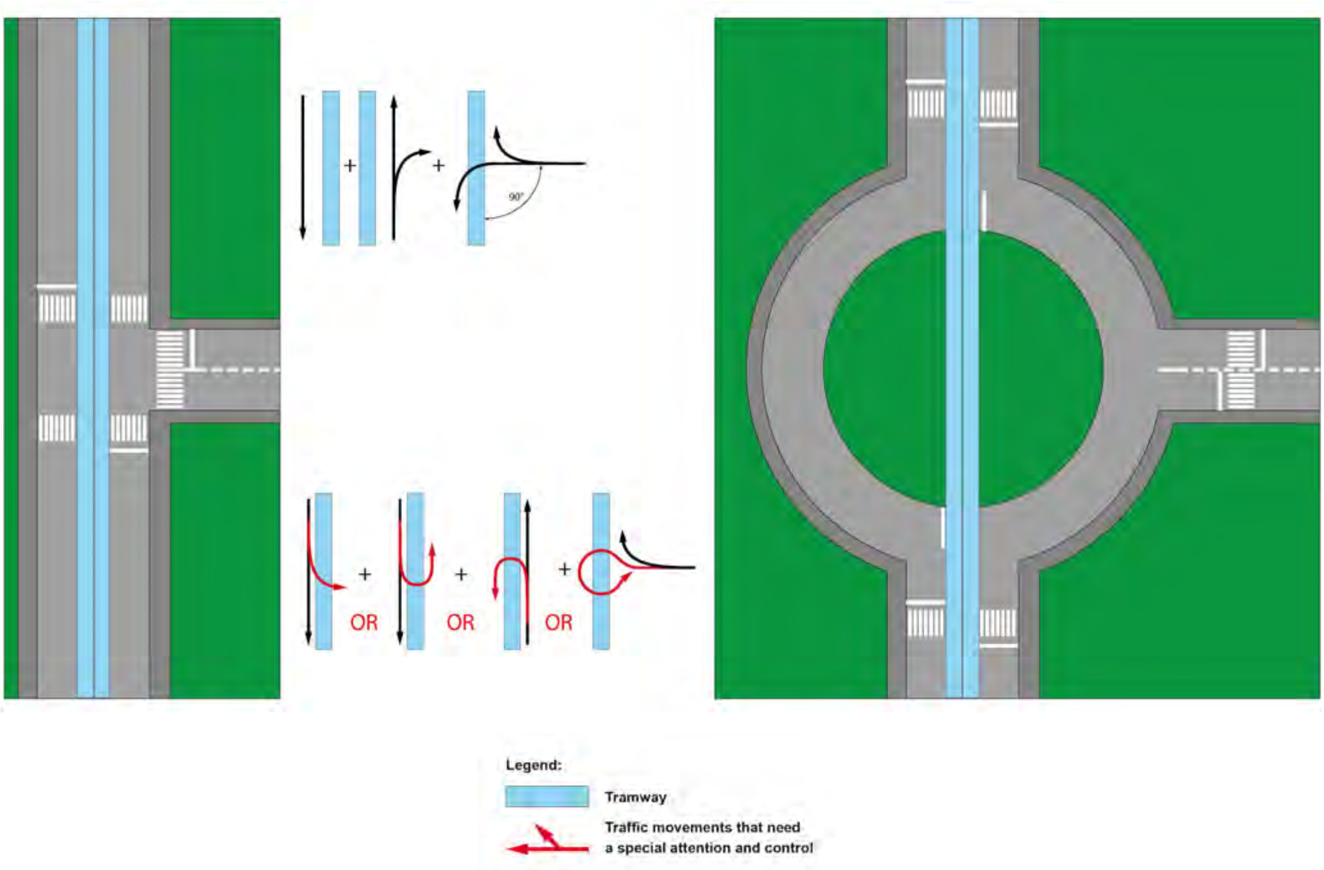


Figure 55 – T junction

If the movements in the junction are more complicated, introducing left turns and/or U-turns in one or both directions (the movements in red in the figure), the roundabout configuration should be considered as an option, because:

- All these movements are transformed into a more perpendicular crossing of the tracks, with a better visibility, as long as the roundabout is well designed.
- The traffic light cycle for a conventional junction would be complicated, whereas the solution of a roundabout is much simpler with traffic lights stopping road vehicles movements only when the tram vehicle is present or approaching.

Roundabouts with four arms:

Similar comments as for roundabouts with three arms can be used for roundabouts with four arms, considering the following figure. In this case, the black movements can be accommodated by a three-phase traffic light cycle. Again, red movements in the figure can be transformed into more perpendicular crossings of tramway tracks by the implementation of a roundabout.

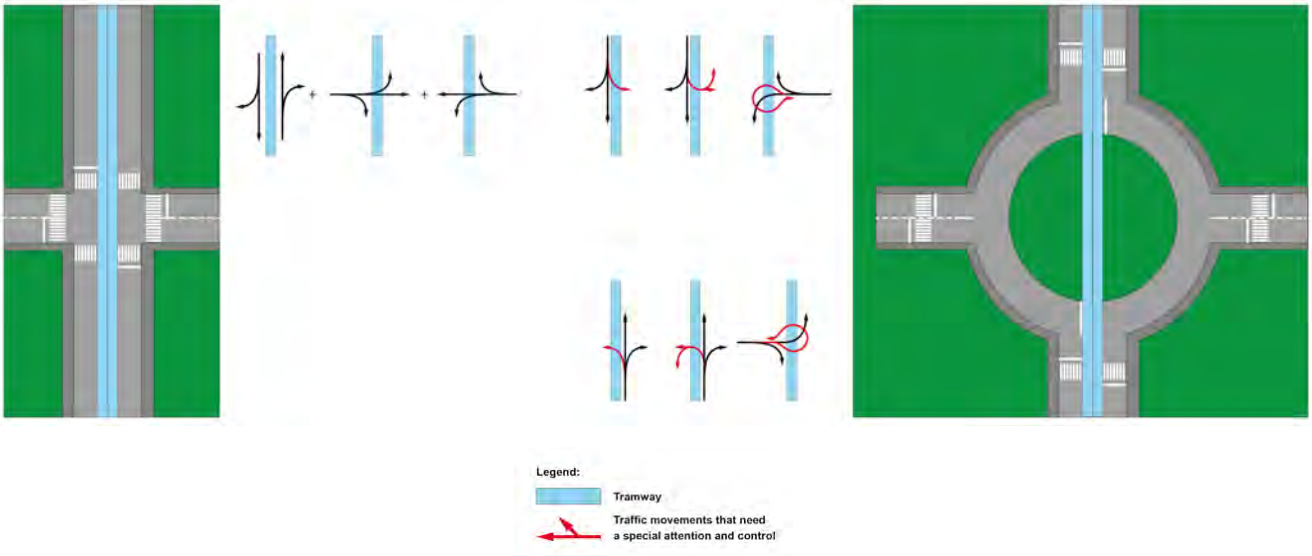


Figure 56 - Roundabouts with four arms

In this case, the stopping zone before the tramway in the roundabout should be carefully designed in order to allow a road vehicle to wait for crossing without blocking the exit of the roundabout to other vehicles.

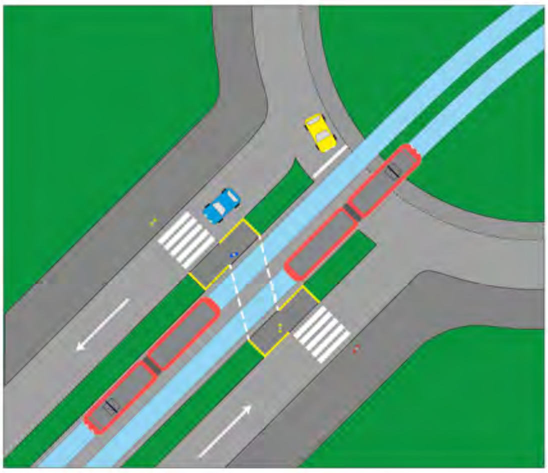
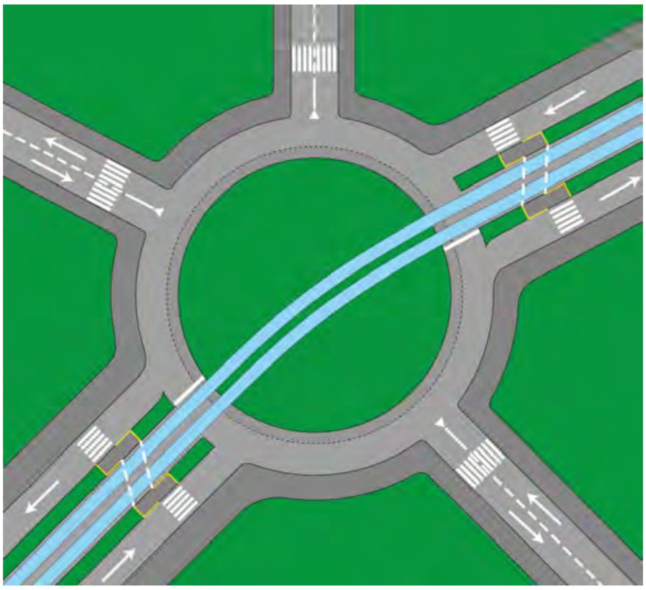


Figure 57 – Example of stopping zone before the tramway on the roundabout

A roundabout layout which is enlarged in perpendicular direction to the tramway tracks can have some advantages and disadvantages:

- A longer space is provided for road vehicles storage. This is important if the traffic volume is high, as road vehicles must stop before the tramway tracks when the tram vehicle is approaching, until the intersection is cleared and the traffic lights allow the crossing of the tracks again.
- A longer perpendicular stretch is provided before the tramway tracks crossing, which improves visibility (and with it, safety) in the crossing.
- Intrusions in the tramway can be avoided by clearly separating it from the adjacent carriageway.
- On the other hand, this solution may increase the speed of road vehicles on the roundabout, particularly where crossing the tramway, reducing safety.

Roundabouts with five arms, four arms in non-perpendicular direction, and other more complicated configurations:



For every type of junction where the incoming streets are not perpendicular, a roundabout can be a way of protecting the tramway tracks from crossings made in a non-perpendicular direction and the respective riskier manoeuvres due to the lack of visibility. In this case, if the roundabout is properly designed (avoiding too many things to focus on at the same time), every crossing over the tracks will be made in a perpendicular direction, improving visibility and safety. An example is presented in the Figure 58, where the roundabout configuration acts as a "shield" for the tramway tracks.

Figure 58 – Five arms roundabout

<u>How to protect the tramway in a roundabout</u>

In the roundabouts of modern tramway systems, the tramway tracks are usually protected by means of traffic lights located before the points where the circle crosses the tramway. In this case, a stop line for the traffic signal should be marked on the carriageway, at a distance of about 1.50 m from the swept path. It must be as orthogonal as possible to the axis of the circle. These traffic lights can be complemented by the sign that indicates the crossing of the tramway (see Figure 59).

In general, it is not necessary to include complementary traffic lights before the entrance of the arms of the roundabout. In such cases, vertical signs should be used to warn about the fact that the roundabout is traversed by tramway tracks (see Figure 59 from the French recommendation). This is important for improving awareness of road vehicle drivers about their lack of priority while the tram vehicle is present.

A9 and AB 25

Signs A9 and AB25 are generally implemented before the entrance of the roundabout.

Sign C20C introduces the presence of the tram track on the swept path limit. When there is no traffic light, C20c is mandatory.

Figure 59 - Static signals in France indicating tram's presence [Source: STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d'un giratoire par une ligne de tramway. Guide de conception (2008)

Nevertheless, sometimes traffic lights can be installed at the access to the roundabout, especially when the entrance is not very far away from the crossing of the tramway, or when the road traffic volume is high.

In existing tramway systems, there are examples of roundabouts where the tramway is not protected by traffic lights. In countries where trams do not have priority over all other street users (e.g., Czech Repulic), this can lead to safety issues and operational problems because the tram has to wait on entering and exiting the roundabout. For new networks, roundabouts with trams without traffic lights are not advisable, because in those cases road vehicle drivers are not used to a tramway. Possible exceptions concern very small roundabouts with low road traffic volume. However, while those cases are not explicitly considered in this chapter, most considerations for design, layout and signage do still apply (with the exception of comments on traffic lights).

Geometry of roundabouts with tramway

The geometry of the roundabout must be appropriate to the traffic demand on the respective junction. This means that the radius of the central platform, the number and width of the lanes in the circle, as well as the distance between the arms and the tramway crossing point must be carefully designed (or redesigned in accordance to new circumstances).

Nevertheless, size is normally linked to the number of lanes, and more lanes increase the number of possible conflicts and are also indicative of higher traffic volumes. Furthermore, vehicle speed rises with the size of a roundabout. Therefore, the greater the size of a roundabout, the higher the potential for collisions. Additionally having several lanes can introduce visibility problems due to one road vehicle obscuring another. In the Figure 60, the accident ratio by roundabout size is presented for the French case.

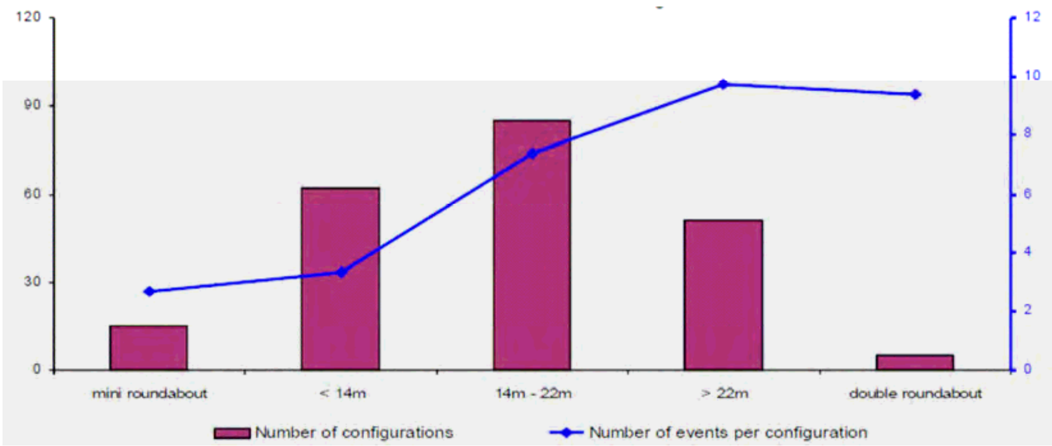


Figure 60 - Event ratio by roundabout size [Source: STRMTG, French national Report on Accidentology of Tramways – 2004-2012 (2013)]

The French study about tramway-roundabout accidents concludes that the use of two or more lanes for road traffic in the entry arms (instead of only one lane) seems to be one of the main risk factors for tramway-roundabouts. So, the French recommendation text [Source: STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d'un giratoire par une ligne de tramway. Guide de conception (2008)] is as follows:

> *"The entries non-parallel to the tramway with more than one lane lead to difficulties on the perception of the tramway and thus unsafe situations; moreover, they lead to an increase of road radius for the same size of the roundabout, which induces higher speeds. Therefore, non-parallel to tramway entries with more than one lane are forbidden and may only be used in exceptional cases.*
>
> *The entries parallel to the tramway can be provided with two lanes only if the road traffic justifies this decision and the pedestrian traffic (volume and nature) allows it.*
>
> *Entries with only one lane are the general solution. They have a width ranging from 3.00 to 3.50 m.*
>
> *Exits with more than one lane are a source of unsafety for pedestrian crossings, so they are generally not recommended and they should be reserved only for exceptional cases.*
>
> *One-lane exits are the general rule. They have a width between 3.50 and 4.00 m."*

Nevertheless, it is important that the capacity of the intersection is adjusted to the capacity of adjoining streets and to the targeted overall capacity of the network. If only one lane is provided for entering and exiting a roundabout with a large traffic volume, the congestion generated can lead road vehicle drivers to disrespect traffic lights, leading to situations that are more dangerous.

If large vehicles need to cross the roundabout, but small size is desired, a hard shoulder can provide extra space for the swept path of the respective vehicles.

Figure 61 – Hard shoulder in a roundabout

Pedestrian crossings in tramway-roundabouts

Pedestrian crossings should be located on each branch at a distance where cars have not yet accelerated to high speeds, but have already left the roundabout and focus on the exiting road and pedestrians. The French recommendation for this distance is 3.00 metres.

Details on the design of pedestrian crossings can be found in chapter 3.6.3.

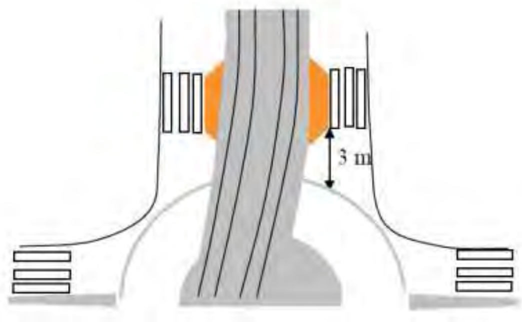
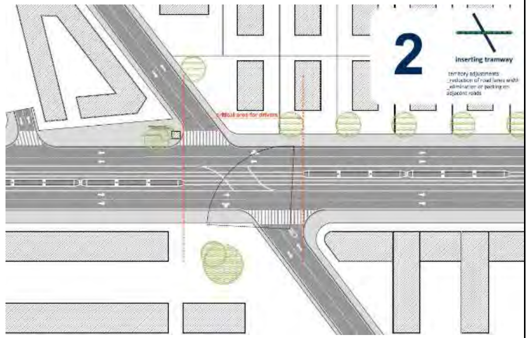
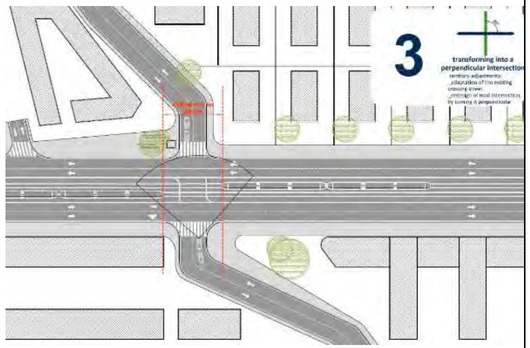


Figure 62 – Pedestrian refuges [Source: STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d'un giratoire par une ligne de tramway. Guide de conception (2008)]

3.6.2.4 Hazards, objectives and measures

Hazards, objectives and measures related to all road junctions and roundabouts with tramway

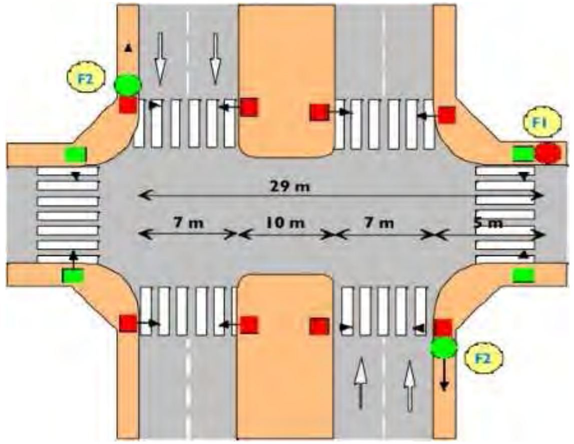
Configuration	Hazard	Objectives	Measures	References - Illustrations
All junctions and roundabouts	Road vehicles entering the segregated tracks	Show the vehicle drivers that they should not go on the segregated tracks	Mark the entrance of the segregated section of tramway with warning signs and use surface not suitable for cars (e.g., grass, deterrent paving, ballast)	IRL1_5 
	Third party driver and approaching tram vehicle cannot see each other because of obstacles (including barriers)	Improve mutual visibility between tram vehicle and other road users	Avoid, remove or move visibility obstacles in the vicinity of the tramway tracks	BE3_1 

Configuration	Hazard	Objectives	Measures	References - Illustrations
	Third party driver and approaching tram vehicle cannot see each other because of blind spots	Improve mutual visibility between tram vehicle and other road users	Increase angle of crossing (more perpendicular) if possible	Insertion with non perpedicular junction:  Same situation converted into perpendicular junction: 

Configuration	Hazard	Objectives	Measures	References - Illustrations
	Third party cannot see traffic signs or signals	Improve visibility of traffic signs or signals for third parties	Avoid, remove or move visibility obstacles in the vicinity of traffic signs or signals	BE3_1 
			Change location or orientation of traffic signs or signals (clearly visible places in the field of vision)	

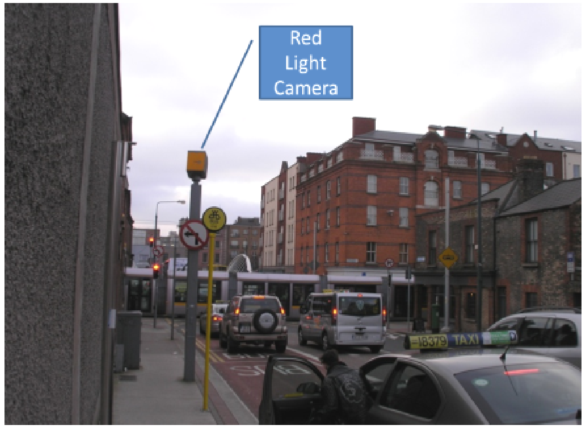
Configuration	Hazard	Objectives	Measures	References - Illustrations
	Third party driver is unaware of tramway tracks	Raise awareness of tramway tracks	Marking the continuity of the tracks through the junction by means of different pavement material and/or colour and/or texture and/or white/yellow boxes and marking the limit of the swept path. Possibilities may be limited by road regulation.	FR3_2: pavement material/color  FR6_1: shark teeth 

Hazards, objectives and measures related to all road junctions and roundabouts with traffic lights

Configuration	Hazard	Objectives	Measures	References - Illustrations
All junctions and roundabouts with traffic lights	Collisions between tram and vehicles or pedestrians at the beginning or at the end of the phase	Free the conflict area between the red phase and the green of the next phase	Depending on the geometry of the junction, calculate a clearance time according to the speeds (10 m/s for vehicles' speed (including tram – but speed depends on track geometry and operation speed and may be slower), 5 m/s for cyclists' speed and 1 m/s for pedestrians' speed)	 In this example: 3 seconds (29m with 10m/s speed) between red light of F1 and green light of F2
	Traffic light infringement by third party driver (excludes intentional violation of traffic rules)	Reinforce traffic light information	Reinforcement of traffic lights by duplication of lights including new ones in the drivers' line of sight (orientation and height)	

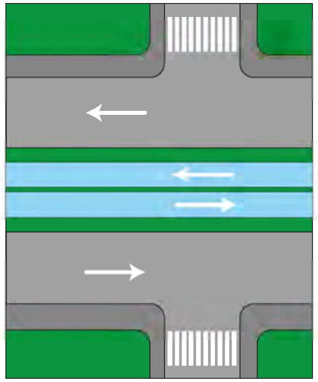
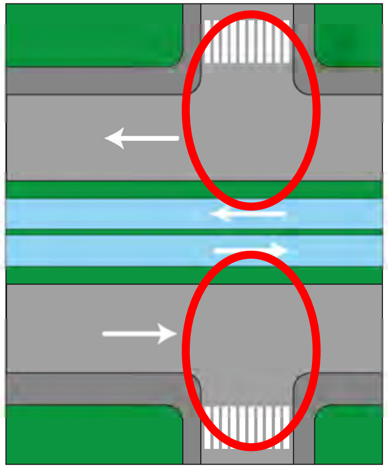
Configuration	Hazard	Objectives	Measures	References - Illustrations
			Improving visibility of traffic light: Reinforcement of traffic light by enlarging the diameter of the red light (for example, 200 mm → 300 mm)	
			Reinforcement of traffic lights by painting of stop lines for drivers to be aware about where they should stop. This solution may not be possible depending on regulation.	PT1_12 
			Improving visibility of traffic lights: Increase angle of signal visibility (for example, extra-wide signals).	France, Bordeaux 
			Improving visibiliy of traffic lights: Use brighter lights (for example, LED signals).	

Configuration	Hazard	Objectives	Measures	References - Illustrations
			Improving visibility of traffic lights: Put backboard behind traffic light.	
			Reinforcement of traffic light by installation of flashing road studs on stop line synchronised with red traffic signal (always subject to approval by the traffic authority).	IRL1_4 
			Reinforcement of traffic light by including an active tram symbol which starts blinking when the tram vehicle is approaching (additional to traditional traffic light - The signal starts blinking and a few seconds afterwards the traffic light changes to red)	ES3_1 

Configuration	Hazard	Objectives	Measures	References - Illustrations
		Enforce traffic light information physically	Traffic barriers (red and white stripes) connected with traffic lights message and tram vehicle presence. This measure is not suitable for urban areas and should only be considered in special cases.	[FR] Lyon 
	Intentional violation of traffic lights	Enforce all regulations	Red-light traffic camera	IRL1_8 

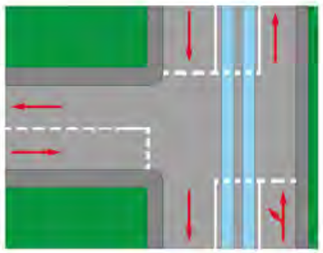
Hazards, objectives and measures specifically related to road junctions

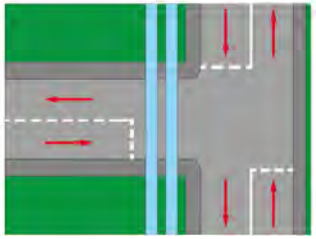
Road junctions with and without traffic lights (all road junctions):

Configuration	Hazard	Objectives	Measures	References - Illustrations
Segregated central track **not crossable** by vehicles (conf. 1) 	Car intruding onto tramway where it is not allowed	Prevent intrusion onto tramway	Lateral protection of the tramway; alert other road users to discontinuity of road (Normally, no conflicts with tram; remaining conflicts are the same as those found in a T-junction on a one-way street)	
All road junctions	Collision between cars arriving from the minor road and tramway	Improve mutual visibility	When it is possible, remove, modify or move objects that obstruct visibility (Examples : change a type of fence, trees or vegetation …)	IRL1_2 / PT1_4 

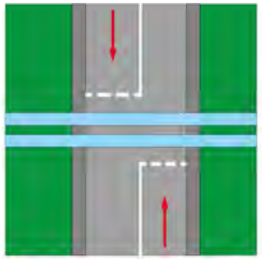
Configuration	Hazard	Objectives	Measures	References - Illustrations
			Install visual aids for users of minor road (Example: convex mirrors; visibility limited by sun and weather, susceptible to vandalism).	France, Lille 
		Reduce the speed of cars approaching the junction	Design on adjacent lanes a smooth ramp right before achieving the junction in order to reach track higher level and also to increase drivers awareness and reducing cars speed.	ES2_17 / PT1_8 / IT1_5 
	Vehicles stopping on the tramway space inside the junction (and waiting to turn left for example)	Mark the continuity of the tracks through the junction	Marking the continuity of the tracks through the junction by means of different pavement material and/or colour and/or texture and/or white/yellow boxes and marking the limit of the swept path. Possibilities may be limited by road regulation.	Ireland, Dublin 

Priority junctions (without traffic lights):

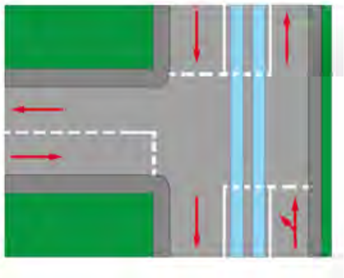
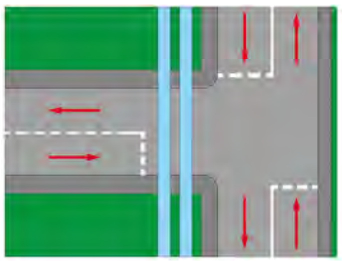
Configuration	Hazard	Objectives	Measures	References – Illustrations
Segregated **central** track **crossable** by vehicles (conf. 2) 	Collision between cars turning to the left and trams going in the same direction from the rear of the car driver (lack of visibility)	Remove the conflict	Make left turn physically impossible by closing the intersection for crossing traffic. (Left turn and crossing must be possible at another location)	BE1_7 / BE1_8 
		Improve mutual visibility	Design the left turn perpendicularly to the tramway with a smooth curve (green space for example) to allow drivers to see if there is a tram arriving at the junction. (This design requires space)	PT1_3 

Configuration	Hazard	Objectives	Measures	References – Illustrations
Segregated track in lateral position, **crossable** by vehicles (conf. 3) 	Collision between cars going towards the minor road (turning to the left or to the right) and tramway coming from the rear	Improve mutual visibility	Design a waiting area for at least one vehicle between the segregated track and the main road. (It allows vehicle going towards the minor road to stop before crossing the segregated track and look if there is a tram arriving. It also allows vehicles coming from the minor road to cross the junction in two phases (segregated track crossing and road crossing)). Depending on circumstances, waiting area for one vehicle may be too small.	

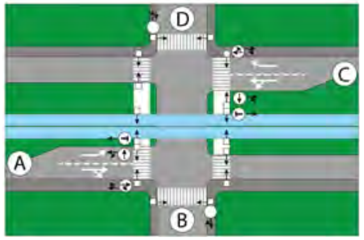
Signalled junctions (with traffic lights) – 1 vehicle phase + 1 tramway phase

Configuration	Hazard	Objectives	Measures	References - Illustrations
(conf. 4) 	Tram appears unexpectedly because of lack of visibility and absence of cross traffic	Improve mutual visibility and awareness of tramway	When it is possible, remove, modify or move objects that obstruct visibility (Examples: change a type of fence, trees or vegetation…)	IRL1_2 
		Reduce speed of approaching road vehicles	Traffic signal remaining on red as normal state. (Signal only turns green when road user approaches junction and no tram is approaching)	

Signalled junctions (with traffic lights) – 2 vehicle phases + 1 tramway phase

Configuration	**Hazard**	**Objectives**	**Measures**	**References - Illustrations**
Segregated **central** track **crossable** by vehicles (conf. 2) and segregated track in lateral position, **crossable** by vehicles (conf. 3)  	Collision between a tramway and a vehicle moving along the tram and crossing it while turning left or right	Avoid this kind of collision	Stop all the streams of vehicle during the tramway phase. (Changing traffic light cycles to an "all red" situation when the tram is approaching – No vehicle in conflict with the tram during the tram phase. The problem of this measure is that it can make the road traffic flow worse and generate congestion if the tram headway is small and the traffic volume is high.)	
			Make left turn or right turn physically impossible.	France, Grenoble 

Signalled junctions (with traffic lights) – special turn-left phase

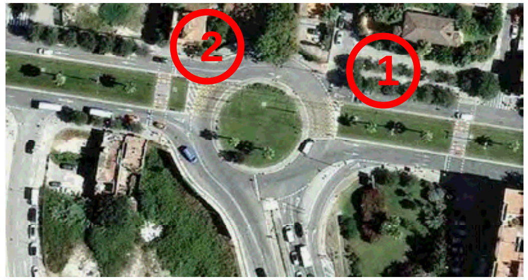
Configuration	Hazard	Objectives	Measures	References – Illustrations
Segregated **central** track **crossable** by vehicles (special turn-left lanes) (conf. 5) 	Collision between cars turning to the left and trams going in the same direction from the rear of the car driver (lack of visibility)	Avoid vehicles turning left starting with the green light of vehicles going straight on and colliding with a tram coming from the rear	Separate the two lanes (straight on and turning left) with a physical separator (« island »)	France 
			Stagger the traffic light line of each movement (put the straight-on stop line 5 metres back from the left turn stop line)	FR1_3  

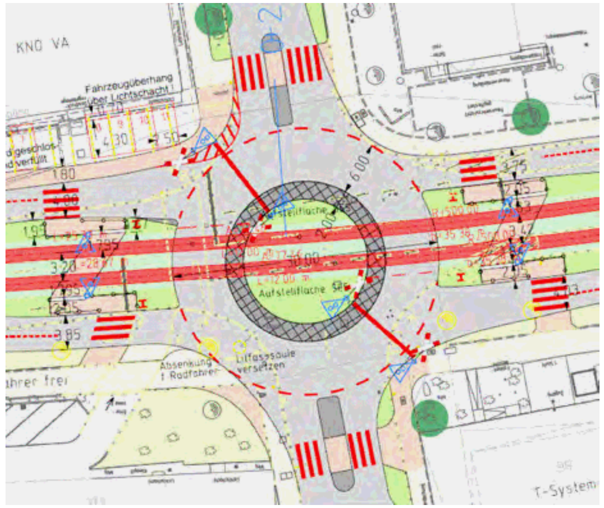
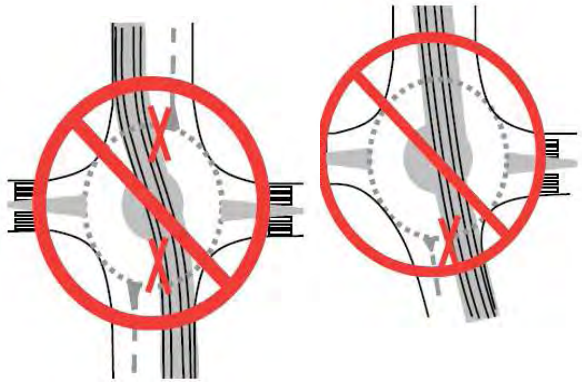
Hazards, objectives and measures specifically related to roundabouts

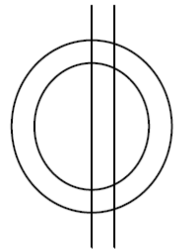
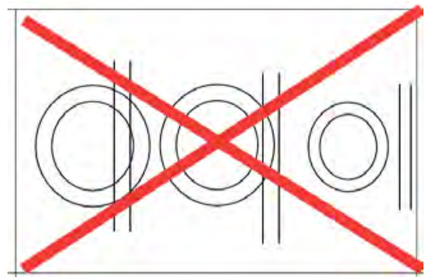
Configuration	Hazard	Objective	Measure	Reference
Roundabout	Third party driver is unaware of the interaction with the tramway on the roundabout	Strengthen perception of central roundabout island	Marking central island (colour, material, sculpture etc.) and/or the ringroad (colour, material) of the roundabout, and clearly marking the tramway swept path	
		Strengthen awareness of roundabout	Vertical roundabout signs at the entrances of the junction (advanced signs)	
	Third party driver is unaware of tram priority in roundabout	Raise awareness of tramway priority	Vertical tramway warning signs of tramway presence at the entrances of the roundabout (advanced signs)	[Source: STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d'un giratoire par une ligne de tramway. Guide de conception (2008)]  A 9  A 9 + AB 25 *(photo SEMITAN)*

Configuration	Hazard	Objective	Measure	Reference
			Vertical tramway warning signs located immediately before the tramway that crosses the roundabout (These vertical signs can be associated to traffic lights (French recommendation))	  R 24 + M 9 z + C 20 c *(photo SEMITAN)* [Source: STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d'un giratoire par une ligne de tramway. Guide de conception (2008)]
			Installation of traffic lights (see measures related to reinforcing traffic light information)	
	Road vehicle stopping in swept path of tramway	Create safe distance between stopped road vehicles and tramway swept path	Stop line with a distance of at least 1.5 metres from tramway swept path	[PT] Porto (Av. Calouste Gulbenkian) 

Configuration	Hazard	Objective	Measure	Reference
	Traffic light infringement by third party driver (excludes intentional violation of traffic rules)	Reinforce traffic light information	Reinforcement of traffic lights by their duplication (entrance of the roundabout and crossing of the tramway). (Installing traffic lights at the entrances of the roundabout can address problems related to short distances between entrance and tramway swept path.)	ES2_19  

Configuration	Hazard	Objective	Measure	Reference
		Simplify traffic light regime	Changing traffic lights cycles to an “all red” situation when the tram vehicle is approaching. (Not to use everywhere: the problem of this measure is that it can lead to the saturation of the junction if the traffic intensity is very high and/or the frequency of the tramway is high, as the capacity diminishes with this kind of traffic light regulation.)	ES1_8  [Source: www.icc.cat]  

Configuration	Hazard	Objective	Measure	Reference
		Enhance understanding of priority and reduce complexity of roundabout	Move stop line with signals by 45° away from tramway.	[DE] Stuttgart 
	Third party drivers' attention is diverted in two directions in roundabout	Reduce complexity of roundabout situation for driver	Avoid layouts where the crossing point with the tramway is immediately after an entrance into the roundabout.	[Source: STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d'un giratoire par une ligne de tramway. Guide de conception (2008)] Examples to avoid 

Configuration	Hazard	Objective	Measure	Reference
			Tramway crossing the roundabout as near as possible to its centre and ringroad crossing as close to the perpendicular direction as possible	[Source: STRMTG and CERTU, French guideline, Giratoires et tramways. Franchissement d’un giratoire par une ligne de tramway. Guide de conception (2008)] Adequate:  To be avoided: 
			Transforming the roundabout into another solution (e.g., classical junction, treat every access arm as an independent junction, over- or underpass).	

3.6.3 Pedestrian crossings

Even though the number of accidents involving pedestrians is not high (approximately one forth of car accidents in France) they tend to produce very severe consequences (same percentage of casualties among pedestrians and car users), mainly due to the difference between the colliding masses. That's why it has been decided to analyse separately the interaction between pedestrians (vulnerable users) and tramways, focusing on the places where main interactions occur, i.e. pedestrian crossings.

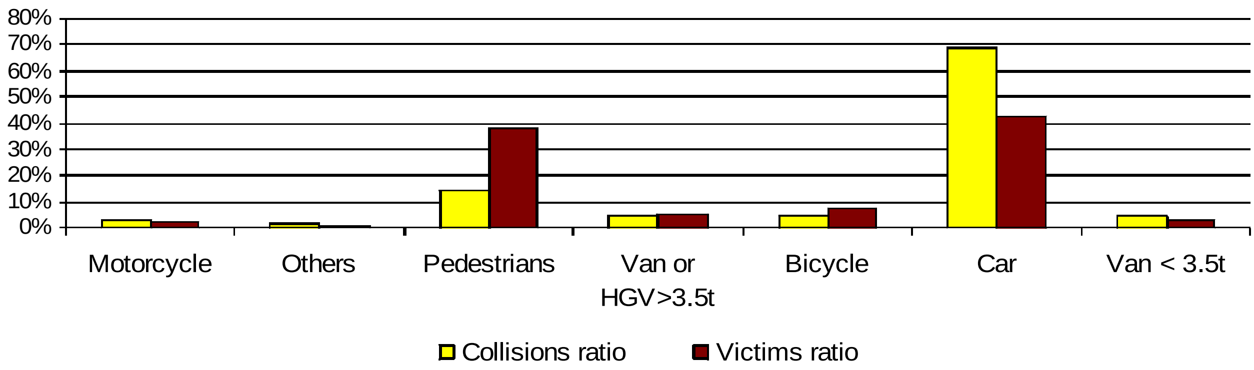


Figure 63 – Distribution of tramway collisions, and then casualties, by type of public space users involved [Source: STRMTG, French national Report on Accidentology of Tramways – 2004-2013 (2015)]

The presence of a specific location should in fact minimize the risk of collision, but sometimes wrong design and bad signaling can contribute to the occurrence of the accident or even be its main cause.

This chapter focuses on infrastructure layout, not pedestrian behaviour, though when designing the infrastructure some measures can be introduced to influence it and reduce unpredictable behaviour. In chapter 3.2 some details were given about this topic.

> Being the place in which most of the interactions between tramways and pedestrians take place, pedestrian crossings signaling and design should be such as to be able to make the user aware of the presence of tram vehicles and tracks, give him/her a good information level about priority rules, separate people from trams and other road traffic in motion.

Some of the main causes of pedestrian accidents can in fact be identified in: pedestrians not obeying safety signs, signals and warning devices; presence of a "second tram"; pedestrian dangerous behaviours due to lack of care; absence of adequate sidewalks, platforms and refuge areas, lack of visibility or more generally a wrong infrastructure location or layout configuration.

Pedestrian crossings can be placed in two different kinds of configurations: crossings located next to stops and stations, crossings along the line between the stations.

When crossings are located next to stops and stations, the speed of vehicles approaching tram stops and stations is generally quite low. Pedestrians who are in the proximity are usually people using the tram system (passengers getting out or about to enter the vehicle), therefore are aware of the approaching tram. However, they tend to take risky and unsafe behaviours related to the need to do not miss the opportunity to get on board or to change trams. Most are seen crossing the tramway along a not authorized route, non-respecting road crossing or crossing near the tail of the vehicle without sufficient visibility to avoid an other possible vehicle coming from the opposite direction. The presence of a stopped vehicle can in fact reduce the visibility of a second one arriving from the opposite direction. The specific issues related to pedestrian crossings close to stops and station are dealt with in chapter 3.6.4.

When crossings are located along the line between the stations, the speed of the vehicle along the tram line, away from the stations, can be at a maximum value which varies according to the type of way (exclusive, semi-exclusive, mixed), area (urban, suburban) and network location (road junction, running section). Pedestrians, in this case, are less aware of the presence of the tram vehicle, especially when the frequencies are low. There are two possible cases: isolated pedestrian crossings and those linked to a road junction. When crossings are related to a road junction, the common solution is to provide pedestrian crossings in each arm of the junction. In this case there are more possibilities of pedestrians interacting with many other road users and in many directions; some ambiguity might arise on the priority of pedestrians against the different traffic components. On the other hand the tram speed through the junction is lower. This may lead to more risky behaviours in addition to those listed in the previous paragraph, and in particular to a distracted crossing by the pedestrian.

A special situation is when a tramway crosses a pedestrian area. In pedestrian areas, pedestrians have priority over vehicles which may be allowed within the area, except on tramways in some national regulations. The safety measures that can be taken in this case must therefore be low impact for pedestrian mobility aiming above all to inform pedestrians of the presence of the tram, without affecting the permeability of the public spaces. The specific issues related to interaction between pedestrians and trams in pedestrian areas are dealt with in chapter 3.6.5.

> Adequate visibility must exist from the pedestrian point of view and give the tram driver also an adequate visibility of the street user.

Pedestrians must be able to identify an approaching tram from a safe distance, before stepping onto and crossing the tramway while not being distracted from observing and interacting with other vehicles, which might endanger the pedestrian or any other street user. The range of visibility must be wide enough to be able to cross the tracks safely before the tram arrives. Vice versa, the distance has to be long enough to stop the tram in time (emergency brake) if the vehicle operator detects unsafe behaviour of a street user.

> The location and continuity of the crossing has to be assured by adequate markings and signs.

Nevertheless the use of zebra markings to signalize a tram lane crossing was found to be confusing. Pedestians are used to have priority over all traffic on zebra crossing, but this is not the case for tramway traffic in every country.

> Due to the differing priority rules between the tramway and the road traffic, a pedestrian barrier might be required at a pedestrian refuge between the tramway and the carriageway. The differing priority rules are a serious safety issue that needs careful consideration.

Pedestrians might violate the priority of trams, coming from the habit of crossing a carriageway with priority on their side. The barrier should reduce the speed of pedestrians and clearly indicate the crossing and the change of priority. Additional warning lights can be installed. It was found that a pedestrian traffic light is often adopted when the volume of pedestrian activity and the tram frequency and/or speed are high, or there is a lack of visibility.

A proper balance has to be found between meeting pedestrians' desires and the tramway operation needs for regularity and speed.

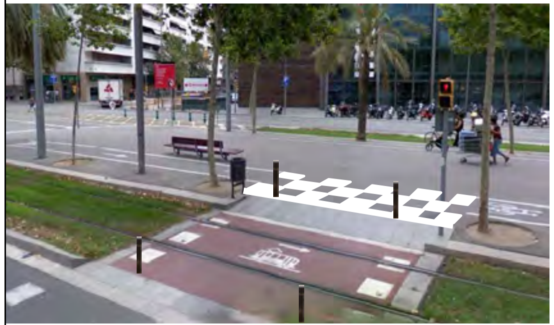
Of course each configuration designed to allow pedestrian crossings requires not a single measure but a set of measures. It has to be assured they are clear, coherent, not providing confusing or conflicting information (for example using redundant signs or one sign blocking the view of other signs).

As general considerations, it was found that safety is increased by pedestrian crossings following the desire lines as short as possible, adequately signalised by markings or signs, provided with refuge areas if multiple car and tram lanes have to be crossed.

The following table summarises a list of typical hazards involving pedestrian crossing a tramway and relevant measures that are commonly adopted to reduce the risk of an accident. These are only examples of solutions whose effectiveness might be highly influenced by the local context, individual behaviour and habits of street users, country specific regulations or by the simultaneous application of other traffic measures not directly linked with the presence of the tramway.

Configuration	Hazard	Objective	Measure	References
Pedestrian crossings in general	Street users not aware of tramway presence	Raising awareness of tramway presence	Use passive warning measures like markings in the pavement, pavement texture and colours differentiation	IRL1_13 
			Use passive warning measures, like vertical signs indicating the presence of a tramway	 PT1_1 

Configuration	Hazard	Objective	Measure	References
			Use passive warning measures like tactile warning strips (specific for visually impaired people),	IRL1_13 
			Use passive prescriptive measures, like vertical signs forbidding the crossing of the line	
	Street users not aware of tram approaching	Raising awareness of tram approaching	Use active warning measures like flashing lights or signs, or acoustic signals	
			Use active warning measures like LED pavement lights. It is necessary to prove the maintainability of the elements before spreading out this solution.	

Configuration	Hazard	Objective	Measure	References
			Use active prescriptive measures like traffic lights	
			Use passive coercive measures, like Z-crossings or chanelling barriers	
	Unawareness of tram approaching	Prevent crossing in very high risky areas	Use automatic barriers activated by the approaching tram, used both for cars and pedestrians. Not a frequently used measure, only in special situations when tram speed is very high, there is a high pedestrian activity or a not solvable lack of visibility	AT1_4 

Configuration	Hazard	Objective	Measure	References
	Pedestrian crossing the tramway anywhere	Make pedestrian crossing clearly identifiable	Use passive warning and prescriptive measures as listed before to favour people crossing in the designated location	
		Provide a safe crossing along the desired lines	Allow pedestrians crossing along the desire lines, if possible	
		Favour pedestrians using a designated crossing	Use uncomfortable pavement in the tramway line, expect in the designated crossing	
		Force pedestrians towards a designated crossing point	Use passive coercive measures, like channeling barriers	

Configuration	Hazard	Objective	Measure	References
	Length of the crossing (multiple car and tram lanes)	Allow pedestrians to divide the crossing in shorter parts	Provide adequate refuge areas to stop during the crossing; if not possible a continous traffic signal has to be implemented	ES2_10 
		Separate the tramway crossing from the road crossing	Provide adequate channeling barriers to force pedestrians change directions to be aware of the possible change in priority rules when crossing the road or the tramway	
	Lack of visibility	Reduce lack of visibility	Remove the visibility obstacles or change the location of the pedestrian crossing, if possible	
		Increase awareness of pedestrians and tram drivers	Use operational measures like tram speed regulations, using the tram horn, provide adequate information to tram drivers	ES2_15 (vertical curve close to pedestrian crossing) 

Configuration	Hazard	Objective	Measure	References
		Increase awareness of pedestrians	Reinforce measures for tram approaching awareness	
	To get the foot trapped in a moving switch while crossing	Provide a safe surface for the crossing	Avoid the combination of switches and crossings in the same location	
	Slip and trip caused by uneven surface	Provide a safe surface for the crossing	Assure a proper maintenance of the interface between rail and street pavement	

3.6.4 Stops and stations

3.6.4.1 General considerations

Stops and stations can be considered as the access point to tramways and LRT systems; being the first contact between the user and the system, those places should be able to provide good information about lines in transit, time (arrival, departure, transit), ticketing system (which can be on board or off board), possible interchanges and services around the area. Passengers can alight on the sidewalk, on the street or on dedicated platforms; all these areas should be dimensioned according to the intensity of the expected flow. It is important for the passengers to have direct and fast accessibility to the stop and a good connectivity with the pedestrian area in the urban environment. There can be differences between stations for tramways and LRT-systems. With LRT, stops are generally less frequent, and the vehicles are often boarded from a dedicated platform; a particular effort is made to set up special stations, segregated from road traffic.

Not all pedestrians are tram users, there are people who only want to use the pedestrian crossing, but even so they need to be aware the presence of the moving tram. Also tram users might adopt a dangerous behaviour in order to board the vehicles as fast as they can. The accumulation of users during the rush hour in the limited space of the platform and the possible presence of stopped vehicles which restricts the visibility of other approaching trams can generate further safety troubles.

Aspects to be considered before choosing a solution for implementation for a new system or modifying an old one:

- Characteristics of the infrastructure (layout, location, type of platform, etc.)
- Traffic control method,
- Volume and type of car traffic,
- Environment (zone of the city, functions of surrounding area, built environment, parking possibilities)
- Operational conditions (running speed, type and colour of vehicles, etc.)
- Way of pedestrians getting to the platforms.

Stops and stations have speficic hazards to be covered when (re)building a layout including, by type of movements and usage of the area:

- People waiting at a stop or station:
    - Pedestrians fall on track when waiting for the tram when the platform is crowded or too narrow
    - Pedestrians fall on track when waiting too near the edge of the platform
    - People wait on the track when the platform is crowded or too narrow
    - Additional distraction of passengers while using headphones, smartphones, etc.

- Pedestrians crossing:
    - When there are staggered quays (not face to face), pedestrians may cross anywhere and in particular behind a tram when a second tram is approaching in the other direction
    - Pedestrians cross between quays to reach the tram or to go to their destination when they leave the tram
    - People cross the station area on a pedestrian crossing without checking if a tram is approaching
    - Pedestrians cross the street on a pedestrian crossing in front of the tram stop and get hit by a vehicle that overtakes the tram
    - Pedestrians cross to reach the tram and get hit by a road vehicle arriving at the same time
    - Pedestrians cross anywhere on street to reach the tram station
    - Additional distraction of passengers while using headphones, smartphones, etc.

    Only pedestrian crossing issues related to the stations are considered in this chapter. For further information please see chapter 3.6.3.
- Vehicles circulating:
    - Road vehicles that overtake a tram when it stops at a station are surprised by another tram or a vehicle arriving from the other direction (mixed traffic)
    - Cyclists who change lanes when a tram stops and get hit by cars coming behind (mixed traffic)
    - People waiting on a central position platform sitting on the road side barrier can fall off in front of an approaching car.

<u>Special configurations</u>

Some stops cannot be classified simply (e.g. final stops within the terminus loop), as shown below:

Figure 64 - Final loop as tram station, Vienna

Possible hazard: with several track crossovers and connections, the hazardous area is not obvious to the pedestrian. It is not easy to recognize from which side the next tram will approach.

Figure 65 - Crossing of several tracks at station area, Vienna

General safety measures at stations (all types)

- "Soft Policy": Lower the approaching speed at stations and platforms with high volume of passengers and increased safety risk;
- Ensure good visibility conditions for arriving tram (e.g. billboards, waste container, design of station buildings (if not transparent) can block the view);
- Well-placed warning signs increase the attention of passengers towards the hazards;
- Marking of interaction areas (e.g. with a red box) draws attention to the possibility of conflicts with different users;
- A handrail or physical barrier to cut off pedestrians crossing at station area;
- Instruction for tram drivers to use sounds to attract attention to their approach;
- Reducing speed of approaching tram;
- A band should be marked at an appropriate distance from the platform edge to deter passengers from standing too close to the edge, using contrasted colours to improve visibility or preferably textured paving;
- Shelters on platform should be placed so they leave sufficient room for passengers to pass.

The aim of the following classification of stops and stations is to define general layout types. Three main characteristics are being used for the categorization, which are mainly influenced by the type of integration into public space:

- The positioning of the tracks within public street space, according to whether the tracks are <u>in a central street position or a lateral street position</u>. This main feature defines whether boarding or alighting passengers will have to cross a traffic lane at some point or not. In the case of a lateral street position, interaction with other street users (crossing passengers) have to be taken into account, when evaluating the associated risks.

- Distinction between stops and stations with a dedicated platform or without a dedicated platform. The absence of a platform is often due to limited urban space. Stops can therefore strongly differ in their dimensions and the available space for safe passenger interaction. Typically, such examples can be found in traditional systems within dense urban areas.

- Distinction between tracks, which are shared with road traffic or separated from lanes with road traffic. Apparently, individual traffic on tracks brings more interaction possibilities between a tram vehicle and motorized vehicle. Therefore it is treated here separately. Again, this is also often due to limited public traffic space. Generally, the separation of tram lanes increases towards the less dense outskirts of the city.

The following diagram shows the decision tree with the described characteristics.

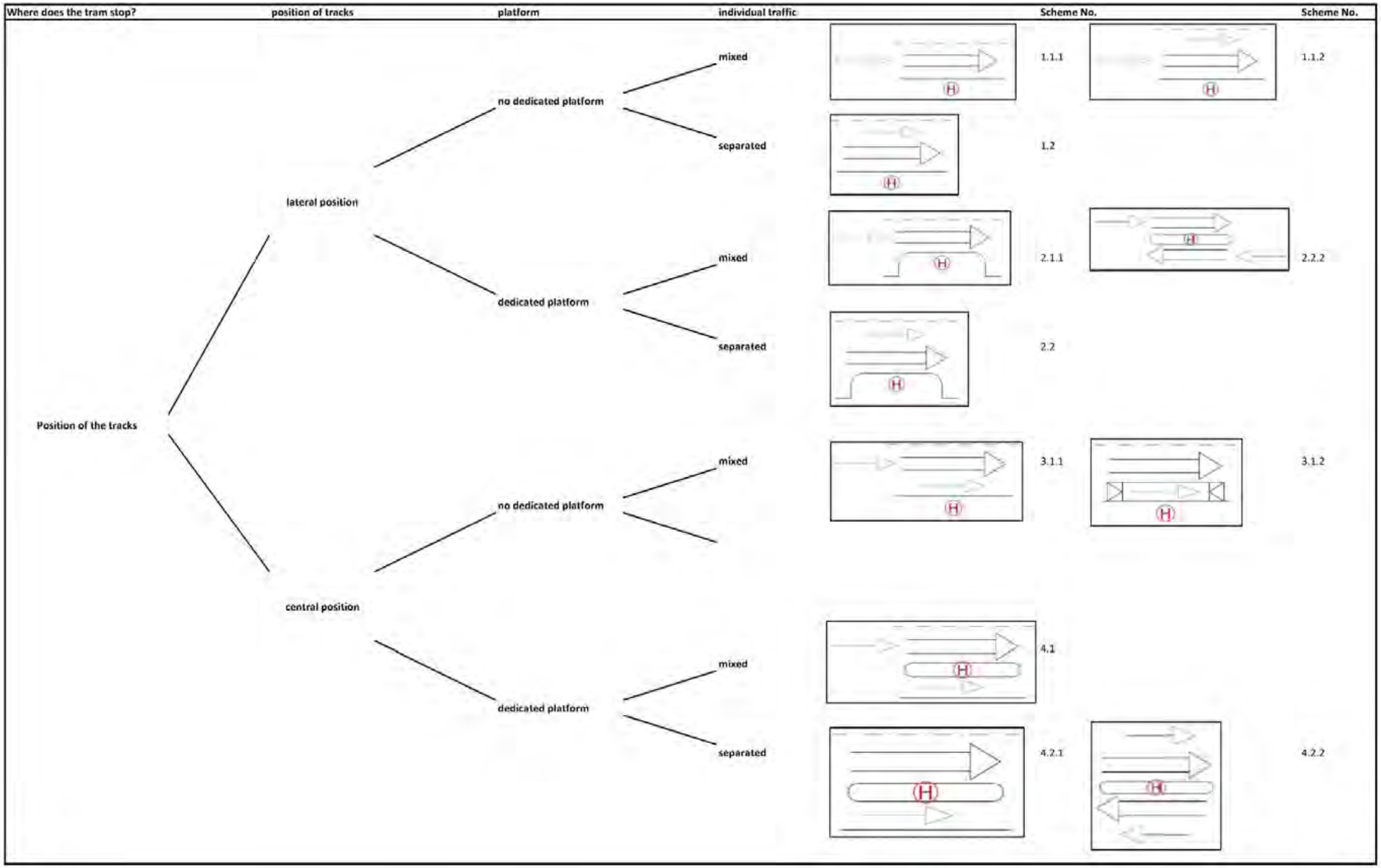
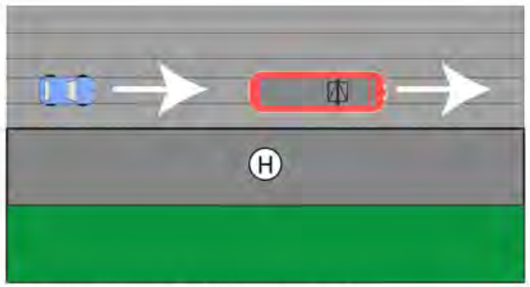
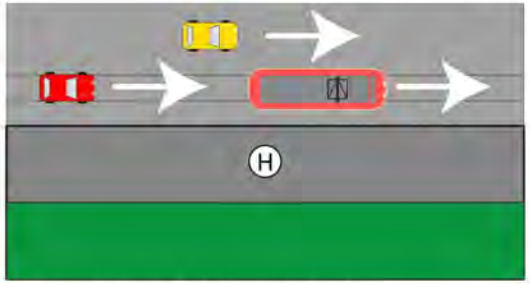
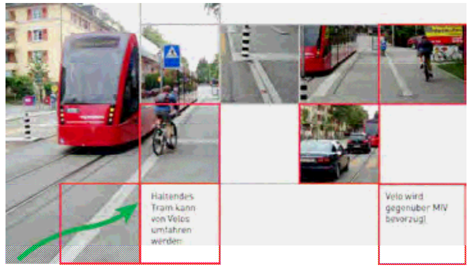
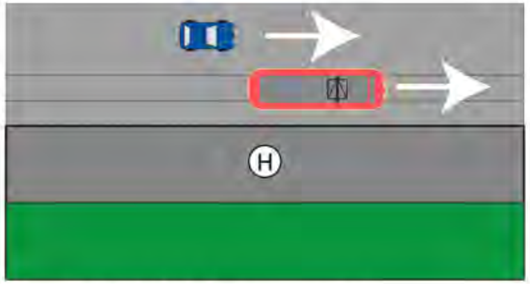


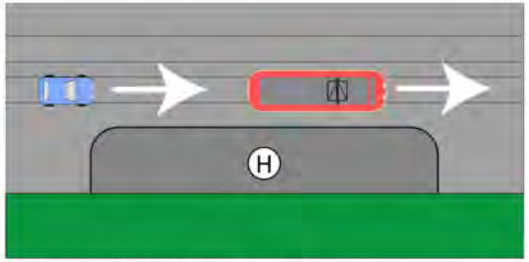
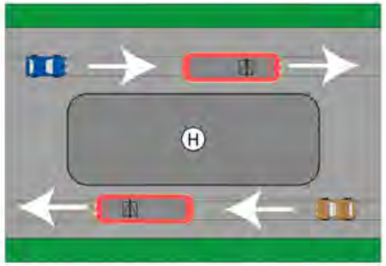
Figure 66 - Main characteristics for the categorisation stops and stations

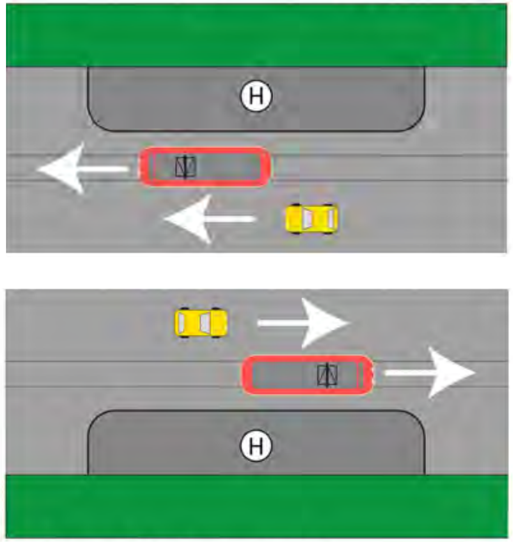
Clearly, the defined layout types cannot cover all types of stops and stations, as this would be outside the scope of this report and would be too exhaustive for the following table. The most important special cases will be addressed in a special paragraph.

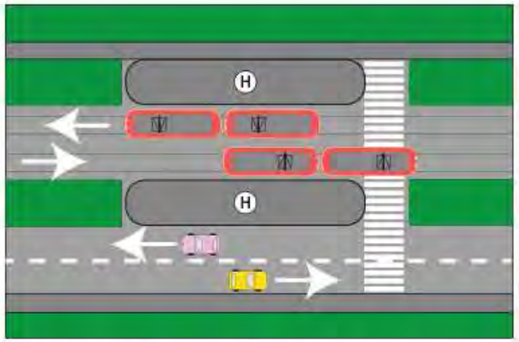
Configuration	Hazard	Objective	Measure	Reference
1.1 Tracks are located in **lateral** position. There is **no dedicated platform**. Tram **shares** the traffic lanes with road traffic. **1.1.1 Configuration with one lane in each direction** shared by vehicles and tram  1.1.1 no dedicated platform - mixed	When there are staggered platforms (not face to face), pedestrians might cross anywhere and in particular behind a tram when a second tram approaches from the other direction.	To channel pedestrians onto a designated crossing	A pedestrian crossing is drawn between the two platforms. Between the two tracks, there is a physical separator except at the crossing.	FR2_1 (Stations) 
	Road vehicles that overtake a tram when it stops at the station surprise another tram or a vehicle arriving from the other direction	To avoid vehicles overtaking the tram when the tram stops in station	To implement a physical barrier between the two tracks. Other types of separator, such as a kerb, white line or rumble strip, can be used; they are less intrusive but may not be so effective. To ensure vehicles stop behind the tram, using Stop-lines etc	FR2_1 (Stations) 

Configuration	Hazard	Objective	Measure	Reference
1.1.2 Configuration with two lanes in each direction: one lane shared by vehicles and trams and the other one only for road vehicles  1.1.2 no dedicated platform - mixed	Cyclists who change lanes when a tram stops and get hit by cars coming behind	To make safe the cyclist's path.	To encourage cyclists to ride behind the station (when space is available)	[CH] Berne 
	Pedestrians cross the street on a pedestrian crossing in front of the tram stop and get hit by a vehicle that overtakes the tram.	To avoid pedestrians crossing in front of the tram	To implement a pedestrian crossing behind the tram stop (such as for bus stops) and channel pedestrians towards it	
	Collision between pedestrian and road vehicle while crossing the traffic lane.	Avoiding collision by stopping pedestrians crossing at any point.		
	Road vehicles which change lanes when a tram stops and get hit by another coming behind, or hit a tram or vehicle coming the other way	To avoid vehicles overtaking the tram when the tram stops in station	Putting roadway marking and signage to prevent incorrect car movements.	 [UK] Sheffield West Street: Road vehicles should not be able to overtake a stationary tram (like the car in this photo is doing)

Configuration	Hazard	Objective	Measure	Reference
1.2 Tracks are located in **lateral** position. There is **no dedicated platform**. Traffic is **separated.**  1.2 no dedicated platform - separated	Pedestrians step onto the track while waiting for the tram, or wait on the track when the waiting area is crowded or too narrow.	To avoid people stepping out of the waiting area into the track area, and make people aware that the tracks are not for pedestrians.	To define the waiting area with markings or low kerbs to show where passengers may stand and the track area where they should not stand.	
			To use awkward materials such as textured paving or ballast in the track areas.	
		Pedestrians walking past the tramstop and passengers who wait for tram share the sidewalk. It should be wide enough.	To widen the sidewalk at the tram stop	[IRL] Dublin 

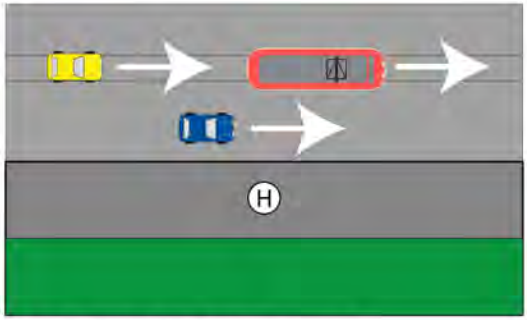
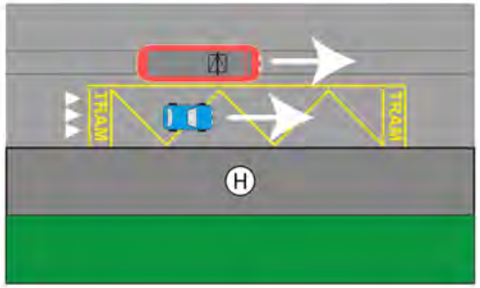
Configuration	Hazard	Objective	Measure	Reference
2.1 Tracks are located in **lateral** position. There is **a dedicated platform**. Tram **shares** the traffic lanes with road traffic. **Two configurations of platform**: **2.1.1** - lateral platform near the sidewalk  2.1.1 dedicated platform - mixed	Pedestrians might step off the platform to cross the tracks, and walk into the path of a car or another tram coming in the other direction, especially if they cross behind a stationary tram.	To channel pedestrians onto a designated crossing	A pedestrian crossing is drawn at one or both ends of the platform. Signs or an uncomfortable surface are used to deter people from crossing at other places	
	Road vehicles might overtake the tram and collide with another tram or road vehicle coming the other way	To prevent road vehicles overtaking the tram	Stop lines and signs to stop vehicles overtaking the tram. Physical separators could be used to prevent vehicles from changing lanes (as in 1.1), but barriers should not be used as the presence of a platform would make the traffic lane too narrow.	 [AT] Vienna: a platform cape is a special form of a platform in lateral position. The cape cuts off the driving lane. A stopping tram blocks the traffic going in the same direction.
2.1.2 - central platform between the two tracks  2.1.2 dedicated platform - mixed	This configuration avoids both hazards mentioned in configuration 2.1.1			

Configuration	Hazard	Objective	Measure	Reference
2.2. Tracks are located in **lateral** position. There is **a dedicated platform**. Traffic is **separated**. **Two configurations**: **2.2.1** - one track is located on each side of the street.  2.2 dedicated platform - separated	Pedestrians fall on track when waiting for the tram	To avoid people waiting for the tram too near to the edge of the platform. And to make pedestrians aware of width of the tram.	A band should be marked 300mm from the platform edge to deter passengers standing too close to the edge, using yellow paint and (preferably) textured paving to aid partially-sighted passengers.	IRL1-2 (stations) 
	People wait on the track when the platform is crowded or too narrow	To make the track uncomfortable to stand or walk on And to make pedestrians aware that tracks are not for pedestrians	To use awkward materials between the rails (sweep...). All traffic lights should be coordinated so the platform can not get crowded.	[PT] Porto 

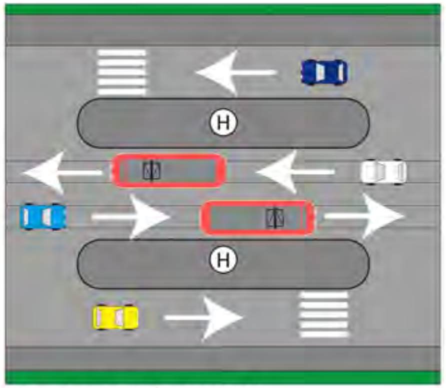
Configuration	Hazard	Objective	Measure	Reference
Tracks are located in **lateral** position. There is a **dedicated** platform. Traffic is **separated**. **2.2.2** - the two tram lanes are in lateral position, on the same side  2.2.2. dedicated platform - separated	Pedestrians cross between platforms to reach the tram or to head for their destination when they leave the tram.	To prevent pedestrians crossing on the track in the station	To implement barriers in the middle of the tracks so that pedestrians are made to use a designated crossing	[FR] Lyon 
			To signal danger for pedestrians: "danger do not cross". In the example shown from Porto, these red alerts (in Portuguese and English language) are disposed along the edge of the platform to discourage people from crossing it at any point. On surface stations they are placed at the centre of the platform and on underground stations they are repeated along it. The character of the prohibition implied by the red colour of the notices is intended to catch the passengers' attention and educate them about respecting the crossing points.	PT1_1 (stations)  
	People lean on barriers and they could fall on the road or could be injured by a car crashing into the barriers.	To avoid people leaning on the barriers	To increase the space between the road and the barriers. To make the barriers uncomfortable to sit on. To raise the height of the barriers. The barriers to be partially transparent.	

Configuration	Hazard	Objective	Measure	Reference
		To channel pedestrians onto a designated crossing	Tactile paving, warning signs, coloured paving may be used to demarcate the crossing	IRL1_1 (stations) 

Configuration	Hazards	Objective	Measures	References
3.1 Tracks are located in **central** position. There is **no dedicated platform**. Tram **shares** the traffic lanes with road traffic. **3.1.1**	Pedestrians have to cross at least one driving lane to board the tram vehicle (after leaving the platform/sidewalk). Handicapped accessibility requirements cannot be met.	Safe passenger interchange	Widening the sidewalk thus reducing the width of the carriageway: it could be necessary to create a refuge for pedestrians in order to avoid interaction with cars. This can be achieved by widening the sidewalk for a distance which covers at least the tram length. The width of the carriageway will be reduced, in order to avoid the presence of cars alongside the tram lane, avoiding the risk of collision with pedestrians. *(this actually leads to the creation of a platform; see tracks in central position, with dedicated platform, mixed road traffic.)*	IT1_1 (stations); IT1_3 (stations); AT2_1 (stations) 

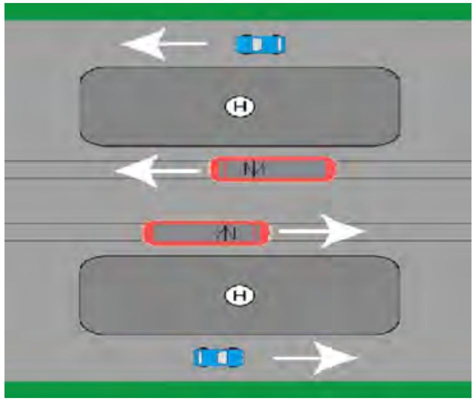
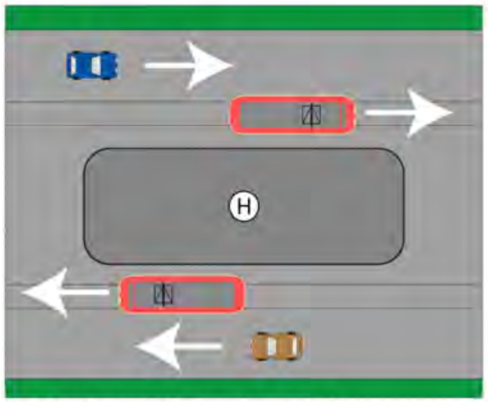
Configuration	Hazards	Objective	Measures	References
 3.1.1. no dedicated platform - mixed	Several cars blocking the lane and also the exits of the tram vehicle leads to bulking of passengers on the lane	Clear motorized traffic from the boarding area between tram vehicle and sidewalk	On demand traffic lights, which block the driving lane for individual traffic at a safe distance to the station for the entire dwell time (“time island”).	AT2_3 (stations) 
	Awareness of car drivers to adapt their driving speed or stop their vehicle accordingly to the situation.	Safe passenger boarding	Different surface types, textures and colours on the driving lane at the beginning of the stop (possible stop line). Combination with aforementioned additional on-demand traffic lights (“time island”)	AT2_3 (stations) 
3.1.2 the driving lane at the tram stop is elevated to sidewalk level to form a boarding area  3.1.2. no dedicated platform - mixed	Individual traffic crossing the boarding area and endangering boarding or alighting passengers	Reduce the hazard of individual traffic crossing the passengers’ boarding area	Raising the roadway so that the roadway is level with the platform enables (a) improved access for persons of reduced mobility, (b) makes a “speed hump” to slow drivers. Additionally, a stopping line directly before the levelled boarding area brings individual traffic to a safe distance from boarding passengers. Due to the levelling of the driving lane, accessibility requirements for passengers with reduced mobility can be met.	AT2_3 (stations) 

Configuration	Hazards	Objective	Measures	References
	After the tram has left the station, passengers might still be left on the driving lane, and they are less protected without a tram vehicle (e.g. people with reduced mobility take longer to clear the lane).	To avoid passengers to be left in the driving lane and hit by car.	Passenger refuge (markings) between driving lane and track alignment adds additional awareness of interaction area to car drivers. It can be used as a refuge for passengers, who are still in the boarding area after the tram has already left.	AT2_3 (stations) 

Configuration	Hazard	Objective	Measure	Reference
4.1 Tracks are located in **central** position. There is **a dedicated platform**. Tram **shares** the traffic lanes with road traffic.  4.1 dedicated platform - mixed	Cars crossing the station in the middle	To avoid conflict between cars and pedestrians in station area	Split the cars and the trams by sending the cars on the adjacent road to the station thanks to signs, marks.	CZ1_1 (stations)  GE1_1 
	People cross the station tracks on pedestrian crossing without checking if a tram is arriving	To make pedestrians aware of the different priorities	Warning signs, pedestrian traffic lights and avoid using zebra markings	GE2_1  IT1_8 

Configuration	Hazard	Objective	Measure	Reference
	People fall from the platform when it is crowded	To prevent accidents between vehicles and people falling from crowded platform	Wider platform, barriers in tram station.	GE3_1 
	Conflicts between waiting and boarding passengers leads to blockage of the platform.	To prevent overcrowding on the approach to the platform.		
	People wait on the track because the platform is crowded or too narrow	To prevent accidents between vehicles and people falling from crowded and narrow platform		IT1_7 

Configuration	Hazards	Objective	Measures	References
4.2 Tracks are located in **central** position. There is **a dedicated platform.** Traffic is **separated**. **Two configurations**: **4.2.1** - two platforms, one on each side of the tracks	People fall on the track because of crowded platform due to narrow space	To avoid the platform getting crowded.	Widen the platform. In France, a width of platform of 3 to 4 metres is recommended in central position and 3 metres for each platform when there are two, one on each side of the tracks.	BE1_2 (stations) 

Configuration	Hazards	Objective	Measures	References
tracks 	People cross the station tracks on pedestrian crossing without checking if a tram is coming	To make pedestrians aware of the succession of different sections on the pedestrian crossing (road section, tram section…) and the different priorities (pedestrians have priority over road traffic but not over trams)	If there is a light-controlled pedestrian crossing on the road, to implement a light-controlled crossing also on track. And preferably, to phase the lights by section crossing to avoid too much waiting time for pedestrians To implement wide refuge between road lanes and tram lanes	[FR] Lyon 
4.2.2 - one platform in the middle of the tram tracks  4.2.2 dedicated platform - separated	Pedestrians cross the tracks and roadway in one movement without checking that both are clear	To ensure that both tramway and roadway are clear when pedestrians cross the road. Alternatively, to ensure that pedestrians are aware there are two separate crossings and they must make sure both are clear.	Suitable phasing of the signals so that pedestrians have time to cross both the roadway and the tramway (but this might cause delay to tram or road traffic). Alternatively, to stagger the tramway and road crossings so that they are not in line The pedestrian crossing across the road is aligned a few metres to one side of the crossing of the tram tracks, so that pedestrians do not cross directly across the road and tramway.	 [UK] Sheffield – University stop.

Configuration	Hazards	Objective	Measures	References
	Pedestrians cross the tracks to reach the tram or to go to their destination when they leave the tram	To prevent pedestrians crossing the track in the station	To implement barriers in the middle of the tracks The barrier is a physical fence. Other methods of dissuading pedestrians from crossing are possible, such as an uncomfortable surface or ballasted track	
			To signal danger for pedestrians: "danger, do not cross". In the example shown from Porto, these red alerts (in Portuguese and English language) are disposed along the edge of the platform to discourage people from crossing it at any point. On surface stations they are placed at the centre of the platform and on underground stations they are repeated along it. The character of the prohibition implied by the red colour of the notice s is intended to catch the passengers' attention and educate them about respecting the crossing points.	PT1_1 (stations)  
		To channel pedestrians on a designated crossing	Tactile paving, warning signs, coloured paving may be used to demarcate the crossing	IRL1_1 (stations) 

Configuration	Hazards	Objective	Measures	References
	Pedestrians cross anywhere on street to reach the tram station	To prevent pedestrians crossing anywhere And to channel pedestrians onto a designated crossing	Tram lane barriers in tram station	BE1_1 (stations) 
	People wait on the track when the platform is crowded or too narrow	To make the track uncomfortable to stand or walk on And to make pedestrians aware that tracks are not for the pedestrians	To use awkward materials between the rails (sweep ...)	[PT] Porto 

3.6.4.2 Special cases for stops and stations

Configuration	Hazard	Objective	Measures	References
1.1 Terminus	Two-way service. Passengers do not know which tram leaves first and if they are in a hurry, they do not look out while crossing tramtracks.	To avoid pedestrians being hit by a passing tram.	Applying ITS tools (information for passengers). Marking pathways. Ensure good visibilty on the platform.	[HU] Budapest, Kozvagohid 
1.2. Stop in turning loops	Passengers have to cross the road every time to access the platforms. Passengers have to cross tram tracks as well in several cases. Tram drivers' visibility of the tram doors is limited in the loop.	Avoid passengers being hit by a car or by a tram. Improve visibility of pedestrian movements.	Place mirrors on the platform. Remove obstructions from the platform. Reduce speed of trams. Avoid platforms on left-hand curves. Apply CCTV inside vehicles.	

Configuration	Hazard	Objective	Measures	References
1.3.1. Pre-sorting stop (different platforms and tracks for trams departing in different direction from the stop) – with platform	Pedestrians cross anywhere on the tracks to access one of the platform, so they can get hit by a tram. Some platforms could be narrow for the waiting passengers, so they can fall in front of an incoming tram.	To provide safe crossing for pedestrians. To avoid waiting passengers falling in front of vehicles.	Dedicated pedestrian crossing, in some cases with traffic lights. Warning signs for waiting passengers. Widening platforms. Placing barriers on platform to influence the movement of pedestrians.	 

Configuration	Hazard	Objective	Measures	References
1.3.2. Pre-sorting stop – without platform	Pedestrians cross anywhere on the tracks to access one of the platform, so they can get hit by a tram. Some platform could be narrow for the waiting passengers, so they can fall in front of an incoming tram.	To provide safe crossing for pedestrians. To avoid waiting passengers falling in front of vehicles.	Dedicated pedestrian crossing, in some cases with traffic lights. Warning signs for waiting passengers. Re-build the stop with a platform and barriers.	 
1.3.3. Pre-sorting stop – with pre-sorting tracks	Gap between platform and vehicle when tram stops on the more distant track – people could get trapped between vehicle and platform.	To avoid people getting trapped between tram and platform.	To relocate the stop, away from the switch.	

Configuration	Hazard	Objective	Measures	References
1.4.1. Bi-directional tracks – stop in lateral position	Collision between tram and car because they use the same lane in opposite directions.	To avoid collision between trams and cars.	To implement an effective signalling system. In special cases (during maintenance work) supervisers should stay on site. Improving information for passengers (PIS).	
1.4.2. Bi-directional tracks – stop in central position	Passengers can fall on tracks or roadway.	To prevent people being hit by cars or trams.	Putting signals for pedestrians to avoid the platform getting crowded. In special cases (during maintenance work) supervisers should stay on site. Improving information for passengers (PIS).	
1.5. Displaced stop position – Tram diverts from the central position in roadway at stations, then returns to central position.	Collisions between trams and cars	To protect both tram and car movements	Signalling with the tram priority and signage to warn car drivers	 [GB] Manchester – Clayton or Cemetery road

Configuration	Hazard	Objective	Measures	References
1.6. Roundabout stop – stop is situated in the centre of the roundabout	Collisions between trams and cars, trams and pedestrians, and cars and pedestrians	Make safe the movements within and around the roundabout	Safe roundabout pedestrians crossings are necessary. Consider an underpass if the traffic flow is high Install signalling to avoid collisions between cars and trams	 [B] Bruxelles – Churchill
1.6 Higher platforms	Passengers possibly falling down from platform. Passengers while walking to platform must cross the tracks each time	To avoid overcrowding on the platform Ensure passengers take a correct route to the platform	To prepare visible and safe pathway.	 [GB] Manchester Piccadilly Gardens

3.6.5 Running sections: general interactions between stations, junctions and pedestrian crossings

These sections covers the running sections of the tramway. The running sections are defined as those sections of tramway between stops, junctions and pedestrian crossings on the network. Intersections (junctions) and pedestrian crossings are shown in chapters 3.6.2 and 3.6.3, and are thus omitted in this table.

Operation conditions

In these sections, trams normally run on sight. Normally, if trams run on line of sight, the speed limits can be about the same as the general road traffic adjacent to the tramway or higher if the tramway is segregated. In mixed zones and pedestrian areas the tram speed can be significantly lower e.g. 10kph in pedestrian zones. However, when there is no signaling system, it is possible for a tram to stop close to another if any problem occours on the network.

Segregated Tramway sections

Geometry of implementation

This can be designed with the tracks on both sides of the street (together or seperated) as well as both tracks in the middle of the street. No matter the position of the tramway is in the street, it is important to guarantee a safe separation between trams and other street users. For example, the swept path which includes a safety margin, can be enough to avoid impacts on operation caused by a car accident, or to prevent driving mistakes caused by cars passing too close to trams.

Tramway surface finishing

Choosing the right surface finishing (hard or soft landscaping) for a tramway, can improve the safety of the tramway by contributing to its good perception. The tramway tracks can be designed as paved, laid with grass or ballasted. The special roadbed should be physically separated from other traffic area to prevent sharing of other street users. This can be done by a kerb, a speed bump or differences in level.

The most important feature of a segregated tramway is that the trackbed is exclusive for trams. The trams run on these sections independently from the rest of the street traffic. These are exceptions to this rule, for example, the shared use of the separate track by buses where access is permitted. This must be specifically indicated.

In the area of street junctions, the segregated tramway is interrupted but the swept path should be clearly defined.

Separators (barriers, bushes, fences, etc)

According to the surrounding area and traffic conditions, different elements can be used as seperators to segregate the tramway. The choice of elements like continuous fences is more indicate to places with more potential risks, e.g. curves or other situations with poor visibility, sections where the tramway is authorized to run with a higher speed limit. On the other hand, separators like bushes, grass, kerbs, bollards, etc, are regulary used to improve perception of the tramway and to control the interactions with the public space, e.g. to guide people to the authorized pedestrians crossings, help car drivers to understand the tramway alignement limits.

Mixed zone sections

These sections are located in the area of street that is used by other modes of transport: the tracks are shared with other traffic. The tramway interacts there deeply with the road traffic and cannot ignore the Road Code.A visual emphasis of the gauge of the track bed should be sought in non segregated tramway. It could be marked by another paving, marked by paiting lines or other equivalent highlight styles. This prevents the use of the tramway for irregular car stoping or parking. A tramway should not drive contrary to the general direction of traffic. Here it can conflict with oncoming persons or authorized vehicles.

In the case of one way street for general traffic, the implementation of the tramway should consider the directions of each track, in order to put in the same way the closer trams and general traffic.

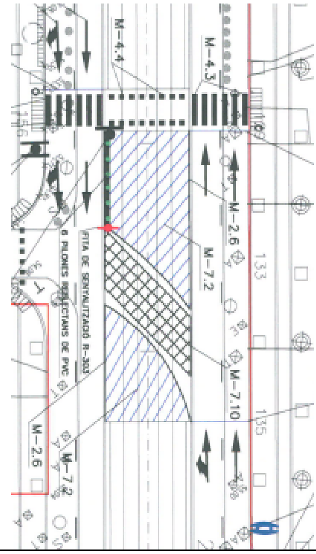
Pedestrian zones sections

These areas are normal blocked to motorized traffic. The tramway in a pedestrian zone must be clearly visible for other street users, or by another paving, marking, or other equivalent.

Crossing facilities for pedestrians and cyclists are not defined in this area.

Configuration	Hazard	Objective	Measure	Reference
1 - Tramway segregation along the street				
Vehicles parked on the edge of the separated tram track	Collision through opening doors of parked vehicles and danger of people who can get when getting close to the tracks.	Prevention of accidents	Sufficient distance between the tramway and the parked vehicles.	 
Segregated track	No visibility through objects such as pilars, billboards, trees, urban furniture and railway bodies	Improve mutual visibility of persons and tram drivers.	Improvement of line of sight and the field of view, though the remove of the obstacle, the relocation of those elements, or, when it is impossible, take implement measures to avoid potential conflits, eg; shape bushes, instal fences, etc.	

Configuration	Hazard	Objective	Measure	Reference
	Intrusion of street users	Increase street users awareness tramway presence and protect tramway	Separation between tramway and adjacent roads: the separation is done through two continuous lines of bushes (and a sidewalk just on one side) parallel to the tramway. Pedestrians can only cross the channel in specific points. The bushes clearly delineates the lane dedicated only to trams. In this way cars and pedestrians have a clear vision of the street and pedestrians are encouraged to cross only in allowed points.	IT1_2  PT1_2 
2 - Tramway perception on mixed streets (cars and cycles)				
Confusing / unclear route	Sweeping the clearance gauge Penetration of vehicles in the track Confusing / unclear route	Prevention of the hazard of collision between trams car, cyclist and pedestrians	Creation of sufficient space between the different types of traffic eg. cars, cyclists, trams and pedestrians	IRL1_23 

Configuration	Hazard	Objective	Measure	Reference
Embedded tramway Left turn on and above the embedded tramway	Obstruction of rail transport Accident through no visual oversight of the tramway	Prevention of accidents	Allow left turn only at defined points Installation of structural roadway separations	ES1_6 
	Unawareness of the tramway	Demarcation of swept path. The swept path of the on-street tramway must be marked.	The swept path is demarcated by the line of the footpath kerbstones or yellow dots painted onto the road surface.	IRL1_12 
3 - Tramway perception in pedestrians areas				
Pedestrian Area - Parking in the tramway for authorized traffic	Cars may block visibility for tramway drivers, and they could be surprised with a pedestrian and cyclists movements.	Avoid lack of mutual visibility for pedestrians area users. Ensure safe route for all type of traffic involved	Prevention of illegal parking by: defining delivery schedules; authorities control by human presence or cameras.	

Configuration	Hazard	Objective	Measure	Reference
	Tram passing through pedestrian area. Contact between persons and trams.	To guide persons entering or leaving the station to safe crossing points on the tramway.	If the pedestrian area is paved with the same material, tactile surface paving is laid at the crossing points so that persons can locate the safe pedestrian crossing. Central areas (waiting refuges) are also provided.	FR1_2 
		To provide a real colour contrast between the two surfaces and to mark clearly the tramway swept path. A difference in paving texture can assist all pedestrians, particularly the visually impaired ones, to make the difference between the tramway and the pedestrian area with the detection cane. Moreover, the detection is increased by the level difference to the platform edges.	The surfacing materials used are black and white paving for all the place and grey paving for the tram platform. The textures of the two materials are different and the pavers are smaller on the platform. There's also a separator between the tramway and the rest of the area, a contrasted kerb with a width and a small height difference.	FR2_1 

Configuration	Hazard	Objective	Measure	Reference
	Interaction between trams and pedestrians	To make pedestrians aware of tram presence.	A pedestrian zone where the tramway circulates at a maximum speed of 30km/h. The track of the tramway is separeted from the "pedestrian area" by a triangular kerb piece that helps people to be aware of the presence of the tramway. When there were no triangular pieces, the tramway's speed was limited to 10km/h Additionally, drivers are told to ring the bell and circulate slowly whenever they see people next to the platform.	ES1_3 
			Pedestrians are separated from the tramway by a different paving material and by bollards.	IT1_6 
			To prevent pedestrians walking along the kerb. To warn pedestrians of the dangers of walking along the kerb. Railings between pedestrian lane and Tram track. When there is a pedestrian lane next to the Tram track, a railing is placed between them to prevent track invasion. Furthermore, Tram speed may be higher due to this safety measure	E 

Configuration	Hazard	Objective	Measure	Reference
	Tram passing through pedestrian area in front of main line railway station. Contact between pedestrians and trams.	To make pedestrians aware of tram presence.	The shared path of pedestrians and the trams in front of the station works as a widened pedestrian crossing. Trams have to cross this area slowly. Changes in pavement type and colour indicate the shared use of the surfaces. There is a line of bollards placed between the pedestrian area (tramlines) and the adjacent road way on the square indicating a warning of traffic for pedestrians.	HU4-1 
	Contact between pedestrians and trams in areas adjacent to restaurants.	Reduce the risk of invasion of the track in pedestrian areas with cafeterias next to the track	In order to avoid accidental encroatchment onto the track, when there are tables and chairs from cafeterias close to track border, railings are placed.	ES2_4 
4 – **Access conditions between surrounding areas**				
Not previewed "wish links" for pedestrians and cyclists.	Potentials conflicts and accidents	Recover safety conditions for street users.	Establishment of defined controled and perceptible crossings for some pedestrians and bycicles and/or create waiting areas on both sides of the tramway with good mutual sight.	

3.6.6 Cyclists and tramways

Interaction with cyclists is an important aspect to consider, especially in cities where the use of bicycle is high.

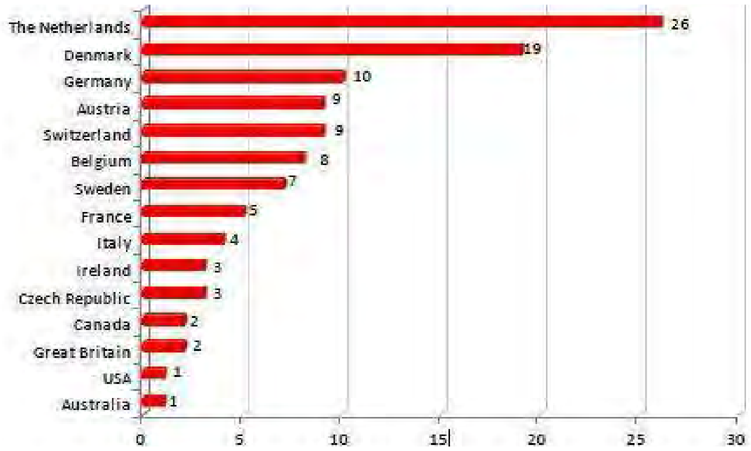


Figure 67 – Bicycle modal share for all journey per country [Source: Directorate General for Internal Policies, Policy department structural and cohesion policies, The promoting of cycling (2010)]

In this situation of promoting alternatives modes to the motorized road traffic, it is interesting to note that the factors which contribute to success of both tramway and cycle networks are often complementary. For example, reducing motorized traffic volume and intensity, mainly on peak hours, in urban areas as a consequence of the introduction of a new tramway system can also result in direct benefits for cyclists in terms of enhanced comfort and safety [Source: Railway Procurement Agency, Light Rail Transit & Cyclists; A Guidance Note for Developers of Light Rail Transit (September 2013)].

On the other hand, to enhance tramway success it is desirable to provide parking slots for bicycles (bicycles racks) in the surroundings of the stops/stations, to encourage multimodal trips.

Bicycles run either on the road (with or without a specific lane for them), as a road vehicle; or they run on the sidewalk (with or without a specific zone included).

Bicycles run on tramway tracks also. In relation to the use of the tramway lane by cyclists, there is not a homogeneous regulation approach in European countries but, except in shared zones, this practice is generally forbidden (although this prohibition is often broken). It is important to note that track rails are slippery, especially when they are wet or icy, and this can lead to cyclist falls. Moreover, many potential hazards arise:

- difference of speed and long braking distances of trams and the fact that it is guided;
- management of both modes at junctions;
- difficulties for the tram in losing its organised priority if driving slower than planned;
- difficulties for the cyclist in escaping or when a tram is approaching;
- priority towards pedestrians;
- the groove of the rails.

An effective measure for avoiding the shared use of the tramway lane by cyclists is to provide an adequate infrastructure for them in the same corridors when implementing the tramway network. But this means that bicycles must be considered in the tramway planning process at an early stage. In general, interactions with cyclists are minimized if the tramway is located at the centre of the street instead of at the side (close to the sidewalk), where cyclists usually run.There will be interaction between trams and cyclists in intersections. The main aspects to consider are as follows:

- If bicycles are running on the sidewalk, there should be designated crossing zones adjacent to pedestrian crossings.
- If bicycles are running on the road, with or without specific lanes, they should behave as road vehicles in the crossing. If traffic lights are provided in the intersection, specific traffic lights for cyclists can be added. On the other hand, advanced waiting zones for cyclist should be provided, before road vehicles, in traffic light intersections, in such a way that cyclists run ahead of them, facilitating their turning manoeuvres and improving road vehicle drivers awareness about their presence.
- The existence of the groove in the rail can be a problem for cyclists, as the bicycle wheel can become caught in it. This problem is especially important when cyclists have to cross tracks at acute angles. Therefore, intersections with bicycle lanes should be designed with angles larger than 60°, and preferably at 90°, for minimising the hazard of cycle wheels being deflected on contact with the rails [Source: Railway Procurement Agency, Light Rail Transit & Cyclists; A Guidance Note for Developers of Light Rail Transit (September 2013)]. This measure has the additional advantage of leading to better visibility and improved awareness.

Figure 68 – Cycle path crossing at right angle the tram tracks, Dublin

- The tram swept path should be marked in interaction zones with cyclists, for allowing them to know where the safe places to stand are. Coloured anti-slippery pavement can be used to highlight potential conflict areas.

3.6.7 From theory to reality

The TU1103 members shared their experiences and background in order to build an approach to the first phase of the Action, collecting examples of good and bad practices and at the same time, organising them by “interaction points” considering the specific place in the network and the main categories of road user.

The questionnaire completed by the operators reinforced the ideas of the Action team about what were the main points on the networks that deserved more attention. There were no surprises from this Questionnaire about the points in the networks with more accidents, generally named hotspots.

The main causes of the accidents are attributed to the disrespect or misbehaviour of road traffic rules or unawareness by third parties. So the question arose in how to implement safe solutions which every involved party of public space perceives and follows.

Our main conclusion, which will be discussed more thoroughly at the end of this report, is that accidents are mainly related to problems of the place where they occur. If the location allows good visibility between tram drivers and other road users, in relation to the permitted speeds, then drivers may have time to stop before contact. Even if the visibility conditions are bad, a good perception of the tramway infrastructure will enhance the road user’s attention, thus reducing the potential risk of accident. And if both visibility and perception are necessarily weak at that point, information through road signs, signage and traffic lights can compensate in order to alert road users and make them aware of the tramway presence. But the best and correct solutions of urban insertion of a tramway system normally consider those 3 factors: - Visibility, Perception and Information, in a well-balanced combination.

4 Lessons learnt and success stories

4.1 Success stories on data collection and analysis

4.1.1 Analysis with Bow-tie approach: the case of Brussels

The Bow-tie is an instrument to analyse accidents (Sources: Lloyd's Register public presentation on http://www.r4risk.com.au/Bow-tie-Analysis.php and http://hkarms.org/ASUS_Server/myftp_web_resources/200090605_HKIE_Bowtie.pdf). Every accident should become an occasion to improve: to broadly analyse which aspects of the transport system can be improved the so-called Bow-Tie graphical representation is useful. Briefly summarized, a bow-tie represents:

- (on the left-hand side) a (partial, converging) tree of causes (inherent weaknesses and triggering events) leading up to the unwanted event, including the actual preventive controls that were in place or failed, together with;

- (on the right-hand side) a (partial, out-going) tree of consequences directly caused by the unwanted event, including the impact-reducing mitigating strategies, that were in place, or failed.

The goal of the Bow-tie is both to get a precise insight into the preventative controls that worked or failed, and to design improvements in the prevention of the unwanted event, as in the mitigating strategies that "buffer" or "decrease" the impact of the unwanted event itself. Strictly speaking, the left side of a Bow-tie is a Fault Tree (and results from a Fault Tree Analysis or FTA), the right side is an Event Tree (and results from an Event Tree Analysis or ETA). The Bow-tie can be used to help simplify risk assessment by allowing one to conceptualize the interaction of causes, controls and consequences of a risk. The following diagram illustrates the process:

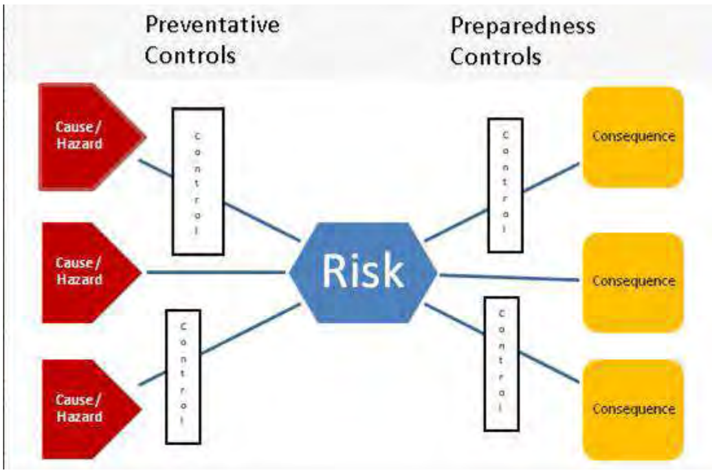


Figure 69 - The principle of a Bow-tie analysis [Source: http://www.doublechecksoftware.com/doublecheck-newsletter-nov-12-bow-tie-risk-analysis-it-isnt-your-fathers-half-windsor/]

It must be understood that the accident under consideration might be one of the many consequences shown on the right, and that - certain barriers being different - the accident itself could have been avoided, or would have a lower impact, or a higher one. All those scenarios that did not lead to the accident under consideration are also visualized on the right, to get a broad analysis on what happened or could have happened.

Another advantage of the Bow-tie method of visualising unwanted events, their causes and their consequences, is the link with Risk Management, the core component of any Safety Management System (SMS). In essence (and according to ISO 31000), the causes on the left are to be registered as “inherent weaknesses (hazards)” that were somehow triggered by “potential threats” and lead to the unwanted event.

Hazards are defined as anything that could lead to harm (human or material), but hazards alone are harmless. They need to be triggered by a statistical event before anything harmful happens. The related risk is then actually defined by *the combination of the harmful impact level with the probability level of the trigger*, of that specific hazard-trigger combination.

Discrete and logarithmic scales for impact and probability levels are used to quantify the risk level, resulting in a typical two-dimensional risk-heat map (a risk-heat map is a tool used to present the results of a risk assessment process visually and in a meaningful and concise way). An example of such a heatmap is given below, together with a typical evolution in time of the risk level:

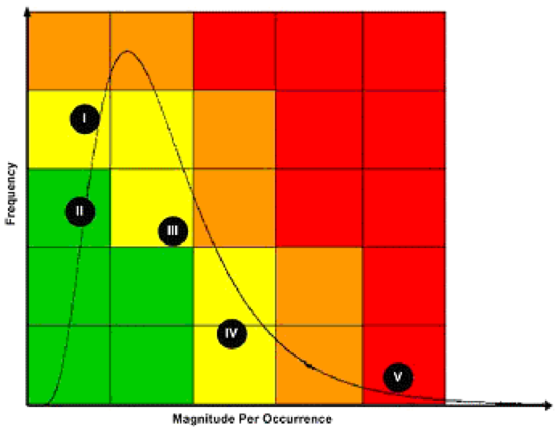


Figure 70 – A risk-heat map example [Source: http://risktical.com/2010/05/11/more-heat-map-love/]

The colours of the heatmap give an indication of the “acceptability” of the risk level. Lower impact, lower probability risks are more acceptable than higher ones. It is very important to note that any organisation dealing with systematically avoiding risks needs to define also those probability and impact levels that become *unacceptable*. In essence, it is compulsory to mitigate such risks (treated towards a lower level). In the absence of a quantified acceptability criterion, the role of deciding on risk acceptance is given to the risk owner, the competent person in charge who can assign all required resources to mitigate the risk.

Bow-ties display the scope of causes, barriers and consequences around an unwanted event. They can be informative to describe a set of influences and dependencies, but will not replace a full case analysis of an individual event.

4.1.2 Near-miss analysis - a study from Stuttgart

There is another pro-active indicator to find potential hotspots: the amount of Emergency Braking. Some networks require some form of recording of these (some only by the drivers, some higher up), and that can be very useful data.

This is linked with No-Blame or Blaming culture. Car drivers in one country can “detect and register/identify” trams executing an emergency brake.

Motivation to investigate this issue

Tram operators keep records on tram/traffic accidents. Evaluating these records might help to determine which type of crossing design is particularly safe and which might have pitfalls in terms of traffic safety. The records on accidents might be complemented by an analysis of "near misses", i.e. of incidents which did not evolved into accidents because the safety means worked well. For this investigation, it is assumed that level crossings with many "near misses" might have some flaws in terms of design or operation.

Situation and main results

Many of the 500 pedestrian level crossings in Stuttgart have been designed or rebuilt to the so-called "Z" standard (picture), forcing pedestrians to walk first towards the closest oncoming tram and thus guiding their attention towards the imminent danger. The safety element "Visibility/Guidance/Attention" dominates the design pattern of this type of level crossings. It is complemented by some other means, one of which is the right of way: the tram traffic has priority over pedestrians crossing.

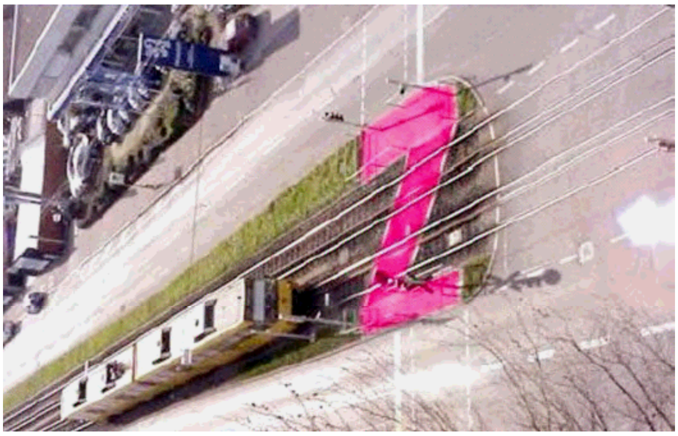


Figure 71 - Pedestrian "Z" level crossings in Stuttgart

However, these traffic regulations are not always properly observed by pedestrians, forcing tram drivers to apply the emergency brake to avoid a collision. If emergency braking occurs frequently at a particular location, this might serve as an indicator for design faults at this spot. SSB drivers are obliged to report such incidents, so SSB is certain that the records on such incidents are comprehensive. Thus the records might be evaluated to detect possible flaws in design or operation of such tram stops.

In Stuttgart, emergency brakings are recorded by drivers reporting to the control centre. There is, however, no regular evaluation or monitoring of the trams' black boxes – this would not be in accordance with data protection regulations. Besides, the mere reading of the black box records without any additional information would not be helpful in interpreting the reasons for emergency braking. In respect of the possible gain in data, this would be misleading and too time-consuming.

Current level of incidents and near-misses

To assess the current level of incidents, SSB first dealt with the period from 1st January 2013 until 20th August 2014. During this period, 147 incidents (including near-misses with emergency braking) were recorded, roughly 7 per month. In 49 incidents, passengers aboard the trams were injured due to the strong deceleration. (There is, by definition, no damage outside the tram in a "near miss" emergency braking incident.)

There are 14 sections in the network where more than one incident occurred, most of them taking place on two sections (16 incidents between “Bihlplatz – Waldeck” on line U1 and 6 between “Wilhemsplatz – Augsburger Platz”, also on line U1). Most of these incidents were caused by car drivers not observing traffic regulations (red lights, right of way).

Road crossings at tram stops were involved in 29 incidents, of which 27 occurred at different locations.

Conclusion: On the SSB network, there are no obvious statistical indications on hotspots concerning near misses between trams and other participants of street traffic. As a matter of fact, SSB has no location with a sufficient number of incidents to allow a proper statistical analysis of near misses. This, on the other hand, might serve as a clear indication of the high level of traffic safety SSB has managed to achieve by applying Light Rail standards.

Results of the upgrade from Tramway to LRT

The upgrading of SSB’s network from tram to Light Rail standards comprises segregated alignment or private right-of-way (just 5% of SSB’s tracks are on-street) and straightened track layout (large radii, mimimum curve radius at 50 m) as well as separated platforms and defined access points from street to platform. This has led to an overall reduction in the number of road crossings. So the switch from tram to LRT operation itself increased traffic safety. The upgrading of the infrastructure to LRT standards triggered a continuous rebuilding of existing road crossings to high safety standards. For this investigation, SSB evaluated its accident records from 1997 to 2013 to determine possible changes in the number of incidents at road crossings which were rebuilt during this period. The focus rested on those crossings, which had a certain reputation for being prone to such incidents:

1. Crossing “Neckar-/Werderstraße”: an additional signal for car drivers turning left was installed, on the opposite side of the crossing and considerably lower than on average. This signal is excellently visible by car drivers. Result: The accidents at this location diminished from an average of 3 per year (between 1997 and July 2000) to an average of 0.5 per year (between August 2000 and 2013). This spot was also analysed for “near miss” incidents. In 2013, there were two of these incidents, each caused by car drivers not obeying the red traffic light.
2. The section between “Berliner Platz” and “Vogelsang”was rebuilt to LRT standards in 1994. It has several crossings where turning left is not allowed. This, in return, has led to frequent accidents between trams and cars which did not respect traffic regulations. In due course, turning left for cars was allowed again on two of these crossings. However, the number of accidents did not decrease. But likewise and under an increasing amount of car traffic, it did not increase, either. So this means the change was rather indifferent to traffic safety – it only reduced the capacity of the crossing.
3. Emergency braking at tramstops: SSB’s LRT network is fully equipped with high-level platforms (95 cm). Access is from either end of the platform, where track-level crossings connect the platforms to the adjacent walkways. The analysis of accidents showed that roughly 66% of the accidents between trams and pedestrians at tramstops take place when trams are approaching the tramstop, 34% take place when trams are departing. SSB tried to assess these figures by analyzing the “near miss” records. However, a lack of incidents prevented this analysis. In 2013, there were only two locations within SSB’s LRT network which had more than two of these incidents. Likewise, they did not manage to identify risky points on a longer row.

Conclusion

The analysis of "near misses" might help to detect potential hotspots of traffic safety. But it must be borne in mind that it increases administrative work if it is compulsory to record these incidents.

There are, however, certain prerequisites which are necessary to obtain useful results:

- The records kept on such incidents should be comprehensive, i.e. reporting of "near miss" incidents should be compulsory (at least of those with emergency braking) and the data needed to assess and analyse the event (such as precise location, type of street user and its movement…) should be provided.
- The number of incidents per location should allow a sound analysis – one or two incidents are too few a number to be analysed properly. But near-misses provide more data than a mere collection of accidents and improve statistical analysis.

To understand what happened during a single "near miss" incident, it might be dealt with and analysed as if it were a true accident. This will give insight on the location in question on an integrated, system-based approach.

4.1.3 The French experience with a tram accident database

This database comes from the fact that the national control authority STRMTG has to collect and produce statistics (Décret n° 2010-1580 du 17 décembre 2010 relatif au service technique des remontées mécaniques et des transports guides). In 2001, the national working group on "tram operation feedback", constituted of French tram operators, defined the aim of "creating an organised and centralised feedback process, homogeneous and complete" (20/09/2001). One of the operators' expectations was to define a statistical database, common to and adopted by all the French operators. Since then, they have proposed which data to be input, and the way to do it through a codification; each year the database is updated with data about new accidents from each network, and new networks and lines are included.

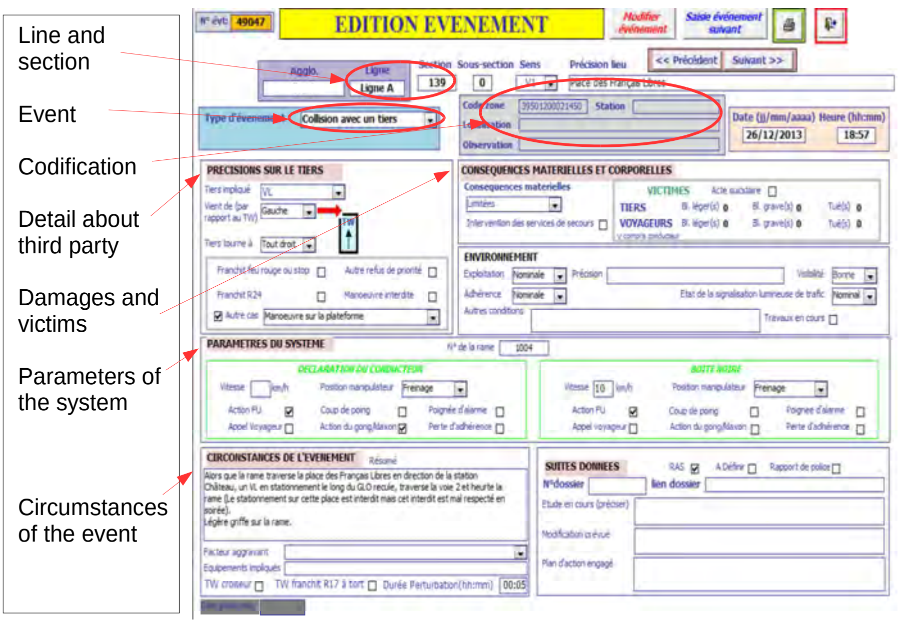


Figure 72 - French accident database screen

In the meantime, each operator may use the database regarding his network to make his own assessments and studies, in order to increase safety.

This database enables the STRMTG to calculate national indicators, which enables identification and analysis of specific issues and tendencies, and allows recommendations to be made about tram urban insertion as a result.

The French tram accident database is actually the combination of two databases:

- The “network” database contains the physical description of all tram lines, each record matching with an elementary section of them,
- The “events” database includes all reported events and their description, each record matching with an event.

The link between both databases is made through the number of the section where the event occurred.

- Each line is divided into homogeneous sections with a number, and then codified. This investment is a big one in terms of time, but then less time is needed for the operators to fill in data about tram accidents.

See more details in Appendix M on the French experience on Tram Safety Management and accident database, presenting:

- *Aims, codification principles and French database contents;*
- *Results and analysis;*
- *Actions resulting from this analysis.*

Being asked in 2014 on the pros and cons of this database, French operators said in the meeting GT REX TW of 26/06/2014 that:

- This database is interesting since there is a great amount of data, since a state office works on it (one dedicated person in the STRMTG), and the data are comparable.
- It is an important investment in time for codification at the starting point, but then it becomes easy. It brings a feedback to operation and brings information for projects/modifications. For some, this database is helpful for the (compulsory) annual report, a sort of “press-button” to give the figures. Still, there is not necessarily an added value on a small scale (one network) but there is at a larger scale (national).
- It is relevant at a national scale because regulation and practice are similar, regarding running conditions and infrastructure design.
- At European scale, cultural behaviour and social/driving context are different. However, some common indicators could be useful in particular categories. Even if tramways are not interoperable, common indicators might be beneficial.
- Regarding the use of indicators from the database: to compare figures between networks is not often relevant, when there are many complicating factors, but to look at the evolution in accident numbers (increases or decreases) in a network and in general may be more interesting.

4.2 Success stories on infrastructure design

Hotspot surveys were returned from 26 cities in 14 countries. The data obtained from the answers to the hotspot survey has been analysed to identify problems, solutions and lessons learnt. Only those reports which show a positive improvement have been included. Because some of the reports did not include any lessons learnt, the success stories described here are from 19 cities. For each entry a brief description of the problem is followed by a description of the solution and the lessons that have been learnt. The succes stories are categorised as:

- Intersections:
  - Left or right turn
  - Roundabout
  - Junction
- Pedestrian crossings
- General interaction points

4.2.1 Intersections

4.2.1.1 Left or right turn (8 cases)

This section concerns situations where other road vehicles turn left or right across the tramway while a tram may be approaching from behind.

<u>Vienna, Austria: Quellenstraße/Herndlgasse, 1100 Vienna</u>

<u>Problem</u>

The tracks are located in the central position of the street Quellenstraße with a designated left turn lane for cars. Herndlgasse is a one-way street. The car lanes and tram tracks are separated by a white line. A ”Keep-off” area on the tracks is marked on both sides of the intersection. Parking spaces exist on each side of street except the side with the additional left turn lane. Previously, traffic signals did not have a separate signal aspect for left turns. Car drivers are not aware of tram approaching from behind and they often stop on the tracks while making a left turn. Visibility of traffic signals is not good (not even for tram drivers), and there is no physical barrier between trams and motor traffic. Cars get too close to the tracks before starting to turn (resulting in side contact, but no head-on collisions). There is a high frequency of trams (1-3 mins interval).

<u>Solution</u>

An additional separate green signal aspect for the straight-ahead traffic lane has been installed, activated automatically when a tram approaches from behind. So when the main traffic signal is red, straight-ahead traffic has a green aspect. Traffic signalling was changed in 2011, with a significant reduction in accidents. No further side-effects have been detected.

Figure 73 - Vienna, traffic signal arrangement for crossing the junction

<u>Lessons learnt</u>

Changes to the traffic signalling arrangement with additional filter signals can reduce accidents significantly.

Brussels, Belgium: Werkhuizenkaai, 1000 Brussel

Problem

Cars were turning left or right across segregated tram tracks and then colliding with trams.

Figure 74 – Brussels, Werkhuizenkaai left and right turning movements [Source: http://geoloc.irisnet.be/]

Solution

Lanes approaching the signals were changed to make either a straight ahead or turning lane, not both, by constructing separators. Tram speeds were reduced further.

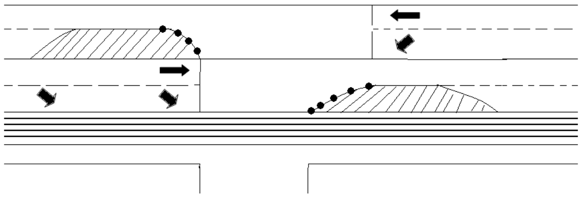


Figure 75 – Brussels, new organisation of lanes

Concerning side effects, there is more traffic congestion for car users. Since the new configuration, the number of accidents has decreased significanty.

Lessons learnt

The construction of seperators between opposing driving lanes can decrease the number of accidents concerning left and right turn crossing the adjacent tracks.

Brussels, Belgium: Hansen Soulielaan – Louis Schmidtlaan, 1040 Etterbeek

Problem

Tramway has its green phase at same time as cars. Only 2 lanes are available and the left lane could be used to make a left turn. Accidents happened at the left turn.

Solution

The measure implemented was to remove parking spaces within 50m of the intersection to create an extra lane for left turns with a specific green phase different from the tramway green phase.

Figure 76 – Brussels, Hansen Soulielaan – Louis Schmidtlaan, creation of an extra lane for left turn

Lessons learnt

Good example of reducing hazards to left turning cars, where adequate space can be created.

Prague Czech Republic: From the tram stop Narodni divadlo (National Theatre) to the tram stop Národní třída (National square), by house number 11

Problem

There were collisions with cars turning left into Karoliny Světlé. In 2013, 24 accidents occurred at this intersection.

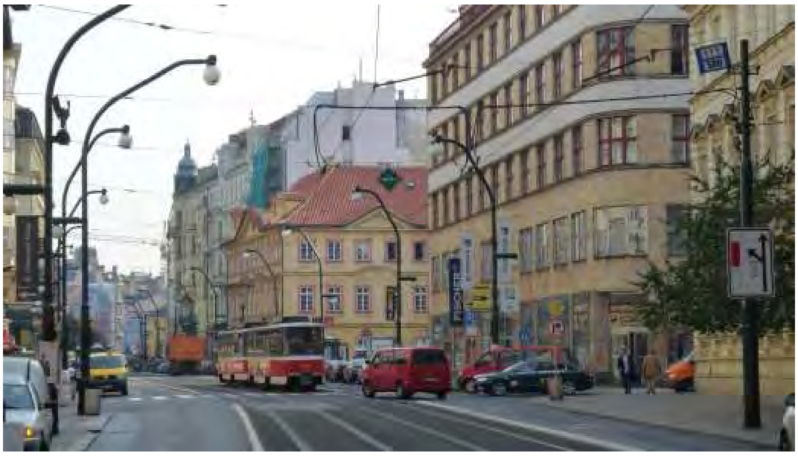


Figure 77 – Prague, concerned street

Solution

For the whole tram line Narodni divadlo to Narodni třída, concrete separators have been built to separate tram tracks from car lanes except at intersections.

Lessons learnt

Using separators between tram tracks and car lanes increases the lateral distance between the vehicles. It can discourage cars from cutting in front of the tram. It channels the vehicles so that they start the left turn at the end of the separator.

Le Mans, France: Intersection Roosvelt – National

Problem

There is a left turn lane across the tramway and an intersection with a road from right. It results in accidents with trams. Tram speed is 25km/h at maximum.

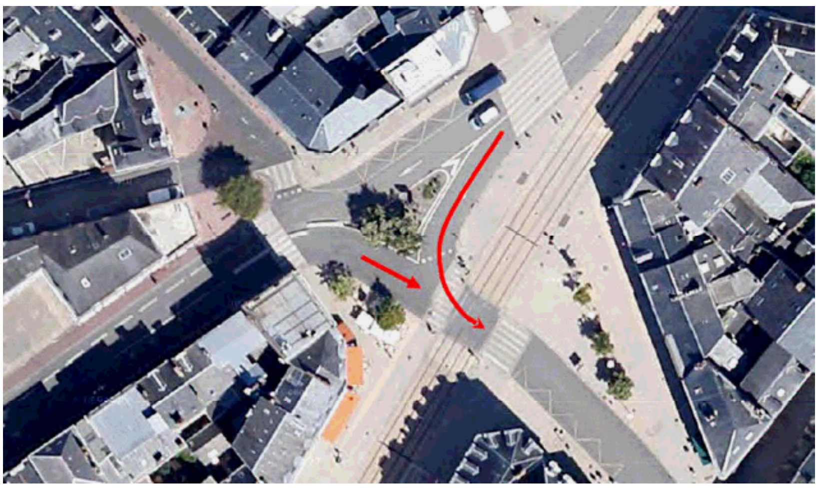


Figure 78 – Le Mans, Intersection Roosvelt – National [Source: KEOLIS Le Mans – SETRAM]

Solution

Additional flashing traffic signals were installed.

Figure 79 – Le Mans, Intersection Roosvelt – National, additional flashing traffic signals

Lessons learnt

There were frequent emergency brake applications before, but few after. Accidents were reduced by half.

> In a left turn, when the visibility of traffic lights is improved, cars travelling in each direction respect them better.

Porto, Portugal: Av. da República in Matosinhos, Line A

Problem

Tramway is on reserved track in central reservation. Left turning vehicles were at risk of collision with trams.

Figure 80 - Porto, Av. da República in Matosinhos

Solution

Left turning traffic movements are prohibited and controlled by traffic signals and road signs. When the tram signal shows "proceed" all road traffic movements are stopped.

Figure 81 - Porto, Av. da República in Matosinhos, traffic signals and road signs to forbid left turn movements

Lessons learnt

An effective method of eliminating hazard of collisions is to prohibit the left turn traffic movement.

Barcelona, Spain: Various traffic signal controlled junctions

Problem

Cars miss the red light for turning left. Road vehicle drivers sometimes do not see traffic signals or do not see them in time and a collision with a tram passing through the junction can result.

Solution

Traffic signals are reinforced by additional signal heads, repeater signals or other traffic management measures to make the situation clearer to drivers. For example, there is a clear reduction of the accidents in Marina Road since their implementation.

Figure 82 - Barcelona, additional lights in Marina/Meridiana

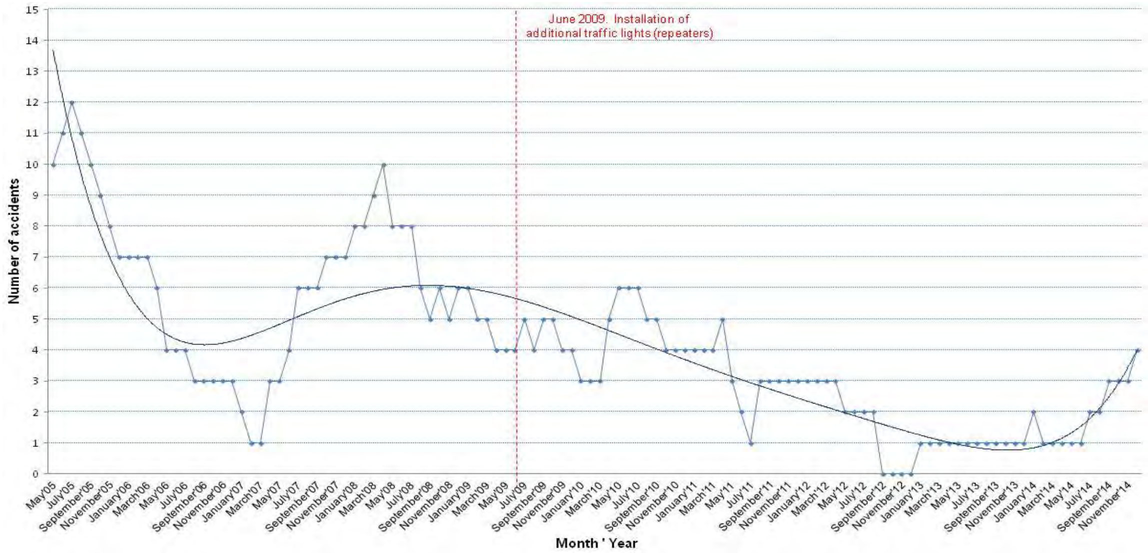


Figure 83 – Barcelona, accumalted accidents in Marina/meridiana junction and identification of the modification's date

Note that afterwards, accidents are occurring again due to a new bike lane implemented by the municipality.

Lessons learnt

> Different ways of reinforcing traffic signs and signals have been demonstrated.

Geneva, Switzerland: Intersection between rue de Carouge and rue Pictet-de-Bock

Problem

Rue de Carouge is a one-way street with one lane for cars, and two tram tracks with tram running on the left side on reserved tracks. At the intersection it is possible for cars to turn left and cross the tram tracks. The cross-way has a stop sign and stop line. Car drivers turning left do not see a tram coming from the same direction and a collision occurs. 8 accidents in 2010, 9 in 2011 and 3 in 2012. Tram speed is approximately 40km/h.

Figure 83 - Geneva, intersection between rue de Carouge and rue Pictet-de-Bock

Solution

Measures were implemented: flashing amber traffic signal when tram is approaching (not enough space for normal traffic signals) and additional training for tram drivers to highlight the dangers at this intersection. It has led to a significant reduction in accidents. However TPG wants to close "Pictet-de-Bock" street for car traffic, to remove the left turn across tram tracks, but they confront political difficulties.

Lessons learnt

> The use of a flashing amber warning light activated by an approaching tram, with targeted tram driver training, can reduce accidents.

4.2.1.2 Roundabouts (8 cases)

Le Mans, France: Roundabout Paul Cézanne

Problem

Cars collide with trams in the roundabout. The maximum speed to cross the roundabout is 30km/h. There is a slight uphill slope in direction 2.

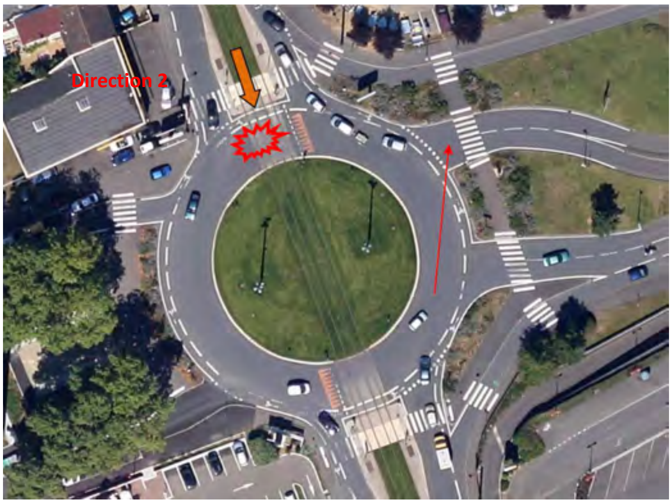


Figure 84 – Le Mans, roundabout Cézanne

Solution

Additional road markings (orange triangles) and additional red flashing “stop” signals (R24) on the same support as the first one and flashing alternately were implemented. Since then, there was a significant reductions in accidents.

However, they have planned additional measures: to reduce from two to one lane the entry shown by the red pointer on the picture and to make it as a junction, depending on trends in the number of collisions.

Lessons learnt

Enhanced markings and signaling illustrate a possibility to increase attention and compliance with give way to the tram at roundabouts.

Montpellier, France: Rond Point de l'Appel du 18 juin

Problem

The junction is in a roundabout, close to slip road from avenue Ernest Hemingway which is an important circulation route. The roundabout has two lanes, the junction is controlled by traffic signals, yellow flashing then yellow and finally red when tram arrives. Disrespect of traffic signals from third parties is the cause of all 28 events, majority are turn right when entering the roundabout. Tram speed is 40km/h.

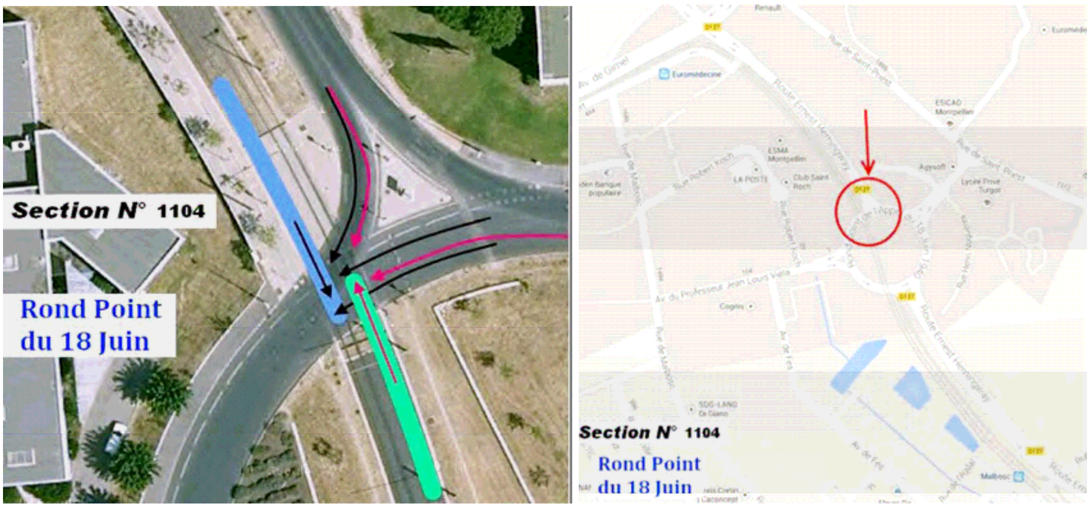


Figure 85 - Montpellier, Rond Point de l'Appel du 18 juin [Source: TAM]

Solution

The scheme implemented was:

- enlargement of red signal aspects to 300 mm;
- traffic lights R11v (with green lens, normal traffic light) instead of R11j (with flashing yellow light at bottom), painting “checkerboard“ at end of 2012 for improvement of track visibility.

Figure 86 - R11v

A small reduction in accidents has been observed. A study has been made of capacity and measures to improve safety in the junction with the council to relocate the traffic signals but no firm recommendations were made.

Lessons learnt

Illustrates use of larger signal aspects, more adapted traffic signals and checkerboard markings to reduce accidents.

Montpellier, France: Rond Point Ernest Granier

Problem

The tramway passes through centre of the roundabout, where there are traffic signals and three lanes in the roundabout. Most accidents were caused by non-observance of traffic signals. Tram speed was 40km/h. They observed 23 events between 2000 and 2009.

Figure 87 - Montpellier, Rond Point Ernest Granier

Solution

With works on third tramline, it was completely reconstructed in 2010. It became a ‘squared’ roundabout junction with one way direction, two lanes with one to turn left and one to turn right, and management of conflicts between trams and cars and cars with cars with traffic signals at each intersection. Positive results were observed with no events since 2009. Such a modification was high cost but is integral to the third line construction.

Figure 88 - Montpellier, Rond Point Ernest Granier, new layout when Line 3 arrived

Car circulation has slowed a little by the decrease of the number of road lanes in the roundabout. It is an expensive and major change but was possible in this specific case.

Lessons learnt

> Major redesign of intersections with changes to geometry, lane markings and traffic signals can have positive results.

Montpellier, France: Place Marcel Godechot

Problem

Tramway runs through centre of roundabout. Non-observance or misunderstanding of traffic signals by road drivers is cause of majority of events. 17 events between 2000 and 2010, 5 events in 2003, 4 in 2004, 2 in 2005, 1 in 2006, 2007, 2009, 2010.

There was a conflict between cars and cars on two streets arriving both close to the tramway alignment, controlled by one R11v (with green lens, normal traffic light) and the other by R11j (with flashing yellow light at bottom). Car drivers were confused as to who had right of way, instead of checking their traffic lights and tram conflict.

Figure 89 - Montpellier, Place Marcel Godechot

Solution

Tram speed was reduced from 30km/h to 20km/h at the entry of station. Awareness campaign was implemented on tram drivers to this particular environment in 2005 and speed reduction in 2010.

They also replaced traffic signals from R11j to R11v.

These were positive measures with no event since 2010.

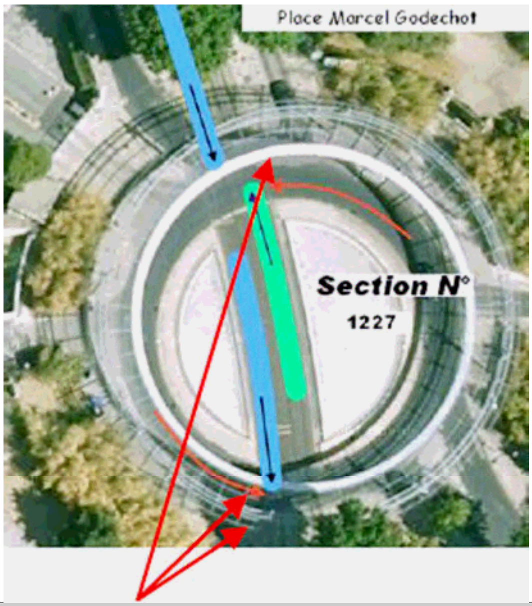


Figure 90 - Montpellier, Place Marcel Godechot, traffic signals changed [Source: TAM]

Lessons learnt

> Driver awareness campaigns concerning speed reduction when entering stations, and change to more common and understandable traffic lights can reduce accidents.

Lyon, France: Parilly

Problem

This roundabout is quite large: it has 4 entries, 2 lanes on the roundabout, car speeds are high, visibility was poor because of trees all around with a fixed obstacle in the island and traffic signals were not well designed.

First accident on T1 line occurred there and led to a serious derailment with 3 injured persons.

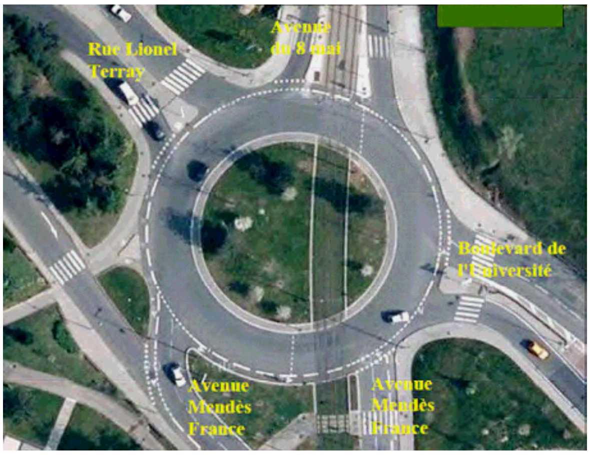


Figure 91 – Lyon, Parilly's layout in 2001 and Figure 92 – Lyon, entrance on Parilly roundabout

Solution

A specific analysis has been done and led to making several small changes concerning traffic lights: their organisation, their type and their size and an improvement of track visibility with swept path better marked on the carriageway. In Lyon, these feedbacks are used to check new projects.

But since there are many cars, there will always be accidents. The layout is not optimal (speed limitations and/or number of entries were not accepted to be reduced by the municipality). There was no accident in 2012.

Lessons learnt

> Managing properly traffic lights, marking traffic lights stop lines and making the tram more visible for street users improved the layout.
>
> Reducing the entry's size would be the best way to reduce cars' speed but municipaltiy doesn't accept this.

Porto, Portugal: Vila do Conde (Line B - S. Brás Roundabout)

Problem

At roundabout with metro (LRT) tracks through centre, some drivers ignore red traffic lights when entering the roundabout and crossing the metro tracks, causing accidents.

Figure 93 - Porto, Vila do Conde

Solution

Diameters of red signal aspect were increased by 10 cm to be better seen from a distance. White stop line painted on the carriageway so drivers know they should stop and pay attention to the traffic lights. The position of signs was rearranged to avoid confusion and obscuring traffic signals.

Lessons learnt

> Clear signing, traffic signals and carriageway markings at roundabout with trams running straight through helped to improve safety.

Barcelona, Spain: Roundabout (Carretera d'Esplugues - Joan Maragall)

Problem

Tramway speeds are high average 40km/h on slight gradient. Cars coming in direction of red arrow take a straight path and do not brake so speed when crossing tracks is high. Accidents at roundabouts are 4.5 times higher than normal intersections.

The accidents occurred on both parts of the roundabout.

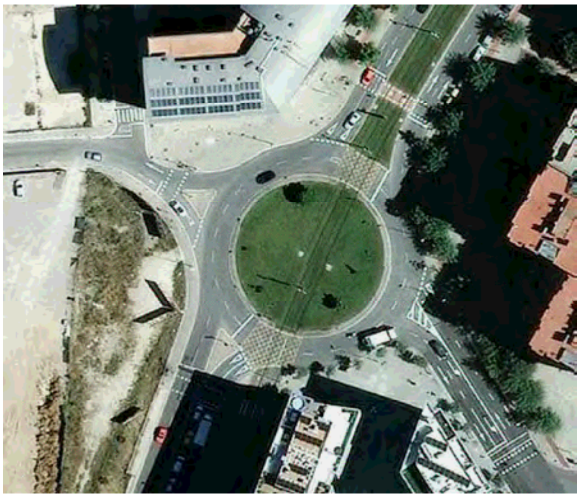


Figure 94 - Barcelona, roundabout (Carretera d'Esplugues - Joan Maragall)

Figure 95 – Barcelona, entrance on the roundabout

Figure 96 – Barcelona, when crossing tram tracks

Solution

Introducing all red phases was proposed but not accepted because of traffic delays. Adjustments made to signal timings and detector locations resulted in 75% reduction in accidents but rate is now increasing again, further measures are planned.

Lessons learnt

Signal timing and tram detector adjustments improved the safety of this roundabout.

Barcelona, Spain: roundabout with tramway running through

Problem

Road vehicles turning left at a roundabout risked collision with trams passing straight through the roundabout in either direction.

Solution

The sequence of traffic signals was changed to close the movements through the roundabout when a tram was approaching. The red lines in the right hand photograph show where red signals were provided to prevent road vehicles moving into the path of a tram. After revising the signals, accident numbers decreased by 80%.

Lessons learnt

Revised signals can resulted in a reduction of accidents with trams at roundabouts.

Teneriffe, Spain: Tres de Mayo Roundabout. Av. 3 de Mayo – José Manuel Guimerá

Problem

The common accident cause was drivers miss the red light. The roundabout exterior diameter is 76 metres.

Solution

They have duplicated the traffic lights located on the edge of the tramway alignment. Another traffic light was installed at the entrance to the roundabout.

Figure 97 - Teneriffe, Tres de Mayo Roundabout, additional traffic lights

Due to a derailment after a collision with a city bus, a new traffic light was installed on the nearest entrance to the roundabout, so that the drivers can only proceed when a tram is not crossing.

Figure 98 - Teneriffe, Tres de Mayo Roundabout, additional traffic lights

No more accidents since 2012 and they have implemented the corrective measures in other points of their network.

Lessons learnt

Traffic lights installation or duplication at a roundabout’s entrances close to the tram tracks were effective in reducing accidents.

4.2.1.3 Junctions (11 cases)

Vienna, Austria: Langobardenstraße # Tamariskengasse, 1220 Vienna

Problem

It is a three way junction, both tram tracks have to be crossed when turning from Langobardenstrasse into Tamariskengasse. Stop line or designated lane for left turns did not exist. There was no single location of accidents but several different accident types. Visibility is reduced due to bridge construction and the junction is located close to a tram stop.

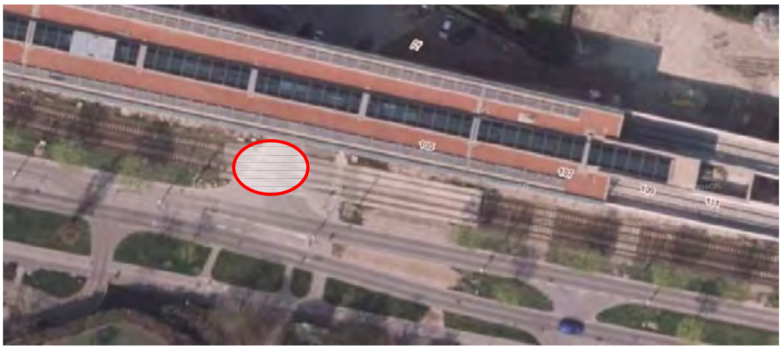


Figure 99 - Vienna, Langobardenstraße / Tamariskengasse junction (before) [Source: ViennaGIS www.wien.gv.at/viennagis]

Solution

In 2010 during course of construction of new Metro station, the junction was completely redesigned and layout of tracks changed. Now only one tram can pass through the intersection at the same time. Traffic signals have been installed on each corner, activated by trams approaching from either side. A left turn lane on Langobardenstrasse was implemented with a stop line in front of tracks for cars coming out of Tamariskengasse. Accidents were reduced to zero after these measures.

Figure 100 - Vienna, redesign of junction (after) [Source: ViennaGIS www.wien.gv.at/viennagis]

Lessons learnt

Major construction works can give opportunity for redesign of traffic and tramway junction with consequent reduction or removal of accidents.

Montpellier, France: Avenue Bologne / Entrée Centre Commercial

Problem

Near Saint Paul station, a junction with an entry/exit of car park (commercial centre St Paul) was originally controlled by "Stop" static traffic signs. Trams enter station at 30km/h and leave at normal speed. Cars do not observe traffic signs turning right or straight on. They had 32 accidents in 13 years.

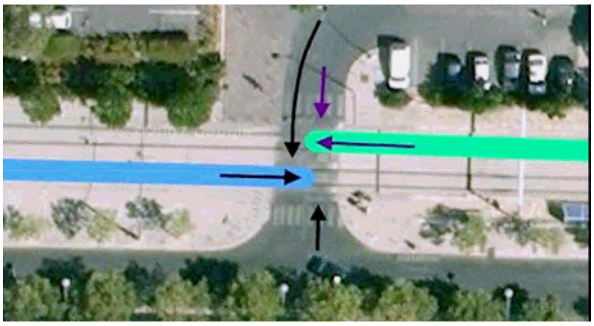


Figure 101 – Montpellier, Avenue Bologne / Entrée Centre Commercial [Source: TAM]

Solution

A "checkerboard" was painted on the road surface inside the junction. The kerbside was rebuilt with borders at 5cm, hedgerow replaced by low plantations, Stop signs replaced with message of "absolute Stop when tram present", installed end of 2012 with a significant reduction in accidents since then.

Figure 102 – Montpellier, zoom on the checkerboard

Lessons learnt

Shows method of improving safety by changes to signs, traffic signals and carriagway markings.

Montpellier, France: Avenue du Doyen Gaston Giraud / Entrée Hôpitaux

Problem

It is the main entry for three hospitals, with circulation difficulties at the entrance and cars potentially waiting on the tracks. Tram speed is 40km/h when crossing the road. There are complex turning movements including U-turns and traffic signals are not observed. There were 29 accidents in 13 years.

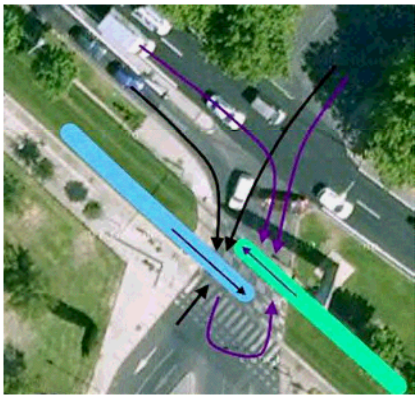


Figure 103 - Montpellier, Avenue du Doyen Gaston Giraud / Entrée Hôpitaux [Source: TAM]

Solution

A “checkerboard“ was painted on the road surface inside the junction. Traffic turning right into the hospital complex must enter a separate “turn-right” lane, which is separated from the main carriageway by a traffic island. Traffic proceeding straight along Av du Doyen Gaston Giraud is prohibited from turning right at the junction and to do so, the proposal has been made to install traffic signals before the junction and a static sign to show turn-right is. Moreover, the right-turn lane was lengthened, the traffic island was enlarged upstream and a right-turn arrow was added to make the separation for right-turning traffic long before the junction. And as advised by the guideline on Urban Junctions – CERTU, on approaching the junction, drivers first encounter the right-turn arrow and a discontinuous line, then a continuous line, then finally the traffic island providing a physical separation. There was a significant reduction in accidents.

Figure 104 - Montpellier, checkerboard added and traffic signals modified

Lessons learnt

It shows method of improving safety by changes to signs and signals and carriageway markings.

Lyon, France: Cordocet Ligne T1/T4

Problem

At the junction between rue de Condorcet and Boulevard du 11 novembre, the tram crosses the major road (2x3 lanes). Despite a 50km/h speed limit for cars, their speed is very high, tram and tracks visibility was poor.

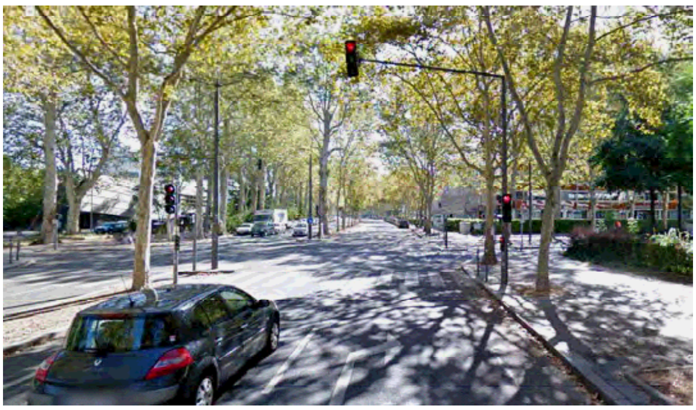


Figure 105 - Lyon, Condorcet and visibility (before)

Solution

Bushes were cut down to improve visibility. Cameras were installed to enforce traffic light compliance. The number of accidents decreased significantly.

Lessons learnt

> Traffic light enforcement and improved visibility can reduce number of accidents at junctions with heavy traffic.

Dublin, Ireland: Luas Red Line, Bow St Junction

Problem

Road junction crossing tramway is controlled by traffic signals and solid timber hoarding on the right hand side restricted sightlines for trams and road vehicles. Road traffic collisions between cars and trams caused by car drivers not being able to see the approaching tram and passing red traffic signals.

Solution

In cooperation with the land owners, a section of the solid timber hoarding was replaced with a mesh type fencing which has improved the line of sight for both tram and road vehicle drivers.

A reduction in incidents and accidents has been observed at this location.

Figure 106 – Dublin, Bow Street Junction. Before and after mesh type fence was installed

Lessons learnt

> This is an example of simple 'common sense' solution to basic sightlines problem which needed negotiations with several parties.

Dublin, Ireland: Junction of Queen Street and Benburb Street

Problem

Analysis of the Road Traffic Collisions (RTCs) and Emergency Brake Applications (EBs) at this junction indicated that the main causation factor was vehicles failing to stop at the red traffic signal. A number of issues were identified at the junction which were deemed to be contributory factors in the number of RTCs and poor road user behaviour:

- Poor intervisibility between trams and road traffic.

- The large yellow box and proximity of the downstream junction.
- Large volumes of pedestrians crossing away from the signalised crossing point.

Solution

The following modifications were carried out at the junction:

- The relocation of the existing pedestrian crossing and traffic signals.
- Moving the vehicular stop line and associated traffic signals on Queen Street some 8.5m south to improve intervisibility at the junction and reduce the effective width of the junction.
- Relocation of the inbound tram signal and stop line and detection to improve intervisibility at the junction.
- Reduction in the extents of the yellow box across the junction.

Figure 107 – Dublin, junction before modification

Figure 108 – Dublin, junction after modification

These modifications resulted in the following improvements:

- Increase junction intervisibility.
- Reduce the effective area of conflict at the junction by bringing the stop line closer to the junction and reducing the size of the yellow box area.
- Provide pedestrian crossings along the pedestrian desire line at the junction.

Lessons learnt

Changing the junction layout can reduce risks of conflicts and improve driver behaviour.

Amsterdam, Netherlands: Frederiksplein

Problem

Green time for tram crossing square was too short, and intersecting traffic had green light before it was safe.

Solution

Traffic signal green times for trams and cars were changed.

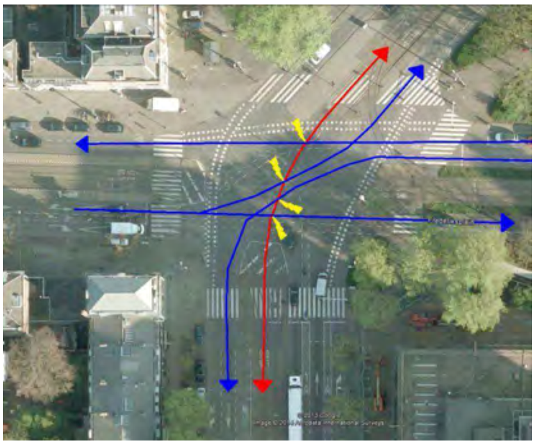


Figure 109 – Amsterdam, Frederiksplein [Source: GVB]

Lessons learnt

Accident rates can be reduced by simple signal timing changes without any detrimental impact on other traffic.

Almada and Seixal, Portugal: Metro Transportes do Sulm: Avenida 25 de Abril

Problem

The tramway runs on reserved track alongside a 2 lane major road. Accidents occurring at this location where a minor road crosses the tramway to join the major road were due mainly to a disregard of red traffic signals, or difficulties in entering the major road, remaining within the swept path of the tramway while awaiting entry to it.

Figure 110 - Almada and Seixal, Avenida 25 de Abril, the minor road

Solution

Road traffic signs and signals were reviewed. It led to coordinate the traffic on the major road with the crossing of the track by road vehicles from the minor road, thus allowing a continuous non-stop crossing of the tracks. The result of this measure was a slight reduction in the level of service for road vehicles on the major road but a significant reduction in the number of accidents.

Lessons learnt

Accidents can be reduced by changes to traffic signs and signals to take better account of minor road turning movements.

Zurich (Glattalbahn), Switzerland: Intersection Weststrasse/Hertistrasse in Wallisellen

Problem

The red signal was not observed by car drivers, cyclists and pedestrians when turning across tramway and conducted to four accidents in 3 years. Tram speed is 60km/h.

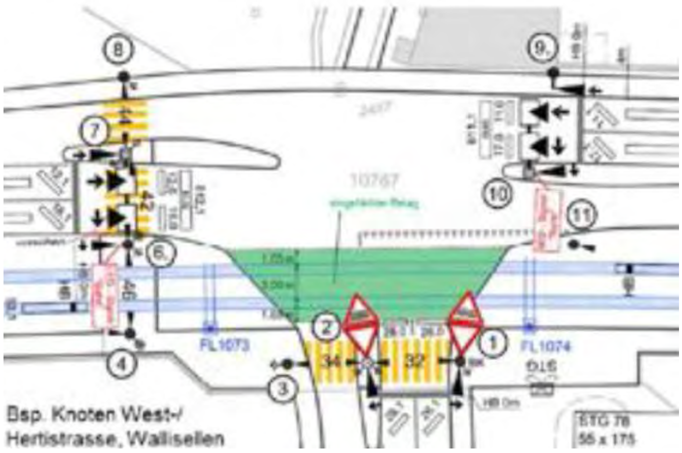


Figure 111 - Zurich, Intersection Weststrasse/Hertistrasse in Walliselle

Solution

They have marked the intersection area in light green and installed a LED-signal “BAHN”.

Figure 112 - Zurich, light green paintings on the ground

Figure 113 - Zurich, LED-signal „Bahn“

Also the signal dependency for pedestrians has been implemented: no “green” at the street crossing when there is “red” on the tram crossing so that pedestrians cannot mix up both signals. Pedestrians may not cross street if the tram crossing is signaled “red”. And barriers were installed to narrow the pedestrian crossing to show cyclists this is not a cycle lane.

Figure 114 – Zürich, signal dependency change

Figure 115 – Zürich, barriers on pedestrian crossing

The short time since implementation doesn’t allow any definite conclusions yet, however one collision between car and tram has occurred since then.

Lessons learnt

A combination of small improvements of different kinds can be applied to resolve specific problems. For example using surface markings, additional warning signs, synchronised pedestrian signaling, barriers channeling pedestrian and cyclist paths.

Manchester, United Kingdom: City Centre, Corporation Street/Balloon Street junction

Problem

Corporation Street was major traffic route into city centre, tramway crosses it at right angles to enter Balloon Street, a tram only street taking trams into city centre. Sightlines are restricted by tall buildings and the junction was a hotspot with 15 incidents between 2003 and 2013. The junction is controlled by traffic signals but some drivers did not see the lights which could sometimes be obscured by parked vehicles.

Solution

Some traffic management changes were implemented including narrowing the carriageway but the route has now been closed as part of major city centre traffic reduction measures and construction of the second city crossing tram line.

Figure 116 - Manchester, Balloon junction

Lessons learnt

Changing the junction geometry can reduce risk of conflicts. A more radical solution is to change areawide traffic management to reduce or eliminate conflicting traffic movements.

Manchester, United Kingdom: Ordsall Lane, Salford

Problem

Segregated tramway crosses a two lane road with traffic signal control. Road vehicles misread or read through to Trafford Road signals resulting in collision with tram. 14 incidents since 2004.

Figure 117 – Manchester, Ordsall Lane

Solution

Grilles fitted to green aspects of signals on Trafford Road to avoid read through by vehicles approaching tramway signals. The Highway Authority has also changed traffic signals coordination to give red signals for each line in the same time.

Lessons learnt

> The individual design of traffic signal details affects safety. Ensure that traffic signals can not be misinterpreted by motorized traffic. The modification of coherent signal timing can be used to avoid misinterpretation.

4.2.2 Pedestrian crossings (6 cases)

Brussels, Belgium: Lambermontlaan, 1030 Schaarbeek

Problem

Tramways have segregated tracks, speed is higher. Pedestrian crossings are not protected by pedestrian lights to cross the tracks. Dangerous situations occur when pedestrian rely on the green light which is meant to cross the street, not the tracks. They observed several pedestrian accidents per year. The red circles show that the tram has its green phase and pedestrians also but only to cross the street not the tracks. Most pedestrians assume the green phase is also valid to cross the tram tracks.

Figure 118 – Brussels, Lambermontlaan and pedestrian phase

Solution

A program was started to install traffic lights at pedestrian crossings. Whereever traffic lights are used for crossing the road they are also used for securing the track segment.

Lessons learnt

Signal controlled pedestrian crossing, which cover the entire length of the crossing, including road and tracks, can increase safety.

Brussels, Belgium: Pantheonlaan, 1000 Brussels

Problem

Tram has segregated tracks located beside the park, on a gradient. The view is blocked by trees on both sides of the tracks. The pedestrian crossings are wide enough to be unlawfully used by service vehicles entering and exiting the park. The park is very popular and frequently visited and visibility at night is poor.

Solution

Trams have been equipped with LED lights and signs were added at pedestrian crossings to remind that priority should be given to the tram. A fence was added over the whole length to force pedestrians to use the crossings, crossings barriers were placed to force cyclists to reduce their speed to cross so; service vehicles can no longer use the crossings to enter the park.

Figure 119 – Brussels, Pantheonlaan and barriers installed

Lessons learnt

When there is visibility problem and obstacles cannot be removed, complementary measures can be used to improve pedestrians safety (fences, LED lights on the tram).

Bremen, Germany: Wachmannstraße Kreuzung Carl-Schurz-Straße

Problem

Pedestrian and bicycle were crossing of Carl-Schurz-Straße via Wachmannstraße, disregarding an approaching tram. Trams run along a priority road on segregated track with max. 50km/h. Cars run parallel on one lane in a one-way-regime with max. of 30km/h. On the street there is a marked pedestrian crossing, also used by pupils. There were a cumulation of accidents leading to an intervention by local politicians.

Figure 120 – Bremen, Wachmannstraße Kreuzung Carl-Schurz-Straße

Solution

The intersection (and with that, also the pedestrian/cyclists crossing) has been converted to full signalisation. Since that (about 1 year) there didn't occur any accident with pedestrians/cyclists.

Lessons learnt

To convert to full signalisation is a heavy measure but successful here.

Milan, Italy: Viale Zara and Viale Testi

Problem

In the past years, they had problems with pedestrians, who crossed the intersection on the crosswalk without looking at the tram. Viale Zara and Viale Testi are the most important ways to get into the center of Milano for those that are coming from the north. There are a new line of undergroung (M5) and 3 tramways (5-7-31).

Figure 121 – Milan, Viale Zara and Viale Testi when problematic

Solution

During the construction of the new Underground M5, they have changed the most dangerous pedestrian crossings by creating paths that forces pedestrians to see if the tram is coming. They do not need any traffic lights.

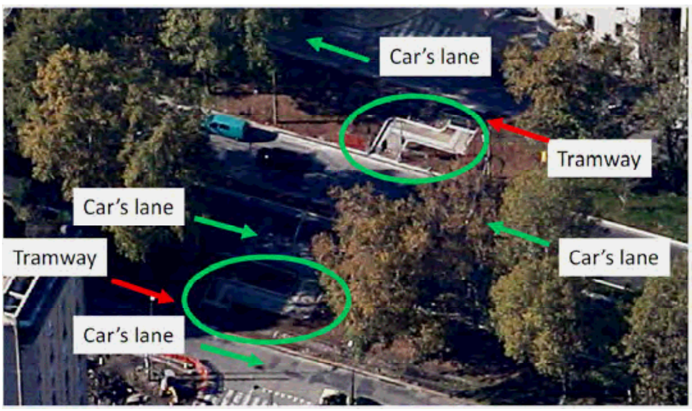


Figure 122 – Milan, Viale Zara and Viale Testi, global new layout

Figure 123 – Milan, to make pedestrians see the coming tram

Lessons learnt

By directing pedestrians to see the oncoming tram, safety was improved without traffic lights.

Bilbao, Spain: Ribera street

Problem

People are crossing the tramway track outside the pedestrian crossing with very limited visibility due to the arches alongside the tramway track.

Figure 124 - Bilbao, Ribera street

Solution

Small internally illuminated signs were installed in footway close to the kerb which are activated by an approaching tram to alert pedestrians. The warning lights were installed in June 2009. Pedestrian accidents have reduced by 60%.

Figure 125 – Bilbao, warning lights

Lessons learnt

This is an effective low cost solution where sightlines are very restricted.

Dublin, Ireland: Uncontrolled Crossings for pedestrians at Luas Tram Stops

Problem

There have been numerous near misses and contacts between persons and trams caused by pedestrians accessing the Luas platforms without looking out for approaching trams.

When walking, pedestrians can spend most of their time focusing on the footpath in front of them. When using smartphones their gaze can also be downward. Because of this pedestrians can easily miss warning signs at a higher level. In addition, high-level signs can be missed as they appear in the peripheral vision and may be lost in visual clutter around the signs.

Solution

They installed prefabricated thermoplastic tram warning pavement markings on the pavement at the uncontrolled crossings points at Luas stops. The pavement markings are placed before the point of conflict to give advanced warning. The colours were chosen to be as close to the current high level signs as possible and the black on yellow gives a very strong colour contrast. The markings only include symbols, for the advantage of a quicker and easier perception.

Figure 126 – Dublin, tram warning pavement marking

Figure 127 – Dublin, tram warning pavement marking at uncontrolled crossing at Luas Stop

Lessons learnt

The tram pavement markings are an effective method for giving a warning to pedestrians to look out for approaching trams before crossing the tramway and supplement the above ground warning signage currently erected at these locations.

4.2.3 Running sections (6 cases)

Montpellier, France: Place Auguste Gibert - Stations Gare Saint Roch L1,2,3,4

Problem

Most accidents in this pedestrian area occurred with non-authorised cars, trucks, and two wheel vehicles forcing tram drivers to make emergency brakes. They observed 30 accidents since 2000, with an average of 4 per year except 2012 (zero) and 2013 (2 events), and 13 emergency brakes by tram drivers in 2013.

Figure 128 - Montpellier, Place Auguste Gibert - Stations Gare Saint Roch

Solution

They have reduced tram speed from 20 to 10km/h and observed significant decrease of events since 2011.

Lessons learnt

> Speed reduction in crowded pedestrian areas can benefit in a decrease of incidents with pedestrians and other users of this croweded place.

Lisbon, Portugal: Calçada de São Francisco

Problem

All accidents reported involve the tram and private cars. The gradient is steep carriageway and footways narrow so very careful driving is required. The characteristics of the street is determined as a perceived as dangerous by the operator.

Figure 129 – Lisbon, Calçada de São Francisco

Solution

Drivers' training was improved focusing on the risky places. The number of accidents was decreased significantly. The outcome is considered positive.

Lessons learnt

Positive reduction in accident rate can result from targeted focus of driver training on specific locations, which are considered as hotspots, based on the operator's experience.

Geneva, Switzerland: Line 18, route de Meyrin, close to the junction with Vaudagne avenue

Problem

The operator observed frequent encroachments of road traffic on tram tracks. No accidents to mention but it was considered as a risky situation.

Figure 130 - Geneva, route de Meyrin

Solution

They've installed red and white small beacons to complete the marks on the ground and physically separate the lanes. This measure was implemented in several places on the network.

Figure 131 – Geneva, red and white small beacons

Lessons learnt

Additionally to white painted lines, physical objects helps street users to respect swept path and lanes.

Zurich (Glattalbahn), Switzerland: Ringstrasse in Dübendorf; three crossings

Problem

Turning car drivers get onto the tram line and get stuck there (ballasted track or slab track on a bridge). 6 accidents in first three months.

Solution

Additional marking (side line), additional traffic sign and posts between the tracks were installed. Since implementation, no wrong turns have occurred. Measures taken have been effective.

Figure 132 - Zurich, Ringstrasse in Dübendorf, three solutions implemented

Lessons learnt

Increased awareness of tramway has decreased number of wrong turns, by additional marking, additional traffic sign and posts.

Dublin, Ireland: James's Street

Problem

The cycle path on James's Street is adjacent to the track. If cyclists continue straight along the track, the cyclists would be in danger of been sideswiped by the tram turning left into the James's Luas Stop. In addition, if the cycle path continued to follow the line of the tram tracks, the cyclists would cross the tracks at a shallow angle. This would increase the risk of the tyres of the bikes getting caught in the groove of the embedded track.

Solution

The alignment of the cycle path moves the crossing point to a safer location and the cycle path is orientated to approach the tram tracks at a safer angle.

Figure 133 – Dublin, cycle path adjacent to tramway

Figure 134 – Dublin, cycle path crossing tramway

Lessons learnt

> The layout reduces the risk of contact between the tram and a cyclist, and cyclists can cross the tram tracks at a safe angle.

Dublin, Harcourt Street

Problem

A segregated section of tramway on Harcourt Street runs adjacent to a carriage way. The segregated tramway and carriageway is marked by a continuous white line. Along a section of Harcourt Street, cars parked illegally in the carriageway. This forced cars into the segregated tramway resulting in numerous road traffic collisions between road vehicles and trams.

Figure 135 – Dublin, Plastic bollards along the white line demarcating the swept path of the tramway

Solution

A row of plastic street bollards was installed along the white line, demarcating the swept path of the tramway. The row of plastic bollards prevents road vehicles from encroaching onto the segregated tramway. The bollards also act as a discouragement to people parking their cars illegally as these cars will now block the carriageway.

Lessons learnt

> Reductions in road traffic collisions after bollards were installed. A good example of a targeted control measure reducing risks of accidents.

4.2.4 Major lessons learnt from these experiences

The HotSpot survey has shown a wide variety of measures that were locally implemented. These measures were individually used to reduce or eliminate hazards and accidents between tramways and other users of public space. Many of these measures are low cost and relatively quick to implement although as the relevant authority is usually involved, reaching agreement can extend timescales.

Typical low cost measures include changing or adjusting traffic signal timings or phases, introducing or improving tram detection and priority signals (signals activated by trams), introducing separate signals or filters for turning traffic, changing lane markings and providing physical separators, and improved traffic signing.

A common cause of accidents is where left turning vehicles (right turning in UK and Ireland) cross a tram track to their left and do not see an approaching tram. Many examples show that the conflict could be removed by signalling the left turn separately, re-routing left turn movements or providing clearer traffic signs or signals.

The examples also showed that major reconstruction works, for example for a new tramway station or a new intersection, also bring the opportunity to re-design the tramway tracks to to reduce or eliminate conflict points between trams and other street users.

Generally, special attention is needed to reduce conflicts with pedestrians and cyclists by improving sight lines, modifying guardrails, introducing chicanes and improved signing and lighting.

Roundabouts with tramways can be problematic. This issue is discussed in detail in chapter 3.6.2.

The speed limit of trams was being reduced in specific situations, especially in pedestrian zones. However the reduction of speed for other street users, particularly cars, should always be considered first, as most accidents affecting trams are not caused by trams but by other traffic participants. It also has to be considered that the reduction of speed is translated directly to a decrease of incidents but can show opposite effects.

Targeted training courses for tram drivers and driver awareness campaigns can result in improved safety.

Many of the features described here can be incorporated in new tram systems or extensions to existing systems to avoid the occurrence of accidents before the system opens.

5 General conclusions from the whole Action

Over the last few decades, the introduction of the modern tramways has raised new issues for countries that have discovered or reintroduced them, while in the meantime, on the other hand, countries with historical tramway networks had the need to modernise their systems, often in a difficult financial context.

This report is the result of sharing European experiences in order to better understand the link between tramway safety and public space layout, to improve this safety as much as possible, through a better management of their insertion in urban areas, and thus to minimise accidents and their impacts on both the transport system and on society. These improvements in tramway safety should help in reducing the number and the severity of accidents between tramways and other public space users (pedestrians, car drivers, cyclists...); it would thus play a part in improving road safety in general and for vulnerable users in particular.

This Action aimed:

- to improve the safety of European tramway networks by leading to a better knowledge and understanding of the causes of accidents,
- to bring to light and identify the link between safety and productivity performance by raising the subject of “increase in safety vs. increase in costs”,
- to decrease the costs of accidents (both maintenance and operating costs),
- to contribute to rationalising and optimising the investment in the tram/LRT system,
- to improve its urban insertion, its safety conditions and its efficiency and reliability,
- and indirectly to assist in moderating the use of individual transport in urban areas.

In Chapter 2, data collection was discussed. It was observed that only a few countries have a mandatory, centralised scheme for recording accidents and recording them in a database. Nevertheless, the TU1103 group believe it is important that all tramway systems collect basic data in a standardised and continuous way, to possibly derive sufficient safety measures from their evaluation (to get valuable statistics, references and tendencies at a large scale, to make general analysis on one specific issue or identify the need for in-depth studies). And an Ideal Accident Report (IAR) was devised as a suggested template to collect all necessary data in order to reach a comprehensive analysis and assessment.

A certain number of other tools for collecting data about accidents were also presented. These include black boxes, reports from drivers and other eyewitnesses, photographs, CCTV images, occurrence books, voice recorders, Street Information Systems...

The different types of useful indicators were also discussed, highlighting some which were thought as the most useful for monitoring tramway safety and precising their uses and limitations.

In Chapter 3, tram infrastructure layouts were analysed and five main interaction points between trams and other road users were identified: road junctions, roundabouts, pedestrian crossings, stops and stations, and running sections (that is, the stretches of track without junctions or stops). The main types of hazards associated with each type of interaction point were identified, key objectives to be achieved defined and possible measures suggested for avoiding them, illustrated by examples where available.

- At junctions, left turns were identified (right turns in UK and Ireland) across the tram tracks as the main risky points, and suggested measures to avoid physically the movement or organise it properly by specific lanes and by making road drivers more aware of the approach of trams. These could include traffic signs and signals, road islands, road markings, left turn lanes, approach as perpendicular as possible to the tracks, stagger the traffic light line of each movement.

- At roundabouts, was pointed out how important it is to make drivers aware that there is a tramway crossing the traffic lanes by means of vertical and horizontal signs, signals, road pavement markings and flashing lights.

- At pedestrian crossings, were identified the main objectives to improve safety which are to make users aware of the presence of tram vehicles and tracks, give them a good level of information about priority rules, protect them from trams and other road traffic in motion. Pedestrians are vulnerable public space users but at the same time difficult to constrain. They walk at random and prefer to cross at the shortest place and this must be taken into account. A proper balance has to be found between meeting pedestrians' desires and the tramway operation needs for regularity and speed.

- At stops and station areas, it was highlighted that the main hazard comes from passengers and other pedestrians crossing the tram tracks and/or the road to reach the platforms; or from passengers waiting on a crowded platform where they might fall into the path of a tram or a road vehicle.

- On running sections, which includes segregated sections, mixed zones and pedestrian sections, different issues were observed but mutual visibility, perception and good information are, as for all interaction points, the key factors for designing a safe tram layout.

In Chapter 4, some examples of success stories from several tramway systems were addressed, from operators indicating the types of location on their systems that had presented risks of accidents, and examples of measures which have been taken to reduce the risks.

Generally, public urban space is designed and built based on regulations and experience. Still, accidents involving trams occur, which are mainly caused by third parties. The major task in avoiding further accidents due to traffic misbehaviour or bad perception is to develop measures which raise the awareness of pedestrians, cyclists and drivers of motorised vehicles. Accidents which involve trams rarely show a systematic character. Therefore, implemented measures are generally highly localised.

The Action was a source of rich and fruitful exchanges between its members who shared their tools, experiences, success stories, and methods and also for all safety authorities and monitoring organisations at different levels, other transport agencies and tramway operators, road network managers, other designers, architects, engineering consulting firms, and research bodies. The TU1103 team provided a pool of knowledge in the subject area, together with a number of successful (and maybe also less successful) experiences from which a large number of people can ultimately benefit. The group has shared strategies and ideas which had been implemented in one country that could have the potential to be transferred and implemented in other countries, possibly avoiding an operator having to learn by mistake, thereby increasing the service for public transport users and economising on resources. Moreover, especially when stakeholders have questions or want to set up an evaluation, it is interesting to see if it has already been addressed somewhere else, in particular in countries with a long experience of trams and LRTs (for example: impact of safety on productivity performance, costs, and on the level of service) and to know what results have been obtained.

This international network proved to be one of the best ways to get out of a "national only" point of view, and to open one's mind to ways of doing/sharing experiences and good practices. The multidisciplinary approach of the project has avoided looking at different situations and issues from only an individual and unique perspective.

However, the knowledge of the statutory context is imperative, to avoid too simplistic comparisons and hasty transpositions of configurations or ways of design and operating. Moreover, behaviour, legislation and safety culture are different from one country to another and local context, restrictions and culture must be taken into account. A solution that works well in one context may not be directly transferable to a different context. It should be considered and perhaps successfully adapted to meet the local needs.

So, after four years of sharing experiences from all over Europe, discovering other methods, gathering knowledge, recognising similarities, learning from our differences… between tram operators, safety authorities, researchers, designers, about safety management, data collection and/or layout solutions, the COST Action TU1103 has successfully presented in this report the essential results produced by this networking.

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N.7 “Tram Priority” – Fabio Politi

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