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Safety and operation of tramways in interaction with public space

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Abstract

The COST Action TU1103 "Operation and safety of tramways in interaction with public space" aimed at contributing to improve tramway safety through improving the management of data collection and the design of their insertion into urban space. The action has shown that across all the countries involved exists a great diversity of tramway systems and safety management mechanisms. Despite this diversity, we have been able to reach some conclusions about the nature of safety issues, the need for relevant information and the operator's essential role. This has enabled us to lay out some practical recommendations on accident data collection, indicators and their analysis. We have also observed a great variety regarding the urban insertion of tramway systems. Some countries pay special attention to protection, using barriers and fences as the general way of inserting the tramway. Other countries try to get a more integrated system, with an easier coexistence with pedestrians and cyclists in the city centre, but still guaranteeing the capacity and adequate speed of the tram when running through the metropolitan area. In any case, tramway systems deal with safety issues that are very similar in all countries, and the solutions and measures applied in some places can be useful for other networks facing similar problems or implementing a new line. This Project is funded by European Cooperation in Science and Technology (COST).

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Tramway; safety; urban insertion

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1. Introduction

This project, undertaken from 2011 to 2015 with support from the European Cooperation in Science and Technology (COST), was aiming at bringing together stakeholders from a variety of organizations across Europe involved in tramway management in order to share experiences and identify key recommendations to improve safety management. The COST Action TU1103 “Operation and safety of tramways in interaction with public space” deals with the improvement of tramway and Light Rail Transit (LRT) safety through a better management and design of their insertion into urban space. After a first phase led on institutional and regulatory aspects, the Action has covered data collection on accidents (tools, indicators...) and infrastructure design (based on existing configurations and feedback from operators, with a hazard consideration). It offers suggestions and best practice for supervisory authorities and monitoring organisations at different levels, transport agencies and operators, road network managers, designers, architects, engineering consulting firms, and research bodies.

After a brief overview of the Action’s scope and general results, this paper proposes monitoring tools, including an Ideal Accident Report and other sources, while suggesting concrete indicators to improve data collection and information sharing. We then introduce the concept of “network hotspots” and show how it can contribute to improve safety management in tramways. Finally, we have a glance on infrastructure design, stating the main aspects that have to be born in mind to make the tramway as safe as possible. European approaches relating urban insertion of tramway systems are very different, but tramway systems across Europe deal with safety issues that are very similar, and the solutions and measures applied in some places can be useful for other networks facing similar problems or implementing a new line.

2. Monitoring tools

2.1. What could be an ideal accident report

Our working group has gathered some examples of accident reports to get an overview of practices and an idea of the content and of the key points not to forget. Then after a brainstorming, an ideal accident report was proposed. Finally, it was checked by all operators and UITP (*Union Internationale des Transports Publics*). The following Ideal Accident Report is a suggested model adaptable to each operator’s needs. But more than a suggestion, it is a detailed list of pertinent data we strongly advise tramways operators to collect, in order:

- to allow later analysis and better understanding by operators but also researchers,
- and to use data for evaluation and accident prevention.

For many operators the use of template check-lists and accident report forms has been successful. A homogeneous design of these documents within the operating company can ensure consistent data acquisition and evaluation. If time allows it, someone else than the tram driver in the tram company should collect information from this one and other sources about the accident (location, circumstances, etc.), help the driver to deal with passengers and save time to restart the operation. This person should reach the accident place as soon as possible and collect the following data:

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

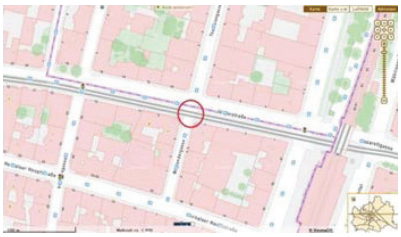

Fig. 1. Ideal accident report: location of accidents.

- 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 type of segregation (physical or visual)
- Environment
  - Fog, snow/ice, rain/storm, leaves on tracks
  - Operational disturbances: degraded service, works, temporary speed limits, maintenance, manifestations
- Actors
  - Identification of tram vehicle, characteristics of third party (e.g. age, sex...)
  - Tram driver's name
  - Involved persons or vehicles (passengers, third parties)
  - Witnesses (if possible)
- Description of accident
  - Drawing or sketch (of intersection, vehicle and persons movements, place of impact on vehicles, signal type – dynamic/static- and location), pictures

Fig. 2. Ideal accident report: sketch over photo.

  - Direction of travel (track 1 or 2 for tram), road (for other involved party)
  - Mark on the floor indicating the final position of the involved vehicles
  - Interview with tram driver
  - Interview with car driver and witnesses (if possible)
  - Classification of accident: use local form (if available)
  - Causes: Left turn, distraction, red light crossing, unauthorized manoeuvre, lack of visibility (influenced by geometry, obstacles, traffic and/or weather, lightening conditions), etc.
  - Description of any unusual facts (consider collecting information for human factor post-analysis)
  - If risk management in place - assign risk to incident
- Technical data
  - - Black box: Speed, emergency brakes, bell, turning signal
  - Radio exchanges recordings
  - CCTV
  - Switches and trackside signalling systems
  - Traffic lights state (phases)
- Consequences
  - Personal (severity of the injuries (light, medium, severe, deceased)) for staff, passengers and third parties
  - Material (to tram, to third party vehicle, or element): severity of the damages (light, medium, severe), technical report if available
  - Infrastructure (severity of the damages (light, medium, severe))
  - Operational (cancelled trips, delays, overspills)
  - (Suggested) classification for consequences: accidents with injuries or heavy material damage / ("Regular") accidents, no injuries / Events with no further safety-related relevance

- Entities 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 parties protection, coordination with responsible entities)
  - Expose immediate corrective measures taken by the operator (for example, lower speed) or other implicated organisms (for example, 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

It is necessary to ensure the consistent and 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, driver's support). Therefore, in theoretical and practical training, employees acquire the required capacities to take appropriate measures in case of an accident. Employees in charge have to participate in drills and practice their skills in data acquisition to ensure a high quality of permanent and structured internal data.

2.2. Other sources of information

Collecting data in the field through a standard accident report immediately after the event is the primary way to obtain necessary information about an accident from direct sources. However, other sources may be used to get relevant information regarding accidents. Moreover, some of them can contribute to dealing with safety issues while analysing the context of tramlines and the interactions between tramways and third parties. Those include for example: automated event recorders ("black boxes") on tramways, CCTV devices on tracks and in front of trams, Traffic handling Information Systems, Police reports, etc.

In particular, near misses can provide critical information. Therefore other tools exist or can be applied to get a better insight of the risks in the network on the one hand, and about the driver's behaviour on the other hand. Tram drivers are trained in defensive driving techniques and are constantly looking out for pedestrians, cyclists and motorized vehicles to prevent a collision. Evidence suggests that these emergency brakes are often in reaction to acts by these third parties. A useful indicator of a precursor to an incident (near miss) is how often and where tram drivers have to brake in emergency. Collect this information will enable us to gather rarer data on risks and provide useful statistics to prevent accidents by identifying risky places – where an accident has not happened yet but is likely to happen in the future.

2.3. Indicators, an output of data

Regarding tram safety, indicators are a useful tool:

- to show the trends in terms of safety, to give general information about it 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 implemented 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.

Behind the general goal of indicators, there is the characteristic idea of comparing things while using figures. While using indicators, people should rather try to compare data themselves and in time; on another side, making comparisons between networks or parts of them is not often relevant and needs to be very carefully done because of the different contexts.

During the state of the art phase, three categories of indicators for tramway safety related to interaction with public space have been identified.

- "Global" indicators

When following trends in order to assess the safety, a comparison can be made - in time (e.g. 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:

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

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

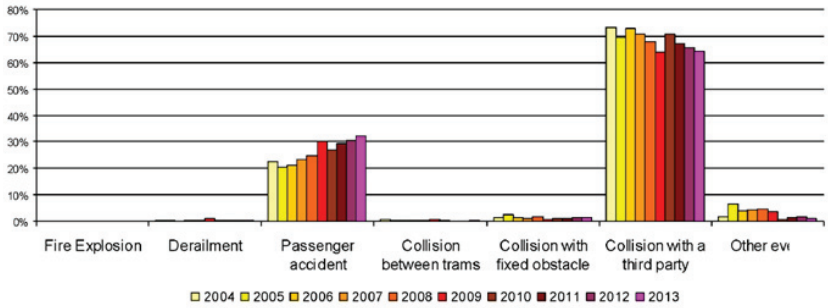

Fig. 3. Relative distribution of events on French tramways networks (STRMTG, Accidentology of tramways - Analysis of reported events: year 2013, evolution 2004-2013, France).

- "Geographical" indicators

This second group refers to indicators calculated and used in reference to localization of accidents. They are used to compare figures regarding:

- different parts of networks,
- various types of places (junctions, stops, etc.),
- spatial localization of accidents.

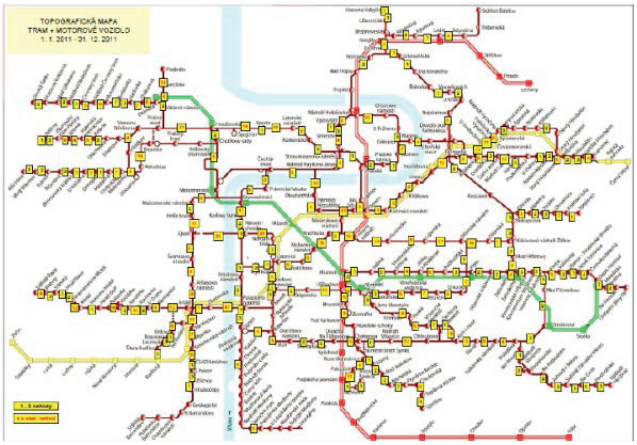

Fig. 4. Location of accidents on Prague network (Czech Republic).

Identification of "hotspots" (see further) is a good example of this use of indicators.

- "Typological" indicators

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

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

We use figures about severity of accidents to determine that pedestrians and cyclists are the most vulnerable victims during accidents.

2.4. Limits of indicators

As far as our aim is not to compare the performance of networks regarding tramway safety, there is no requirement for authorities, operators or regulation bodies to produce and use exactly the same indicators.

This leads to a first limit which is the availability of data required to produce safety indicators. A second limit is the existing difference in definitions in the data collection tools. For example, some countries do not separate collisions between trams and collisions with other vehicles, while fixed obstacles can be part of the rail systems. A third limit is linked with different context of accidents and operation: frequencies of tramways, nature and level of traffic, layout (segregation of tracks, regulation and signalling), users' behaviours, etc. Moreover, regarding this kind of information, an additional (and strong) limit may be the unavailability of data regarding car traffic (especially to compare places).

2.5. Some examples of the most useful indicators

Setting up common definitions and similar ways of calculating and using indicators would be a very good thing to enhance mutual comprehension, sharing and cooperation between operators, safety authorities, cities, researchers, etc. But if figures are not directly comparable, methods, ways of doing and safety policies are. To have unique indicators everywhere would also be very useful for researchers dealing with tramway safety for avoiding 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, requiring human, financial, and technological resources. The choice and definition of these indicators is to be made while considering their relevance and potential use, but also by taking into account the fact that data is to be gathered by operators, and originally for most of them by the tram drivers.

Whatever the definitions of data used, the core issue is to make the context of data or indicators explicit 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 to maintain same ways of doing over time.

Representative indicators must be statistically significant; however, it is difficult to establish a minimum number of records in an absolute way. In any case, an important issue is to give information about the size of the sample (number of events, or configurations, etc.) on which the indicator is based.

In the example, only indicators with significant number of junctions are relevant – (number of configurations = red bars).

Through the discussion facilitated by the project, we have identified a list of key indicators which we believe are the most useful for tramways safety monitoring. Among those, we have selected a reduced number which can be considered core data to be collected by the operator.

- Global indicators
  - Number of accidents (raw data): counted accidents during the period
  - Number of fatalities, injured persons (raw data): counted injured / fatalities during the period
  - Accidents per train x km per year (ratio): number of accidents divided by number of kilometres run

- Geographic indicators
  - Number of accidents per place (raw data): number of accidents per places per period
  - Distribution of accidents by types of places (relative): percentage of accidents for each type of line section
  - Distribution of victims by types of places (relative): percentage of victims (fatalities, injured) for each type of line section
  - Number of accidents per number of type of places (ratio): number of accidents on each type of place divided per number of each type place (during a period/ each year)
- Typological indicators
  - Distribution of accidents by third parties (relative): percentage
  - Distribution of injured and fatalities by third parties (relative): percentage
- Economic indicators
  - Number of lost kilometres/ number of planned km (ratio): length of non-operated services divided per total length of planned km.

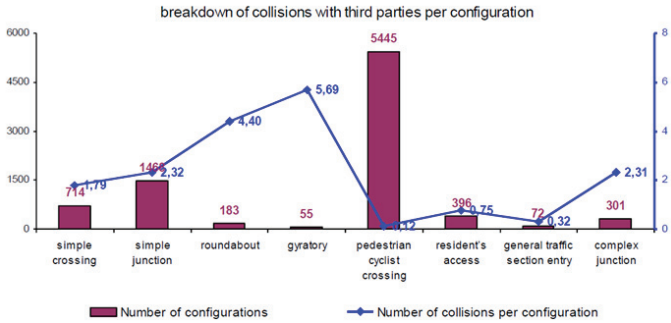

Fig. 5. Example of graph with number of events (STRMTG, Accidentology of tramways - Analysis of reported events: year 2013, evolution 2004-2013, France).

For each indicators, a table 1 has been set up to highlight the main characteristics. An example is given here:

Table 1. Example of one indicator's description.

Distribution of accidents by third parties (relative)	
Nature	Percentage; distribution by types of third parties: pedestrians, cyclists, bikers; vehicles.
	Vehicles might be distributed regarding main categories (cars and lorries at least)
Category	Typology
Representation	Tables
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	Setting up solutions to avoid accidents at local scale

2.6. A main issue at the local level: the identification of hotspots

This word "hotspot" means here a specific location on the tram network defined as one of the places in the urban area where the most accidents (collisions) occurred, in a fixed period. However, it has appeared during discussions that this word was used with different meanings and to illustrate different safety approaches. Indeed, there are

several possibilities to identify hotspots, while counting the number of accidents per location all along the line (for the last year or for the last x years):

- People may focus on highest ones (in absolute values) (Fig. 6 up left) or on those which are above a minimum number (e.g. 3 per location during the period) (Fig. 6 up right).
- It is also possible to calculate the augmentation/diminution rate and focus on the locations with the highest increase of collisions (Fig. 6 down left).
- It is also possible 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 (Fig. 6 down right).

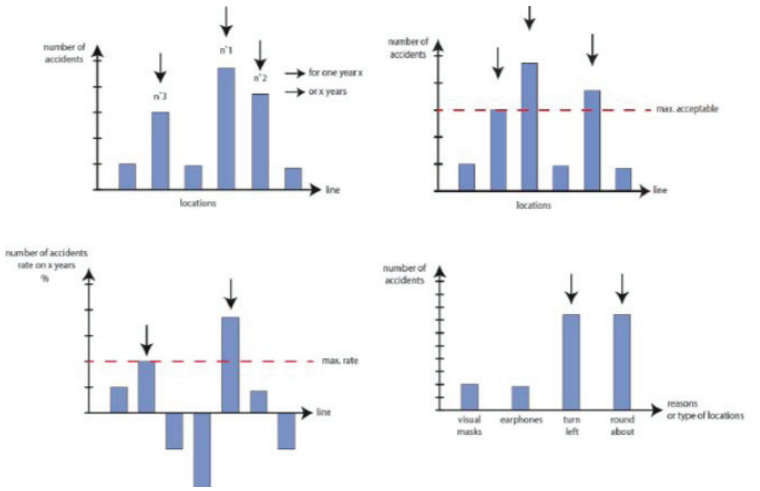

Fig. 6. Different possible identification of hotspots.

Besides data regarding accidents (reactive hotspot identification), information given by drivers, line managers and trainers can also contribute to hotspots identification, because these people on the field may predict potential accidents somewhere before they happen (pro-active identification). One should foresee a channel of communication to that audience, and make sure they receive feedback every time they report an issue.

There are different possibilities to identify hotspots: 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. The consequences of this identification are to know where to put most efforts. There is no management in particular to highlight, but all can be complementary. However, to identify hotspots and have at least a view on a few years on all spots along the tramline is a good starting point: identification of hotspots is the first step before in-depth post analysis and proposals of improvements (traffic signals, traffic lights, paints, tram driver trainings, safety street usage campaigns, etc.). This “classification” (n°1, n°2... or all spots above x accidents on x years...) is a way to know where to focus efforts (time to observe, to analyse, financial investments).

3. Infrastructure design

3.1. Main aspects of tramway infrastructure design in relation to safety

Three main concepts have to be considered in tramway design for guaranteeing safety: the visibility between the tram and other street users (road vehicles drivers, pedestrians and cyclists); the perception of the system (and information to other street users), and the tramway protection in its interaction with them.

The first one, visibility, is an essential aspect for guaranteeing tramway safety. During the design of the layout, visibility has to be born in mind from the beginning, in order to avoid subsequent problems. Generally, the main considerations about visibility are:

- For the case of visibility in road junctions, the best way of guaranteeing it is by making the junction arms perpendicular between each other. Even if the existing streets were not perpendicular before the implementation of the tramway, sometimes the junction can be transformed to a right-angled one with some slight modifications, if the space is available (see Fig. 7a&b).
- On the other hand, both in junctions and in running sections, several aspects related to visibility have to be considered: the removal or movement, if possible, of elements that impair visibility between street-users and the tram (see Fig. 7a&b); and the provision of adequate lighting conditions to guarantee visibility at night or in any other specific circumstances that can limit it.
- Additionally, it is important to bear in mind the visibility of signs and traffic lights. Measures for that, identified during the Action as usually utilized by operators, can be: the elimination, if possible, of elements that impair visibility of signs and traffic lights; the use of oversized signs in specific troublesome locations; the enlargement of red traffic light diameter; the use of brighter lights (for example, LED), but considering the possible blinding effect, especially at night; and the use of a backboard behind traffic lights.

In any case, it is common to have some zones of the tramway network where visibility is poor due to the geometry of the tracks (sharp horizontal or vertical curves), to the streets layout (narrow streets), and/or to the existence of specific obstacles that cannot be removed or relocated. In those cases, the lack of enough visibility has to be mitigated by strengthening perception and protection measures.

On the other hand, visibility is specifically crucial when the tram is present or approaching. Nevertheless, even when that is not the case, the other street-users have to be aware of the existence in the street of some zones that do not belong to them (but to the tram). Raising this awareness is the objective of perception and information measures (whether the vehicle is present or not). Among measures related to perception, the more important ones in infrastructure design are: finishing of the tracks with different material, colour or texture than the surrounding areas (see Fig. 8b&c); and marking the swept path of the vehicle.

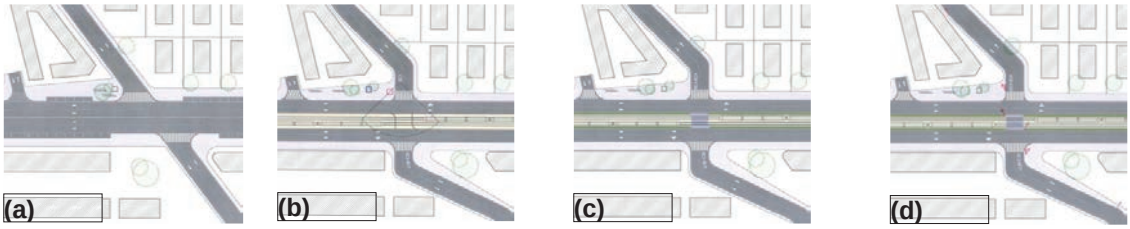

Fig. 7. Measures for visibility, perception and protection in relation to road vehicles in a tramway implementation. a) Condition of the junction before the tramway implementation. b) Visibility: transformation of the existing non-perpendicular junction into a right-angled one; elimination of visibility obstacles (green circles and change of obstacle from the red position to the blue one) + Perception: tramway tracks paved in a different material or colour than the adjacent lanes. c) Perception: clear identification of crossing zone by colour contrast + Protection: vegetal separator. d) Protection: vertical road signs (long and short distance signs) + Traffic lights.

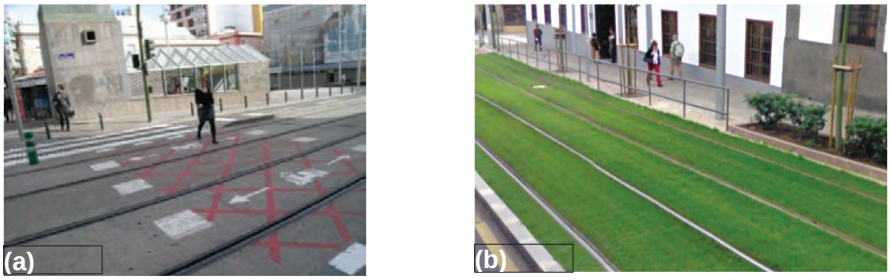

Fig. 8. Measures for perception (information) and protection in relation to pedestrians in a tramway implementation. a) Perception (information): pavement marking. b) Protection: barriers (metallic and vegetal barrier).

For improving perception of the tramway system, several information measures can be used, like vertical and horizontal informative signs, as the ones addressed to pedestrians at pedestrian crossings (see Fig. 8a).

Finally, the protection of the tramway system in relation to other street-users is also very important, both for assuring safety and for allowing trams to run at adequate speeds in some specific zones. Measures for protection can be physical barriers (for instance, separators from traffic lanes or fences and barriers for pedestrians – see examples in Fig. 7c and 8b), and prescriptive signs and traffic signals for road vehicle drivers (see Fig. 7d).

3.2. European approach to tramway insertion in relation to safety

In Europe there are different approaches to the insertion of tramway systems. Some countries pay special attention to protection, using barriers and fences as the general way of inserting the tramway system, with a predomination of right of way of Category B (separated) and even A (controlled) as defined by Vuchic (2007), and with an approach closer to that of the heavy rail. Other countries try to get a more integrated system, with an easier coexistence with pedestrians and cyclists in the city centre, using in some stretches even Category C (shared) as defined by Vuchic (2007), but still guaranteeing the capacity and adequate speed of the tram when running through the metropolitan area (mainly with Categories B and sometimes A). Both styles provide adequate safety and can lead to good results, as long as citizens understand the priority rules and how they should behave in the surroundings of the tramway system. This understanding is, very often, determined by the history and tradition of tramway systems in the country, and by the existence (or not) of a national approach in the introduction of new systems. In any case, even with the particularities, the solutions and measures applied in some places can be useful for other networks facing similar problems or implementing a new line.

During the Action, the main interaction points of tramway systems were identified, and classified in five main categories: road junctions, roundabouts, pedestrian crossings, stops and stations, and running sections (any location of the tramway out of junctions, roundabouts, pedestrian crossings and stops). For each of these interaction points, the main safety principles were stated, and a table was developed identifying hazards, objectives, and common measures used by operators to avoid those hazards. All this work is gathered in the final report of the Action (Fontaine et al., 2015), which is available in its website: www.tram-urban-safety.eu.

4. Conclusion

Whatever the organisation and the level of safety, the existence and quality of safety-related data remains a crucial pillar, and the operator is the core actor in the collection and use of such information. The collection of data immediately after the tramway accident is crucial for the subsequent investigation of the root causes, and if some specific facts are missing in that moment, it can be very difficult to gather them later. This is why a list of contents of the Ideal Accident Report has been included in this paper.

On the other hand, indicators are a very useful tool to assess the safety of a network, and its evolution in time. Operators use several kinds of indicators that have been listed in the paper, but limits to their use are also important, and have been stated.

Finally, one of the main ways to make a tramway as safe as possible is a good design of its urban insertion, considering the three main aspects stated in the paper: the visibility between the tram and other street-users (road vehicles, pedestrians and cyclists), the perception of the system (and information to other street users) and the tramway protection in its interaction with them.

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