LRT urban insertion and safety: European experiences

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ABSTRACT

This paper provides a rough design toolkit for improving the safety of LRT (Light Rail Transit) urban insertion. This toolkit has been prepared after the analysis of more than 130 examples of good and bad practices related to LRT urban insertion in 13 European countries, which have taken place during the first working phase of the COST Action TU1103, "Operation and safety of tramways in interaction with public space".

The paper deals with the design of the following aspects: pedestrian pathways at stations/stops; platform design and station/stop location; pavement treatment on shared space; pavement treatment on segregated channels; LRT separators on segregated channels; intersections (left-turn intersections, roundabouts, pedestrian and cyclist crossings, innovative solutions at intersections); LRT channel differentiation and protection by means of pavement, marks, fences and barriers; and OCS (overhead contact system) poles location.

1 INTRODUCTION

The COST Action TU1103, "Operation and safety of tramways in interaction with public space", deals with the improvement of streetcar and Light Rail Transit (LRT) safety through a better management of their insertion into urban spaces.

In the first Working Phase of the Action (WP1) an inventory of the current situation has been made, for every participating country: Belgium, Czech Republic, France, Germany, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Spain, Switzerland and United Kingdom. This inventory is related to three main subjects: institutional and regulatory aspects in relation to LRT safety; data collection on accidents at national and local levels; and infrastructure design.

The aim of this paper is presenting part of the work done by the Working Group 3 (WG3) during WP1, related to the third point: infrastructure design. WG3 first conclusions are going to be presented, and they intend to be a rough design toolkit for improving the safety of LRT urban insertion, through the explanation of some good and bad practices identified during WP1. This toolkit can complement the TCRP 137 and 17 reports [1, 2] with a European perspective.

2 METHODOLOGY

The first task carried out by the Working Group Members (WGMs) was the identification of the interaction points (the main points of the LRT 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 noted that "interaction point" term has a wide meaning in this case, including interaction locations and other interaction elements as well (signaling and signage).

Once these interaction points were identified, examples of good and bad practices related to them were gathered by the WGMs from each country. Then, these examples were analyzed leading to the conclusions about LRT design that are going to be presented in the third section of this paper.

The kinds of LRT Rights of Way considered in this work were Category B (segregated) and Category C (shared) as defined by Vuchic [3].

2.1 Interaction points identification

The need to study separately the stations/stops and the rest of the infrastructure (called between-stations) was the first conclusion achieved when trying to identify the interaction points. This distinction is made due to the important differences between those two kinds of zones, both in relation to LRT operation and to users/pedestrians' behavior.

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

In relation to users/pedestrians' behavior, most people around stations/stops are the users of the system, so they are aware of the approaching vehicles as they want to board them. Hence, it could seem that these zones would be safer because of this awareness. Nevertheless, there are several circumstances that make the stops particularly troublesome points:

- Users hurrying to catch the LRV, which can lead them to behave in a riskier way.
- The tendency to cross the tracks via inappropriate paths, in order to get a 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 edge usually marked in bright color for users to keep away from it).
- The possible existence of standing LRVs which restricts the visibility of other approaching LRVs.

On the other hand, the other street users in between-stations zones can be less aware of the existence of the LRT system or, more commonly, of the approaching of a LRV. This fact can lead to additional risks in these zones.

Once this distinction (stations/between-stations) was made, the WGMs considered which users of the streets would conflict with the system. Obviously the answer is that every other user of the street (road vehicles, pedestrians and cyclists) is a candidate to conflict with the system.

Finally, a brainstorming session was undertaken by the WGMs in order to identify the different kinds of interaction points that can be encountered, as well as the conflicting third parties for each of them.

2.2 Interaction points data collection

Once the interaction points were identified, the next step was the gathering of information about good and bad design practices for them in the different countries participating in the Action.

For this purpose, a template sheet was prepared in such a way that each WGM could fill it in with his/her country examples, in order to have a standardized source of information. 29 examples were gathered for stations/stops and 106 for between-stations sections. The analysis of these examples leads to some first conclusions that are going to be presented in the third section of this paper, and that can be considered as a rough design toolkit for improving the safety of LRT urban insertion.

3 DESIGN FIRST TOOLKIT FOR GETTING A SAFER LRT URBAN INSERTION

3.1 Stations/Stops

3.1.1 Pedestrian pathways at stations/stops

The first conclusion obtained for stations/stops is the need to establish and clearly identify (by means of appropriate signage) a safe pathway for pedestrians to cross the tracks in the stations/stops. This pathway (pedestrian crossing) is usually located at one or both platform ends. Examples of the signalization of these pathways and their explanations are presented in Figures 1a to 1f.

Sometimes signage is not enough for pedestrians to behave properly, and some elements (usually light barriers) are used to force pedestrians to cross on the designated zones. On the other hand, light barriers are utilized in many occasions to direct the path of pedestrians before crossing so they are faced in the direction of approaching LRVs. Some examples of this kind of barriers are presented in Figures 1g to 1j.

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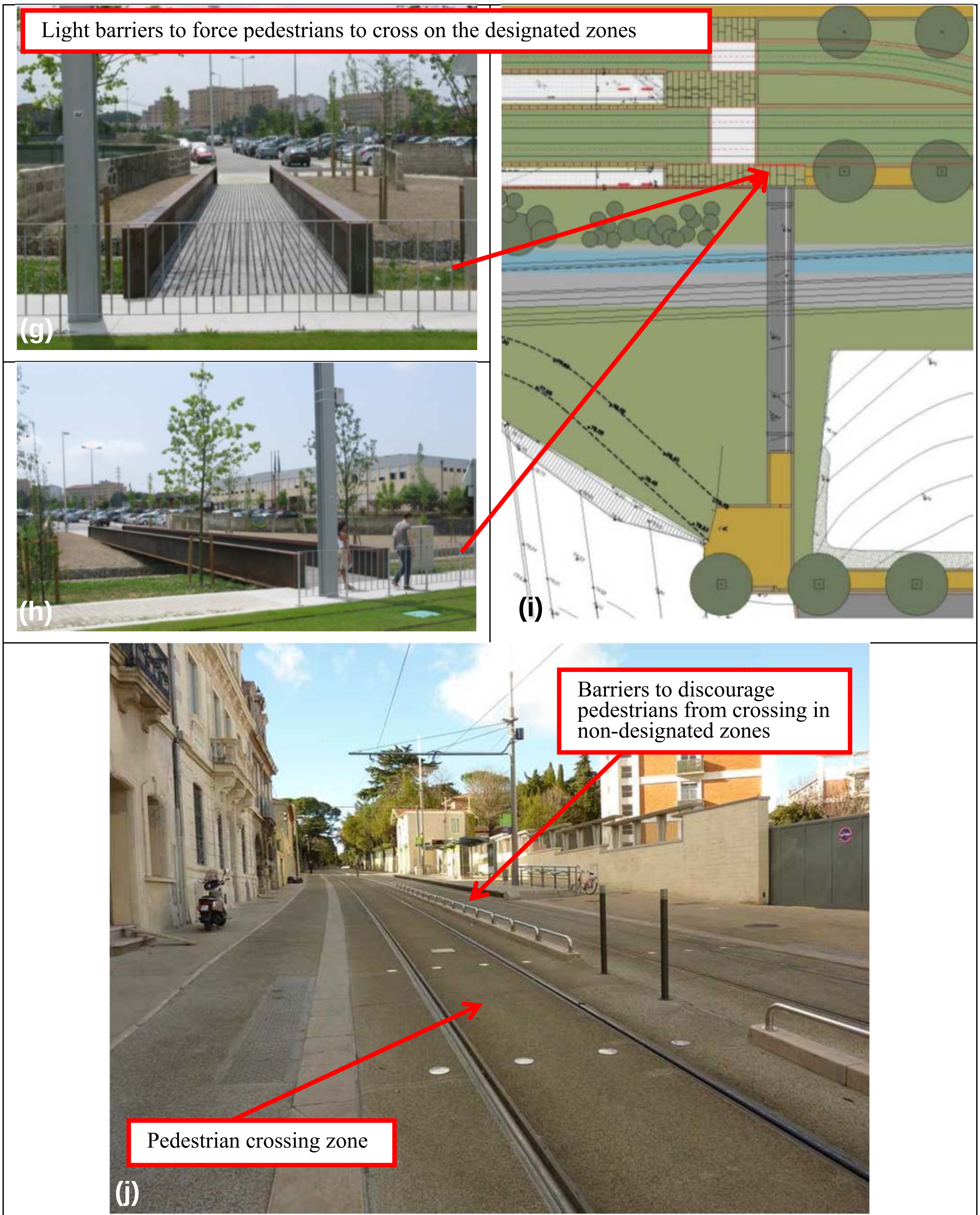

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FIGURE 1 Pedestrian pathways at stations/stops. a,b,c,d&e) Pedestrian pathway signalization in Porto (Portugal); f) Signage in Barcelona (Spain); g,h&i) Light barriers in Porto; j) Light barriers in Montpellier (France)

3.1.2 Platform design and station/stop location

Platforms should be wide enough to have room for all the users. Additionally, when there is a road lane at the back of the platform, it is advisable to provide a barrier in order to prevent users stepping off the platform into the road lane. Bad and good practices are presented in Figures 2a to 2c.

On the other hand, the closer the platform to the LRV the better, not only from the safety point of view, but from the operational one (quicker boarding and alighting leading to shorter stop times). Several examples are presented in Figures 2d and 2e.

Additionally, platforms should have an adequate fall in order to get a good drainage. The longitudinal fall should preferably be minimum 0.5% and transversal fall 2.5% towards back of the platform (away from track), in order to avoid the possibility for a wheelchair to fall on tracks by an unnoticed movement caused by the slope. This design imposes the need for an additional drainage channel on back of platforms (Figure 2f).

Finally, the platform location and design is a key point to take into account at interchange stations. Figures 2g and 2h show a good design of an interchange between bus and LRT with its explanation.

Very good discussions about the design and safety of different LRT stop solutions applied in Melbourne (Australia) are presented in [4,5,6].

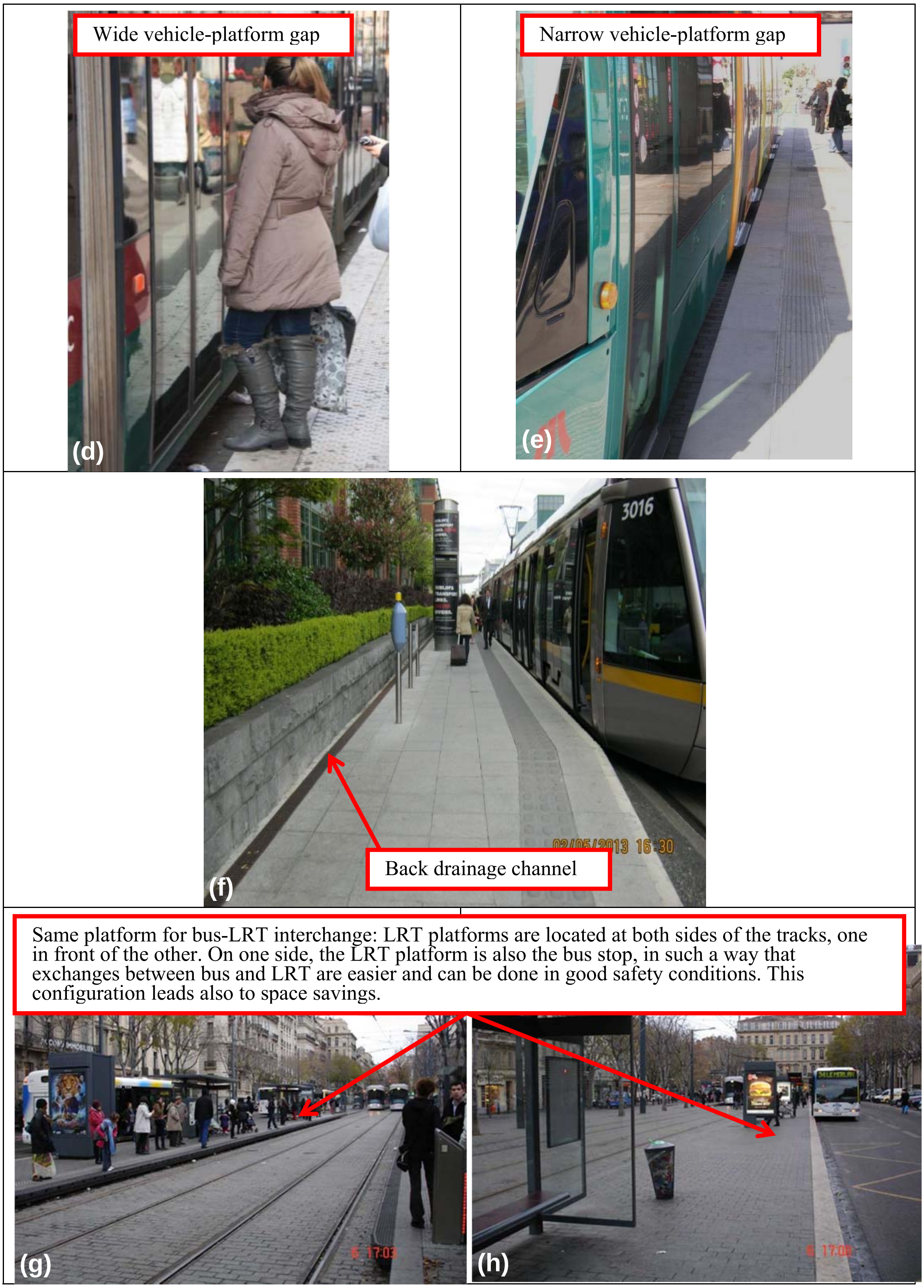

FIGURE 2 Platform design and station/stop location. a&b) Narrow platform without back barrier in Rome (Italy); c) Good platform design with back barrier in Dublin (Ireland); d) Excessive platform-vehicle gap in Rome; e) Narrow platform-vehicle gap in Tenerife (Spain); f) Back platform drainage channel in Dublin; g&h) Interchange between bus and LRT in the same platform in Marseille (France).

3.2 Between-stations

3.2.1 Pavement treatment on shared space

One way of inserting the LRT system into the urban fabric is the use of streets that are only dedicated to pedestrians, cyclist (in this case) and the LRT system itself. These zones are called shared space. Speed must be limited on these zones in order to avoid incidents/accidents from happening, as the operation mode is completely on sight and the LRT has not priority over pedestrians and other street users.

Additionally, an adequate treatment of the pavement must be done in order to ensure that pedestrians and cyclists are well aware about the zone occupied by the LRV when running on the street. This pavement differentiation can be achieved by means of its texture or its color and material (Figures 3a to 3e).

3.2.2 Pavement treatment on segregated channels

A subject that might be important for safety, although sometimes is not considered in relation to this topic, is the pavement treatment on segregated channels (category B as defined by Vuchic [3]), due to two reasons: the type of pavement can encourage or discourage the use of the LRT tracks by other users (road vehicles, pedestrians, cyclists); and it can reduce or increase the damages caused when an accident happens.

In this sense, the more discouraging finishing is ballast, as it makes very difficult (or even impossible) for a car or a bicycle to run on it, and very uncomfortable for a pedestrian to walk on it. Nevertheless, as ballast is not always a good option for finishing tracks on urban fabric, other solutions are usually considered. An interesting one is the use of turf track (track finished with a vegetation covering). This kind of solution is very discouraging for car-drivers and cyclists, but the effect over pedestrians is controversial, as depending in cultural background there are operators that consider it encouraging (as people jogging or walking with dogs tend to use the tracks), while other operators consider it discouraging (as it is not convenient to walk on a smooth grass coverage). In any case, when considering the use of turf track other subjects must be borne in mind (see [7]).

The most encouraging pavements for track trespassing are the ones usually utilized as street pavement (asphalt, concrete, stone, etc.), as they are the most comfortable for walking on them, and they make it possible for road vehicles and bicycles to run on them.

Two examples of pavement treatment on segregated channels are presented in Figures 3e and 3f.

Same material (granite) with different textures to identify LRT channel in a shared space

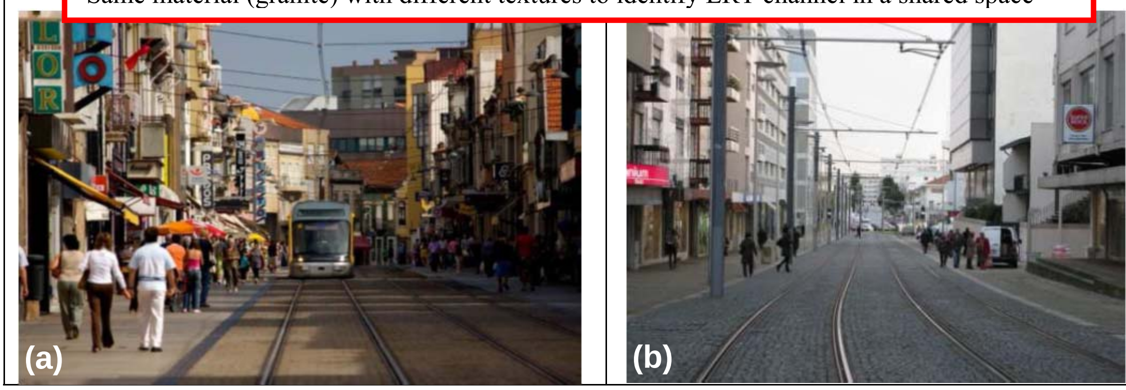

FIGURE 3 Pavement treatments on shared spaces and segregated channels. a&b) Shared space treatment in Porto; c) in Bordeaux (France); d) in Marseille; e&f) Segregated channel treatment in Berlin (Germany).

3.2.3 LRT separators on segregated channels

An effective approach to improve LRT safety in segregated channels is the use of an adequate separator. The more impassable the separator is, the better the safety for LRT and other street users. Nevertheless, the selection of the separator type is closely related to the street section and width. For instance, an impassable separator can lead to traffic flow problems where there is only a narrow lane for general traffic. On the other hand, the use of passable separators makes it easier for the LRT channel not being respected by drivers or for road vehicle drivers to park illegally as they know that the traffic flow will be ensured by the circulation over the LRT tracks.

There is a wide variety of separators which can improve the LRT systems, but they have to be carefully designed and maintained for avoiding some undesired effects.

An important aspect is the need to forbid parking along the lane adjacent to the LRT separator (Figure 4a). This measure, that seems pretty obvious for countries that use LRT, has to be borne in mind in countries where these systems are new.

The separator can be a continuous line of green bushes (Figures 4b to 4e), which has a dissuasive effect on pedestrians and, specially, on car and bicycle drivers, to cross the tracks. Green separators have several positive impacts due to the increase in the amount of green zones in the city. Nevertheless, they have some disadvantages, as the need for maintenance of the green area, as well as the visibility problems in case that the green species grow too tall. The Irish Railway Safety Commission establishes that the total height of shrubs and any container should not exceed 600 mm so as to avoid places of concealment for children [8].

Other kinds of separators can be used. The most common ones are curbs, bollards, and narrow sidewalks (see Figures 4f to 4h).

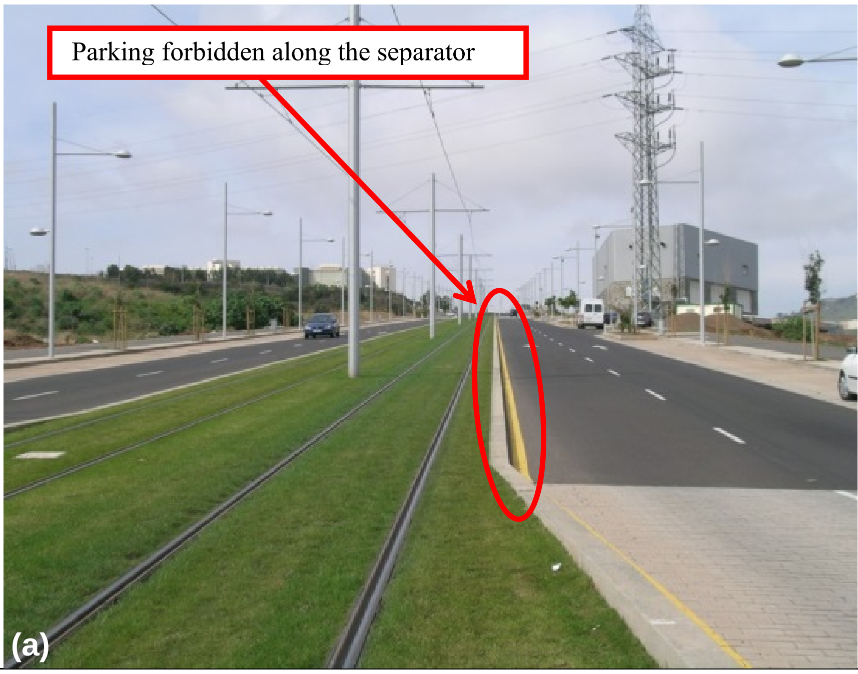

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FIGURE 4 LRT separators on segregated channels. a) Parking forbidden along the separator in Tenerife; b,c,d&e) Green separators in Porto; f) Sidewalk-alike separator in Montpellier; g) Curb separator in Montpellier; h) Curb separator between both LRT directions in Montpellier.

3.2.4 Intersections

Obviously, an important aspect of light rail design in relation to safety concerns intersections, as they are the main points where LRT interacts with other users (especially when it runs on a segregated channel). Different types of intersections are presented in this section. On the other hand, as reference, several treatments for LRT intersections where LRVs run at a speed higher than 55 km/h are presented in [9], and a discussion about signalization understanding is made in [10].

Left-turn intersections

In general, when designing a LRT system, left-turn intersections of road vehicles running on the LRT channel should be avoided whenever it is possible. The reasons are that these movements are considered as one of the riskier situations (as road vehicle drivers sometimes misread or do not obey traffic signals) [11,12,13], and that left-turn intersections generate a more complicated signal cycle which leads to more delays and a more difficult signal priority for LRT. There are feedbacks with accidents on turn-left/right configurations in France.

In order to avoid this kind of movements, left-turns are sometimes transformed into a different maneuver where the car-driver crosses the LRT channel in a perpendicular way (either green arrow instead of red arrow in Figure 5a or three right turns starting beyond the cross street).

Another way of converting a left-turn into a perpendicular crossing is the one presented in Figures 5b and 5c, where a green space is designed to force road vehicles to enter the junction at right angles, allowing better visibility of approaching LRVs. This solution is simple and easy to implement, if the needed space is available.

In any case, as some road vehicle drivers tend to disobey the left-turn prohibition, sometimes additional measures accompany the signals (Figures 5d and 5e).

In spite of the previously stated, sometimes left-turns over LRT tracks are allowed, especially when there is no other convenient option. In those cases, it is common to make a specific treatment of the intersection to guarantee that the traffic lights are properly understood and that car-drivers do not disobey them without realizing.

Figures 5f to 5h show the case of a left-turn intersection in Montpellier (France), where a specific left-turn lane is provided. In the operation of traffic lights, straight-on vehicles and left-turn vehicles do not pass at the same time: green light for straight-on vehicles is given at the same time as green light for LRT, while left-turn vehicles must stay stopped in this phase of the traffic light cycle. The stop line for straight-on vehicles (and their traffic lights) is set back 5 m from the left-turn stop line. This avoids the risk that the left-turn car-driver starts at the same time as the vehicles near him/her, thinking that the green light for straight-on vehicles applies to him/her too, and colliding with the LRV that is running straight-on on its tracks.

Several measures for improving left-turn intersections safety or for avoiding violation in prohibited left-turn locations are presented in [11,12,13]. On the other hand, the hook-turn seems to be a safer way of allowing road vehicles to turn right crossing the LRT tracks in Australia [14].

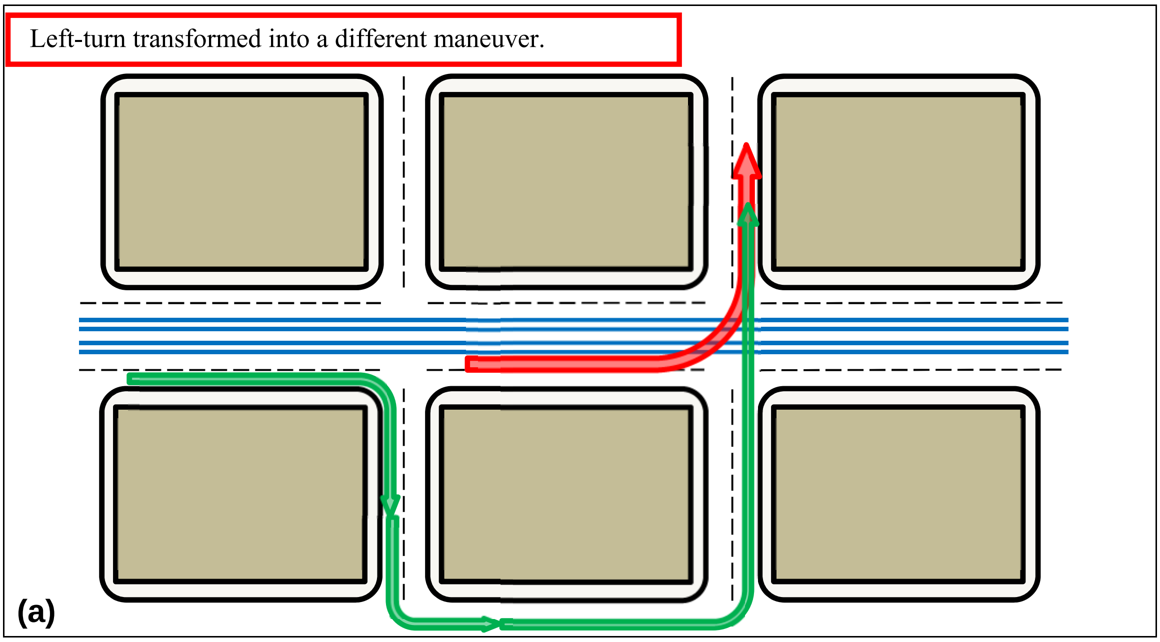

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FIGURE 5 Left-turn intersections. a) Transforming a left-turn intersection into another kind of maneuver; b&c) Transforming a left-turn into a perpendicular intersection in Porto; d&e) Avoiding forbidden left-turns by means of bollards in Barcelona; f,g&h) Improving traffic lights readability in Montpellier.

Roundabouts

Roundabouts are a very common solution for road junctions in Europe, as they provide a safe and almost continuous traffic flow. The three main advantages of roundabouts are: road vehicle drivers have to reduce their speed when approaching the roundabout, leading to an increase in safety at the junction; the roundabout avoids the need for traffic lights, reducing the operation and maintenance costs; the junction capacity increases due to the almost continuous traffic flow and the elimination of dead-times produced by traffic lights.

Nevertheless, the junction operation changes when a LRT system is added to the roundabout. LRT is usually implemented running through the roundabout center. The roundabout works as a conventional one when LRVs are not present, but traffic lights are provided to give LRVs priority when they approach the roundabout. One important issue is the need to avoid the misreading of the roundabout and the traffic lights by car-drivers, which can easily lead to an accident or incident. On the other hand, it is important that car-drivers encounter the LRT channel as near to the perpendicular direction as possible, to improve the visibility and awareness of the LRT presence. Additionally, if vegetation is provided in the roundabout, the use of tall trees and species should be avoided to guarantee a good visibility between road vehicle and LRV drivers. The recommended covering is grass or low shrubbery (see Figure 6a).

Figures 6b and 6c show the traffic light treatment used for roundabouts in Tenerife (Spain).

A problematic roundabout design is presented in Figures 6d to 6f. In this case the LRT crosses the roundabout off-centered, and there were several accidents because car-drivers had green light for entering the roundabout (traffic light 1) but then they found a red light for crossing the LRT channel (traffic light 2). The green light 1 is thought for those cars who want to continue straight-on but the consequence is that many drivers that wanted to turn left entered in the roundabout and they did not expect to see a red light 2, as in roundabouts without LRT the car-driver always has the priority once he/she has entered the roundabout. The solution was to change the traffic light cycle, implementing a red light for the entrance to the roundabout whenever the LRV is approaching.

Finally, another problematic roundabout is the one presented in Figures 6g to 6i. At the north entry the LRT channel is located on the entering side of cars in the roundabout, in such a way that car-drivers arriving focus their attention on the ring road (on the left) instead of on the LRT channel and the traffic lights. Several accidents have happened here. The solution that is going to be implemented is the relocation of the road alignment away from the tracks (see green line in Figure 6g), in such a way that road vehicles will enter the roundabout far away from the LRT tracks, and road vehicle drivers will encounter the LRT tracks in a perpendicular way once they are in the roundabout.

Source: Google

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Problematic roundabout with road entering the roundabout too close to the LRT channel, leading to road-vehicle-drivers focusing attention on ring road but not on LRT channel and traffic lights → Solution: modification of road alignment to put it away from the tracks (green line).

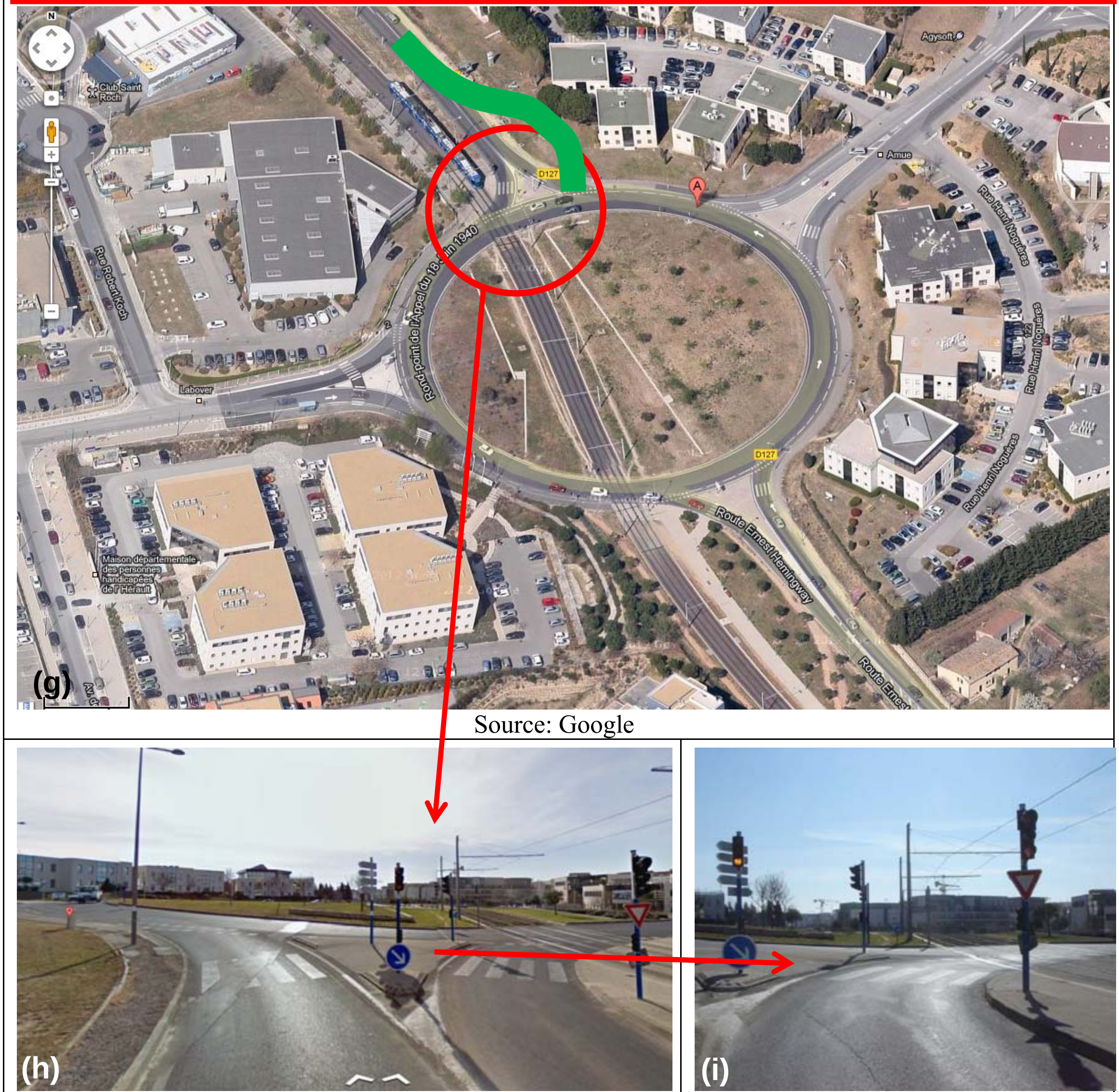

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FIGURE 6 Roundabouts. a) Low vegetation in a LRT roundabout in Tenerife; b) Traffic lights for different approaching directions in Tenerife; c) Double small traffic lights for improving awareness in Tenerife; d,e&f) Modification of traffic lights operation for improving roundabout safety in Barcelona; g,h&i) Modification of the road layout for improving roundabout safety in Montpellier.

Pedestrian and cyclist crossings

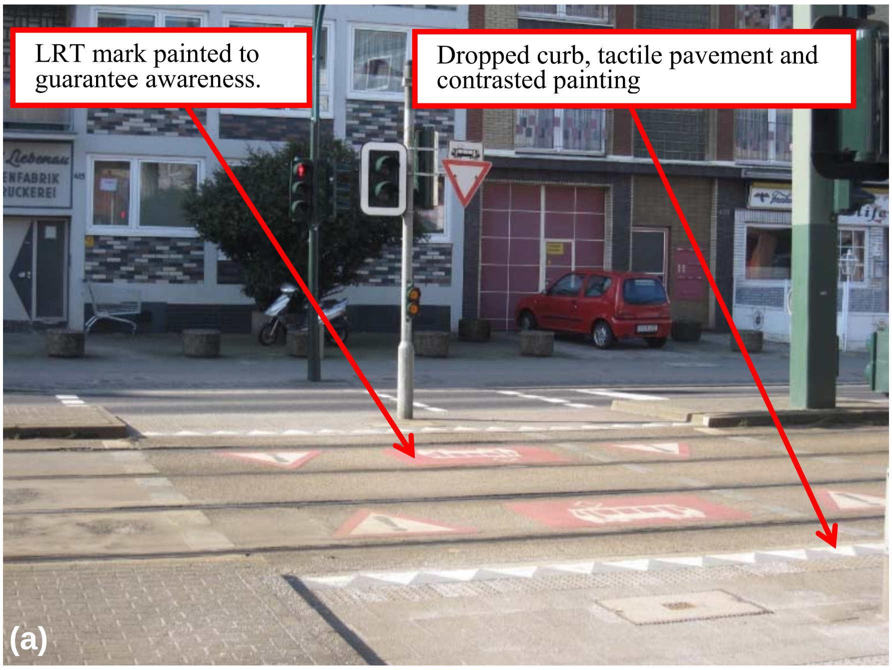
Particular attention should be paid to the safe design of pedestrian and cyclist crossings.

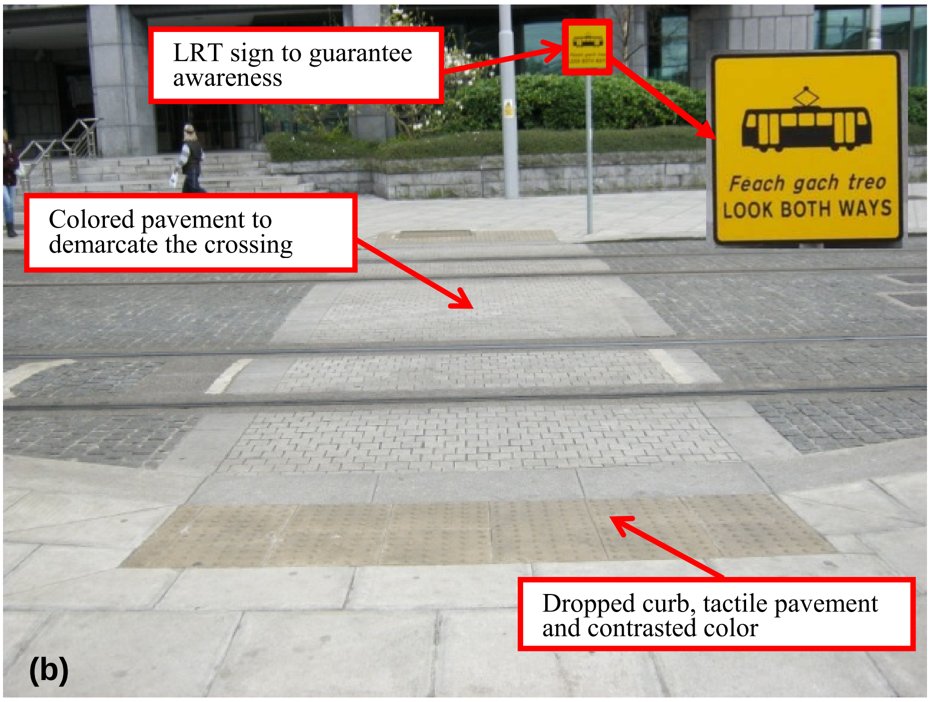
It is important to note that in many European countries LRT has priority over the rest of the traffic when running on the streets. Hence, it is common to avoid marking the LRT channel with zebra crossings, which give priority to pedestrians. In any case, the designated zones for crossing are usually marked in any other way, to guaranty a clear identification of allowed zones for crossing. Special attention should be made to visually and mobility impaired people. Figures 7a and 7b show the design of two different pedestrian crossings.

Figures 7c and 7d show a well-designed pedestrian crossing in Tenerife (Spain), while a common solution in some German cities (Z-crossing) is presented in Figure 7e.

A change in a pedestrian and cyclist crossing design to improve safety is presented in Figures 7f and 7g. In this zone a pedestrian footpath and a cycle lane run adjacent to a segregated channel of Dublin LRT. Due to the configuration of the carriageway, the footpath and the cycleway changes sides of the track along this segregated section. Cyclists entered the crossing in one movement, without stopping and looking for oncoming LRVs, creating hazardous situations. It was decided to install a chicane to slow cyclists down and to force them to approach the tracks at right angles. Before implementing this solution, RPA (Railway Procurement Agency) carried out CCTV to observe cyclists behavior and RPA/Veolia/Local Authority installed a mock-up with cones to trial proposed installation before construction.

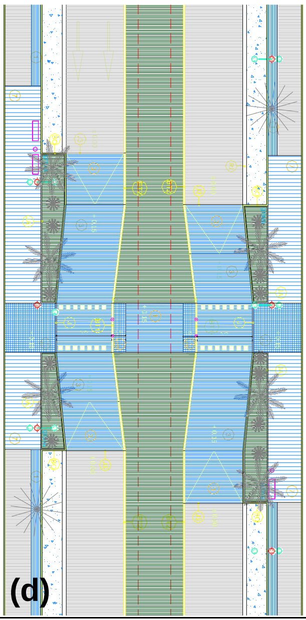
Figures 7h to 7j show the design of a cyclist crossing in Dublin. Finally, two bad examples are presented in Figures 7k to 7m.





Well-designed pedestrian crossing in a wide straight avenue:
- Pedestrian refuges between the general traffic lanes and the LRT tracks to allow pedestrians to cross the street in two stages
- These refuges imply a change in the direction of general traffic trajectory, and they are elevated in relation to road surface to match the sidewalk height → More convenient for pedestrians and oblige to reduce the speed to road vehicle drivers
- Bollards installed in the interface between road lanes and LRT tracks, to eliminate the possibility that car-drivers use this pedestrian crossing for running on the tracks and change their direction

(c)

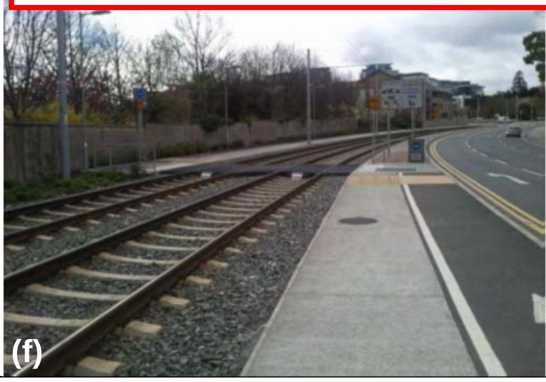


(d)

Z-crossing: it obliges pedestrian to cross the tracks facing always the direction of the incoming LRV, in such a way that it is very difficult not being aware of an approaching LRV

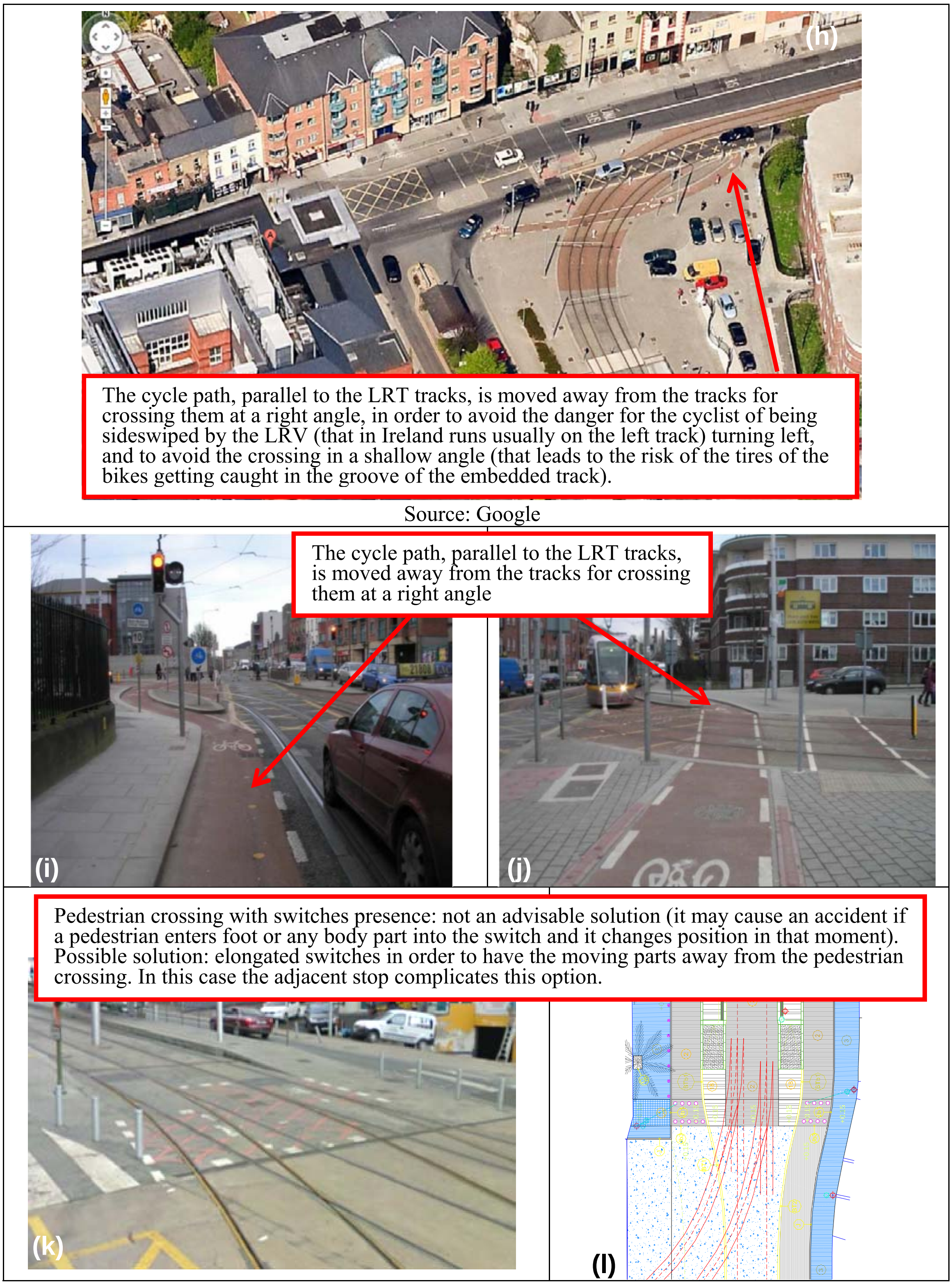
(e)

Change in a pedestrian + cyclist crossing to avoid crossing the LRT channel in one movement, obliging cyclist to initiate the crossing of the tracks in a perpendicular direction.



(f)

(g)


(h)
The cycle path, parallel to the LRT tracks, is moved away from the tracks for crossing them at a right angle, in order to avoid the danger for the cyclist of being sideswiped by the LRV (that in Ireland runs usually on the left track) turning left, and to avoid the crossing in a shallow angle (that leads to the risk of the tires of the bikes getting caught in the groove of the embedded track).
Source: Google
The cycle path, parallel to the LRT tracks, is moved away from the tracks for crossing them at a right angle
(i)
(j)
Pedestrian crossing with switches presence: not an advisable solution (it may cause an accident if a pedestrian enters foot or any body part into the switch and it changes position in that moment). Possible solution: elongated switches in order to have the moving parts away from the pedestrian crossing. In this case the adjacent stop complicates this option.
(k)
(l)

Pedestrian crossing located near a hump, which can result in pedestrians not being able to see approaching LRVs (40 km/h speed in this zone). Possible solutions: decrease in speed limit for LRVs (pedestrians have more time to see the vehicle coming and reciprocally); installation of an active signaling system (lights flashing when the LRT is coming); and, the obvious one, to change the pedestrian crossing location if that is possible.

Source: Google

FIGURE 7 Pedestrian and cyclist crossings. a) Pedestrian crossing in Dusseldorf (Germany); b) Pedestrian crossing in Dublin; c&d) Pedestrian crossing in a wide avenue in Tenerife; e) Z-crossing in Stuttgart (Germany); f&g) Before and after pedestrian and cyclist crossing modification in Dublin; h,i&j) Cyclist crossing in Dublin; k&l) Switch presence at the pedestrian crossing in Tenerife; m) Pedestrian crossing near a hump in Tenerife.

Innovative solutions at intersections

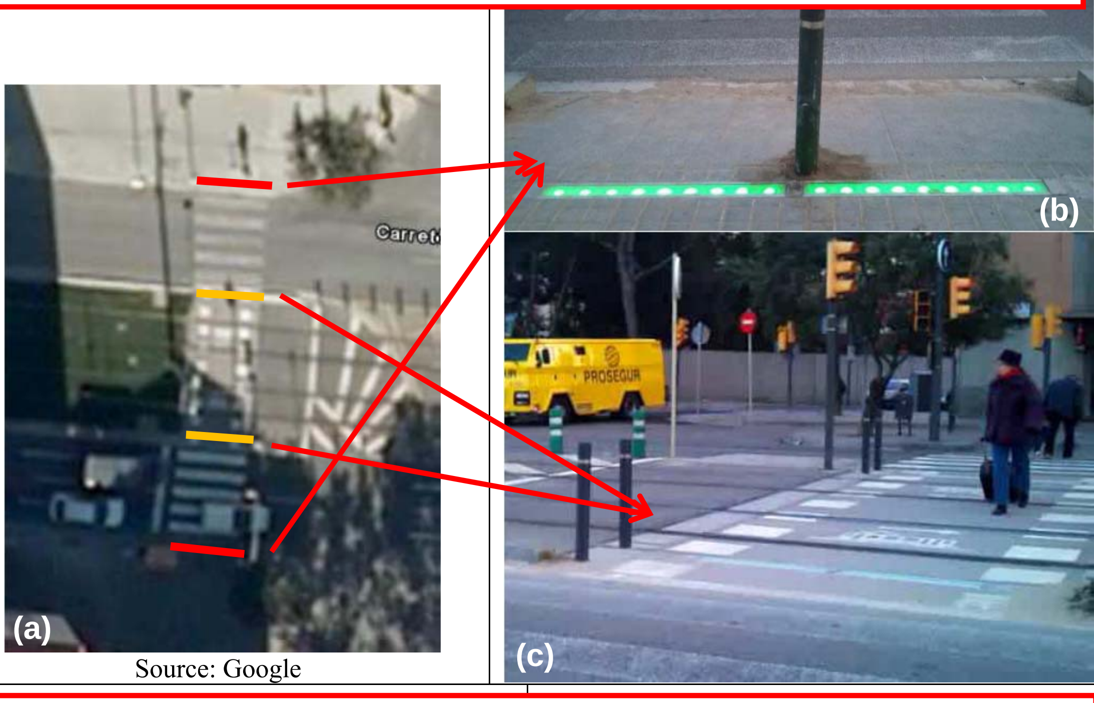
Other innovative solutions at intersections are related to the use of additional dynamic traffic lights, whether for increasing the awareness of pedestrians and road vehicle drivers about the LRT presence, or for fining car-drivers who do not observe the traffic light indications.

Figures 8a to 8c show the use of LED lights embedded in the pavement for improving awareness of pedestrians who are crossing. A similar solution, but for road vehicle drivers, is presented in Figures 8d and 8e. A discussion about the effectiveness of this solution in Houston (Texas) for avoiding red light running at LRT intersections is made in [15].

A solution for avoiding confusion between two traffic lights in close junctions is presented in Figures 8f and 8g.

Finally, Figure 8h presents the solution of installing red light cameras at the junction for photo enforcement. This solution is used in Los Angeles as well [9].

LED lights embedded in the pavement for improving awareness of pedestrians who are crossing. The LEDs adjacent to the sidewalk repeat the pedestrian signaling (red/green), while the LEDs adjacent to the LRT channel are orange and flash when the LRV is approaching.
The main disadvantage of this solution is its cost: it is an expensive and difficult solution to implement, as it implies civil work.



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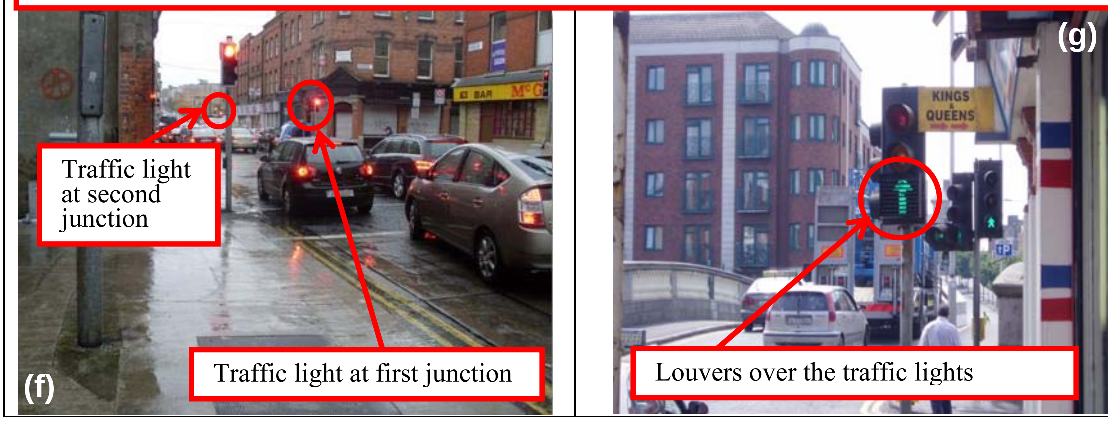
Flashing red road studs (to display in conjunction with red traffic signal) provided in a junction where the analysis of the road traffic collisions indicated that the main causation factor was vehicles failing to stop at the red traffic signal

Location with a “see-through” problem: the car-driver sees the green lights of the traffic lights in the second junction and does not notice the red lights at the LRT junction applicable to him/her, and mistakenly thinks he/she has a green light at the LRT junction.
Solution: provision of louvers over the traffic lights.



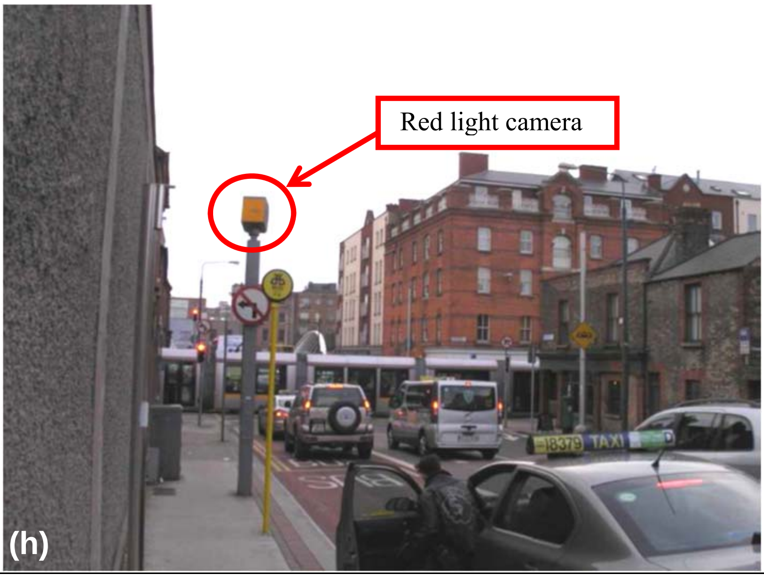


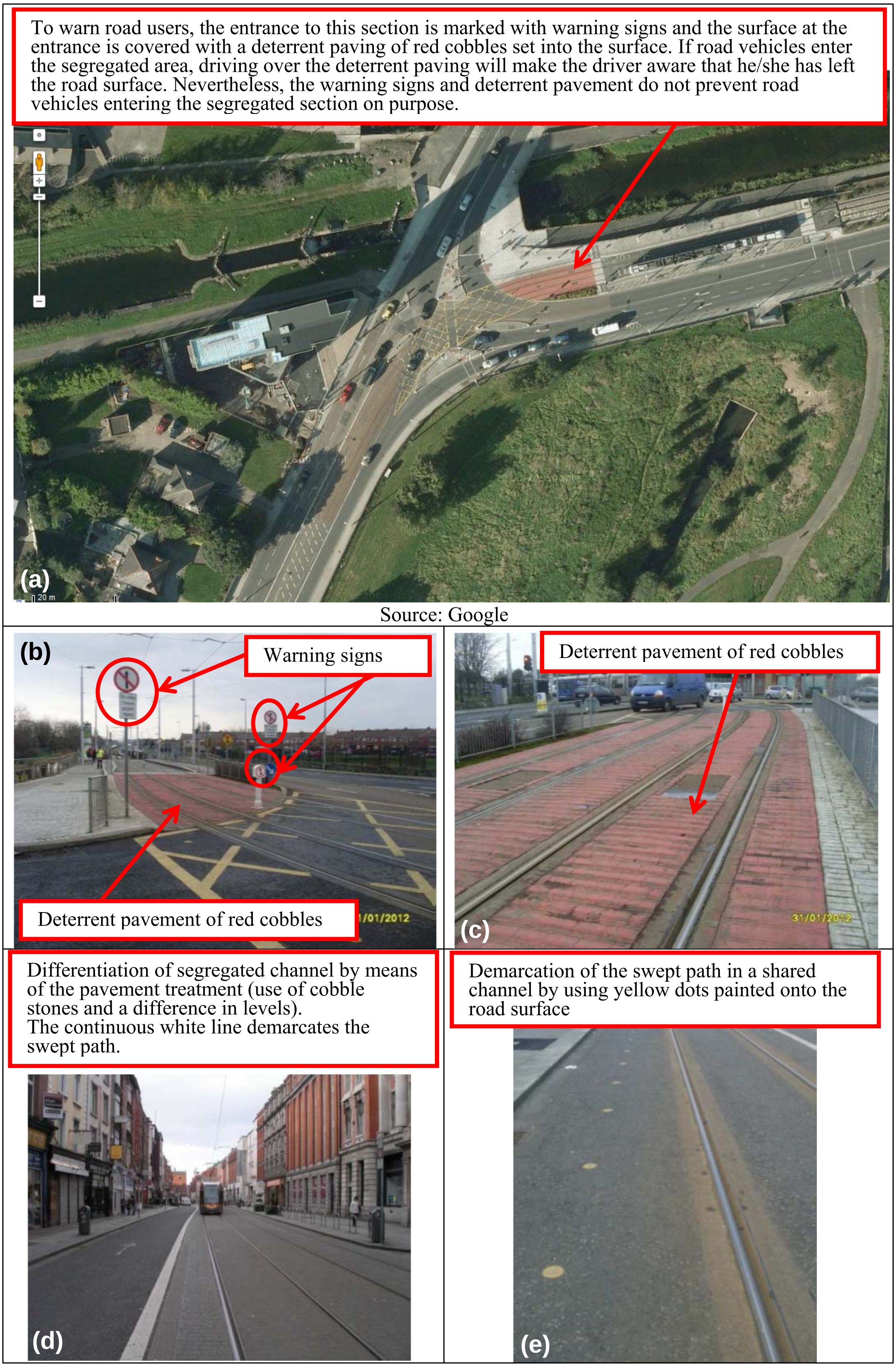
FIGURE 8 Innovative solutions at intersections. a,b&c) LED lights embedded in the pavement in Barcelona; d&e) Flashing red road studs in Dublin; f&g) "See-through" problem with louver solution in Dublin; h) Red light camera in Dublin.

3.2.5 LRT channel differentiation and protection by means of pavement, marks, fences and barriers

Another important aspect in LRT design is the adequate differentiation of LRT channel, whether it is segregated or shared. LRT channel differentiation for segregated zones is important in order to clearly communicate to road vehicle drivers that they are not allowed to use part of the street. LRT channel differentiation in shared zones improves safety as it marks the swept path of the LRVs. Sometimes, fences need to be provided (where possible) in order to avoid an inappropriate use of the tracks by pedestrians or cyclists. In other occasions, the installation of barriers is advisable to guarantee that other street users do not interfere with the LRT operation.

Figures 9a to 9c show a road junction with the explanation of the measures taken to avoid road vehicles to enter the segregated LRT tracks. Figure 9d shows the differentiation of the segregated channel by means of the pavement treatment. Figure 9e shows the demarcation of the swept path in a shared channel by using yellow dots painted onto the road surface.

Figures 9f and 9g show the use of barriers to protect LRT channel from pedestrians in Tenerife. Finally, Figure 9h shows the provision of a fence for avoiding pedestrian crossing.


To warn road users, the entrance to this section is marked with warning signs and the surface at the entrance is covered with a deterrent paving of red cobbles set into the surface. If road vehicles enter the segregated area, driving over the deterrent paving will make the driver aware that he/she has left the road surface. Nevertheless, the warning signs and deterrent pavement do not prevent road vehicles entering the segregated section on purpose.
(a)
Source: Google
(b)
Warning signs
Deterrent pavement of red cobbles
Deterrent pavement of red cobbles
(c)
Differentiation of segregated channel by means of the pavement treatment (use of cobble stones and a difference in levels).
The continuous white line demarcates the swept path.
(d)
Demarcation of the swept path in a shared channel by using yellow dots painted onto the road surface
(e)

Source: Google

FIGURE 9 LRT channel differentiation and protection by means of pavement, marks, fences and barriers. a,b&c) Pavement treatment to avoid LRT tracks trespassing by road vehicle drivers in Dublin; d) Pavement treatment of a segregated channel in Dublin; e) Demarcation of swept path on shared channel in Dublin; f&g) Barriers for avoiding invasion in Tenerife; h) Fences for avoiding pedestrian crossing under a flyover in Tenerife.

3.2.6 OCS (overhead contact system) poles location

It is advisable that OCS poles and other obstacles are always away from junctions in the usual direction of LRV running, because when a crash between a car and a LRV occurs, the LRV may drag the car along certain distance. If a pole is placed near the junction then the car may be squashed between the LRV and the pole. If the pole is located at least at the LRV stop distance from the junction this situation is avoided. This LRV stop distance can be calculated as [16]:

$$d = \frac{v_0^2}{(2a)} + v_0 \cdot t_r \quad (1)$$

Where d is the length of the zone without fixed obstacles (LRV stop distance); a is the LRV deceleration (2.8 m/s^2 for emergency brake type 3, with sand, according to [17]); v_0 is the LRV speed when passing through the intersection, in m/s, which will be related to the intersection configuration; and t_r is the equivalent response time (0.85 s [17]).

In Valencia several OCS poles have been moved away from intersections due to several fatal accidents between LRVs and cars where the car was smashed with the catenary pole [18].

4 CONCLUSIONS

This paper deals with the safe design of LRT urban insertion in the following aspects: pedestrian pathways at stations/stops; platform design and station/stop location; pavement treatment on shared space; pavement treatment on segregated channels; LRT separators on segregated channels; intersections (left-turn intersections, roundabouts, pedestrian and cyclist crossings, innovative solutions at intersections); LRT channel differentiation and protection by means of pavement, marks, fences and barriers; and OCS (overhead contact system) poles location.

The conclusions achieved by Working Group 3 during the first Working Phase of COST Action TU1103, "Operation and safety of tramways in interaction with public space" have been presented in this paper. These first findings and the expertise of the COST Action members will be the base to make guidelines for a safe LRT design during the second phase (comparison/analysis/best practices) and third phase (prospects and recommendations) of the COST Action. During these phases the Action members will try to get information about before and after studies of the consequences of some of the measures presented in this paper.

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