Use and design of safe roundabouts in Light Rail Transit (LRT) networks

Re-submission date: October 20th, 2016.

Number of words: 5249

Number of figures: 9

Number of tables: 0

Equivalent number of words: 5249+9·250=7499 words.

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ABSTRACT

While travelling at-grade in an urban environment, a Light Rail Transit (LRT) system needs to traverse road intersections of various complexities. These intersections, including roundabouts, are major hazardous locations in LRT networks. There are several documents related to the treatment of conventional LRT intersections for guaranteeing safety, but almost no reference to LRT roundabouts design, except for the French guidelines. This paper addresses safety issues related to LRT roundabout design. The paper contains, firstly, the explanation of the differences between the roundabout management with and without an LRT running through it, and the consequences for road vehicle drivers’ behavior. Secondly, the appropriateness of using a roundabout in the insertion of an LRT in a specific intersection is discussed. Finally, the main considerations for designing a safe LRT roundabout are presented: provide adequate visibility; improve perception by pavement, markings and signs; improve protection by separators, finishing of the tracks and traffic lights; and finally, design a good insertion of the LRT in the roundabout, as well as an adequate roundabout size.

1 INTRODUCTION

While travelling at-grade in an urban environment, a Light Rail Transit (LRT) system needs to traverse road intersections of various complexities. For a good insertion of the LRT system in the urban environment, these at-grade intersections should be regarded as roadway intersections rather than railway level crossings, except for the case of high LRT speeds or fully separated systems.

Driving through an intersection or a roundabout is a complicated matter and usually involves complex maneuvers during which all street users (motorists, cyclists, pedestrians and LRV-Light Rail Vehicle- drivers) must continuously assess the positions, speeds and intentions of other street users. Consequently, at-grade intersections and roundabouts are usually considered by practitioners and researchers as major hazardous locations in LRT networks. The COST (European Cooperation in Science and Technology) Action TU1103, “Operation and safety of tramways in interaction with public space”, has corroborated this assumption [1].

This COST Action dealt with the improvement of streetcar and Light Rail Transit (LRT) safety through a better management and design of their insertion into urban spaces. 34 entities from 14 European countries and Israel participated in the Action. Participants included LRT agencies, safety management entities and research bodies, and the UITP (International Association of Public Transport).

One of the aspects studied during this COST Action was the identification of hotspots (hazardous locations), defined as “A place in the urban area where the most accidents or collisions occur in a fixed period of time”. A questionnaire on hazardous locations identification was conducted during the Action among 24 agencies from 13 different countries based on their crash rates (see the final report of the COST Action [1] and [2, 3]). Information about 89 hazardous locations was analyzed, and the majority of them (85%) were at-grade intersections (being 28% roundabouts, although these figures are not normalized considering the number of roundabouts and regular intersections in each network). Consequently, special attention should be given in determining the layout and the adequate design of each at-grade intersection of an LRT line/network.

Several publications are focused on LRT at-grade intersections. As reference, several treatments for LRT road intersections where LRVs run at a speed higher than 55 km/h are presented in [4], while [5] focuses on systems running at lower speeds. A discussion about signalization understanding is made in [6]. In [7] several measures for improving LRT safety are studied, including the identification of some US networks which applied them. Additionally, several measures for improving left (or opposing) turn intersections safety or for avoiding violation at prohibited left (or opposing) turn locations are presented in [8, 9, 10]. Finally, hook-turn management of right-turns crossing LRT tracks in Australia (where road vehicles drive on the left) is discussed in [11].

Although LRT roundabouts have also been identified as important hazardous locations by the COST Action participants and LRT agencies, there is almost no reference in scientific literature to this kind of intersection, apart from the ones related to the COST Action. The main exception is the French guidelines on LRT roundabouts [12].

This lack of information is the reason why the COST Action has addressed this subject in depth, and why this paper is focused on LRT roundabouts. The structure of the paper is as follows: section 2 explains the differences in the management of a roundabout with and without an LRT running through it, and its consequences for road vehicle drivers’ behavior; section 3 deals with the appropriate use of roundabouts in the insertion of an LRT line in the urban fabric; section 4 presents some of the general and...
specific aspects that need to be considered to design a safe LRT roundabout. The paper ends with conclusions, acknowledgements and references.

2 DIFFERENCES IN ROUNDABOUT MANAGEMENT WITHOUT AND WITH LRT

A roundabout is a circular intersection in which road traffic flows in one direction on a circular road around a central island. Normally, it does not include traffic lights and the incoming traffic always yields to the traffic already on the circular road [13].

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

- they transform left (or opposing) turns into right turns, avoiding interference with opposite and side traffic;
- they are U turning points;
- they can avoid the need for traffic lights at an at-grade intersection, eliminating dead-times and reducing the operation and maintenance costs;
- they can force road vehicle drivers to reduce their speed when approaching.

The roundabout operation changes when an LRT system is implemented. A common way of including a modern LRT line in a roundabout is with the tracks running through its center, protected by traffic lights located before the points where the circular road crosses the LRT tracks.

There are examples, in existing LRT systems, of roundabouts where the LRT is not protected by traffic lights. Nevertheless, for new networks, this solution is not advisable. Possible exceptions concern very small roundabouts with low road traffic volume.

The way in which the usual LRT roundabout (with traffic lights) functions is as follows: the roundabout works conventionally when the LRV is not present or approaching (priority for road vehicles that are on the roundabout). Nevertheless, traffic lights are provided in the circular road of the roundabout, immediately before the crossing of the tracks, which give priority to approaching or present LRVs. Therefore, road vehicle drivers will have the priority while running on the roundabout only when the LRV is not in the vicinity, but have to yield (stop before the traffic lights) if an LRV is present or approaching.

These changes in priority lead to the need for the road vehicle driver to change his/her attention when running on the circular road, as shown in Figure 1.

![Figure 1](https://via.placeholder.com/150)

**FIGURE 1** Conflict of LRT presence in the roundabout with the usual attention of road vehicle drivers. Source: [1]
This change of roundabout operation when an LRV is present can cause problems. For example, in France the accident rate per roundabout is much higher than for general intersections (see Figure 2), and roundabouts are regarded as unsafe [14], although there are differences depending on the size and design of the roundabout. In other countries, these problems are not as evident and roundabouts are considered a viable option for specific cases. It is important to note that for making comparisons in the number of accidents among different kinds of configuration, several aspects that may influence the data have to be considered, such as the traffic volume, the speed of the vehicles involved, the number of streets converging in the intersection and their configuration.

![Figure 2 Number of events per type of configuration in French LRT networks. Source: [14]](image)

3 WHEN TO USE A ROUNDABOUT IN AN LRT NETWORK?

The main question that arises from the previous considerations is: When is it reasonable to use a roundabout in an LRT line? The generic answer 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 at-grade intersection controlled by traffic lights. These reasons are related to the movements that need to be allowed at the intersection, or to the configuration of the streets that converge on the roundabout, and are stated in the following paragraphs.

Nevertheless, when thinking about the movements that need to be addressed in a specific at-grade intersection, a study of the surrounding area should be made: sometimes it is possible to avoid a specific movement in one point, allowing it more easily and safely nearby (for example, allow a left (or opposing) turn at another intersection, or by circumventing the blocks and making a perpendicular crossing of the LRT line -see [15]-).

3.1 Roundabouts with three arms (T at-grade intersections)

In the case of a T-intersection, a roundabout layout is not advisable if the movements allowed in the intersection are the ones in black in the lower left part of Figure 3. These movements can be accommodated by an intersection with two-phase cycle traffic lights.

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

- All these movements are transformed into a perpendicular crossing of the tracks, with a better visibility, as long as the roundabout is well designed.
- The traffic light cycle for a conventional at-grade intersection would be complicated, whereas the solution of a roundabout is much simpler with traffic lights stopping road vehicles only when the LRV is present or approaching.
3.2 Roundabouts with four arms

Similar considerations as for roundabouts with three arms apply to roundabouts with four arms (Figure 4). In this case, the black movements of the lower left part of the figure can be accommodated by a three-phase traffic light cycle. Again, the red movements in the lower right part of the figure can be transformed into perpendicular crossings of LRT tracks by the implementation of a roundabout.

Figure 3 Roundabout advisability in an intersection with three arms. Source: [1]
3.3 Roundabouts with five arms, four arms in non-perpendicular direction, and other more complicated configurations

For every type of at-grade intersection where the incoming streets are not perpendicular, a roundabout can be a way of protecting the LRT tracks from crossings made in a non-perpendicular direction and the corresponding riskier maneuvers 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 Figure 5, where the roundabout configuration acts as a “shield” for the LRT tracks.
4 SAFE DESIGN OF ROUNDABOUTS IN LRT NETWORKS

4.1 General aspects of safe LRT design and its application to roundabouts

The three main general design aspects to ensure a safe insertion of the LRT in the urban fabric are: the visibility between the LRT and other street-users and the visibility of signs and signals; the perception of the system (and information to other street-users); and the LRT protection in its interaction with them.

These three aspects, which are described in more detail in [2], have the following application to the design of an LRT roundabout.

For avoiding problems related to visibility, the following points need to be considered:

- The crossing of the tracks by the circular road of the roundabout should be as close to a right angle as possible to avoid blind spots. The consequences of this requirement to the insertion of the LRT in a roundabout are explained in section 4.2.
- Appropriate sight distances, both while approaching the roundabout and being in it are of major importance for its safe operation. Special care must be taken so that road equipment and street furniture (signs, guard rails, crash barriers, overhead catenary system and utility poles, shelters, lamp, posts, planting, etc.) do not impair visibility. For this, it can sometimes be necessary to remove or move certain obstacles which were previously near the zone where the new LRT tracks are built.
- Additionally, no element should impair the visibility of traffic signs or signals. For this, it can sometimes be necessary: to remove or move certain obstacles which were previously near the traffic signs or signals; to change the location or orientation of traffic signs or signals to places that are clearly visible by the corresponding street user; to increase the usual size of the signs or signals in specific troublesome locations; or to use any other measure that enhances the visibility of the signs and signals.
- Sufficient lighting of at-grade intersections must be provided in order to reduce crash risk at night.

In relation to perception and information of the LRT system, a roundabout that has an LRT traversing it should be readily recognized as such by other road users, both when approaching the intersection and when traversing it. If the LRV has priority, this should also be highlighted in the design of the intersection. For this purpose, road vehicle drivers can be assisted by:

- highlighting the LRT zone: for example, marking the continuity of the tracks by finishing them with different material, color or texture than the surrounding areas until the limit of the swept path;
- road markings and signs: for example, LRT warning signs before the entrances of the roundabout (advanced signs) and immediately before the crossings of the LRT tracks by the circular road of the roundabout; and marking stop lines on the carriageway for the traffic.
signals before the crossings of the LRT tracks at a minimum distance of 1.5 m from the swept path of the vehicle, to create a safe distance between stopped road vehicles and LRVs in motion.

- appropriate intersection layout: for example, strengthening the perception of the roundabout central island (by marking it with a different color, material, etc.) and of the circular road (color, material).

All these elements should make it obvious what sort of behavior is expected from road vehicle drivers. Additionally, the design of the intersection should consist of easily recognizable elements in order to make the layout and the use of the intersection simple and easy to understand for road vehicle drivers, particularly those who are not regular users of the intersection. The excessive use of signs should be avoided to prevent confusion.

Finally, the protection of the LRT system in relation to roundabout design may include physical protectors (curbs, fences, bollards) for avoiding intrusion of the tracks by road vehicle drivers. For the same purpose, the surface of the tracks can be made unsuitable for road vehicles (e.g., finishing it with grass, deterrent paving or ballast). Additionally, the main measure related to protection in roundabouts is the use of prescriptive signs and traffic lights for road vehicle drivers before the crossing of the tracks by the circular road. An important consideration for guaranteeing safety is related to the avoidance of the infringement (either intentional or unintentional) of these traffic lights by road vehicles drivers. A discussion about several measures for achieving this objective is presented in section 4.5.

As summary, Figure 6 presents the most common measures used to improve safety in LRT roundabouts, related to perception and protection.

Figure 6  Most common measures to improve safety in LRT roundabouts, related to perception and protection. Source: [16]

4.2 Insertion of the LRT in the roundabout

Besides potential problems with lack of visibility, perception and information, the main problems in roundabouts are related to unsuitable insertion of the LRT in the roundabout.

If the LRT crosses the roundabout off-centered, or the road entrances to the roundabout are too close to the tracks, the road drivers’ attention may need to be diverted in two different directions. Therefore, road vehicle drivers have to focus on the road vehicles coming from the left in the circular road of the roundabout, but they have to immediately change their attention to the traffic lights which protect the crossing over the LRT tracks (and to the LRVs coming either from the right or the left). Hence, special care needs to be taken to avoid a roadway entrance to the roundabout too close to the crossing of the LRT tracks. Examples of these situations, which need to be avoided, are presented in Figures 7a to 7c.
Additionally, as stated in section 4.1, to ensure visibility by the insertion of the LRT in the roundabout, the crossing of the tracks by the circular road should be as close to a right angle as possible. See bad and good insertion solutions related to this aspect in Figures 7d to 7g.

![Image](a)
Source: [12]

![Image](b)
Source: [12]

![Image](c)
Source: [1]

![Image](d)
Source: [12]

![Image](e)
Source: [12]

![Image](f)
Source: [1]

![Image](g)
Source: [1]

**Figure 7** Good and bad examples of LRT insertion in the roundabout.

a, b & c) Not-advisable configurations with roadway entrances to the roundabout too close to the tracks crossing; d) Not-advisable configurations related to the angle of the intersection between the circular road and the LRT tracks; e, f & g) Advisable configurations related to the angle of the intersection between the circular road and the LRT tracks.

### 4.3 Roundabout size and number of lanes

An important general consideration to be born in mind for the safe design of at-grade intersections and roundabouts in LRT networks is that the geometry of the intersection must be appropriate to the traffic volume.

For the case of roundabouts, this means that the radius of the central island, the number and width of the lanes in the circular road, as well as the distance between the roads entering the roundabout and the LRT crossing points, must be carefully designed (or redesigned in accordance to new circumstances when the LRT is being inserted into an existing roundabout).

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 larger the size of a roundabout, the higher the potential for...
crashes. Additionally, having several lanes can introduce visibility problems due to one road vehicle obscuring another. In Figure 8, the accident ratio by roundabout size is presented for the French case.

![Figure 8](image)

**Figure 8** Accident ratio by roundabout size. Source: [14]

The French study about LRT roundabout accidents [14] concludes that the use of two or more lanes for road traffic in the roads entering the roundabout (instead of only one lane) seems to be one of the main risk factors for LRT roundabouts. Therefore, the French guidelines text is as follows [12]:

“The entrances non-parallel to the LRT with more than one lane lead to difficulties on the perception of the LRT zone 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 LRT entrances with more than one lane are forbidden and may only be used in exceptional cases.

The entrances parallel to the LRT can be provided with two lanes only if the road traffic volume justifies this decision and the pedestrian traffic (volume and nature) allows it.

Entrances 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, therefore 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 be 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 high traffic volume, the congestion generated can foster the disrespect of traffic lights by road vehicle drivers, leading to more dangerous situations.

4.4 Additional specific aspects related to LRT roundabouts safe design

In any LRT roundabout (and therefore, in any of the cases presented in sections 3.1 to 3.3), the stopping zone before the LRT in the roundabout should be carefully designed to allow a road vehicle to wait for crossing the tracks without blocking the exit of the roundabout to other vehicles (see Figure 9). Additionally, 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 circular road and are focused on the exiting road and pedestrians. The French guidelines for this distance is 3 meters [12].
A roundabout layout which is enlarged in the perpendicular direction to the LRT tracks is sometimes used. This 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 LRT tracks when the LRV is approaching, until the intersection is cleared.
- A longer perpendicular stretch is provided before the LRT tracks crossing, which improves visibility (and with it, safety) in the crossing.
- Intrusions in the LRT zone can be avoided by clearly separating it from the adjacent carriageway by rigid elements.
- On the other hand, this solution may increase the speed of road vehicles on the roundabout, particularly where crossing the LRT zone, reducing safety.

4.5 Safety improvements for LRT roundabouts by measures applied to traffic lights

As stated in section 2, the usual way of managing an LRT roundabout is with traffic lights for road vehicle drivers located immediately before the crossings of the LRT tracks by the circular road. These traffic lights will change to red every time that a LRV is present or approaching, giving the priority to the LRV.

In general, it is not necessary to include complementary traffic lights on the streets that enter the roundabout, but the roundabout has to be readily recognized as one with LRT tracks traversing it (as stated in section 4.1). Nevertheless, sometimes traffic lights can be installed also at the road entrances to the roundabout, especially when the entrance is very close to the crossing of the LRT tracks, when the road traffic volume is high, or when the roundabout has proved to be a risky point and no other measures are effective. In this last case, one solution to avoid risk could be to implement traffic lights at each entrance to the roundabout, and to change to an “all red” situation every time that the LRV is present or approaching, forbidding the access to the roundabout for road vehicles until the roundabout has been cleared of LRVs. This solution cannot be used in a general way, as it can lead to the saturation of the at-grade intersection if the traffic volume is very high and/or the frequency of the LRT is high, as the capacity diminishes with this kind of traffic light regulation.

In any case, an important consideration to ensure safety in LRT roundabouts with traffic lights (wherever they are located) is avoiding the infringement of these traffic lights, either intentional or unintentional, by road vehicles drivers. There are several measures of traffic light reinforcement that can be applied to try to avoid the unintentional infringement in places that are specially complicated, for example:

- enlargement of the diameter of the red light (e.g., changing from 200 mm to 300 mm), use of brighter lights (e.g., LED) or use of a backboard on the traffic light;
- duplication of traffic lights including new lower ones in the drivers’ line of sight;
installation of flashing road studs embedded in the pavement on the stop line, synchronized with red traffic signal (a discussion about the effectiveness of this solution in Houston, Texas, is made in [17]);

• including in the traffic light pole an active LRV symbol which starts blinking when the LRV is approaching, a few seconds before the traffic light changes to red;

• enforcing traffic light physically with railroad gates (with red and white stripes) connected with the traffic lights message and the LRV presence. This measure is not suitable for central urban areas and should only be considered in special cases, as it interrupts auto traffic for a much longer duration, having a negative impact in the roundabout performance.

For the case of intentional violations, one measure that can be applied is the use of red-light cameras, which automatically fine drivers who do not respect a red traffic light. This solution is applied in Los Angeles LRT [4].

Several examples of application of this kind of measures are shown in [1, 15].

## 5 CONCLUSIONS

Roundabouts are a very common solution for intersections without LRT in some European countries, as they provide a safe and almost continuous traffic flow, transforming complicated maneuvers into right turns. Nevertheless, the roundabout operation changes when an LRT system is implemented through it, with the loss of priority of road vehicle drivers when the LRV is present or approaching. Sometimes, this change in the roundabout management can lead to confusion, and this is why LRT roundabouts should not be used as a general solution, but only when there are strong reasons that make this configuration more advisable than a conventional at-grade intersection controlled by traffic lights. These reasons are normally related to the movements that need to be allowed at the intersection, or to the configuration of the streets that converge on the roundabout.

If a roundabout is selected as the most suitable solution for a specific LRT intersection, it has to be carefully designed to ensure a complete understanding of the situation by road vehicle drivers. The general design aspects related to visibility, perception and protection of the LRT system have to be born in mind. In addition, the insertion of the LRT in the roundabout has to be appropriate to avoid situations where the road vehicle drivers’ attention needs to be diverted in two different directions. Moreover, the size and number of lanes has to be as small as possible, but in consonance with the traffic volume. Furthermore, the design of the stopping zone before the LRT tracks, the pedestrian crossings on the exits and the shape of the roundabout have to be considered to ensure safety and a good performance of the roundabout. Finally, some measures can be applied to traffic lights for avoiding the infringement by road vehicles drivers, either intentional or unintentional, in specifically troublesome locations.

## 6 ACKNOWLEDGEMENTS

Authors thank the European Cooperation in Science and Technology (COST) for funding the COST Action 1103.

Authors thank all the members of the Action, as well as other contributors, for the data and work provided. Writing this paper would have not been possible without their inputs.

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