Roundabouts and tramways

Crossing of a roundabout by a tramway

Design guide

Version last updated in June 2017

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The “References” Collection of Cerema

This collection consists of all reference documents pertaining to the state of the art in the domains of expertise of Cerema (methodological recommendations, technical rules, know-how, etc.), in a stabilised and validated version. Intended for specialists as well as non-specialists, its educational and concrete wording aids in the appropriation and application of the recommendations by the professional in an operational situation.

Acknowledgements

This work constitutes an update of the guide that was initially published in 2008 by the Certu and the STRMTG, and is based on a critical review of this work by a panel of users.

The list of contributors to the initial version and the members of this panel are given in the annexe.

The new version was drafted by Yannis Lagarde, in charge of studies at the Cerema Méditerranée, under the coordination of:

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- and Marine Blancheton, tramway specialist at the tramways division of the STRMTG.

We thank everyone who contributed to the drafting of this guide through their participation in the initial version, in its critical review or in the final review of this updated version (refer to the lists in the annexe).

Foreword

Against the backdrop of the high rate of development of the tramway networks, a few cities have chosen to develop road intersections that are crossed by a tramway in roundabouts.

However, initial feedback has proven that this configuration gives rise to several issues, mostly related to the right-of-way conflict that results from this type of layout, thereby resulting in a higher rate of accidents between trams and third parties on these crossroads as compared to other types of crossroads with a tramway.

While the roadworks layout guide for public transportation, published by the Certu in January 2000, quickly became a reference in matters of the urban insertion of public transportation, there was still a need to update it on the particular subject of roundabouts.

It led the Certu and the STRMTG to publishing, in 2008, a specific design guide for crossing a roundabout with a tramway, based on the feedback and experience that was available at that time.

The continuous development of tramway networks, the modifications made on the existing networks and the progressive consolidation of feedback in terms of safety through data of accidents provided by the operators, all helped in developing reflections and judging the relevance of the recommendations concerning the layout and signalling of roundabouts crossed by a tramway.

Thus, there was a need to update these recommendations, and this document is therefore an update of the 2008 guide. It is based on a critical review of the initial version by a panel of professionals who participated in various ways in the tramway projects and their operation, as well as on the nation-wide analysis of accidents involving trams on these intersections.

Since the initial version of this guide was published, certain recommendations have proven their worth and a few new ways have also emerged; however, the rate of accidents between trams and third parties on roundabouts remains relatively higher than that on other types of crossroads with a tramway. Therefore, this configuration should be chosen only if sufficiently justified and the principles stated in this guide must be followed.

Caution:

The transposition of this information to the case of a Bus Rapid Transit Service (BRTS) should be handled with extreme care, and should only be considered if the BRTS is truly operated like a tramway. The bus remains a road vehicle that is not constrained by a guidance system, with different characteristics (smaller size, not forced to follow a predefined track, better ability to turn and superior braking capacity). Therefore, the bus is not forced to cross the central traffic island as it is the case of a tramway, even though this choice would be better in terms of comfort and service level. For more information, please refer to the document named “Giratoires et bus à haut niveau de service (BHNS) – Recueil et analyse des pratiques existantes” published by the Cerema in 2016, which highlights the points to be kept in mind and the questions to be raised while inserting a BRTS in roundabouts.

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Introduction

As part of the tramway projects, the choice of a roundabout is often linked to its proven effect on slowing traffic speed, as well as the possibilities of U-turns that it offers , which makes it easier to develop traffic plans. Quite naturally, it is rather tempting to preserve this configuration when it already existed before the tramway was created.

However, the circular right-of-way specific to roundabouts conflicts with the right-of-way granted to trams by the traffic regulations, which results in a complex road configuration for its users. This appears to be corroborated by the accidentology, which highlights an increased risk of accidents between trams and third parties on this type of crossroads.

From the point of view of the “tramway” system, the pertinence of this layout is therefore questionable, and an in-depth reflection must be conducted by the designers before validating the decision to create or retain a roundabout on the path of a tramway.

Despite everything, for global questions of the layout of public space and traffic management, the roundabout is probably the most appropriate type of crossroads in a given urban context. It is therefore necessary to limit the risk of accidents as much as possible, by adapting the geometric configuration and signalling of the roundabout to the tramway. This remains the main subject of recommendations in this updated version of the guide, which aim at guaranteeing the safest, most legible and most comprehensible layout possible to the user.

Compared to the original guide, this update aims at clarifying the recommendations, by specifying them for certain configurations, and supporting them by referencing the statistical operating results from the national database of the STRMTG “Tramway events”.
The summary of the guide, unchanged from the 2008 version, is divided into five main chapters.

Chapter 1 explains the issues related to the crossing of a roundabout by a tramway, and the need to make the layout as legible and as comprehensible as possible for the user.

Chapter 2 describes the various possible configurations for the positioning of the tramway platform when crossing the roundabout, and indicates which configurations are forbidden or should be avoided.

Chapter 3 gives a more detailed explanation of the geometry and adaptations required in the case of roundabouts that are crossed by tramways through the centre or on one of their branches.

Chapter 4 emphasizes the need to ensure a good perception of the layout by describing the visibility and legibility of the various components of the crossroads.

Lastly, **Chapter 5** describes the static signalling and traffic lights and their implementation for facilitating the crossing of the roundabout by trams.

In addition to these recommendations that are applicable to every roundabout, it must be reiterated that it is essential to have consistent and homogeneous layouts on the same route, thus allowing the user to better understand the operation of the type of approaching crossroads and to adapt his behaviour accordingly.

Moreover, since these recommendations are based on feedback that is relevant only to a sufficient number of roundabouts of the same type, this guide cannot be used for special roundabout configurations, which must be analysed specifically. It also does not apply to signal-controlled crossroads with central traffic islands and signal-controlled traffic circles, the design and operation of which follow different rules than those applicable to roundabouts.

1 The issues related to the crossing of a roundabout by a tramway platform

1.1 The basic principles of roundabout functioning

The definition of the "roundabout with a circular right-of-way" is taken from two articles of the french road traffic code :

- Article R110-2 states that a roundabout is "a square or crossroads having a central platform that cannot be physically traversed, circled by a one-way road (anti-clockwise direction), which branches out into different roads and which is announced by specific signalling. However, roundabouts may include a central platform that can be physically traversed[1], which can be mounted by drivers when the size of their vehicle forces them to do so";
- Article R415-10 specifies that "a driver coming to a roundabout is required, irrespective of the classification of the road that he is about to leave, to give way to users travelling on the road that circles the roundabout".

Roundabouts are thus different from signal-controlled traffic circles, which are circular crossroads equipped with traffic lights at each entry to manage conflicts between road traffic entering the circle.

It also differs from signal-controlled crossroads with a central island (Cafaic), which are crossroads having a large central island and traffic lights for waiting vehicles and managing conflicts within the crossroads.

As proven by observing behaviour[2], the operating mode of the roundabout is well-established in the subconscious of users, and this link appears to be very strong between this operation and their perception of the roundabout through the layout and the signalling specific to this type of crossroads. In fact, when a user comes upon a roundabout, his attention is focused on the users driving in the circle and on those arriving from the branches to the left, to whom he may potentially have to give way. Once travelling in the ring, the user, now having the right-of-way, then turns his attention to vehicles entering the roundabout by the following entries (arriving from his right).

1.2 The impact of the tramway on the operation of a roundabout

The installation of a tramway platform that crosses the roundabout does not fundamentally change users' perception of it; for them, these crossroads are still a "roundabout" with the same right-of-way rules as described above, and the same resulting behaviour.

1 A roundabout is described as a mini-roundabout when the platform is fully traversable.

2 Refer to the studies on "Analyse approfondie de l'accidentologie d'aménagements urbains" (Inrets – June 2003); "Cinématique sur les carrefours giratoires" (Setra / Cete Normandie Centre – June 1992); "Cinématique des 2RM sur les carrefours giratoires" (Cete Normandie Centre – February 2011).

However, when a tramway platform crosses a roundabout, the user driving on the ring loses his regulatory right-of-way at its crossing, in pursuance of Article R. 422-3 of the traffic regulations:

“When a railway track is constructed on a road or crosses it at grade, the right-of-way belongs to the equipment that normally travels on this railway track”.

The operation of the roundabout is therefore temporarily disturbed by the presence of the tram, while the rules of right-of-way between road users remain unchanged (right-of-way of road vehicles travelling in the circle over those entering it).

The presence of a tramway platform in the roundabout thus brings an additional layer of complexity in the configuration and operation of an intersection that is already quite complex in nature, where drivers are not used to having to stop, especially in the ring.

This is corroborated by the feedback accumulated on the French tramway networks, especially since 2003, via the use of the “Tramway events” database administered by the STRMTG.

In 2006-2015, the percentage of collisions with third parties, when compared based on the type of intersection, is higher at roundabouts as compared to others (excluding signal-controlled traffic circles). It should be noted that these figures take into account all collisions with trams, including those without victims, but do not take into account the volume of traffic at the crossroads.

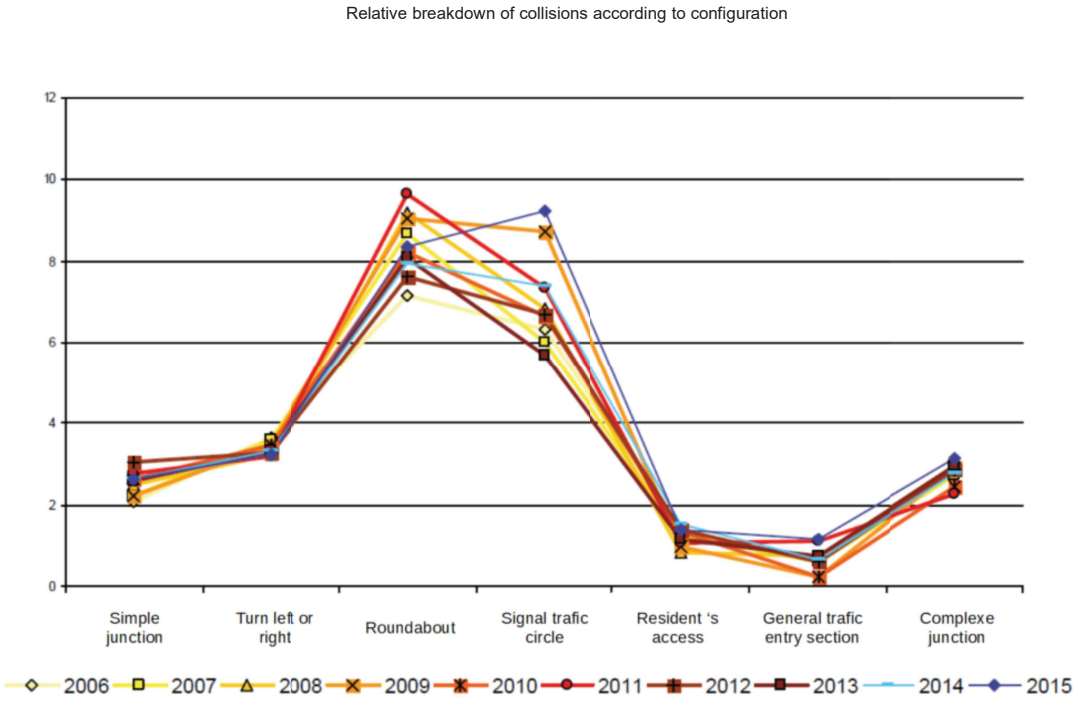


Figure 1: estimate of the collision risk (source STRMTG)3

3 The “turn intersections” are those where the driver on a lane parallel to the tramway has to turn to the left or right to cross the platform (this movement being lawful) when not in the “roundabout” or “traffic circle” configuration.

On arriving at a roundabout crossed by a tramway, the user must focus his attention on the tramway platform while also remaining attentive towards the other drivers, and must adapt his behaviour accordingly.

It is therefore essential that :

- the layout must be legible and understandable whith a geometry adapted to the road user immediately perceives the way it works, to avoid ambiguity, which is always a source of insecurity;

- road users are obliged to reduce their speed when approaching and crossing the intersection;

- the roundabout functioning is as optimized as possible in relation to the tramway crossing to ensure the credibility of the system, respect and therefore safety.

2 The relative positioning of the roundabout and the platform

The crossing of a roundabout by a tramway platform is closely linked to the configuration of the area and the positioning of the platform with relation to the roads (axial or lateral layout, or not even in the middle of the road) on both sides of the crossroads.

Two essential principles must be followed:

- cross the central traffic island as close to its centre as possible, in order to promote crossing the circular road perpendicular to it;

- distance the platform to be crossed as much as possible from the road entries, in order to enhance the perception of drivers and to allow them sufficient reaction time.

Hence, the crossroads should be crossed by the tramway by cleanly crossing the central island, or by avoiding it and the circular road completely and cutting across just one branch at a sufficient distance from the ring. All other layouts are risk-factors and may cause dysfunctions; hence, they are to be avoided.

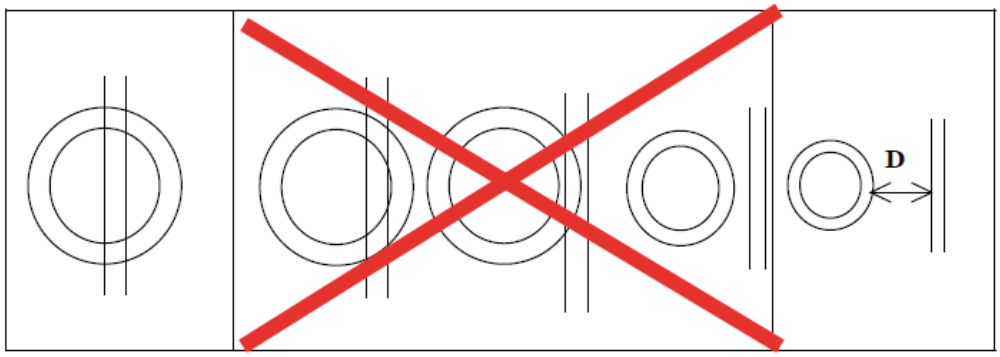


Diagram 1: relative positioning of the platform with respect to the circular road of the roundabout

2.1 Layouts to be avoided

Configurations where the tramway platform is installed laterally next to the entry of vehicles to the roundabout (diagrams 2 and 3) are forbidden, since they result in the vehicle crossing being immediately downstream of, or even in line with their entry to the circular road.

The driver is therefore faced with two conflicts at the same time, with users having the right-of-way coming from two different places: the vehicles travelling in the circular road and the tram crossing it. This case is also confronted with signalling installation and perception issues, especially those intended to manage conflicts with the tramway.

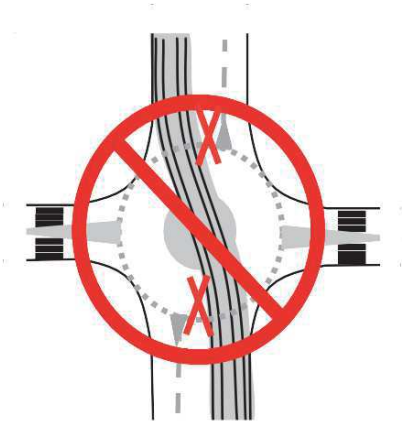


Diagram 2

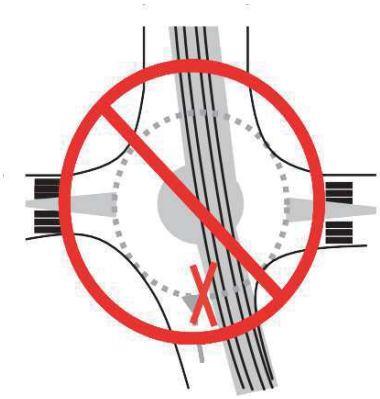


Diagram 3

Users approaching this type of entry focus their attention on the circular road and to their left, to the detriment of the platform and its associated signalling. Therefore, these configurations must be avoided.

2.2 Acceptable layouts

5.2.4 2.2.1 Favourable case: axial installation on opposite sides

The axial installation of the tramway platform on opposing and aligned branches on opposite sides of the roundabout is the best configuration, as it ensures the best possible compliance with the essential principles mentioned above (crossing at the axis, sufficient distance between entries and platform).

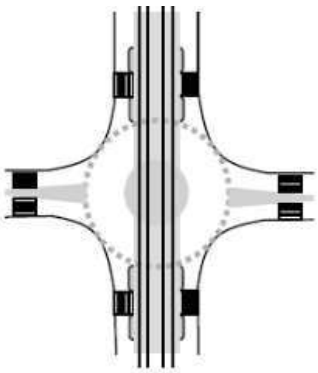


Diagram 4 : The axial installation on opposite sides results in a legible layout

Photos 1 and 2 : examples of roudabout crossings by a tramway in an axial site

It is harder to cleanly bisect the central traffic island if the axial platform has to turn towards the right of the roundabout. This is still possible if the angle between the branches concerned is not too acute and if the roundabout is sufficiently large (without exceeding the values recommended in chapter 3 of this guide (refer to § 3.2.1)).

Otherwise, it is preferable to completely “shunt” the roundabout, but the axial installation would then lead to partially bisecting (in one direction) the two branches concerned; here, it is necessary to maintain a sufficient distance between these intersections on the branches and the roundabout (see below in § 2.2.3).

2.2.2 Conceivable case: lateral installation on at least one branch

Configurations where the platform is installed laterally on one or two branches are conceivable provided that the platform is to the side of the vehicle exit with respect to the roundabout.

However, they force exiting drivers to cross the platform simultaneously with exiting the circular road. Therefore, there is a risk of confusion at this level between the road and the platform if the materials used are not clearly different.

Hence, the layout is more complicated than on an axial site, and more users are forced to cross the platform, some of whom (those turning towards the left) are even forced to cross it twice.

One should also keep in mind the problems of perception of the signalling in this type of configuration (refer to chapter 5).

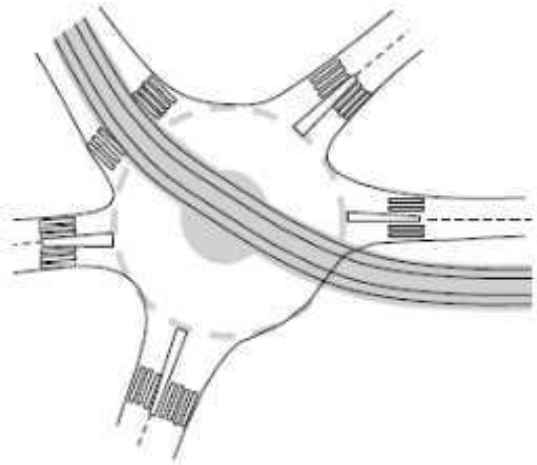


Diagram 5: acceptable configuration

Photo 3: the lateral positioning on the north branch is acceptable, given the wide angle with the previous branch.

This configuration also necessarily requires the platform crossing and the perpendicular entry located upstream on the circular road to be closer to each other, especially on small or medium-size roundabouts. Yet, it is necessary to leave sufficient distance between the entry and the platform crossing, related to the driver’s reaction time for adapting his behaviour and to stop if needed. This minimum distance can be modified based on the conditions of entering and travelling across the roundabout; generally, it is 15 metres, which corresponds to the stopping distance for a speed of 20 km/h (traffic speed on the circular road).

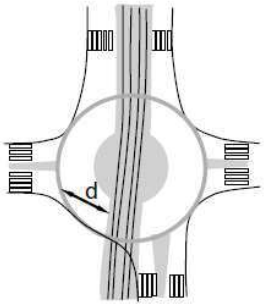


Diagram 6: distance d is measured between the limit of the circular road ("yield the right of way" line) and the GLO[4] limit of the tramway.

2.2.3 Special case: crossing a branch outside the roundabout

When the platform is installed laterally on the same side of the roundabout, the crossroads can be crossed without bisecting the circular road. However, it does have to cross the intermediate branch (diagram 7).

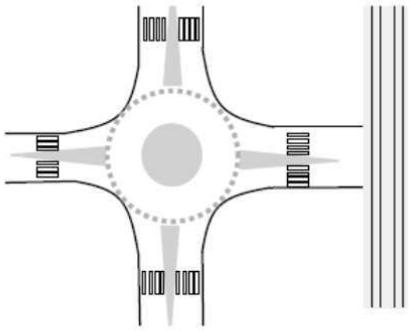


Diagram 7: the crossing of a branch is, in fact, a simple junction close to the circular road.

Photo 4: tramway in a lateral installation adjacent to a roundabout

If the tramway installed axially is curved adjacent to the roundabout, it is also possible to avoid crossing the circular road, but this results in (partially) intersecting one or two branches close to the roundabout.

- At the entry, it has been proven that the behaviour of users who notice a roundabout is conditioned by its operation and its right-of-way principles; they anticipate their insertion, at the risk of not paying attention to the platform crossing, or not even noticing it. The risk is even greater if this platform is hidden by the surroundings or other elements (parallel pedestrian or cycle crossing, plants, urban furniture, etc.).

  There may also be a risk of the traffic queue getting backed up on the platform from the roundabout entry when there is heavy traffic.

4 GLO: clearance gauge (corresponds to the projection on the ground of the maximum volume covered by the guided vehicle travelling on the platform)

- At the exit, the driver, whose attention is focused while entering and crossing the roundabout, naturally relaxes. Therefore, he must be given sufficient reaction time of 1 to 2 seconds before forcing another event on him. This reaction time and the resulting distance vary based on the orientation of the roundabout's branches (this distance cannot be less than 15 metres, corresponding to an average exit speed of 20 km/h from the roundabout).

Photo 5: intersection with the entry on the roundabout upstream of the circular road

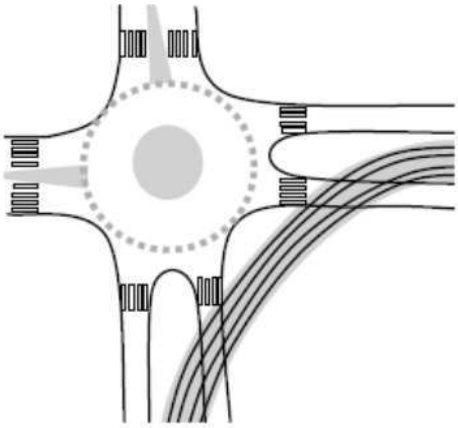
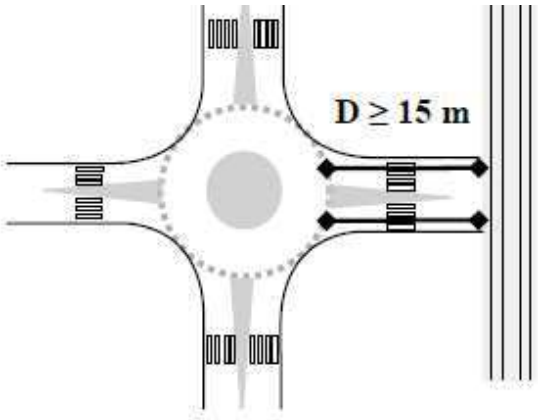
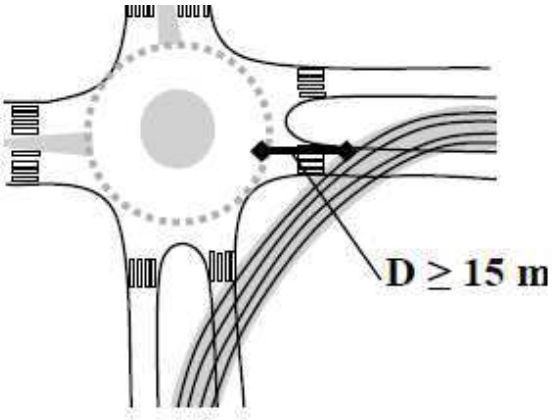


Diagram 8: curved tramway adjacent to the roundabout; the axial installation results in cutting across each branch in one direction

These configurations, where the platform intercepts a roundabout branch, can also result in risks of a traffic queue being backed up on the circular road if there is heavy traffic at the roundabout exit and a high tram frequency (refer to the annexe "Determining the residual capacity for vehicles").

For all these reasons, in all cases of a partial or complete crossing of a branch of a roundabout, it is necessary to distance it as far as possible from the circle, in order to limit interactions between the roundabout and the platform crossing. Feedback and observing existing situations have shown that, in these configurations, the risk is high on entering as well as exiting the roundabout.





Diagrams 9 and 10: distance D is measured between the limit of the circular road ("yield the right of way" line) and the GLO of the tramway platform.

Where the tramway platform is installed laterally on two neighbouring branches of the roundabout, there is no interaction with the crossroads; however, pedestrian crossings must be handled with caution.

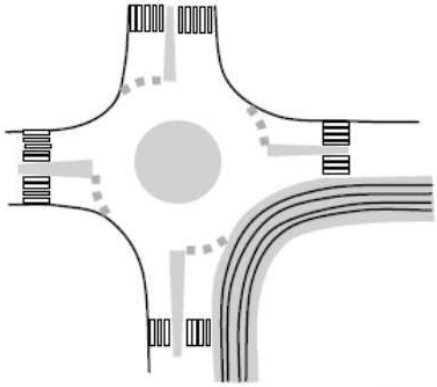


Diagram 11: tramway platform without direction interaction with the roundabout (apart from pedestrians)

Photo 6: pedestrian crossing close to the roundabout

3 The geometry, rules and limits

3.1 The basic principles of design of roundabouts

All basic principles of design of roundabouts (“Sécurité des routes et des rues”, “Guide carrefours urbains”, “Voirie urbaine – Guide d'aménagement”) are applicable to roundabouts with tramways:

- a roundabout is, above all else, a crossroads, and must have at least three branches; the higher the number of branches, the larger is the roundabout;
- the central traffic island is circular; it may be slightly oval provided that the speed limit on the circular road is low (ratio between the large and small radii should be less than or equal to 1.2);
- it is greatly preferred for the island to be centred on the axis of the existing roads connected to it;
- the width of the circular road is constant;
- the roundabout must be perceptible and identifiable as such by all approaching users;
- the layout must be legible and easily comprehensible to all;
- the visibility must be ensures, especially on a 2-metre strip bordering the central island and with the left quarter of the ring visible for 10 metres before the entry;
- the entries and exits must never have more than one lane unless forced by the capacity;
- all trajectories must have a sufficient deflection between branches, with radii of less than 100 metres;
- no rigid obstacle should be located opposite the entries, nor on the potential trajectories of out-of-control vehicles;
- the longitudinal profile must have a slope of less than 6%;
- in urban settings, it is preferred for the size of the roundabout (outer radius) to be relatively small with respect to the conflicts to be managed and the deflections to be ensured;
- the geometry of the roundabout must allow articulated buses or heavy trucks to use it.

3.2 Adapting these principles to roundabouts with tramways

The rules mentioned above, especially those related to the size and number of lanes at entry, must be applied with even greater strictness for roundabouts with tramway crossings, by adapting them where needed as per the recommendations described in the following paragraphs.

Installing a tramway platform crossing a roundabout is easier for roundabouts having three or four branches. Installations on roundabouts with a greater number of branches will require more in-depth studies, taking the information included in this guide into consideration.

3.2.1 The outer radius of the roundabout

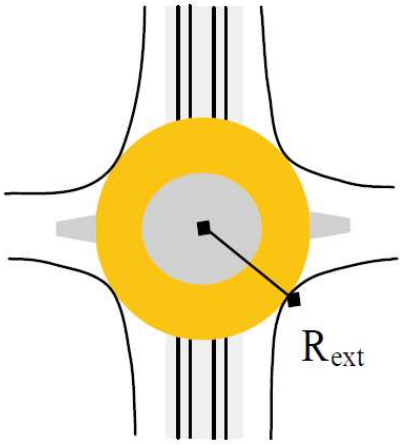


Diagram 12: definition of the outer radius of a roundabout

Using the “Tramway events” database for the 2006-2015 period shows that the risks of accident increase with the value of the outer radius of the roundabout.

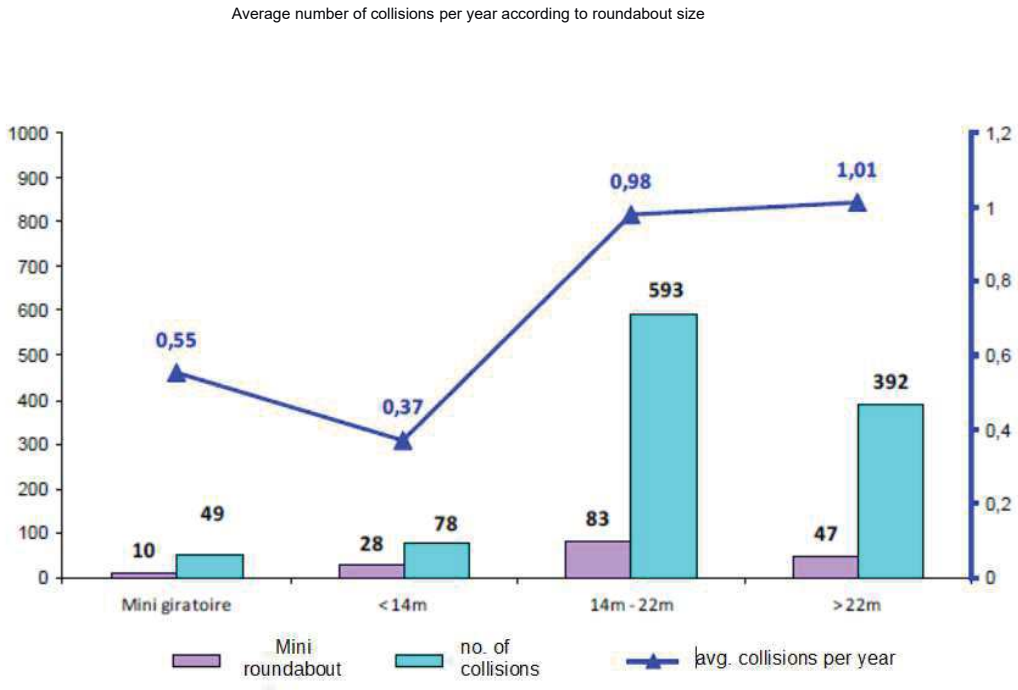


Figure 2: Average, according to the roundabout radius, of the nimber of collisions per year per roundabout, for roundabout whose geometry has not changed during the periodof 2006– 2015 (source STRMTG).

The axis of the ordinates represents the number of sections and collisions per year to the left, and the average number of collisions per year and per section to the right, for each category of roundabout.

The ratios of collisions per roundabout class thus show that mini-roundabouts and compact roundabouts with an outer radius of less than 14 metres encounter less collisions than large or medium-size roundabouts, which can possibly be explained by the low volume of traffic and lower speeds on this size of roundabout. However, the ratio for mini-roundabouts is based on a small sample.

Moreover, the class of medium-size roundabouts shows, beyond radii of 16 metres, significant heterogeneity in terms of configuration (radius, circular road width and number of lanes at entry) and number of accidents.

- An outer radius of 14 to 16 metres (a single lane on the circular road) appears to correspond to a sufficient size, while still maintaining a relatively low collision ration, whereas roundabouts with radius greater than 16 metres require an in-depth reflection.
- Compact roundabouts with an outer radius of less than 14 metres make the installation of signals on the central island difficult, or even impossible.
- Mini-roundabouts are fully traversable and can only be considered for moderate traffic. This type of roundabout comes with issues of perception and legibility (with possible consequences on accidents between third parties) and installation of signalling.
- Roundabouts with outer radii of more than 22 metres, referred to as large roundabouts, are reserved for rare configurations, and require an in-depth reflection. These large roundabouts may result in higher speeds on the circular road, which are hazards to safety as well as the operation. This is all the more important when the roundabouts are crossed, either in the axis or on a branch, by a tramway platform.

3.2.2 The width of the circular road, the traversable strip

The "Tramway events" database, for the period of 2006-2015, indicates that roundabouts with narrower circular roads (< 6 metres) experience less collisions between trams and third parties.

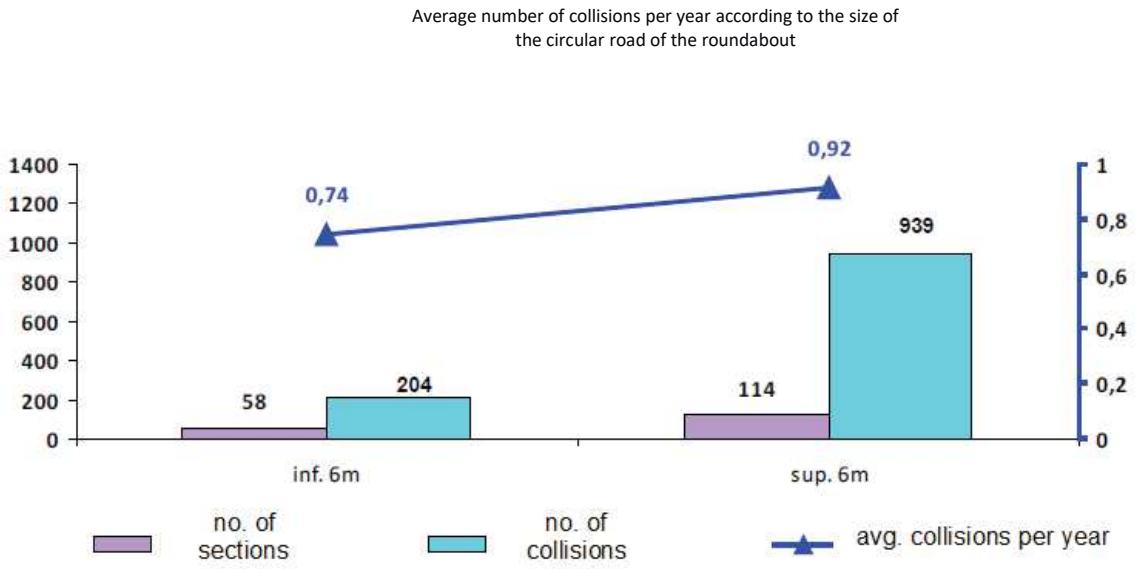


Figure 3: average, according to the size of the circular road, of the number of collisions per year per roundabout, for roundabouts whose geometry has not changed during the period of 2006-2015 (source STRMTG).
The axis of the ordinates represents the number of sections and collisions per year to the left, and the average number of collisions per year and per section to the right, for each category of roundabout.

The desired objective of the layout is to prevent two vehicles from crossing the tramway platform side by side, by reducing the width of the ring to a single traffic lane.

For this purpose, the systematic arrangement of a traversable strip of 1.5 to 2 metres around the central traffic island enables reducing the width of the circular road itself to 5.50 metres, or even to 5 metres if possible.

A total width of 7 metres effectively enables large vehicles to use the roundabout, provided that the entries and exits are correctly designed.

The cross slope of the traversable strip must not exceed 4%; the projection with respect to the circular road is approximately 3 cm.

The traversable strip must be clearly identified as separate from the running surface and must be sufficiently dissuasive in terms of comfort, especially for a driver, while still retaining the same adherence and the same bearing capacity. For this, certain types of road courses and markings can be used.

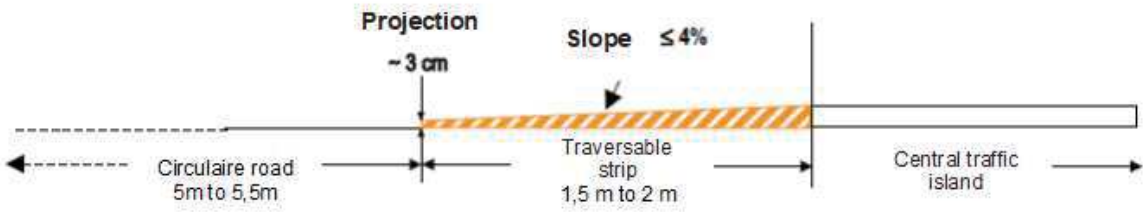


Diagram 13: cross section of a roundabout with a traversable strip around the island

3.2.3 Entries and exits

> 3.2.3.1 Entries

The “Tramway events” database, for the period of 2006-2015, indicates that roundabouts with a single entry lane experience less events.

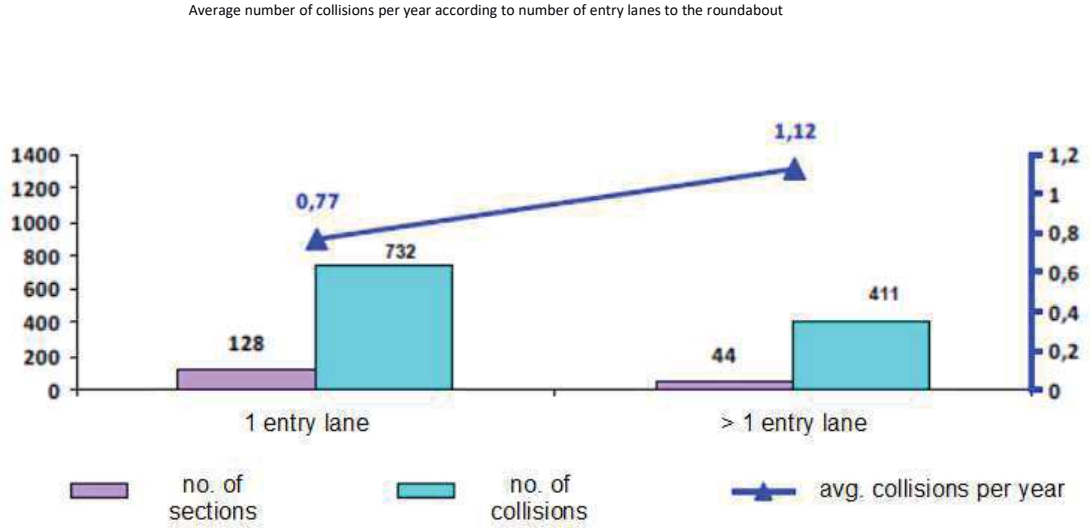


Figure 4: average, according to the number of entry lanes, of the number of collisions per year per roundabout, for roundabouts whose geometry has not changed during the period of 2006-2015 (source STRMTG).
The axis of the ordinates represents the number of sections and collisions per year to the left, and the average number of collisions per year and per section to the right, for each category of roundabout.

As stated in § 3.1. above, multiple-lane entries should be considered only if imposed by the capacity of the roundabout. In fact, this configuration would widen the circular road, increase the deflection radius and therefore the speed of the vehicles, causing an increased risk-factor on the crossroads.

The basic rule for any roundabout, which is therefore to **prescribe a single entry lane on the branches, is all the more important if it's a roundabout with tramway**, in light of the accidentology feedback mentioned above.

For a conventional roundabout, the width of the entry lane is between 3 and 4 metres. **If it's a roundabout with tramway, it will be reduced to 3 or 3.5 metres.**

Entries with more than one lane are therefore to be avoided and may be reserved for rare cases only. In this configuration, the total width of the entries would be a maximum of 6 metres.

The need to add a second lane must be justified by an in-depth analysis of the traffic level and directional movements (high number of turn-left movements) at the crossroads and a demonstration of an effective increase in capacity. This possibility must be reserved for cases where it is inacceptable for traffic queues to be backed up at the roundabout entry, resulting in lowered operational and safety conditions of the road network (e.g. highway feeder road).

The use of two-lane entries must be accompanied by enhanced signalling upstream of the crossroads.

These recommendations must also be applied in cases where the platform does not cross the circular road, but crosses a branch outside the roundabout (refer to § 2.2.3), to prevent the risk of excessive acceleration.

> 3.2.3.2 Exits

On roundabouts, **single-lane exits** (width between 4 and 5 metres) **are the general rule**, since those with more than one lane have increased risk-factors, especially for pedestrian crossings.

When tramways are present, **the width will mostly be between 3.5 and 4 metres** (maximum 6.50 metres for two-lane exits), to prevent excessive speeding on the circular road.

Two-lane exits must thus be reserved for rare cases when imposed by the traffic.

It should also be ensured that the roundabout exit radius does not allow speeding.

The recommendations on the number of lanes and their width also apply if a branch is crossed by a platform close to a roundabout. **In particular, two-lane exits must be prohibited.**

3.2.4 Pedestrian crossings

It is necessary to apply the general recommendations, concerning pedestrian crossings at roundabouts, mentioned in the guides *"Carrefours urbains"* and *"Guide d'aménagement de la voirie pour les transports collectifs"* of the Certu and the IUTCS document *"Tramway et traversées piétonnes – Principes d'aménagement"*.

Crossings for pedestrians are normally placed on each branch at a distance of 2 to 5 metres from the "yield the right of way" line, except in special cases related to visibility.

Their regulatory marking must be broken at the tramway platform; however, it is recommended to mark out the crossing to ensure the continuity of the guidance and the funnelling of pedestrians.

It is also recommended to place traffic islands between the road lanes and the tramway platform, as well as between roads going in opposite directions, unless the total length to be crossed by the pedestrians is less than 8 metres. Traffic islands allow differentiating the spaces to be traversed, gaining information on the complexity of the crossing and splitting the lengths to be crossed.

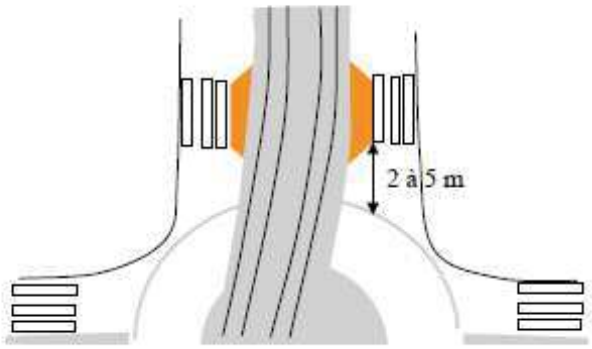


Diagram 14: recommended position of a pedestrian crossing at a roundabout exit

Traffic islands must be comfortable in size, suited to the context and especially to the expected flow of pedestrians. A width of 1.50 metres is not sufficient, as it would not be enough for a pedestrian with a stroller or a cycle. A minimum length of 2 metres must be guaranteed, as recommended by the various guides of Cerema on urban layouts.

In the case of a lateral site, two islands, one of which should be between the traffic lanes for vehicles going in opposite directions, may be necessary.

Photo 7: pedestrian crossing of a lateral site close to the roundabout (source: Cerema)

Photo 8: management of a platform crossing by a signal R25 (source: Cerema)

Pedestrian crossings of roads adjacent to roundabouts are not signal-controlled. If the roundabout is equipped with traffic lights that manage tram/vehicle conflicts, the pedestrian crossings of the tramway lanes may also be managed by traffic lights. In this case, using the R25 signal is highly recommended to avoid any confusion.

4 The perception of the layout

A roundabout crossed by a tramway must be perceived and identified as such. As specified in § 3.1, the general rules of visibility and legibility of a roundabout apply, but must be supplemented to take into account the distinctive features that arise due to the potential presence of a tram in a roundabout.

4.1 Specific principles of visibility

For a roundabout crossed by a tramway, it is necessary to ensure good visibility of the signalling that is specifically related to the presence of the tramway (refer to chapter 5), especially for the signals located on the island.

Moreover, it is also vital to guarantee a good reciprocal visibility between the tram and users.

Therefore, in addition to the normal installation rules of road signalling and the general layout principles of roundabouts, **any landscaping, architectural or other element on the traffic island or adjacent to a roundabout, which may be a potential visual obstacle for the tram drivers or for users, must be prohibited.**

4.2 The legibility of the layout - The choice of materials

For an automobile driver, the legibility of a roundabout is related to the ease of identification of its major components (central island, circular road) and the understanding of the right-of-way and the trajectory to be chosen. Poor legibility may lead to loss of control, dangerous manoeuvres, driving in the wrong direction and refusing to give right-of-way.

In the case of roundabouts bisected by a tramway platform, its presence must be announced clearly.

For the tram driver, the legibility of the roundabout is linked to the ease of noticing potential conflicts with the other moving users, vehicles and pedestrians, and therefore to the ease of noticing the entries, the circular road and the pedestrian crossings.

The legibility for the tram driver is supplemented by marking the position of users at rest with respect to the platform and the clearance gauge (GLO).

4.2.1 For medium and large roundabouts

In a roundabout of conventional design, with an outer radius of at least 14 metres, the driver's perception of the continuity of the circular road is generally established quite easily, even if it is visually interrupted by equipment on the platform; however, a driver sometimes has difficulties in noticing the presence and position of the tramway platform.

For these layouts, it is recommended to mark out the continuity of the platform and the clearance gauge with materials, to the detriment of the continuity of the circular road.

Photos 9 and 10: marking of the platform to enhance the perception as compared to the circular road (source: Semitan)

4.2.2 For small roundabouts

On the contrary, for smaller roundabouts, and especially for mini-roundabouts, the platform is easily perceivable by itself owing to its proportions, and often to the detriment of the perception of the circular road; the speeds of vehicles are generally lower.

Photo 11: marking of the central traffic island of a mini-roundabout (source: Semitan)

For these roundabouts, the perception of the island and the ring road should be emphasized, without omitting the marking of the GLO.

4.2.3 Case of crossing a branch of the roundabout

The case of the crossing of a branch outside a roundabout is similar to the “conventional” case of a simple platform crossing. Irrespective of whether it is at the entry or exit of the roundabout, the driver is focussed on his roundabout exit or entry manoeuvre and risks being less attentive to the platform crossing.

As with all tramway platform crossings, it is therefore important to clearly mark the GLO and the difference in treatment between the platform and the roadway.

Photo 12: marking of the platform crossing a branch of the roundabout

5 Signalling and principles of operation

5.1 Static signalling

5.1.1 Basic signalling of a roundabout

The general operation of a roundabout, based on giving right-of-way to the vehicles travelling in the circular road, is shown via police signs, in accordance with the provisions of the ruling of 1967 on road signalling and the articles of the Inter-ministerial instruction on road signalling (IISR), and especially its Articles 9-2, 42-10, 65 , 83-1 and 83-4.

The following are also mandatory for all roundabouts:

- **its pre-signalling using an AB25 sign; it must be positioned upstream of the crossroads, at a distance that varies based on the context, configuration and speed limits. In a built-up area, it is generally 10 to 30 metres;**

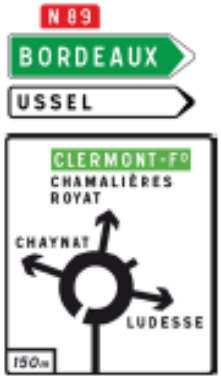
- **the marking of the "yield the right of way" lines at the entries**

The AB3a sign "yield the right of way" at the entries of the roundabout is optional in a urban area, but it is nevertheless recommended for enhancing the understanding of the crossroads' operation, even more so as the visibility of the AB25 sign is not always optimal in urban areas and the ground marking wears off rapidly.

In addition to this intersection signalling, there are other (optional) signals generally found at/around roundabouts, which contribute to the identification of the roundabout and to the conditioning of user behaviour:

the J5 beacon, installed at the roundabout entry on the traffic islands, and the B21 and B21a1 signs installed on the central traffic island, contribute to "guiding" the users;

- the milestones signalling (D21 signs), installed in position in the roundabout, especially on key arteries and in peri-urban areas, helps in orienting users;



- the D42b diagrammatic sign, mostly used in peri-urban areas and on key arteries; installed upstream, it contributes to the conditioning of user behaviour on approaching a roundabout, especially for those not familiar with the area and those who are searching for markers and route signs.

As regards horizontal signalling, the marking is generally limited to the “yield the right of way” line, the marking of the edges of the island and the marking of the pedestrian crossings.

No border or axis marking is, in principle, required on the circular road. Nevertheless, the edge of the central island of a mini-roundabout can be marked using a broken strip, which can help in enhancing perception.

5.1.2 Specific static signalling related to the tramway

If a tramway is crossed by roads, specific signalling may or must be implemented: **this advance signalling using the A9 sign is mandatory if this crossing is managed by traffic lights, and optional otherwise** (refer to Art. art 35-2 and 72-1 of the IISR).

When a tramway platform crosses the roundabout or one of its branches, this signalling must therefore, where necessary, be installed in addition to the static signalling mentioned in the previous paragraph. **It is often useful, especially on entries that are not parallel to the platform, or if the latter crosses a branch.**

According to the IISR, the installation distance of the A9 signal is 150 metres outside of built-up areas and between 0 and 50 metres in a built-up area, with a distance close to 50 metres being recommended

When the platform crosses the traffic island of the roundabout, signals AB25 and A9 should preferably be placed on a common support, in order to characterise this specific configuration.

The signalling of the position using the C20c signal is not mandatory unless there are no traffic lights (traffic lights with three colors). Given the problems of perception of the platform, its use is recommended in all cases, and especially at and close to roundabouts.

By definition, it should be installed as close as possible to the platform, consistent with the marking of the clearance gauge. If there are barriers traffic lights, it is highly recommended to install the C20c sign on the same support as the lights to make it easier for the user to connect it and the tramway.

When the traffic lights are a R24 signal, it is possible to supplement it by a M9z plaque stating "FLASHING RED - ABSOLUTE STOP".

If traffic lights connected to the passage of the tram are installed, this may result in placing stop lines (refer to § 5.3.2.3).

photo 14: plaque associated with the R24 signal and with C20c (source: Semitan)

5.2 Traffic lights

From a regulatory point of view, no dynamic signalling is required to manage conflicts between drivers and trams, since the latter have the right-of-way in accordance with the traffic regulations (Art. R422-3).
However, given the complexity inherent to the configuration and the overlapping of this rule with the right-of-way in roundabouts between drivers, it is highly recommended to confirm this right-of-way of the tramway using traffic lights.

It may be possible to do away with such traffic lights in the following special cases only:

- the traffic is moderate and consists of users who are familiar with the area (residential area, for instance);
- the perception and legibility of the layout are good;
- the reciprocal visibility is very good;
- the tram speeds are moderate.

Therefore, these only apply to small roundabouts (or mini-roundabouts) and require an in-depth and case-by-case analysis.

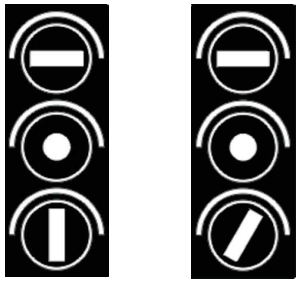
Most of the time, it is necessary to manage the conflicts between trams and other users with the help of traffic lights. These signals must be as consistent as possible with the usual right-of-way of roundabouts, which always remains the rule between drivers.

This dynamic management is essential if one or more branches are crossed close to the roundabout, given that users may possibly be surprised by it.

5.2.1 Signalling for trams

The platform reserved for trams is equipped with R17 / R18 signals that can be installed to the right or immediately to the left of the tramway track concerned, or even repeated if imposed by the visibility conditions, in accordance with the provisions of the IISR (Art. 110-7).

If the tramway platform crosses the central traffic island, it will not be enough to contain an entire train; therefore, it is useless, and even inappropriate, to install a signal upstream of the second crossing. A single R17/18 signal should be placed upstream of the first crossing in each direction of travel, for managing both road crossings (and also any pedestrian crossings associated with the roundabout).



R17 R18

5.2.2 “Barrier” traffic lights for road vehicles

Since the traffic lights in question here are only meant to manage conflicts with the tramway, they should logically be installed as close as possible to where the tramway platform is traversed by the road concerned, and therefore on the circular road if the central traffic island is traversed.

These “barrier” signals must force road vehicles to stop when a tram is crossing, and must be consistent with the conventional right-of-way on roundabouts when the tram is absent.

In principle, it is possible to use stop signals traffic lignts (R24) or traffic lights (R11v or R11j).

R24 stop signal R11v traffic lights R11j traffic lights

- The R24 stop signal has the advantage of being transparent when it is off, and is therefore perfectly compatible with the right-of-way on the circular road of a roundabout between users. However, since there is no yellow light, there cannot be absolute compliance with the red for the first few seconds.

- The R11v set of three traffic lights (green-yellow-red) does not cause any ambiguity as regards the right-of-way between drivers; it has the advantage of being perfectly known to users; however, the presence of the set of three traffic lights on a roundabout is inconsistent with the right-of-way on the circular road and may cause confusion with a signal-controlled traffic circle, especially concerning the management of pedestrian crossings at the roundabout exits.

- The IISR generally does not recommend using the R11j signal, since it is a source of confusion between the nominal operation and downgraded operation of a set of three traffic lights; this is also valid in this particular case of use, which has the same disadvantage that the R11v signal can possibly cause the roundabout to be mistaken for a signal-controlled traffic circle.

The “Tramway events” database, for the period of 2006-2015, gives the following results concerning barrier signals:

Barrier signalling	Average events per year	No. of roundabouts
R24	1.086	18
R24 reinforced1	0.610	37
R11v	0.781	27

Table 1: average of the number of collisions per year per roundabout (for roundabouts whose geometry and signalling has not changed during the period of 2006-2015. The averages for the unusable categories (number of roundabouts less than 4) are not shown (source STRMTG).

Analysing the feedback gained from the networks of roundabouts, especially using the “Tramway events” database and certain particular studies, has not allowed definitively concluding on the relative effectiveness of these different signals, given the diversity of the situations and the multitude of contributing factors (geometric characteristics, traffic, additional signalling, etc.).

Hence, a choice must be made after a detailed, case-by-case study, by comparing their respective advantages and disadvantages with the local context, the configuration and especially the possible presence of additional signalling at the entries (refer to § 5.2.3 below).

The feedback however, showcases the interest in making the traffic lights as visible as possible, taking into account the particular configuration of the roundabout.

Photo 15: the R24 barrier signals are doubled at different heights to enhance their perception (source STRMTG)

5 Reinforced R24 signal: three or more lights

Thus, in the case of the R24 signal, it has been proven that it gives the best results when it is "reinforced", with accidents being reduced by 20% on an average (reduction evaluated on 24 roundabouts that underwent the sole modification of the reinforcement of R24 barrier traffic light - no signalling upstream - accidentology data for the period of 2006-2015)

5.2.3 Traffic lights at the road entries of the roundabout

In principle, there is no need to implement traffic lights at the entries of a roundabout whose island is traversed by a tramway when it is equipped with barrier signalling.

This additional signalling may nevertheless be useful, or even necessary, in certain particular cases. Especially if the width of the entry and the circular road (including the width of the traffic island usable by vehicles), combined with the high volume of traffic, results in two vehicles being able to move side-by-side at the entry of the circular road.

Moreover, when barrier traffic lights cannot be physically installed on the circular road, they must be installed at all entries; this is especially the case of mini-roundabouts and very small roundabouts.

Photo 16: at this mini-roundabout at a general traffic entry section, the traffic lights for vehicles can be installed only at the entries (source STRMTG).
This will then become a signal-controlled traffic circle or signal-controlled crossroads with a central traffic island, which are not covered in this guide.

In these different hypothetical cases, we cannot use the R11v if we wish to maintain the roundabout's normal operation, since its installation at the entries will manage conflicts between drivers owing to these traffic lights, and the right-of-way will no longer be yielded to the circular road 1.

On the contrary, installing an R11j signal is conceivable, even if it is not explicitly stated by the IISR.

Combining the R11j signal at the entry with the R24 barrier signal is not recommended, since the combination of flashing lights with different meanings (flashing yellow on the R11j means go whereas flashing red on the R24 means absolute stop) could be a source of confusion for drivers.

The “Tramway events” database, for the period of 2006-2015, gives the following results concerning signals at the road entries of roundabouts:

Upstream signalling	Barrier signalling	Average events per year	No. of roundabouts
R11j	none or static	0.519	10
	R11v	0.949	8
	R11j	0.617	7

Table 2: average of the number of collisions per year per roundabout (for roundabouts whose geometry and signalling has not changed during the period of 2006-2015). The averages for the unusable categories (number of roundabouts less than 4) are not shown (source STRMTG).

Keep in mind that it is difficult to draw actual conclusions from these figures, since the number of crossroads taken into account is relatively low.

5.2.4 Traffic lights for road vehicles when a branch of the roundabout is traversed

Notwithstanding the proximity of the roundabout, the configuration is that of a simple crossing of a tramway platform, for which the three types of signalling mentioned for barrier signalling can be used (§ 5.2.2 above).

Photo 17: R11v barrier signals at a crossing of a roundabout branch

5.3 Implementation of traffic lights

5.3.1 Operation

When there is no tram (standby position), all of the signalling intended for the vehicles is switched off in the case of R24 signals, or green (flashing yellow) in the case of R11v (R11j), and the signals for the trams are closed (horizontal bar).

The tram should be taken into consideration sufficiently early so that the crossroads can be stabilised (platform cleared, vehicles stopped upstream) when it arrives and so that it does not have to stop or slow down too much.

However, the delay between the stopping of the road traffic (barrier signals turning red) and the arrival of the tram must be limited to ensure that the system remains credible and the capacity of the crossroads is not altered too much. This is important for roundabouts, where the road traffic is, by definition, self-managed and the users are not used to stopping. A delayed arrival of the tram would only incite users to continue travelling, or even restarting and breaking the red lights.

If traffic lights are present at the entries, they must switch to red latest at the same time as the barrier lights.

The normal operation of the roundabouts must also be resumed as soon as possible once the tram has passed, for the same reasons of credibility and impact on the capacity.

Once the tram enters the crossroads, the R17 signal intended for it can be closed, in accordance with the regulations in force.

The signals intended for automobile drivers return to their off position (R24 switched off or R11v/j turning green/flashing yellow) earliest when the front of the tram exits the zone of conflict and latest when the rear of the tram clears this zone. If the lights remain red even after the tram exits, the driver must be able to clearly associate this with the arrival of another tram from the opposite direction.

A good understanding of the approach time, the average journey time, the proper positioning of detectors and monitoring the settings over time are all essential for optimising the operation of crossroads and the impact of tramways on traffic, on capacity plans as well as on safety.

5.3.2 Installation of signals

> 5.3.2.1 Positioning of signals

Concerning the barrier signals on the circular road, the need to guarantee an optimal visibility of the signals, for all users travelling on the roundabout or adjacent to it, results in repeating them by placing them on both sides of the circular road, irrespective of whether they are R11 signal or a R24 stop signal.

As regards the latter, with respect to national feedback (refer to § 5.2), it is also recommended that at least one of the two traffic lights placed on both sides of the road are installed at two different heights, which improves their perception by users approaching the roundabout.

The number and orientation of the traffic lights are to be optimised on a case-by-case basis, such that at least one signal is visible irrespective of the driver's position and where he is coming from.

Photo 18: Repeating the R24 barrier signals allows optimising their perception by all users (source: Cerema)

When traffic lights are placed at the entries of the roundabout, they must, pursuant to the IISR (Art. 8), be placed to the right side of the road, on the same support as the AB3a sign

"yield the right of way" which then must be added to the R11j signal on each entry.

Note: it is possible to repeat this traffic light on the traffic island to the left of the entry, especially for two-lane entries.

The signals (R11 or R24) placed like barriers on a branch of a roundabout traversed by the platform must also be placed to the right of the road, on the same support as the C20c signal (see above). It is possible to repeat the traffic light on a support above the traffic lanes. If there is a traffic island between lanes for traffic moving in opposite directions, it is also possible to repeat the signal on it.

If this separator is not present, the IISR provides the possibility of repeating the R24 signal to the left of the road, which could be useful for improving perception, especially on exiting the roundabout.

Photo 19: the presence of a traffic island enables repeating the R11j signal at the entry of the roundabout (source STRMTG)

Photo 20: repetition of signals at a crossing of a roundabout branch (source: Cerema)

Unlike signals intended for automobile drivers, the R17/R18 signals can be repeated beyond the zones of conflict and opposing traffic lanes (IISR, Art. 109-4). In the case of roundabouts, these signals can be repeated on the central traffic island or beyond the circular road if this helps to optimise the driver's perception.

> 5.3.2.2 Height of the signals

The specifications of the IISR related to the height, sizes and other characteristics of traffic lights (6th part, Art. 109-4) are also applicable to roundabouts:

R24 stop signals must be positioned at a height between 1.50 metres and 4.20 metres;

R11 signals must have a clearance of 2 metres if they are installed on a footpath, shoulder or island accessible to pedestrians, and the axis of their upper light must be at a maximum height of 4.20 metres.

Moreover, all signals, illuminated and static, must comply with the road services department's accessibility rules and must therefore have a minimum clearance of 2.20 metres if located on a pedestrian pathway.

Alongside ensuring that these regulatory obligations are followed, the height, size and appearance (contrast, etc.) of the signals must be adapted on a case-by-case basis for optimising users' perception of them.

Photo 21: the R24 signal is installed at less than 2.20 metres since it is not a space used by pedestrians (source: Cerema)

> 5.3.2.3 Stop lines of traffic lights

When a traffic light is placed like a barrier to manage the crossing of the tramway site, it is highly recommended to mark out the stop line of the traffic lights as suggested by the IISR (Art. 117-4).

As a general rule, it is recommended to position it at approximately 1.50 metres upstream of the clearance gauge (GLO), it should not be located downstream of the signal itself. It should be as orthogonal as possible to the axis of the ring road.

It can be reinforced by a continuous line.

Glossary

BRTS Bus rapid transit service

BIRMTG Bureau interdépartemental des remontées mécaniques et des transports guidés

Cafaic Carrefour à feux avec îlot central

Cerema Centre d’études sur les risques, l'environnement, la mobilité et l'aménagement

Certu Centre d’études sur les réseaux, les transports, l’urbanisme et les constructions publiques

Cete Centre d’études techniques de l’équipement

Cub Communauté urbaine de Bordeaux

Glo Gabarit limite d’obstacle (Clearance gauge)

IISR Instruction interministérielle sur la signalisation routière

RATP Régie autonome des transports parisiens

Semitan Société d'économie mixte des transports de l'agglomération nantaise

STRMTG Service technique des remontées mécaniques et des transports guidés

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Software

Girabase v4.0 (Certu)

Annexe 1: determining the residual capacity for vehicles

Regardless of the policy followed for travel, it is always useful to make provisions for the operation of crossroads.

There is no specific method for verifying the operation of a roundabout traversed by a tramway, but tests can be conducted using conventional methods on roundabout dimensioning, such as the Girabase software or even other traffic simulation software.

In all cases, it is necessary to know:

- the current or predicted road traffic, in the form of hourly directional traffic;
- the frequency of passage of trams or at least the number of passages during peak hour, both directions combined, and including any “light running” (out of operation) passages;
- the average time for neutralising traffic at each pass.

For the capacity calculations with Girabase for instance, the operation can be estimated by artificially increasing the traffic by an inverse coefficient of the proportion of time where the roundabout operates freely.

For example, if trams pass thirty times during peak hour and if each of these passes causes an interruption of the traffic for an average of twenty seconds, the roundabout will freely function for 3,600 seconds per hour (3,600 - 20 x 30), i.e. 5/6 of the peak hour; the operation of the roundabout will thus be verified using traffic with an added coefficient of 6/5.

The capacity calculations performed using the Girabase software enable evaluating the average and maximum backing up of queues on each of the branches of the roundabout and thus measuring their impact on the layout. This information can be especially useful for the configurations described in § 2.2.3.

The simulation software enables viewing the operation of the crossroads, or even a set of similar crossroads. Since only certain parameters influencing the capacity are taken into account, there is no certainty as regards the validity of the results.

However, it should be noted that this operating information is only related to traffic, and that it is important to also take into account information related to safety, such as the comprehension and legibility of the roundabout entries by the users.

Annexe 2: contributors to the drafting of the work

The following contributed to the initial drafting of this work, as part of a task force:

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With the collaboration of the transport authorities, tramway network operators and especially:

- the CUB, traffic authority in Bordeaux;
- the Semitan, operator in Nantes;
- the Régie autonome des transports parisiens (RATP)

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Roundabouts and tramways
Design guide for tramlines crossing roundabouts

The feedback from studies conducted on the field of tramways accident shows that roundabouts crossed by a tramline can have safety issues. The design and operation of such roundabouts then have to be done carefully once preliminary studies have led to choose this type of junction.

As they were aware of this fact, Certu and STRMG published a specific guideline about these layouts in 2008, designed to complement the « Guide to road layouts for public transport » published in 2000.

While the number of tramway networks has been increasing, updating this book became appropriate, mainly by using the feedback from existing lines.

This document therefore is an upgrade of the guide published in 2008, which is based on a review of this initial guide by a panel of users and the use of the « tramways events » database from 2006 to 2015.

Glorietas y tranvías
Cruce de una glorieta por una línea tranviaria Guía de diseño

La experiencia en el ámbito de los accidentes tranviarios muestra que el cruce de glorietas por una plataforma reservada puede plantear problemas de seguridad. Por lo tanto, si los estudios preliminares conducen a la elección de este tipo de intersección, su diseño y su explotación se deben realizar cuidadosamente.

Conscientes de este hecho, el Certu y el STRMTG publicaron en 2008 una guía de diseño específico para esta configuración, destinada a complementar la guía de diseño de vías para los transportes colectivos publicada en 2000.

Con el aumento del número de redes tranviarias, se hace oportuna la actualización de esta obra, utilizando principalmente la experiencia de las líneas existentes.

Por ello, la presente obra constituye una actualización de la guía de 2008, fundamentalmente basada en su relectura crítica por parte de un panel de usuarios y la explotación de la base de datos «incidentes tranviarios» sobre el periodo 2006-2015.

Cerema, public expertise for the sustainable development of territories

The Cerema is a public establishment, created in 2014 for providing greater scientific and technical support in the design, implementation and evaluation of public policies of urban layouts and sustainable development. A studies and expertise centre, its goal is to spread awareness and scientific and technical knowledge, as well as innovative solutions for territorial projects in order to improve the living environment of citizens. Combining both expertise and a multi-disciplinary approach, it provides methodologies, tools and feedback from all key players in the territories: local governments, State bodies and scientific partners, associations and individuals, engineering departments and companies.

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