Chapter 2
First Developments of Different Roundabout Types

2.1 Introduction

In the years from 1913 to 1914, Hellier suggested circular traffic systems at places, where several main roads would meet and the main connection of the circular system would prevent overload. At the conference of the local governmental committee on the subject of main roads in 1914, this idea was accepted as positive under the condition that the traffic requirements were met (every intersection should have sufficient empty space, and lawns alongside the intersections would be desirable). The initial phase of development in Europe was interrupted by the First World War. When the British Road Transport Board was set up in 1918, it was suggested that the roads of France should be the model for Europe. Gyratory systems were also used in the USA but there was great difficulty in regulating traffic, local ordinances were unenforceable and flouted, and there was no uniform rule of the road throughout the country. In 1924, at a US national conference, rights of way at intersections, and warning and stop signs were proposed. The "circus" idea continued to spread in the United Kingdom and was frequently recommended for busy junctions of more than four roads. During 1925–1926 a lot of gyratory systems were introduced in London. These were simply one-way systems around existing squares with fairly sharp corners. Unfortunately some of the important principles implied in Henard's concept, e.g., the entries into gaps during circling, operating over a short distance, were being lost. The transfer of these movements to a straight road caused differences in speeds at the conflict points but this may at first have been unimportant when all traffic speeds were quite low. The design was based solely on commonsense and experience [1].

Notwithstanding the foregoing, we could say that the first serious study of roundabouts began after the First World War and lasted until the late thirties of the last century. At that time it created many new ideas, some of which were implemented within modern roundabouts.

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The second period of in-depth research began in the fifties and lasted until the late sixties of the last century. During this time many new types of roundabouts were created which are still being implemented. This period also included a change of the priority rule, which completely changed the designs of roundabouts.

2.2 Trend to Non-circular Islands

The trend of using roundabouts was formally recognized in 1929, when collaboration between the Ministry of Transport and the Town Planning Institute of the United Kingdom resulted in the issue of the first "guidelines", which recommended that at crossings of one or more major roads, space should be provided for traffic to circulate on the "roundabout" system, and thus gave general guidelines for roundabout design. According to some sources [1], this was the first official use of the term "roundabout".

However, no doubt influenced by the conversions of many square and rectangular spaces to roundabouts, there was an assumption that a flat-sided central island shape was essential for the weaving of traffic, which was observed to take place on the outer sides. Splitter islands were made narrower and polygonal central islands were to have sides with minimum lengths of 110 ft., matching the number of entries, in order to "allow the traffic to sort itself out" [1]. The width of the circular carriageway was set at up to 40 ft. and a 30 ft. radius was declared for the central island corners. These suggested layouts included a four-arm (Fig. 2.1), and a six-arm roundabout with a hexagonal central island (Fig. 2.2) [1].

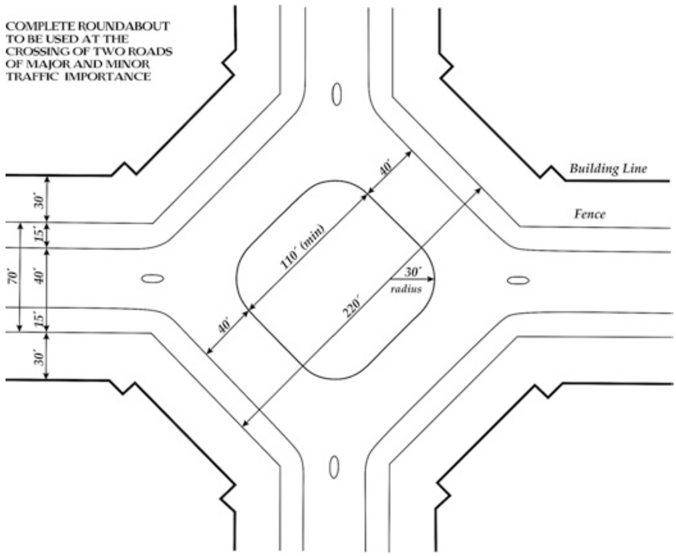


Fig. 2.1 Suggested layout of the four-arm roundabout [1]

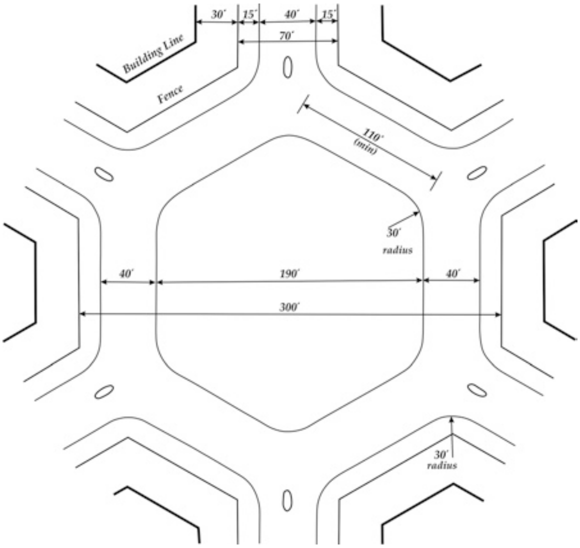


Fig. 2.2 Suggested layout of the six-arm roundabout [1]

Fig. 2.3 Piccadilly circus, original form—old postcard

This idea led changes to some of the existing roundabouts; circular central islands (Fig. 2.3) were replaced by hexagonal central islands (Fig. 2.4). Interestingly, it should be mentioned that the polygonal central islands of roundabouts were used again in the fifties of the last century, but only for a short period.

Fig. 2.4 Piccadilly circus, changed form—old postcard

By the mid-thirties, roundabouts were included in plans for solving traffic issues in the centers of many cities. In 1933, Watson set the following priorities: decreases of congestion, timely synchronized driving through the intersection, more comfortable traveling, safer traffic flow, reduction or complete elimination of police traffic controls at intersections and reductions of interferences in the courses of traffic [1]. According to Watson, the main downsides were inappropriateness and danger to pedestrians, and the danger of shoplifting in those cases where there were many heavy vehicles on the roundabout driving passed shops on the central island. With the increase in traffic, the number of traffic accidents also increased in the United Kingdom. In addition to increasingly faster motor vehicles, horse-drawn carriages were also part of the traffic as well as a large number of cyclists and pedestrians. At that time, there were no specific traffic rules applicable for pedestrians crossing a street. Later on, streets with two-directional carriageways were proposed, with dividing lanes in the middle, emergency lanes, cycle lanes and corridors for pedestrians, thereby preventing conflicts occurring due to the different speeds. These guidelines are indicated in the layouts of roundabouts in 1937 (Fig. 2.5) [1].

It is necessary to point out that some roundabouts from that time still exist, and carry out their roles very well (Figs. 2.6 and 2.7).

Later on, there was a proposal to use a round central island, planted with bushes, thus preventing pedestrians crossing the central island. This idea generated a new form of roundabout. Roundabouts acquired slightly expanded entries

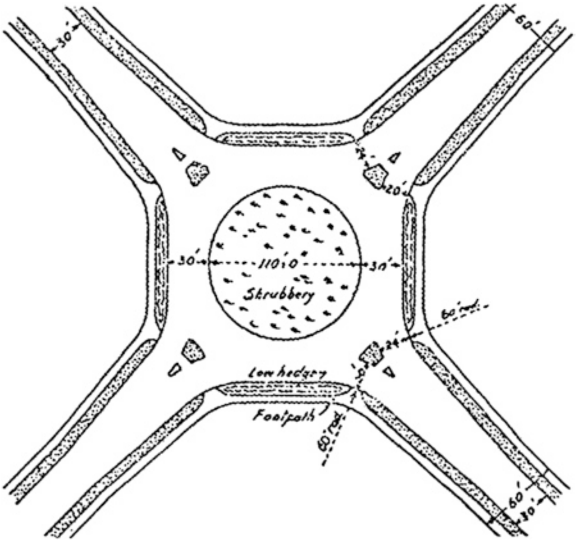


Fig. 2.5 Typical layout of roundabout according to MoT circular 390 [1]

Fig. 2.6 Square roundabout with square island; Coventry

Fig. 2.7 Square roundabout with circular island; Coventry

for easier turning to the left (in the UK), curved entries and splitter islands at the entries, containing marked pedestrian crossings and exits larger than the entries (faster–easier exit from the roundabout) [1].

2.3 The Period of Intensive Experimentation with New Layouts

As said before, the second period of in-depth research began in the fifties and ran until the late sixties of the last century. During this time many new types of roundabouts were created which are still being implemented.

By 1966 the situation at peak hour congestion and control at roundabouts had become intolerable. It needs to be stressed that the first roundabouts differed from recent roundabouts in the right-of-way rule. The vehicle at the entry had the right-of-way over the vehicles in the circular flow. This resulted in large radii of roundabouts and with narrow splitter islands—all with the purpose of acquiring the longest possible circular segments, where the weaving maneuvers of traffic flow took place. The dimensioning of roundabouts of that time and the calculation of capacity were based on Wardrop's definition of practical capacity [1], coming from the capacity of a circular segment between consecutive entries, where the weaving of vehicles' maneuvers took place. The deficiencies of this kind of traffic management at roundabouts began to show with the growth of motorized traffic. By giving priority to the vehicles at the entries, the vehicles on the circular carriageway began to pile up. Due to the increased motorized traffic, the traffic at these intersections came to a complete halt, since any potential queue at one of the circular segments would block the operation of the entire roundabout. Therefore, due to rapidly increasing traffic in the seventies in the UK, the blockage phenomenon at standard roundabouts caused a lot of confusion within the traffic system, in particular at places where uneven flows at fast entries caused the slower circulating vehicles to give priority to the faster entering vehicles. The uninterrupted entry-flow caused interruptions in the circling of traffic in the circular flow, and thus congestion.

New forms of layouts were created for roundabouts at the more overloaded access roads in London. One of the proposed solutions was also a change in the traffic regime—the right-of way. For this purpose, they conducted a few experiments under real conditions at the existing roundabouts. General application of this rule of taking away the priority of the vehicles at the entry became effective in November 1966, and over a few months actually changed the concept of roundabouts totally. It eliminated the problem of congestion, improved capacity, diminished the number of traffic accidents and at the same time caused a complete change in the philosophy of operating performance and the designing of roundabouts. By giving the right-of-way to vehicles in the circular flow, the problem of a roundabout's capacity was transferred from the weaving area to the area of entries onto a roundabout. This caused the need for widening access roads at the entries, while the size of the central island began to lose its meaning regarding practical capacity [1].

The consequences of the new rule-of-way were diminished roundabouts of the same capacity (less required space), increased traffic safety, and roundabouts' blockages at much higher traffic loads. Some layouts of the roundabouts of that time are presented in following.

2.3.1 One-Lane Roundabout

The standard one-lane roundabout (Fig. 2.8), which is the more numerous type of roundabout all over the world, has only one lane at each of the entries and exits, as well as on the circulatory carriageway (or roadway). For pedestrians and motorized vehicles, this type of roundabout seems to be the safest type amongst all types of "classic" or "standard" grade intersections.

The dimensions of the outer diameter differ from country to country, but is usually between 26 m (as a minimum; better 29 m) and (in some countries) 45 m.

A standard one-lane roundabout has a central island, made up of two parts: the traversable (truck apron) and non-traversable parts. The center of a modern one-lane roundabout provides a visual barrier across the intersection for the drivers entering it (Fig. 2.9). These functions assisted the drivers when focusing only on the traffic coming towards them along the path of the circle (and non-motorized participants).

Fig. 2.8 Typical Slovenian one-lane roundabout

Fig. 2.9 Visual barrier across central island; sculpture of wales; south France

Globally, pedestrians are prohibited (except in Mexico (Fig. 2.10), Vietnam and a few other countries) from entering the central islands of roundabouts, but there exist also some differences in the case of assembly roundabouts (Fig. 2.11).

Fig. 2.10 Roundabout with pedestrian crossing into central island; Teotihuacan, Mexico

Fig. 2.11 Assembly roundabout with motorbikes' parking at central island; near Italian border with France

Due to the needs of larger vehicles (swept path for turning) the circular carriageway must be wider than the usual lane. Having only 26 m diameter, the circular lane must be wider by up to 8 m (and at 29 m diameter 6.5 m is enough—if it includes a traversable ring—truck apron). This type of roundabout can be applied in urban as well as in rural areas.

Deflection on entry is used to maintain low speed operations at roundabouts. Drivers must maneuver (are “deflected”) around the central island, at speeds of 25–40 km/h.

For pedestrians the walkway crossings (usually zebra crossings, which impose an absolute right of way for pedestrians) the entries and exits should be built at distances of 5–10 m from the margin of the circle (because of the waiting spaces at the entrances and exits).

While roundabouts can reduce accidents overall compared to other junction types, crashes involving cyclists may not experience similar reductions for some designs. Looking globally, the only remaining significant risk at a single-lane roundabout (in some countries) involves cyclists. Accordingly, the cyclists’ lanes in the guidelines for roundabouts’ designs differ from country to country, but here we can point out three different types of cyclists’ management (Fig. 2.12).

In continental European countries (except Holland), painted cycle lanes at the peripheral margins of circulatory carriageways are not allowed since they have proven to be very dangerous for cyclists. In Germany (and some other countries e.g., Slovenia) with a traffic volume of up to about 15,000 veh/day, cyclists can be safely accommodated on the circular lane without any additional installations in urban areas. In Germany, even if the approaching lanes of the roundabout are equipped with separated cycle tracks, the two-wheelers are guided to the normal traffic lane at the approach in order to guide the cyclists through the single-lane roundabout and lead them back on to a cycle track after leaving the intersection, towards the desired direction [2].

Above a volume of 15,000 veh/day, separate cycle paths (three types) are regarded as being useful in most countries. These, however, should also have a distance of around 5–10 m from the circle at the point where they are crossing the entries and exits. Shorter distances have negative impacts from the traffic safety and capacity point of view. At closer distances the visibility regarding cyclists is impeded for the drivers of trucks, and waiting places (between the margin of the

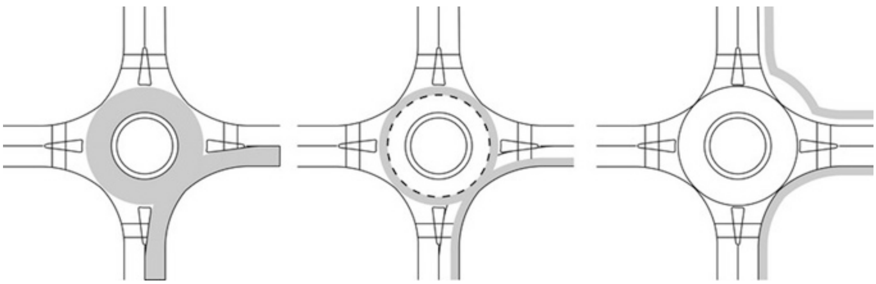


Fig. 2.12 Three different types of cyclists’ managing

circle and the inner edge of a zebra crossing) at entries and exits have a strong influence on the capacity.

If the adjacent footpaths of a roundabout are improperly designed, there is increased risk for persons with visual impairments. This is because it is more difficult (than at a signalized intersection) to detect by hearing whether there is a gap in the traffic adequate enough for crossing.

Lighting is very important, even though there are countries in which the lighting of roundabouts is optional. There are two types of lighting on roundabouts; on the central island and out at the peripheral margin of the circulatory roadway. Some countries have had bad experiences with lighting pools at central islands (because incoming drivers were being blinded by the light).

The figures about the capacities of one-lane roundabouts differ from country to country (human behavior), but may be expected to handle approximately 20,000–26,000 veh/day. It is very important to know that under several traffic conditions, a roundabout may operate with less delay than an intersection with traffic signal control or all-way stop control. Unlike an all-way stop intersection, a roundabout does not require a complete stop by all entering vehicles, thus reducing both individual delay and delays resulting from vehicle queues. A roundabout may also operate much more efficiently than a signalized intersection because the drivers are able to proceed when traffic is clear without the delays that occur while waiting for traffic signals to change. It also needs to be stressed that these advantages also reduce air pollution from many idling vehicles waiting for traffic lights to change, which is a very important criterion in residential areas.

2.3.2 Square Roundabout

We can distinguish between two types of square roundabouts according to their origins. The first type originated from those initial old town squares with four or more intersecting roads, initially intended only for horse-drawn vehicles and pedestrians (Fig. 2.13).

Later it became necessary to separate pedestrians from motorized traffic. Thus, at the outer edges of the square, a circulatory carriageway was created, intended only for motorized vehicles, while the remaining part became an elevated platform intended for pedestrians only. These square roundabouts at their inceptions did not include splitter islands neither pedestrian crossings (Fig. 2.14).

As a rule, they were round or oval, often containing trees, grass, sculptures, fountains, and benches for recreational use.

At the beginning, there were no traffic rules, and square roundabouts were without splitter islands and pedestrian crossings. Later on, there was a need to introduce traffic rules. First, the vehicles at the approach had the right of way and splitter islands and pedestrian crossings were initiated.

It is necessary to stress that many square roundabouts from that time still exist, and that they carry out their roles very well. Nowadays, they are usually signalized

Fig. 2.13 Town square; Maribor, Slovenia—old postcard; about 1890

Fig. 2.14 Town square—60 years later; Maribor, Slovenia—old postcard; about 1950

because they are mainly located in city centers (large traffic volume) or because they are intersected by the subsequently implemented suburban railways. These types of square roundabouts can be found all over Europe in the older and larger towns (Fig. 2.15), and also in the rest of the world.

The second group of square roundabouts is more recent. Usually they occurred because the traffic regimes on the existing roads had changed. The basic

Fig. 2.15 Prague, Czech Republic

characteristic of this group of square roundabouts is that they do not have a round central island, but a rectangular or a square one. In general, there are two types: those with tangential approaches and those with combinations of radial and tangential approaches.

A square roundabout with tangential approaches (Fig. 2.16) deals with two-lane approaches only (and are intended for two-way traffic), while the circular roadway can be two- or three-lane (and are intended for one-way traffic only). Sections between one approach and the following exit must be sufficiently long, so that weaving maneuvers can be performed. The straight parts of a square roundabout enable high speeds; therefore, we must devote a special attention to the traffic management of the non-motorized participants. As a rule, the management of non-motorized participants is implemented on another level or by traffic lights. When considering tangential access, the traffic regime with a yield traffic sign is not appropriate, therefore most of these square roundabouts are equipped with underpasses at least if not with traffic lights together with appropriate public lighting.

At a square roundabout with a combination of radial and tangential approaches (Fig. 2.17) we are dealing with several two-lane approaches (intended for two way traffic) and several one- way approaches (intended for one-way traffic only). As a rule, the circular roadway is one-lane; however it can also be two-lane (intended for one-way traffic only). In the cases of one-lane circular roadways, there is no need for long straight parts because there is no weaving of traffic flows. There are also cases of two-lane roundabouts where the right-hand lane is intended for parallel parking.

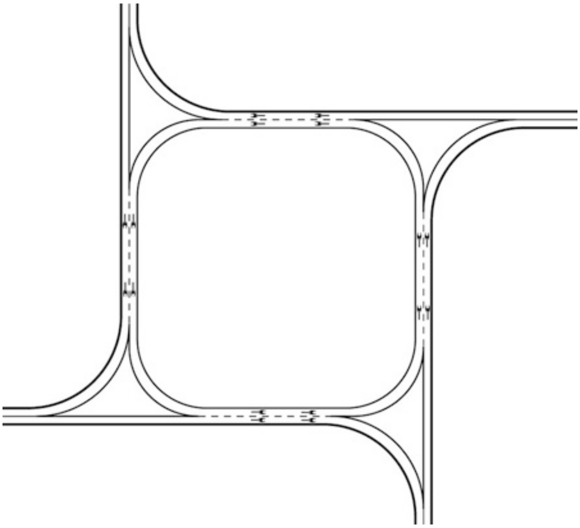


Fig. 2.16 Square roundabout with tangential approaches

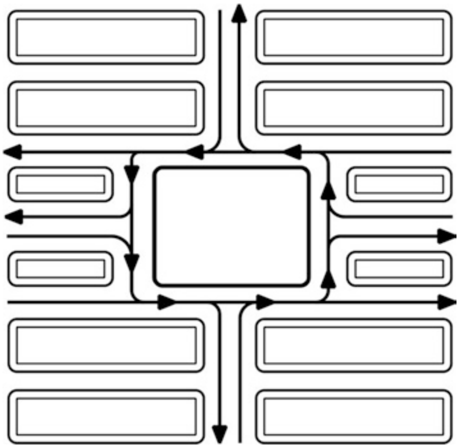


Fig. 2.17 Square roundabout with a combination of radial and tangential approaches

This type of square roundabout includes exclusively entering, exclusively exiting or combined (entry and exit) approaches. The numbers of each individual type of approach depend on traffic needs.

This type of square roundabout does not present as much danger for non-motorized participants as square roundabouts with tangential approaches, since fewer approaches are tangential (while others are radial). Combined approaches are radial (T intersections) and slow down the traffic, which provides a higher level of traffic safety. A T-intersection (90° turning left or right) is a natural traffic calming measure, and because of that cyclists and pedestrians are not in conflict with motorized vehicles at these points.

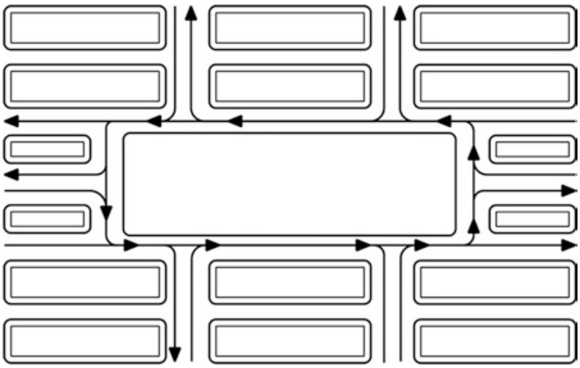


Fig. 2.18 Square roundabout with a combination of radial and tangential approaches on two squares of streets

However, we must pay attention to the navigation of pedestrians and cyclists through one-lane approaches. The speeds may be higher because of tangential approaches; therefore traffic calming measures can also be implemented as well as traffic signalization of the whole square roundabout, even though under well-regulated conditions it is also possible to implement a yield traffic regime.

It needs to be emphasized that this is a very good solution in everyday life, when the systems of the streets have already been built, when it intersects perpendicularly (radial intersection of several streets is rare), and when it can no longer be changed because of the build-up surrounding it. We must also emphasize that a square roundabout of this shape can be implemented not only with one square of streets but also with two or more (Fig. 2.18).

The capacity of a square roundabout with a combination of radial and tangential approaches is lower compared to the first type; however, the level of traffic safety is higher (lower speeds, no weaving, half of the approaches are radial…).

The inside (central islands) of both types of square roundabouts are easier to access compared to the standard roundabout, regardless of whether we are dealing with a signalized pedestrian crossing or an underpass (according to the author's experience, pedestrian crossings leading towards central islands have been implemented in a few countries only).

2.3.3 Large Roundabout

Roundabouts were previously designed on the assumption that the weaving movements of vehicles took place on the circulatory carriageways. The early assumptions of roundabouts' designs were that larger roundabouts would carry more traffic than smaller ones of similar shapes and that the longer sides of the "weaving sections" would improve capacity. Roundabouts with an inscribed diameter well in excess of 100 m were suggested in 1945 for typical arterial road peak traffic flows. Before the change in the priority rule (and even for some time afterwards) large roundabouts were preferred for providing protection against "lock-up" at traffic peaks [1].

Fig. 2.19 Large roundabout; from HCM 1950 [2]

In the US, in the years following the World War II, roundabouts in urban areas were hardly used, and outside urban areas roundabouts were merely an exception and not a rule. The advice during planning was that, due to the deficiencies of roundabouts or rotaries, their application should be limited. They were more often used as a solution to the crossings of a greater number of roads in rural areas with enough space for their application (Fig. 2.19). Roundabouts gradually replaced the standard intersections, while their advantages were nullified by the increasing traffic in the US. At that time the idea of multiple level intersections came to life.

Roundabouts of that time were of large dimensions, especially on high-speed roads. It was expected that roundabouts should not significantly influence the speed of vehicles. The result was roundabouts of stretched (oval) shapes, which gave priority to the transit traffic and emphasized the right-of-way of the traffic at the entry. Several such intersections are also still in use in European countries (Fig. 2.20).

The formation of "weaving sections" at the roundabout was taken from the weaving of traffic between the connecting directions of a cloverleaf (common ramp for entry and exit). This method of calculation showed that the weaving maneuver was as a principle, dependent on the lengths and widths of the weaving areas and on the structures of the traffic. Planned speeds for the weaving areas at the roundabouts of that time were from 65 to 110 km/h. The belief at that time was that roundabouts with low speeds would amount to a low-level of traffic service,

Fig. 2.20 Large roundabout of stretched—oval shape, León, Spain; postcard

because it would be impossible to reach a sufficient number of weavings. Such an opinion still prevailed in 1965, when creating the Highway Capacity Manual [3].

Presently, large roundabouts are no longer constructed, as they are outdated for several reasons. Large roundabouts, especially those with faster traffic, are unpopular with some cyclists. This problem is sometimes addressed at larger roundabouts by taking foot and cycle traffic through a series of underpasses or alternative routes. In rural areas, large roundabouts require huge space and long splitter islands further increase the cost. The same situation occurs in urban areas—large roundabouts "eat up" a lot of urban space. Temporary widening and outside diameter space requirements increase the running costs of construction as well.

Therefore, new large roundabouts are no longer constructed presently, while the existing ones are being reconstructed into some more suitable types of intersection in terms of traffic safety. This means smaller entrance radii, reductions in the number of lanes at entries and exits and along the circulatory roadway, or the provision of traffic signals at such roundabouts (Fig. 2.21).

2.3.4 Double-lane and Multi-lane Roundabouts

The basic reason for the construction of two- and multi-lane roundabouts was an expectation that the capacities of such roundabouts would be duplicated.

Fig. 2.21 Large roundabout with traffic signals; Berlin, Germany—postcard

Consequently, roundabouts of two shapes were implemented in the past: with two lanes at entries/exits and as a single lane along the circulatory carriageway, or with two lanes at entries/exits and two lanes along the circulatory carriageway; the purposes of which were to increase (duplicate) their capacities. During the early seventies of the past century, there were a large number of such roundabouts constructed in the UK, and also in other European countries later on (Fig. 2.22).

After a while, the reality contradicted all the technical assumptions and numerical calculations that supported the introduction of such a type of roundabout.

Let us start at the beginning. The main advantage of a one-lane roundabout, compared to the "standard" intersection, is the elimination of conflict spots (somewhere also "points") of the first (crossing) and second (weaving) grade, and the reduction of conflict spots of the third grade (merging, diverging). Theoretically, the classic four-arm (somewhere also "four-leg") intersection has 32 conflict spots (16 crossing, 8 merging and 8 diverging), while the one-lane four-arm roundabout has only 8 conflict spots (4 merging and 4 diverging) (Fig. 2.23).

If there are two circular lanes, the number of conflict spots increases by the number of weaving conflict spots, which theoretically equals the number of arms, however, this number is still lower than 32 (Fig. 2.24). But, from the practical point of view, we are not only speaking of conflict spots at the multi-lane roundabouts, but also of conflict sections (sequences of conflict spots), since there are no predetermined spots for drivers where they must change lanes along the circulatory carriageway.

Fig. 2.22 Multi-lane roundabout; Ljubljana, Slovenia

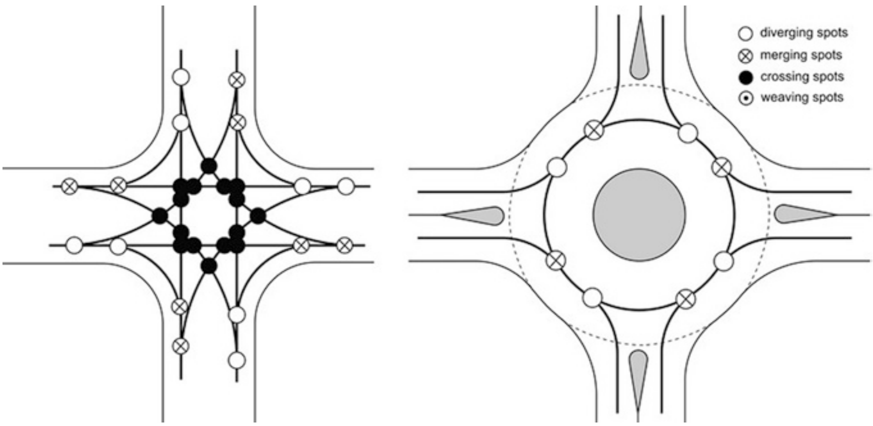


Fig. 2.23 Conflict spots at a four-arm "standard" intersection and a four-arm roundabout

At multilane roundabouts with two-lane entries and exits, the traffic-safety conditions are even slightly worse (Fig. 2.25). In this case, there are conflicts at the spots of crossing the circulating lanes at the entries and even bigger in the course of changing traffic lanes along the circulatory carriageways. However, by far the most dangerous is the maneuvering when leaving the roundabout.

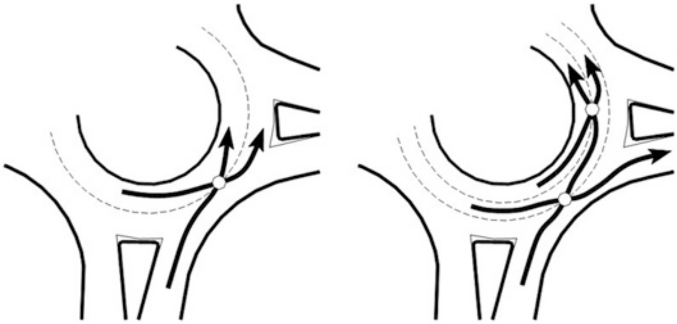
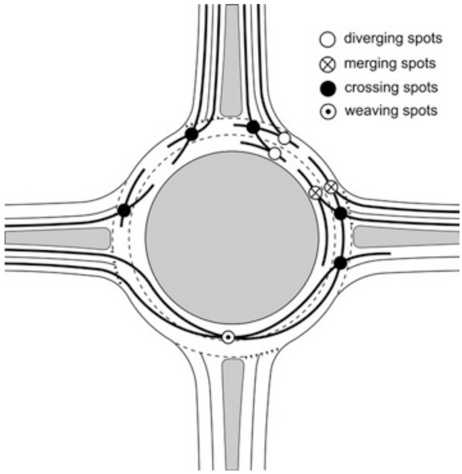


Fig. 2.24 Conflict spots at the multi-lane roundabouts with one entry lane

Fig. 2.25 Conflict spots at multi-lane roundabouts with two-lane entries and exits



Conflict spots at multi-lane roundabouts with two-lane entries and exits are located at the following areas:

- roundabout approaches (weaving, when approaching the roundabout);
- entry onto the roundabout (and crossing a circulatory traffic flow);
- multilane circulatory carriageway (weaving in the course of changing traffic lanes);
- leaving the roundabout (and crossing a circulatory traffic flow);
- roundabout approaches (weaving, when driving away from a roundabout).

It is necessary to stress that it is possible to reduce the numbers of some conflict spots with certain measures; however some types of conflict spots cannot be eliminated because they are characteristics of the roundabouts' types.

As mentioned before, the main reason for the introduction of these types of roundabouts was based on expectations that their capacities would increase substantially. Later on, real-life contradicted all the technical assumptions and numerical calculations. Namely, in many countries, it was figured out that the second lane along the circulatory carriageway contributed to increased capacity only by an additional 30 % (and not by 100 % as originally expected and mathematically predicted in a rather illusionary way). The fact that the second lane in the circulatory roadway increased the capacity by only 30–40 % was replicated in several countries; however, we would only point out Austria, Lithuania [4], Germany [5] and Slovenia [6]. It was also discovered that on these types of roundabouts, the level of traffic safety was significantly lower than at one-lane roundabouts. There were many reasons for that. One of the more important reasons was surely the fact that in the past, two-lane roundabouts that were too small were being constructed in those countries which contradicted the statutory rule of the mandatory use of inner circulatory traffic lanes in those cases when the driver does not leave the roundabout at the next exit (an average driver did not have sufficient length to change the driving lane along the circulatory carriageway). The second reason was that the inner circulatory traffic lane along the circulatory carriageway was avoided by younger and more senior drivers as they felt insecure when changing.

Over the years, these types of roundabouts have gained a bad reputation regarding their safety and their limitations regarding capacity which (in spite of the large consumption of space) did not exceed an ADT beyond 40,000 veh/day.

Following the above-mentioned findings and the fact that we are now familiar with newer and safer types of two-lane roundabouts (with significantly larger capacities and levels of traffic safety), some countries (e.g., The Netherlands, Slovenia) have even forbidden the constructions of new “standard” two-lane roundabouts in their recent regulations. The existing two-lane roundabouts in these countries are being reconstructed into some safer two-lane roundabout types (e.g., into turbo-roundabouts). As it seems the only exception is the compact semi two-lane roundabout in Germany (Fig. 2.26). As a first approach towards larger roundabouts, a new intersection type has been created, the compact semi-two-lane circle. The ideas for this type were first described in a German preliminary

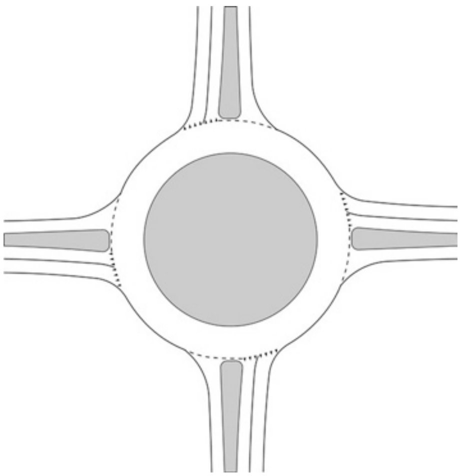


Fig. 2.26 Compact semi-two-lane roundabout; sketch

document in 2001, accepted as guidelines from 2006, and consequently these new types were built by several municipalities and highway authorities [5]. The design of compact two-lane roundabouts is similar to the concept of one-lane roundabouts. The main difference is the width of the circular lane. It is wide enough for passenger cars to drive along side by side, if required. However, the circle lane has no lane markings. Large trucks and buses are forced to use the whole width of the circulatory carriageway when making their way through the roundabout.

The outer diameter of this type of roundabout is 40–60 m, the circle lane width being 8–10 m, and without lane markings (to prevent drivers from overtaking). The number of entry lanes is in accordance with traffic volumes (one- or two-lane), but always has only one-lane exits. It is necessary to point out that no cyclists are allowed on the circulatory carriageway. These roundabouts are today state-of-the-art solutions in Germany.

2.3.5 Mini-Roundabout

Information on where and when the first mini-roundabouts in the world were implemented is inconsistent. However, the widespread belief is that the "traffic circles", as applied by Eno in the first decade of the 20th century in America were the first real mini-roundabouts [1].

The traffic used to circle around a central pole or a stone tower known as the "dummy cop", and the traffic ran in one direction. Later on, small mushroom-shaped islands started to be introduced, mostly on roundabouts with a minimal diameter of 10 m. Some old documents show that the state of Connecticut (where Eno was from) was the first and maybe the only administrative area that used a central island, marked merely by white coloring. Eno's mini-roundabout with a "target" in the center was composed merely of a central circle, 60 cm wide and marked by white coloring, surrounded by two white concentric circles, 30 cm wide, situated at a distance of 30 cm. The total diameter thus amounted to 3 m [1]. This was the origin of the target type of mini roundabout still widely used in the UK (Fig. 2.27), Malta and Australia.

Later, studies and analyses on the suitability of mini-roundabouts' applications were performed, which resulted in guidelines (in 1971) on mini-roundabouts with flat or slightly domed central islands having radii of up to 4 m. These roundabouts are known as the real "mini-roundabouts". The experiments continued until 1975, when mini-roundabouts became regulated by law in the UK. Since then, mini-roundabouts in the UK have been used in urban areas but only exceptionally in transitory areas. Thereby the operation of intersections situated within a small space was improved. The first roundabouts were implemented only for three-arm intersections and were only later introduced at intersections with four arms.

The main use of mini roundabouts in the UK is during the conversion from other intersection types, including traffic signals. The main criterion for safe operation is an appropriate speed of vehicles at all entries into a roundabout, which

Fig. 2.27 The origin of the mini roundabout, still widely used; Salisbury, the UK

should amount to a maximum of 50 km/h. If the central island has a diameter of 4 m or less, no raised island (or street furniture) is permitted on it, in order to allow long vehicles to over-run. In these cases, the central island is slightly domed and painted with white reflective paint.

Mini-roundabouts in the UK have been presented by many authors, particularly by those UK experts who have been intensively involved in the development of the UK mini-roundabouts for decades, and any new findings are immediately transferred to new standards and guidelines. It is especially worth mentioning Clive Sawers who is—in the perspective of being a "non-Englishman"—probably the best expert in the area of mini roundabouts in the UK and his books have been read all over the world. "Mini-roundabouts—A Definitive Guide" [7] is essential reading for all engineers, designers and traffic safety auditors practicing in this field and important too for planners and town centers designers. The book contains sound advice on site selection, layout details, and crossroads, a simple capacity test and much guidance on features of design that contribute to traffic safety.

The last standards for the geometric designing of mini-roundabouts were published in 2007 [8]. A typical UK mini-roundabout has to have a central island, composed of a circular solid white road marking between 1 and 4 m in diameter that is capable of being driven over (see Fig. 2.28). A vehicle proceeding through the mini-roundabout must keep to the left of the white circle unless the size of the vehicle or the layout of the mini-roundabout makes this impractical. Although the standard is nominally intended for trunk roads, there are very few mini-roundabouts on such roads. It is very important to stress that UK mini-roundabouts should only be used

Fig. 2.28 Recently designed mini-roundabout; Hendon, London

on urban single carriageway roads where the speed limit is 30 mph or less, and the 85th percentage dry weather speed of traffic is less than 35 mph within a distance of 70 m from the give way line. They are seen as a remedial measure for a poorly performing priority junction rather than a junction type in their own right [9].

The last UK standards for the geometric design of mini-roundabouts states that mini-roundabouts must not be used at new junctions or where the traffic flow on any arm is less than 500 veh/day. Four-arm mini-roundabouts should not be used if the total inflow in the peak period exceeds 500 veh/h. No mini-roundabouts should have five or more arms, although double mini-roundabouts may be used at a pair of closely spaced priority junctions.

In general, UK mini-roundabouts are not considered as being speed reduction measures as such, but are suitable for use as part of an urban traffic calming scheme. Because mini-roundabouts were previously designed according to the roundabout standard, they follow the same general principles, often having entries which flare into two (narrow) lanes (which is unique regarding other European countries when creating mini-roundabouts), and because of this the inscribed circle diameter should not exceed 28 m.

Splitter islands may be curbed or may be created using road markings (just painted). They must be curbed (Fig. 2.29) where otherwise vehicles would find it easier to pass on the wrong side of the white circle. Deflection by the white circle is not essential, but a lateral shift at the entry of at least 0.8 m, normally on the offside, is considered good practice.

Fig. 2.29 Curbed splitter island; Cambridge

The circles of UK mini—roundabouts may be domed to deter light vehicles and to improve conspicuity (in most other European countries creating mini-roundabouts, the term “may” is replaced by the term “must”). The maximum recommended height at their centers is 10 cm for a circle of diameter 4 m, with smaller diameter domed circles reduced pro-rata. What is very interesting is that domed circles should not be used if they are likely to be run over by buses, thus avoiding possible discomfort to passengers. What is also need to be stressed about traffic safety is that models for safety at their mini-roundabouts were developed a long time before [10]. Some links report that today there are about 5,000 mini-roundabouts around the UK and a great deal of experience has been gained from their application.

Today, this type of roundabout is also in frequent use in many other European countries. It has proven to be a very good experience in e.g., Germany, France, Austria, Switzerland, Slovenia, and Croatia. These countries, however, have slightly changed the original mini-roundabout layout by altering conditions for their implementations, provided different traffic signs and the layouts of the central islands. Therefore, we present below the experiences in some other European countries. First, it is necessary to point out the fact that at present each country creating mini-roundabouts has adopted its own guidelines for mini-roundabouts’ design, where such rules might be substantially different.

Germany has now 25-years of experience with different types of modern roundabouts, including mini-roundabouts. Experiments with mini-roundabouts in Germany began in 1995 in the state of Northern-Westphalia, and the leader of that experiment was Prof. Brilon [11]. Experiments included 13 intersections that were

Fig. 2.30 Typical German mini-roundabout; suburb of Bochum

converted from non-signalized intersections into mini-roundabouts (Fig. 2.30). The success was overwhelming. They could carry up to 20.000 veh/day without major delays to vehicles, they could easily be built—sometimes without significant investment costs—and they turned out to be very safe [5].

German mini-roundabouts can be applied only in urban areas and have inscribed circle diameters of between 13 and 24 m (measured between the curbs), the circulatory carriageway widths are between 4.5 and 6 m, and with cross-slopes of 2.5 %, which must be inclined towards the outside. It is not sufficient to establish central islands just with some road markings, so central islands have—in the center—maximum heights of 12 cm above the circular line. In order to convince drivers to accept the roundabout driving rules, a minimum curb height of 4 or 5 cm has been identified from experience.

Experiments with rural mini-roundabouts have also been performed. As a result, mini-roundabouts are no longer recommended outside built-up areas, due to safety reasons.

As an interesting feature, it is worth mentioning that they provide their mini-roundabouts with a special traffic sign indicating a mini-roundabout (Fig. 2.31), which is, according to the author of this book, a very good idea.

We should also mention that new research on mini-roundabouts is continuously going on in Germany [12].

Good experience with mini-roundabouts is also observed in France, both three- (Fig. 2.32) and four-arm mini-roundabouts. Mini-roundabouts in France are in

Fig. 2.31 Traffic sign in mini-roundabout; suburb of Cologne

Fig. 2.32 Typical French three-arm roundabout; Provence

Fig. 2.33 Domed circle and curbed splitter islands; suburb of Nice

frequent use, created usually in urban areas at locations with limited space options. Splitter islands may be curbed or may be created using road markings (if there is enough space they are curbed).

The circles of the French mini-roundabouts need to be domed in order to deter light vehicles and to improve conspicuity (Fig. 2.33), and deflection is also very important at French mini-roundabouts.

Almost the same situation exists in Slovenia (Fig. 2.34). Their mini-roundabouts (both three- and four-arm mini-roundabouts) can be applied only in urban areas and have inscribed circle diameters of between 13 and 24 m, the circulatory carriageway widths are between 4.5 and 6 m, and with cross-slopes of 2.5 %, which must be inclined towards the outside. It is not sufficient to establish central islands just with some road markings. Central islands of the Slovenian mini-roundabouts need to be domed, and—in the center—maximum heights of 12 cm above the circular line. In order to convince drivers to accept the roundabout driving rules, a minimum curb height of 3 cm has been identified from experience.

Good experience with mini-roundabouts is also observed in Italy, even at this moment they do not have their own guidelines for mini-roundabouts (Fig. 2.35). Mini-roundabouts in Italy are in frequent use, created usually in urban areas at locations with limited space options. Splitter islands are usually curbed, and circular islands are usually domed.

A little bit different situation is in The Netherlands. It seems they do not prefer mini-roundabouts, even though some have been built (Fig. 2.36). They have

Fig. 2.34 Typical Slovenian three-arm mini-roundabout; Maribor

Fig. 2.35 Italian mini-roundabout; Sanremo

Fig. 2.36 Mini-roundabout with painted central island; Maastricht, The Netherlands

none of their own mini-roundabout's guidelines, and their philosophy is that "the English term mini-roundabout does not refer to the outside diameter of the roundabout but to the diameter and the shape of the central island". They do not prefer mini-roundabouts for two main reasons:

- white painted central island does not function as drivers over-run it or find it easier to pass on the wrong side of the white painted central island;
- requirements of the deflection criteria are not met.

But, what they really prefer instead of a mini-roundabout is a specific type of neighborhood traffic circle, the so-called "punaise" ("pushpin" or "road stud type roundabout"), presented in Sect. 4.4.

2.3.6 Double Mini-Roundabout with Short Central Link Road

The test-track experiments commenced in 1967 were working on the basic principle of making better use of spaces available at junctions. Various outline shapes and methods of control were compared for a particular area of intersection widening. Although not entirely unexpected, the success of the experimental off-side priority control roundabouts featuring small islands and widely flared entries was very encouraging. This period of intensive public road experimentation with new layouts continued for several years in the UK, at least until 1972. The boundaries of driver acceptance were established in principle during this period. A range of applications were produced to suit various conditions. Initially mini islands were used at large roundabouts but not all of these had adequate deflection. Mini islands were found to be more successful at the urban intersections of small areas, as an alternative to priority junctions. Many other specialized layouts were developed at that time. Double and multiple island roundabouts and ring junctions were found to have advantages at some sites [1]. One of them is the double roundabout with a short central link road (with joint splitter islands), also called “closely spaced roundabouts”, which is still in frequent use in some countries. This solution may be constructed as a double mini-roundabout (Fig. 2.37) or, alternately, as a two standard one-lane roundabout. Both solutions require standard dimensions for these two types of roundabouts. Accordingly, these roundabouts’ dimensions are identical to the dimensions of individual roundabout types. Such a type of roundabout is most frequently located at an existing H intersection (i.e., two T or + intersections of a short distance).

Numerous roundabouts of this type (particularly with mini-roundabouts) from the early seventies are still used in the UK (Fig. 2.38).

It is interesting to mention that such a solution is used rather frequently in Croatia, especially recently (Figs. 2.39 and 2.40). Over recent years, namely, there have been quite a lot of such examples applied in urban areas of Croatia. In most cases the solution includes mini-roundabouts.

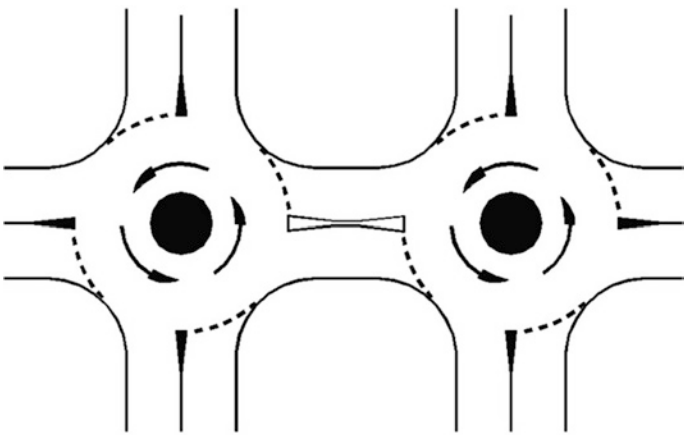


Fig. 2.37 Double mini-roundabout with short central link road; sketch

Fig. 2.38 Double mini-roundabout with short central link road; suburb of Coventry, the UK

Fig. 2.39 Double mini-roundabout with short central link road; city of Zagreb, Croatia

Fig. 2.40 Three arm double mini-roundabout with short central link road; island Rab, Croatia

2.3.7 Dumb-Bell Roundabout

During several past decades, ramp intersections were configured as "standard diamond interchanges", but some 30 years ago, the promotion of a new solution started, often called a dumb-bell roundabout (due to its aerial resemblance to a dumb-bell, a piece of equipment used in weight training) (Fig. 2.41).

The dumb-bell is a "hybrid" combining the diamond and the roundabout, which makes it a very close relative of both, as one is a direct descendant of the other. In short, it combines the capacity benefits of a (usually) one-lane roundabout with the smaller footprint and single bridge of a standard diamond junction.

A dumb-bell roundabout is a better solution than a "standard diamond interchange" because of several reasons. It can generally handle traffic with fewer approach lanes than other intersection types. This type of roundabout reduces construction costs by eliminating the need for a wider flyover [diamond—minimum three (usually four lanes), dumb-bell—just two lanes], and less space. As a rule, drivers within a "standard diamond interchange" driving at high speeds may

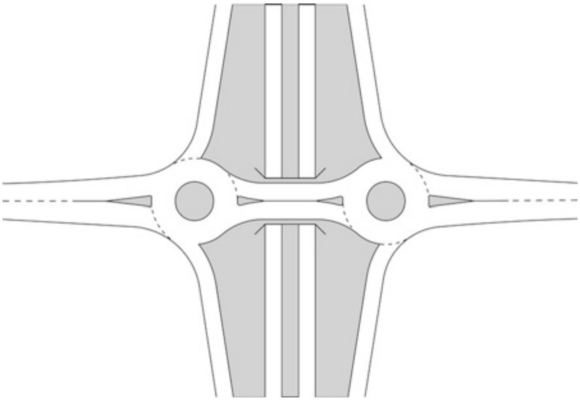


Fig. 2.41 Dumb-bell roundabout; sketch

accordingly find approaching ramps difficult. At a dumb-bell roundabout, speeds are significantly lower, as two roundabouts are a measure for traffic calming. Importantly, this type of roundabout has a low number of conflict spots (Fig. 2.42). At a "standard diamond interchange", drivers might make a mistake and turn towards the wrong direction at the ramp. At a dumb-bell roundabout, such an option is significantly lower. A dumb-bell roundabout even provides the possibility of completely eliminating the option of driving in the wrong direction—using the adequate deflection of a ramp. This configuration also allows for easy U-turns.

This type of roundabout is very common in different European countries (Figs. 2.43 and 2.44) and elsewhere. It seems that the more numerous dumb-bell roundabouts are located on the Canary Islands, where virtually all ramp intersections are constructed as a dumb-bell roundabout.

This type of roundabout is also becoming increasingly common in the USA. Examples of dumb-bell roundabouts are located mainly in Minnesota, Arizona, California, Indiana and in some other states.

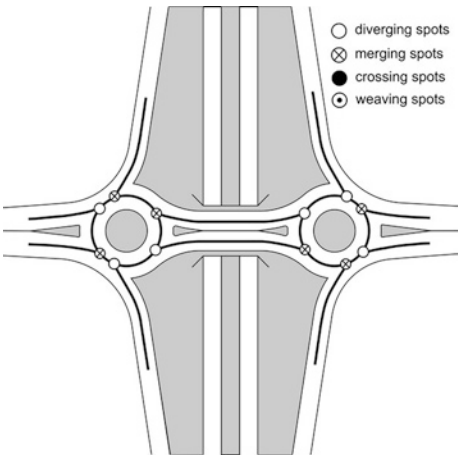


Fig. 2.42 Conflict spots on a dumb-bell roundabout

Fig. 2.43 Dumb-bell roundabout on motorway; The Netherlands

Fig. 2.44 Dumb-bell roundabouts on motorway; Slovenia

The main disadvantage of this type of roundabout is lower capacity than at the roundabout interchange with two roundabouts working less skillfully than one. The second disadvantage is that it is difficult to build this type of roundabout where a large roundabout has been built prior to the new one.

2.3.8 Ring Junction

Ring junction (or chain roundabout or magic roundabout) is, as is known to the author of this book, known only in the United Kingdom, and even there, there are only a few examples.

In general, this type of roundabout (Fig. 2.45) is located at a junction of more than four roads and consists of a two-way road around the central island with a few mini-roundabouts where it meets the incoming roads. The basic characteristic of this type of roundabout is that traffic may proceed around the main roundabout either clockwise (in the UK) via the outer lanes, or anticlockwise using the inner lanes next to the central island. The inscribed circle diameter is about 60 m. At each mini-roundabout the usual clockwise flow applies (in the UK).

A "ring junction" was formally defined for the first time in the TM.H2/75 [13]. It was defined as "an arrangement where the usual clockwise one-way circulation of vehicles around a large island is replaced by two-way circulation with three-arm mini-roundabouts and/or traffic signals at the junction of each approach arm with the circulating carriageway". The guidelines also state that ring junctions have been found to work well in solving problems at existing large roundabouts and that the conversion to a ring junction is an effective solution for very large roundabouts which exhibit entry problems. A ring junction will not operate successfully unless the signing is clear, concise and unambiguous [1].

It seems that the world's best known ring junction is in Swindon in Wiltshire, known as "Magic Roundabout". Its name comes from "The Magic Roundabout",

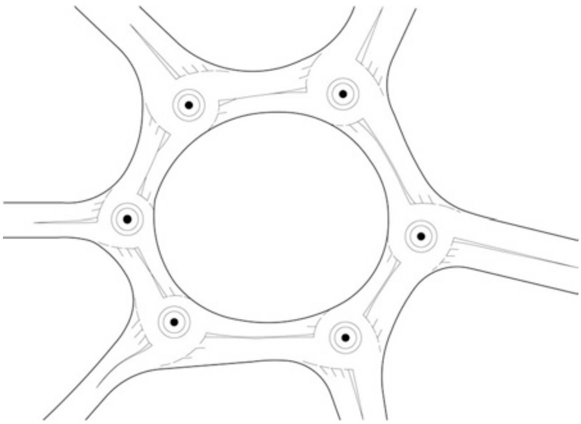


Fig. 2.45 Ring junction—left-hand driving; sketch

in the original French as “Le Manège enchanté”, a French-British children’s television program, created in France. The Magic Roundabout was constructed in 1972, according to the design of Frank Blackmore, of the British Transport and Road Research Laboratory. The solution consists of five mini-roundabouts arranged around a sixth central, anti-clockwise roundabout. Traffic may proceed around the main roundabout either clockwise via the outer lanes, or anticlockwise using the inner lanes next to the central island.

When the roundabout complex was first opened, the mini-roundabouts were not permanently marked out and could be reconfigured while the layout was finely tuned. A police officer was stationed at each mini roundabout during this pilot phase to oversee how drivers coped with the unique arrangement. In 2005, it was voted the worst roundabout in a survey by a UK insurance company, and in 2009 it was voted the fourth scariest junction in the UK [14]. However, the roundabout provides a better throughput of traffic than other designs and has an excellent safety record, since traffic moves too slowly to do serious damage in the event of a collision [15].

Similar systems (with five or six mini-roundabouts) can be found in various places in the UK (Colchester, Hemel Hempstead, High Wycombe…).

So, as previously stated, roundabouts in different countries differ in their layouts, and there is no “only one truth”. A certain solution which is safe in one country could be very dangerous in another, and verbatim copying of foreign results could be dangerous and can lead to effects that are completely opposite than expected.

2.3.9 Roundabout with a Transitional Central Island

The importance of the central island of a roundabout has been extremely high from the very beginning of roundabouts’ developments. In 1929 Watson criticized the decision of the London Traffic Committee for favoring squares or diamond shapes. These tended to increase the approach and entering speeds and also slow down the speed of rotation. It ensured that entrance would begin to take priority, and with the increasing general speed and volume of traffic, frequent “locking” would eventually occur. Watson’s suggestions for overcoming the committee’s “architectural objections” to circular islands included partial, split or double roundabouts [1].

A roundabout with a transitional central island is usually called a “hamburger roundabout” (the name came from the aerial view: the two halves of the central island look like the “bread”, and the splitter island between two roads represents the “meat”) but the terminus “split-roundabout”, and “through-about”, and “cut-through” roundabout are also in use (Fig. 2.46). The hamburger roundabout is a type of roundabout with a straight-through section of carriageway regarding major roads. It has a split central island with a splitter island between the two halves of the central island. The width of the intermediate splitter island is equal to the

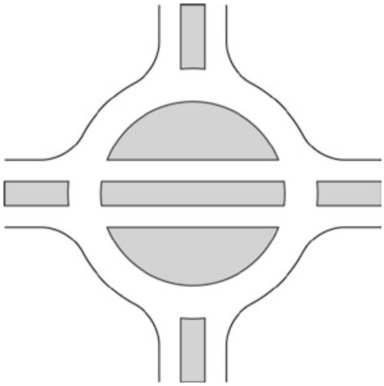


Fig. 2.46 Hamburger roundabout; sketch

length of one heavy vehicle or one bus (or more, but not less). The inscribed circular diameter of the hamburger roundabout is about 60 m or more.

It could be constructed as a one- or two-level roundabout. There are few variations of this type of one-level solution. One of them, in frequent use in the Canary Islands (Fig. 2.47) also includes splitter islands on approaches (Fig. 2.48) and for right turners (Fig. 2.49).

In the UK and Ireland this type of roundabout is still in frequent use, and is also very common in Spain and Portugal. This type of at-grade hamburger roundabout is often traffic signal controlled because of the large number of conflict spots (Fig. 2.50), and always lighting.

There is also a variation of hamburger roundabout on two-levels (Fig. 2.51). The main carriageway goes straight through the middle of the junction at one level (under or overpass), with short ramps connecting it to the roundabout at other levels. This variation of a hamburger roundabout is always traffic signal controlled.

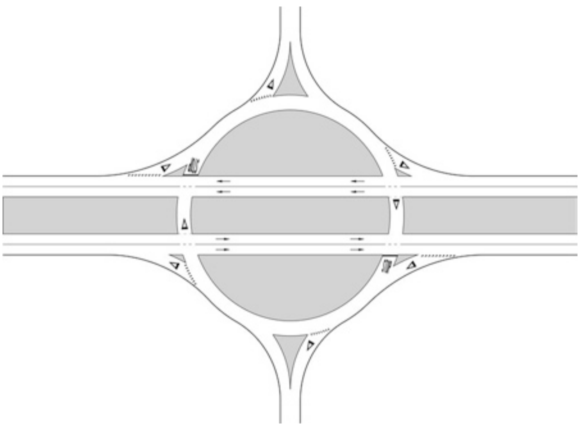


Fig. 2.47 Hamburger roundabout with splitter islands for right turners; sketch

Fig. 2.48 Stop and yield signs on the crossing with a straight-through section of carriageway

Fig. 2.49 Yield at the entrance of circulatory carriageway

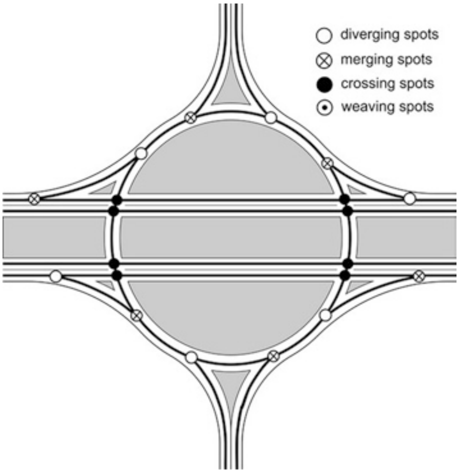


Fig. 2.50 Conflict spots on an at-grade hamburger roundabout

Fig. 2.51 Two-level hamburger roundabout; Barcelona, Spain

2.3.10 Roundabout with Segregated Right-Hand Turning Lanes (Slip-Lanes)

Standard one- or two-lane roundabouts (also some alternative types of roundabouts) sometimes incorporate segregated lanes for right-hand turners ("slip-lanes" or

Fig. 2.52 Segregated right-hand turning lane; Maribor, Slovenia

"segregated right-turning lanes" or in some European countries called "bypasses" or "free-flow lanes" or a "channelized turn lanes"). A slip-lane is a separate right-turning lane (Fig. 2.52) that lies adjacent to a roundabout, and allows right-turning movements to bypass the roundabout itself. A slip-lane provides traffic relief by allowing right-turning traffic to bypass the roundabout instead of passing through. A slip-lane is not a dedicated right-turn lane within a roundabout approach. The purpose of a slip-lane is to separate the flow of right-turning traffic, reduce delay and vehicle conflicts within the roundabout to improve capacity and safety.

The segregated right-turning lane is a recognized method in many countries (e.g., the UK, France, The Netherlands, Germany, the USA, Poland, Czech Republic, and Slovenia) of increasing capacity at a roundabout where a high proportion of the flow turns right. But, in some of these countries, guidelines advise that they can lead to speeding [16]. Therefore, it is necessary to stress that the designer needs to consider a number of factors, especially if vulnerable participants onto a roundabout are expected.

Two basic types of segregated lanes are known; non-physically segregated and physically segregated right-turning lanes. A non-physically segregated lane is a right-turning lane from a roundabout entry to the first (next) exit, separated from the roundabout entry, circulatory carriageway and exit by means of an island delineated using road markings only. A physically segregated right-turning lane is a right-turning lane from a roundabout entry to the first (next) exit, separated from the roundabout's entry, the circulatory carriageway, and the exit by means of a curbed island and associated road markings.

In both types, vehicles are channeled into the right-hand lane by road markings, supplemented by advanced directional signs. They proceed to the first (next) exit without having to give way to other vehicles entering into the roundabout.

Segregation by road markings is more common (drainage, snow plugging…) but it can be less safe as it can be subject to abuse by vehicles over-running the non-physical (painted) island.

Three different layout options for designing segregated right-turning lanes are known basically (Fig. 2.53), depending on the number of vehicles turning right-hand and on land availability:

- stop line at the roundabout's exit approach;
- yield line at the roundabout's exit approach;
- acceleration lane—a free-flow lane (Fig. 2.54).

From the capacity point of view (but not also from the traffic safety of non-motorized points of view) the best solution is with an independent lane for right-hand turning (Fig. 2.55).

Roundabout with independent lanes for right-hand turning is not an appropriate solution if vulnerable participants onto roundabout are expected. In that case, several other layouts' variations are possible, depending on the types of participants into a roundabout (Fig. 2.56). Layouts' variations differ from country to country because of local circumstances (human behavior and traffic culture).

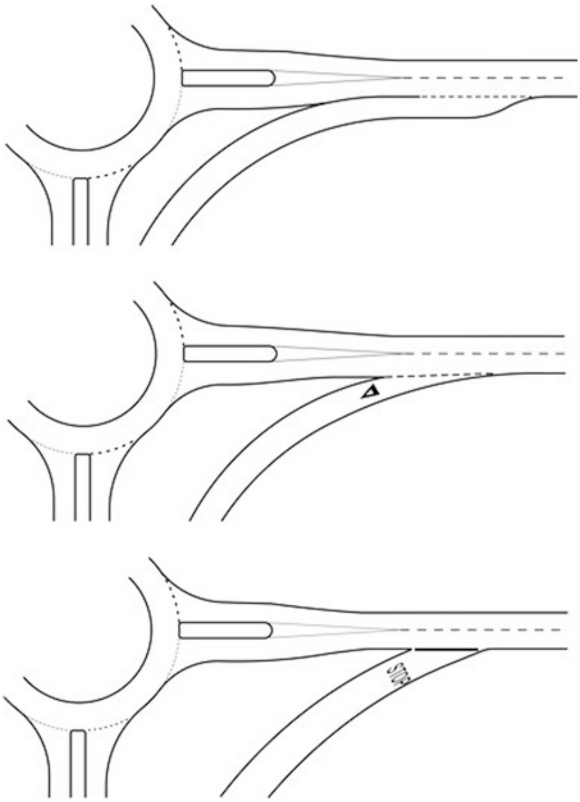
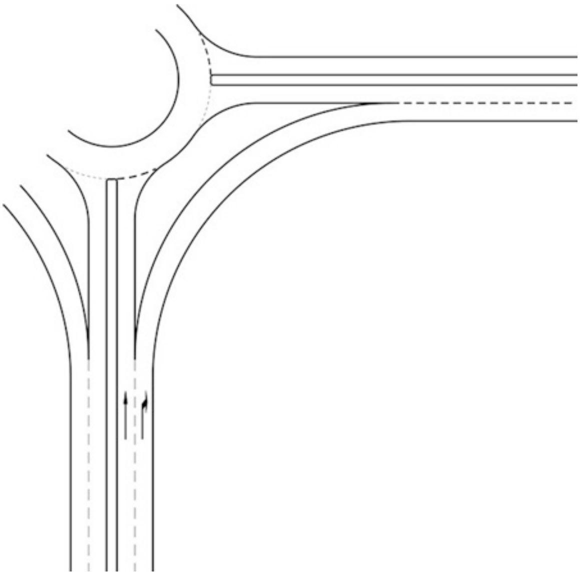


Fig. 2.53 Three different layout options for designing segregated right-hand turning lane

Fig. 2.54 Roundabout with four segregated right-hand turning acceleration lanes; City of Varaždin, Croatia

Fig. 2.55 An independent lane for right-hand turning



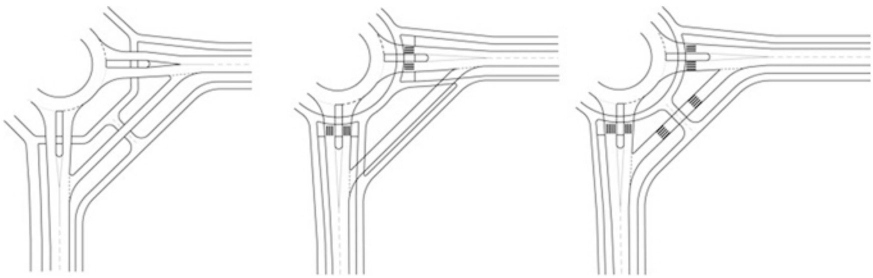


Fig. 2.56 Layouts' variations of segregated right-hand turning lanes if non-motorized participants are expected

The use of segregated right-turning lanes requires the designer to consider a number of factors (mostly traffic safety, capacity, and non-motorized participants) and should only be considered where its introduction would result in:

- an increase in the overall capacity of the entry or roundabout in question (compared to an alternative design);
- an improvement in the roundabout's safety (reduction of accident numbers or severity);
- provisions for pedestrians and cyclists.

The designer should determine whether facilities for non-motorized users are necessary, because segregated right-turning lanes can present particular difficulties for non-motorized users due to:

- possible high speeds of motorized vehicles;
- the extra widths of the carriageways at the entry and exit to be crossed;
- vehicle and non-motorized user conflicts due to large differences in speed at the pedestrian crossing;
- insufficient widths provided on pedestrian islands within physically—segregated right-turning lanes;
- confusion of vehicle flow direction due to the segregated nature of the right-turning lane.

As written above, if facilities for non-motorized users are necessary, the designer should determine whether they can be catered for adequately with a reasonable degree of safety and convenience within the roundabout design [16].

2.3.11 Signalized Traffic Circles

First, it is necessary to know that there are differences between signalized traffic circles and squares on the one hand and traffic signal controlled roundabouts on the other hand.

Signalized traffic circles and squares originated from the initial, old town squares with four or more intersecting roads. As written in Sect. 2.3.2, these old traffic circles and town squares are nearly always traffic signal controlled nowadays, because they are mainly located within city centers (usually with a lot of traffic). Traffic signals were initially installed on traffic circles and squares as part-time signals operating at peak periods, and this application is still common. The first experiment of traffic signals at a traffic circle in the UK was in 1959 [1].

Two main reasons exist for signalization of traffic circles and squares: entry flows were unreasonably balanced or old circulatory systems have been created as a result of multiple entry arms. Congestion was caused by tidal traffic conditions:

- high circulating speeds on large traffic circles or squares, which may make it difficult for other traffic to enter;
- when the major flow dominates the traffic circle or square to the extent that the remaining arms of the traffic circle or square experience severe difficulty;
- when a minor flow to the left of the major flow is dominant on the circulatory carriageway.

In these circumstances traffic signals have been installed at traffic circles and squares to counteract predictable operating imbalance by creating gaps in the circulating traffic.

The signalized roundabouts are a little bit different than signalized traffic circles. The signalized roundabouts originate from the UK and go back to the early seventies of the previous century; however, not until 1991 can we speak of their rapid expansion. From that year on, signalization became a popular method of traffic control in roundabouts and is now known also in the USA, Australia, Sweden, Ireland, The Netherlands, Germany, Belgium, Denmark, Turkey, Poland, and Slovenia. The traffic signal controlled roundabouts are discussed in Sect. 4.5.

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