# Quality of service (QOS) of Urban roundabouts: a literature review

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*Abstract:* - Nowadays roundabouts have been a widespread design solution, in urban and rural areas, mainly due to their efficient traffic control and their safety performance. They provide several advantages in comparison to signalized and stop-controlled intersections. While there is generally acceptance by researchers that roundabouts create operational and safety benefits, their acceptance by the general public is not at the same level, as past research has demonstrated strong public sentiment against roundabouts. The Highway Capacity Manual (HCM2010), describes specific techniques to evaluate the traffic handling ability of a transportation facility of roundabouts through measuring the Level of Service (LOS). It also introduces the concept of Quality of Service (QOS) to assess the perceived performance of the transportation facility from the viewpoint of drivers and travelers. It has been assumed that both LOS and QOS are interacting equally to roadway operating agencies, transportation engineers, and other decision makers.

The paper presents basic characteristics of a modern roundabouts. The clarification of the definitions of QOS and LOS of roundabouts is also presented and a review on the recent published research related to LOS and QOS of urban roundabouts is being carried out. Through this review, the authors intend to identify the factors affecting the two indexes. Moreover, in this paper a number of surveys through questionnaires about public opinion on roundabouts is reviewed and their results of "before and after" analysis are presented.

*Key-Words:* - Roundabouts, Level of Service, Quality of Service, Capacity, User perception, Public opinion

## 1 Introduction

Roundabouts have been a widespread design solution mainly due to their efficient traffic control and their safety performance.

Modern roundabouts are circular intersection that control and divert vehicles to travel around a central island [1]. They differentiate from traffic circles in basic design features in traffic control, pedestrian access, parking and direction of circulation features. Table 1, presents the comparison between the traffic circles and roundabouts.

The most important characteristic of a modern roundabout is the “yield at the entry” rule to all entering approaches, namely entering traffic to give way or yield to vehicles within the circulatory roadway. According to this rule, approaching vehicles must wait for a suitable gap in the circulating flow before entering the circle, therefore circular traffic is preserved against congestion. Excess flow queues on the approaches, allow continuous flow of the circulating stream. Basic design features are the deflection, flare, splitter and central islands, and truck aprons. Deflection is the use of small radii on the entrance and exit approaches, which guides drivers into an easy transition from the approach into the roundabout [3] and forces drivers to slow down to safely maneuver about the central island [4] [5]. The splitter island design element is typically a raised concrete island that improves deflection of vehicles and provides protection for pedestrians midway through crossing [6]. Flare is the widening of the approach, by adding another lane, so the roundabout can accommodate more vehicles. This feature is meant to increase capacity at the intersection [4] [9] and keep the roadways before and after the intersection at minimum widths [3]. The last feature is the truck apron that accommodates for the turning paths of large trucks, such as fire trucks [7]. The feature design is based on these vehicles and the central island radius. Figure 1 shows a typical layout of a modern roundabout.

**Table 1**. Comparison of circular intersections and modern roundabouts, [5].

| Element | Traffic Circles | Modern Roundabouts |
|---|---|---|
| Size | Large circle outer diameter | Smaller circle outer diameter |
| Speed | Higher speeds for entering and circulating vehicles | Lower speeds for entering and circulating vehicles due to "yield at point" rule |
| Capacity | Vehicles need larger gaps in the circulating traffic flow reducing the volume of traffic processed | Flared entry provides high capacity in a compact space |
| Safety | Higher speeds reduced number and severity of crashes<br>Improve safety for vulnerable users | Slower speeds reduced number and severity of crashes |
| Other | Priority to circulating vehicles | Priority to traffic flows entering from branches |

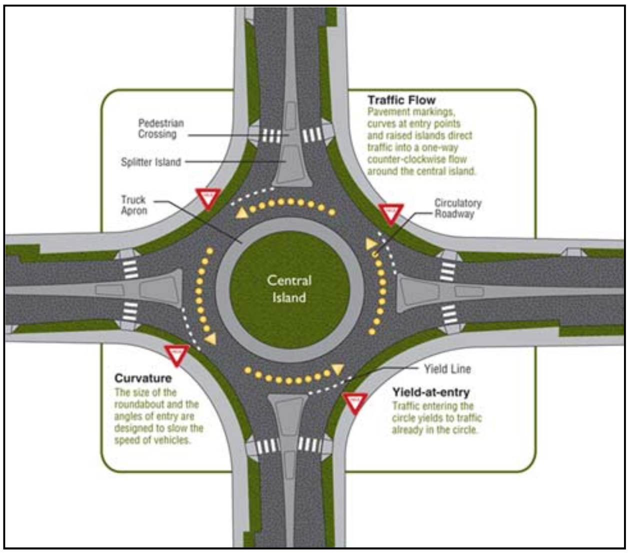


**Fig. 1** Design features of modern roundabouts [9]

## 2.1 Types of roundabouts

Based on the most common design standards [1, 8,9], roundabouts are categorised according to their size and number of entering lanes to the following categories:

a) Mini-roundabouts, Fig.2a
b) Single lane and compact roundabouts, Fig.2b
c) Multi lane roundabouts, Fig.2c

Mini-roundabouts are limited to applications for low speed urban areas. Their design is based on small diameters providing a single-lane circulatory roadway with a fully traversable central island [1]. Compact and single lane single roundabouts consist of a single lane entry-exit at all legs and one circulatory lane. These roundabouts are also typical of urban environments [7]. They differ from mini roundabouts on the larger inscribed circle diameter, the non-traversable central island with apron, and the higher speed operating values [8]. Finally, multilane roundabouts have at least one entry with two or more lanes, or may include roundabouts with entries on one or more approaches that flare from one to two or more lanes. The circulatory roadways are designed wider in order to accommodate more than one vehicles travelling side by side [9]. They are better suited in suburban or rural areas with increased traffic flow. Figure 2 describes all three different types.

*a.) Typical mini roundabout* [6]

*b.) Typical single lane roundabout* [7]

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*c.) Typical two lane roundabout* [8]

**Fig. 2** Different types of roundabouts

## 2.2 Advantages and Disadvantages of Modern roundabouts

Under certain conditions and appropriate selection of site, roundabouts provide a number of significant advantages compared to other types of intersections. The most significant advantages of roundabouts are road safety and capacity [2]. Modern roundabout design improves the safety of intersections by eliminating or altering conflict types, by reducing speed differentials at intersections, and by forcing drivers to decrease speeds as they proceed into and through the intersection [4]. Its geometric element parameters, along with the crash experience, assists on the optimization of the safety of all vehicle drivers, pedestrians, and bicyclists [13].

The second dominant advantage of modern roundabouts is their overall operational efficiency compared to all other forms of traffic control. Unlike all-way stop intersections, a roundabout does not require a complete stop by all entering vehicles, which reduces both individual delay and delays resulting from vehicle queues. If there is no traffic in the roundabout, they don't have to stop at all. Additionally, they operate more efficiently than a signalized intersection because drivers are able to enter from different approaches at the same time [1,13].

While traditional intersections force vehicular traffic to slow down and stop, modern roundabouts improve traffic flow and reduce vehicle idling times at intersections. Given that roundabouts improve the efficiency of traffic flows, they also reduce vehicle emissions and fuel consumption. Vehicles continue to advance slowly rather than coming to a complete stop, resulting in reduced noise and air quality impacts and fuel consumption [2,5]. As a result, roundabouts are considered as one of the most efficient forms of intersection control that can improve fuel economy and vehicle emissions [1,12]. Furthermore, even when traffic volumes are high, vehicles continue to advance slowly rather than coming to a complete stop, which may improve air quality and produce energy savings by reducing acceleration/deceleration and idling manoeuvres [12, 13].

The cost of building a roundabout is comparable to installing a digital traffic signal. However, maintenance and electrical costs are much less expensive. Over the life of the intersection, the cost savings are significant [3]. This is very important in areas where the budget for public works projects is lower than ever before. Moreover, when societal costs is associated with crash incidence, roundabouts are often less expensive than other intersection control alternatives [4]. Reducing drivers speed and delays saves time and fuel [7].

Despite these clear advantages for a roundabout, there are some issues to be aware of. Roundabouts are relatively new, that means that in certain areas they form un unfamiliar installation for most drivers. As a result, vehicle users are not comfortable when approaching a roundabout, fact that leads to a neglecting behavior for the yield upon entry rules and confuses drivers on the rules they have to follow [3, 11].

Roundabouts eliminate the need for waiting at traffic signals and they help prevent high speed accidents from occurring at intersections. By imposing slowing down traffic at intersections, roundabouts slowdown the overall pace of traffic entering the junction. This slow pace can, during peak traffic hours, create a dense “queue” of vehicles waiting to navigate the roundabout, which can lead to slow speed accidents. This can be especially difficult for vehicles that are in a hurry, like ambulances [4].

A roundabout can be unsettling to a pedestrian, depending on age, mobility, visual impairment, or ability to judge gaps in traffic. A pedestrian, at first glance, can have to adjust to roundabout operation. This includes the crosswalk location, which is behind the first stopped vehicle, or 6 m from the yield point [9].

Finally, roundabouts usually require more space than stop or traffic signal control at the intersection itself, and will often encroach outside a typical right-of-way due to its size and the alignment of the exits. Therefore, with proper analysis, planning, design, and education for the public (particularly in areas where a roundabout will be new), roundabouts are successful in helping to keep people moving safely and efficiently. Based on all above the main

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advantages and disadvantages of roundabouts are summarized in Table 2.

**Table 2**. Advantages and disadvantages of roundabouts.

| Category | Advantages | Disadvantages |
|---|---|---|
| Safety | Reduced conflict points compared to uncontrolled intersection.<br>Lower operational speeds result to fewer and lighter accidents. | Unfamiliarity increases accidents |
| Capacity | Traffic resulting in the acceptance of smaller gaps.<br>Roundabouts result to higher capacity/lane than signalized intersections since there is no waiting time for green light | Coordinated signal network at signalized intersections might increase overall capacity network.<br>Difficulty in accommodating long load vehicle turning movements |
| Delay | Yield at entry design eliminate delays during off-peak.<br>Drivers adjust their speed to take advantage of approaching gaps in circulating traffic | Drivers may not like the geometric delays which force them to divert their cars from straight paths.<br>In case of queuing, drivers enter the in shorter gaps, causing delays on other legs and the number of accidents. |
| Cost | Maintenance costs of signalized intersections is higher than roundabout maintenance.<br>Accident costs are lower | Initial construction costs may be higher<br>In certain cases roundabouts may require more illumination. |
| Vulnerable users | Splitter islands provide a refuge for pedestrians<br>Lower speeds - traffic volume improve safety for bicyclists. | Tight dimensions create an uncomfortable feeling to bicyclists.<br>Longer travel distances for vulnerable users Roundabouts may increase delay for pedestrians |
| Environmental impact | Enhanced aesthetics by landscaping<br>Reduces air and noise pollution, as well as fuel consumption. | Multi Lane roundabouts require more space |

## 3 The concepts of Level & Quality of service for roundabouts

The level of service (LOS) of an intersection has a significant effect on the overall operating performance of that. LOS reflects the quality of service as measured by a scale of user satisfaction and is applicable to each of the following modes that use roadways: automobiles, trucks, bicycles, pedestrians, and buses. LOS is defined as a term which denotes a range of operating conditions that occur on a transportation facility when it is accommodating a range of traffic volumes. More specifically according to HMC 2010 the LOS of intersections is defined as "a quantitative stratification of the quality of service into six letter grade levels", expanded from A through F, with A being the best and F being the worst. Typically three parameters are used under this and they are speed and travel time, density, and delay [1,24].

Under the light of this description, the method proposed to evaluate LOS for roundabouts according to HCM 2010 (Chapter 21) is the same with the one used for the unsignalized intersections "roundabouts share the same basic control delay formulation with two-way and all-way STOP-controlled intersections" [1,29]. The specific manual indicates that the most dominant criteria for the determination of the LOS of a roundabout is delay and volume/capacity ratio [1]. In other words roundabout LOS is defined in terms of the average control delay of each movement on the minor street.

The delay values defined for the different categories of the LOS for control delay and volume capacity ratio are presented in Tables 3 & 4 respectively

**Table 3**. LOS thresholds based on delay [1]

| LOS | Description | Control Delay (s/veh) |
|---|---|---|
| A | Highest driver comfort; free flowing | 0-10 |
| B | High degree of driver comfort, little delay | >10-15 |
| C | Acceptable level of driver comfort; some delay | >15-25 |
| D | Some driver frustration; moderate delay | >25-35 |
| E | High level of driver frustration; high levels of delay | >35-50 |
| F | Highest level of driver frustration; excessive delays | >50 |

Control delay quantifies the increase in travel time that a vehicle experiences due to the traffic control as well as provides a surrogate measure for driver discomfort and fuel consumption.

**Table 4**. LOS thresholds based on delay & v/c ratio [1]

| Control Delay (s/veh) | LOS by volume-to-capacity ratio | |
|---|---|---|
| | v/c ≤1,0 | v/c ≥1,0 |
| 0-10 | A | F |
| >10-15 | B | F |
| >15-25 | C | F |
| >25-35 | D | F |
| >35-50 | E | F |
| >50 | F | F |

In the latest edition of the HCM [1] it is well cleared that it is equally important the operational performance of an intersection based on the viewpoint of the driver's, traveller perception. The combination of the performance measures related to an intersection is the quality of service. According to the HCM 2010 the concept of QOS is defined as "a traveller based perception of how well a service or facility is operating"[1, 24]. The Quality and level of service handbook [24] reports that quality and level of service are different but they are interconnecting. LOS is applicable only to automobile analysis, while QOS is related to the non-automobile modes.

Research has shown that there are more than 45 factors that influence the perceived QOS. The primary ones are considered to be:

1. traffic characteristics
2. geometry of the installation.
3. travel time,
4. speed,
5. delay,
6. number of stops incurred
7. travel time reliability,
8. manoeuvrability and
9. comfort,
10. convenience,
11. safety,
12. user cost,
13. availability of facilities,
14. services,
15. facility aesthetics, and
16. information availability

The selection of service measure for the Highway Capacity and Quality of Service (HCQS) manual is guided by two principles. The first principle declares that the service measure for each facility should represent speed and travel time, manoeuvrability, traffic interruptions, comfort and convenience in a manner most appropriate to characterizing QOS for the particular facility being analysed. The second principle assumes that the service measure chosen for facility should be sensitive to traffic flow. HCM 2010 also mentions that the service measure should reflect travellers' perceptions, useful to operating agencies, directly measureable in the field and should be estimable given a set of known or forecast conditions. In terms of roundabouts traffic flow is categorised into interrupted flow facilities. Interrupted flow facilities have fixed causes of periodic delay or interruption to the traffic stream, such as traffic signals or STOP signs. [1,24]

Up to date, none of the existing methodologies has been developed to describe drivers' degree of satisfaction at roundabouts. In the absence of such research, HCM 2010 defines the service measure and thresholds for roundabouts consistent with those for other un-signalized intersections or road segments with interrupted flow [24].

### 3.1 Review on the parameters of Quality of service (QOS)

While there is no past work on roundabouts quality of service, the number of studies seeking drivers' opinions about factor affecting their trip quality has increased in recent years. In order to understand and develop the QOS concept one need to know the different uses and limitations of driving simulator, human factors involved in transportation, and different situations where a driver feels uncomfortable. Such measures include drivers' comfort, convenience, anxiety, and preferences [29]. That kind of data is derived through interviews and questionnaires.

Fred Hall et al., 2001 studied "freeways quality of service and what really matters to drivers and passengers". The results of focus group sessions were reported in which a group of commuters discussed their views about determinants of the freeway quality of service that they experienced. The most important determinant for them was the total travel time, in addition to traveller information, safety, and manoeuvrability [30].

Aimee Flannery et al. 2008, studied the analysis and modelling of automobile users' perceptions of quality of service on urban streets. In this study the researchers tried to identify which factors enter into users' perceptions of quality of service and the interface between modes on urban streets, also described the research efforts which had been taken to analyze and model automobile level of service from driver's perspective. Correlation analysis was conducted to identify the relationships that may exists between the dependent variables. The result showed five effective variables were contained in the model; stops per mile, median type, width of parking lane, presence of exclusive left turn, and presence of trees." [23]

G. A. McKnight, A. J. Khattak and R. Bishu, in 2008, conducted a survey study in Nebraska in to which they tried to identify relationships between characteristics of drivers and knowledge (i.e. familiarity and unfamiliarity) of roundabout navigation. Results of the study revealed that familiarity appears in younger and specialty drivers that understand the rules of roundabouts better than unfamiliar and older car drivers. [16].

Soren Underlien Jensen in 2012 studied “pedestrian and bicycle level of service at intersections, roundabouts and other crossings”. The study developed methods for quantifying pedestrian and cyclist stated satisfaction with signalized and nonsignalized intersections, roundabouts, mid-block crossings, pedestrian bridges and tunnels. The results provided a measure of how well urban and rural crossings accommodate pedestrian and bicycle travel [16].

Ibrahim Hashim Khliefat in 2014 analyzed " drivers perception of quality of service on urban roundabouts". The findings of this study show that the quality of service perception of urban roundabouts is influenced by several factors, including approach level of service, pavement quality, pavement marking, pedestrians’ activity, clarity of road signs, and presence of landscaping. examined the factors affecting the The findings of this study show that the quality of service perception of urban roundabouts is influenced by several factors, including approach level of service, pavement quality, pavement marking, pedestrians’ activity, clarity of road signs, and presence of landscaping [31].

Van der Bijl et al., in 2011 studied “drivers' perception and acceptance of waiting time at signalized intersections”. The study was conducted with video survey support. They focused the research on three different categories of affecting factors:

**1.** intersection,
**2.** signal scheme and
**3.** traffic characteristics.

In this study the researchers demonstrated that the perceived waiting time depends on other factors such as the number of stops in the queue and the presence of red light interruptions between adjacent intersections instead of only the actual waiting time, [27].

## 4 Public opinion of roundabouts

The introduction of the modern roundabout to the transport network is fairly new. The rules of the modern roundabout were made law in the UK in 1966 [8], but it wasn't until the late 90’s that modern roundabouts started to expand around the world. [13]. There have been several main concerns with constructing a roundabout, which includes concerns of the ability of the public to comprehend the new intersection rules, whether roundabouts were safe, and whether they were effective in managing traffic.

Public opinion in surveys has shown that communities generally tend to exhibit negative perceptions toward roundabouts particularly during the period prior to construction. Since public opinion has been a major concern with roundabout installation, researches have focused on surveys inquiring the opinion of the locals regarding roundabouts to each respective study.

There are many studies that inquired why drivers opposed to the roundabouts felt this way. Often, the same reasons were cited for both that the drivers found the intersection to be confusing, unsafe, and/or they just preferred a signalized intersection over a roundabout [19] [10]. Another reason drivers stated for opposition was a belief that the roundabout caused more congestion, yet the study in which this remark was made found significant reductions in delay and the number of vehicles stopping [10].

Generally younger drivers were most supportive, and support was found to decrease consistently with age. Older drivers comprised a high percentage of respondents that opposed roundabouts, where some acknowledged they opted for alternative routes in order to avoid trying to navigate the roundabout [11].

### 4.1 Review on the Public's opinion of roundabouts

Various studies have examined the public perspective on current, under-construction, or future roundabouts at specific locations. Some of the most current studies are shown below.

Redington, in 1997, conducted a survey of persons who lived and worked near a single-lane roundabout at Keck Circle in Montpelier. Among surveyed road users, "favorable" and "very favorable" responses outnumbered "unfavorable" and "very unfavorable" responses by a four-to-one margin. There was very little variation in perceptions among walkers, bicyclists, and drivers. Positive survey responses expressed the smooth flow of traffic, the increased ease of accessing businesses adjacent to the intersection, the attractiveness of the roundabout, and its safety. Negative survey responses centered on driver behavior - failure to yield, drivers not following the rules, and need for education of drivers [19].

Richard A. Retting, 2002, managed many projects related to the investigation of public opinion reaction before and after the construction of several roundabouts [17].

The same year he further examined public perceptions regarding a single-lane that was part of a roadway realignment project [17]. A substantial change in public opinion was indicated after construction when the proportion of drivers opposed to the roundabout.

Likewise, in another study in Kansas showed that after construction, there was a substantial change in public opinion. The large reduction in the proportion of drivers strongly opposed to the roundabout provides evidence that opinions of even those with strong negative perceptions initially tend to become more accepting of roundabouts over time [20].

Pier Gårder in 2002, has analyzed the long-term effects of the reconstruction of a single-lane roundabout in Gorham. He conducted questionnaire surveys to gather opinions of motorists and residents in the vicinity of the roundabout on four different occasions: before reconstruction, just after reconstruction, as well as three years and five years later. Residents near the roundabout were more positive than those living further away. Over time, respondents tended to be more favorable regarding roundabouts and this change in attitude generally continued in the years following construction as drivers become more familiar with roundabouts [12].

In a study conducted by the City of Olathe [14, 10], residents were interviewed by telephone to obtain their opinions about specific roundabouts located in the city. This survey provides further evidence that exposure increases driver familiarity, comfort, and perceived safety of roundabouts and grade-separated cycle paths).

A study was carried out by Jørgensen E. and Jørgensen N., 2002 in Denmark aimed on finding out how roundabouts ought to be designed in order to provide cyclists with the highest level of safety possible. Seven urban roundabouts of different designs were analyzed through video recordings. Entry and exit flows, errors in the use of the roundabouts by cyclists, and interaction with other road users were recorded. At all roundabouts, the cyclists were in some way separated from motorized traffic, either by a solid white line forming an outer circle, or by small islands. The conclusion was that cyclists do not obtain the same safety effect as motorists at roundabouts. Information available on the design of the evaluated roundabouts was rather poor, but all seven of them seemed to be rather large. The authors suggest that traffic safety could be improved for cyclists if the inscribed diameter of the roundabout was smaller. At mini-roundabouts, all road users have to share the circling area, which promotes interaction and safety [26].

In another similar research conducted Retting et al. in 2006, conducted a similar research to the one made in 1997, following the same procedure to examine public opinion of a roundabout at the intersection of Route 29 and Route 40 in Greenwich, NY. The analysis revealed that after construction, the proportion of drivers favoring the roundabout was increased. Drivers opposed to construction of the roundabout provided multiple reasons, the most common being that the roundabout was confusing or unsafe [18].

## 5 Conclusion

In recent years, roundabouts are a common type of intersection mainly due to their safety performance and efficient traffic control.

Level of service and Quality of service are two indexes in order roundabout operation to be evaluated. LOS is a measure used to relate the quality of traffic a service, is defined by given thresholds in terms of delay and volume to capacity ratio. QOS is a combined measure to assess the perceived performance of the transportation facility from the viewpoint of drivers and travelers through a series of factors. QOS is separately defined into the HCM 2010 but it is not described in terms of thresholds. The various factors consisting the determination of the quality of service have been specified over the years through various scientific researches mainly interviews and questionnaires addressed to road users. Both LOS and QOS are simultaneously useful to roadway operating agencies, members of the community, and decision makers. Definition of QOS has two practical implications:

a. how user's perceives the service of the given installation and
b. how decision makers will use the resulting "felling".

On the other hand, definition of LOS is necessary in designing the analysis of life of the installation.

Despite the fact that roundabouts are growing fast due to the major advantages they offer to road network, their public acceptability is not always given. Their implementation has often resulted to use unwillingness. The main objection related to their use is unfamiliarity.

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