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Critical Review of Round About Design Research Approaches and Application to Indian Conditions

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***Abstract*— The study is intended to carry out a detailed review regarding the roundabout design practices currently following all over the world and the major innovative steps towards same. Due to the limitation in the standards that adopted to design this type of intersections, the prior aim is not got satisfied and thus the smooth traffic on the intersections could not be achieved because of unexpected queue and delay. To resolve this issue on roundabouts, many researchers are focused on new innovative methods in this domain. The current study reviewed those works in a detailed manner which includes innovations towards geometry, reviewing codes & guidelines use of micro simulation software and optimization techniques. Researchers suggest that using some advanced methods rather than conventional methods will give more appropriate results so that the design can be done in an efficient way. Also, the suitability of Highway Capacity Manual in Indian traffic conditions has been studied by many researchers and concluded that an adjusted multiplicative factor shall be adopted to consider the mixed traffic condition and lane changing behavior. This factor is purely a function of critical gap and follow up time. The Passenger Car Unit values corresponding to distinctive category of vehicles according to the turning movement have been found out by researchers using time occupancy method which is not included in the IRC 65-2017 [15]. These modifications can be incorporated in the current design practices and limitations of IRC can be rectified to some level. Also, this study shows that the pedestrian flow along with their behavioral approach should be considered to choose the control measures at intersection.**

***Keywords*— roundabout, geometric design, critical gap, follow up time, adjustment multiplicative factor, heterogeneous traffic condition**

I. INTRODUCTION

The roundabout is a type of at-grade intersection that has arms where the vehicles converge and enforced to take turns in an orderly manner around the central island. This type of intersection is purely controlled by traffic signs. It is one of the safest types of intersection since they are dedicated to low-speed driving and all traffic will take a movement in the same direction or left turns and across traffic can be eliminated. Also, it offers the pedestrian safety in a great extent since there is no need to look in direction of traffic. The conflict points are comparatively fewer and therefore the accident rates are also very low at roundabouts. Diverging, merging, and weaving are the common actions taken by the driver in a roundabout intersection. Here, the common angular crossing of at-grade intersections can be replaced by weaving movements and therefore the occurrence of accidents will be less. Even though a little extra distance needs to be travelled except left turns, a smooth and ease turning movements can be achieved.

The demand of roundabouts is increasing day by day as it has many benefits. As a part of National Cooperative Highway Research, it is found that the crashes caused by roundabouts are reduced by 75 percent and fatalities by 90 percent compared to normal traditional intersections. One of the main reasons behind this is the traditional four-legged signalized intersection has 32 conflict points, and at the same time a single lane roundabout has only 8. Since the roundabouts are continuously moving and yield controlled, it is possible to handle huge traffic and it can reduce congestion on approaching roads. It has less maintenance cost as it requires only electricity for streetlights at night and for nearby landscaping. Even though it has a lot of advantages over other kinds of intersections, the condition and efficient working of roundabouts in India are poor. This might be due to the design guidelines followed by the practitioners. Certain parameters were not taken into account for the design, since a pure conventional method is followed. Now, there are a lot of innovative approaches emerging to design roundabouts more efficiently which includes simulation using software's, optimization techniques, and more practical guidelines and so on. Therefore, this study is intended to do a comprehensive study on the analysis and design of roundabouts by reviewing literatures and other resources. The traffic and operational conditions of roundabouts in India is given Figure 1 [13].

Fig. 1, Traffic and operational conditions of roundabouts in India [13]

II. LITERATURE REVIEW

The exploration towards the advancement of roundabout design in order to enhance the efficiency was done by many researchers. Roundabouts are widely used in India for the roundabout design even though the guidelines are formulated from the HCM. Srinath Mahesh et al. (2016) [13], conducted a study to find the entry capacity of roundabouts by measuring

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the entry flows for different circulating flows at entry locations. The operation efficiency is checked by taking queue formation as an indicator. It is found that a negative exponential distribution is exist between entry flow and circulating flow. In addition, it is noted that the entry capacity at field using IRC 65-2017 [15], is quite higher than the capacity given by HCM equation. Sonu Mathew et al. (2017) [14], conducted a study to modify HCM equation so that it can be applied for Indian mixed traffic conditions. A negative exponential behavior has been found between entry flow and circulatory flow. Ashish Kumar et al. (2019) [18], conducted a study for the development of an entry capacity model for roundabouts using Multiple Linear Regression (MLR) analysis under Indian mixed traffic flow conditions. Influence Area for Gap Acceptance (INAGA) method is followed to determine the critical gap and follow up time considering drivers behavior. The variables selected for the study is critical gap, follow up time, speed, circulating flow, and lateral clearance with respect to Central Island. All these variables are proven significant for the capacity model development. Tamara D et al. (2020) [23], conducted a study on the importance of vehicle movement simulation in swept path analysis. It is recommended that the design vehicle's movement by swept analysis should include in the early project stages to ensure the usage of optimal design geometry rather than at the end of design process.

IRC 65-2017 [15] is limited to the design of certain geometries only which might not be suitable for the traffic as well as site characteristics. Antonia Pratelli et al. (2022) [3], presented the two-geometry roundabout to avoid the problems caused by the normal conventional roundabouts. The primary goal of this research to find an alternative to a multi-lane roundabout. The entry capacity model suggested was a function of ring width, circulating flow, incoming flow, outgoing flow, width of the central island, and width of the entrance lane. Alfonso Montella et al. (2012) [1], presents a review of the Australian, France, Switzerland and USA roundabout geometric design standards and identified the inconsistency of the Italian standards. It is advocated to have specific guidelines for each type of roundabouts suggested to keep the lane continuity throughout the roundabout by providing consistent number of exit lanes. They have also mentioned that emphasis should be given to entry path radius since it is an imperative parameter to control speed as well as to improve safety. Ana Bastos Silva et al. (2014) [24], explained the operational problem with the conventional roundabouts and the advantages of using turbo roundabouts. There are a lot of safety issues associated with the conventional one due to the improper driving behavior at the entrance portion, circulatory paths, exit zones and to the consequent weaving maneuvers within the island. A Turbo roundabout is a variation or up gradation of conventional one where the drivers are forced to lead a specific or exact path based on the destination. Ahmed I. Z. Mohamed et al. (2020) [2], conducted a study to propose a methodology for calculating the capacity of mega elliptical roundabout. It is a new type of intersection in the form of an elongated ellipse which combines the best functions of a conventional roundabout and the unconventional median U turn. Sasa Ahac et al. (2021) [10], gives the overall idea about the modern roundabouts by comparing the guidelines and norms used in Austria, Croatia, Netherlands, Germany, France, Switzerland, and Serbia. The comparison of these guidelines based on the terrain type is well explained here.

Apart from the above-mentioned research areas, past studies were there related to the application of simulation and optimization techniques using the software packages for the geometric design. Atif Mehmood et al. (2006) [6], conducted a study to optimize the geometric design of roundabouts. It is very clear that the main objective of the roundabout design is to maximize the traffic safety and operational efficiency. And the traditional designing procedure cause variations in the performances significantly even if it is a minor change and eventually the entire design procedure will be tedious and time consuming. This paper gives an optimization model which provides the geometry of roundabout that mainly optimizes operational efficiency and design consistency. Khaled Shaaban et al. (2015) [5], conducted a study to compare the performances of the two simulation tools i.e., SimTraffic and VISSIM in modeling of roundabouts under different scenarios created based on traffic volume, proportion of trucks, proportion of left turning movement, etc. Vincenzo Gallelli (2008) [12], shows that the software VISSIM can give a flexible platform that allows the user to model a roundabout more realistically. They have explained that there are three fundamental features which are very significant to do the simulation for roundabouts. Those are speed, traffic assignment, and priority rules. In addition, driver behavior can also be added. F G Practico et al. (2015) conducted a study which aims to explore the usage of micro simulation along with experimental investigation in order find the relationship between operating speed and geometry of roundabouts. Also, to calibrate the model to ensure the quality that how realistically the results can be produced. Wonho suh et, al (2018) [11], conducted a study to calibrate a simulation model of the roundabout by altering the minimum acceptable gap and other related parameters. They have analyzed different scenarios by changing the input and observed that the minimum gap time has significant impact on the capacity of roundabouts.

The pedestrian safety at the roundabouts is a serious issue since a continuous movement of vehicles is expected most of the time. Researchers explored the gap accepted by the pedestrians while crossing the intersection by considering both behavioral as well as statistical approach. Valeria Vignali et al (2020) [20], conducted a study to suggest measures in order to increase the conspicuity of pedestrian crossing at roundabouts such as zebra crossing in advance of the intersection, installation of median refuge island, and placement of yield here to pedestrian islands. The study results show that the zebra crossing and median refuge island are most recommended countermeasures. Marcus A. Brewer et al (2006) [25], evaluated the pedestrian gap acceptance by taking into account of both behavioral as well as statistical approach. They described that the pedestrians did not wait always to clear the road, instead, they start crossing the road by anticipating the lanes would be clear and this is called rolling gap. The statistical analysis results show that the acceptable gap lies in the range of 5.3 and 9.4 seconds. All the gaps between 1s and 5s are rejected by the road users. Vinod Vasudevan et al (2020) [21], conducted a study to understand the gap acceptance behavior of pedestrians at unsignalized intersections. Different

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composition of pedestrians such multiple, individual, and group are considered for the study and the difference in critical gap has been found out. Also, the distracted pedestrians and not-distracted pedestrians have been taken for the study. Chiara Gruden et al (2022) conducted a study on the comparison of pedestrian behavior In Italy and Slovenia and found that Italian's mean crossing time as 8.27s and Slovenian's mean crossing time as 5.94s. Also, they added that the pedestrian speed of crossing at roundabout is higher than the signalized and other unsignalized intersections. This is probably because of the less comfortable feel experienced by the pedestrians while crossing the roundabouts. Chintaman Bari et al (2022) [22], conducted a study to find the influence of pedestrian for the roundabout design in mixed traffic condition. It is found that the entry capacity will get reduced as the number of pedestrians increased.

III. PROBLEM STATEMENT

The road network in India runs million kilometers with high traffic demand. Intersections are one of the core parts need to be selected and designed in a such way considering the priority, delay, safety, and many more other aspects. Out of all the type of intersections, roundabouts have more advantages depending upon traffic and other criteria. The procedures followed for the design of roundabout as per IRC guidelines have certain limitations that need to be modified. It is very tedious, and some important parameters were not discussed. Since the roundabouts play a key role for the smooth and ordered movement of traffic, the design should be much more appropriate and practical in nature. Therefore, the final output after the design should satisfy all the requirements with minor adjustments. The contribution from the researchers and other guidelines to Indian condition can mitigate those limitations to some extent. Finding what all corrections and modification need to be incorporated in the IRC guidelines from the available resources and innovative approaches is the main motivation behind this study.

IV. SCOPE AND OBJECTIVE

The study is intended to do a detailed review regarding the roundabout design guidelines currently practicing all over the world and innovative approaches towards the same by researchers. In India, IRC:65-2017 is followed to design the roundabouts which has certain limitations, and it reflects many traffic related problems in the realistic condition. This study will be beneficial to incorporate appropriate changes in the current guidelines and bring an adequate working of roundabouts in India.

V. DISCUSSION

The roundabout analysis can be done by mainly three ways i.e., analytical, empirical and simulation models. The analytical models use the concept of gap acceptance theory, also called probability theory while the empirical models are completely relying on field data for the development of geometric design features with the performance measures. Usually, the empirical models are better than analytical ones, but it requires huge amount of data regarding the congested roundabouts for the calibration. And the micro simulation models are based on the car following theory and lane changing behavior. Most of the codes and practices follow the gap acceptance theory which has some complex assumptions mainly regarding the driver behavior. Therefore, it is not possible to get authentic results about the roundabout geometry. Also, now we can see an ever-increasing use of roundabouts to solve most of the traffic issues as demand is high. To solve this problem, it is better to go for micro simulation modeling with the use of software packages which can provide roundabout analysis using different input parameters. This can be mainly divided into two categories i.e., deterministic, and stochastic simulation models. Deterministic models can analyze the roundabout performance by using a couple of equations and correlation can be done by considering some parameters such as queue length, delay, and capacity. Some of the examples are SIDRA, Rodel, Arcady, Kreisel etc. The latter one uses interval-based simulation to describe the traffic operation and the examples are VISSIM, Integration and Corsim.

Micro simulation models have higher scope on the traffic operation analysis of roundabout design. It is possible to analyze the performance of the design using these simulation software and changes can be made accordingly. Most of the software have in built options to set the priority rules, reduced speed zones, routing decisions and a lot more which would be very useful for the micro simulation of roundabouts. Using this, it can finalize the geometrical elements by performing several runs using different parameters and can review the performance by analyzing queue length, delay time, and other indicators. Some of this software's have inbuilt Wiedemann's car following model which considers the physical and psychological aspects of driver. It is very much required to do the calibration to match the field results.

Selection of shape of geometry is one of the prior steps of roundabout design. Other than the conventional geometries, a lot are innovated geometries such as two geometry roundabouts, mega elliptical roundabouts, turbo roundabouts and modern roundabouts are there. These geometries have certain advantages over the normal traditional one we are using. The two geometry roundabouts are introduced to provide equivalent capacity and safety as similar as single lane roundabouts. This kind of roundabouts usually have outer edge is elliptical while the central island is circular which can perform both single and multi-lane benefits. The major advantages of single lane roundabouts are they can give low-speed movements which provide safer crossing, increased capacity, and easier and safer accommodation of pedestrians. But too much traffic volume cannot be taken by this single roundabout. Therefore, conversion of the single lane to a multilane is mandatory in most cases. But the disadvantage of this is, it can create sideswipe collisions due to the increased vehicle path curvature. Therefore, the curvature of the vehicle trajectory followed by the vehicles at intersection arises may hurdles in the case of multi-lane roundabouts. The other problem associated with the multi-lane roundabout is accidents caused due to lane change behavior among the drivers. The two geometry roundabouts have shorter queue lengths, shorter delays, and reasonable traffic jams compared to conventional roundabouts. In addition, it gives high capacity and safer movements

Mega elliptical geometry is another form which has elongated ellipse combines the effective functions of both roundabout and

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unconventional U-turn. This type has mainly three important parts i.e., ellipse roadway, weaving sections, and non-weaving sections. Here, the central island is elongated on the major highway for providing enough length for weaving sections. Also, it has an ellipse element which helps heavy vehicles to make U turn on basic ellipse roadway. The main attraction of ellipse element is which can provide suitable roadway for heavy vehicles.

Now, turbo roundabouts are spread throughout the world as an alternative of multi-lane roundabouts. But the guidelines for the same is not available in IRC:65-2017. These type roundabouts consist of spirals which are composed of segments of circular arcs having larger radius. Here, Central Island is equipped with three or four legs possessing raised lane dividers to lead guided traffic flow by preventing vehicles from the usage of full carriageway and thus reducing the conflict points. A Turbo roundabout is a variation of conventional one where the drivers are forced to follow a specific path based on the destination. For this, the carriageway consists of continuous spiral paths, using curbs to separate the lanes in the entry, circulatory and exit zones. The main intention for the installation of curbs is to eliminate the occurrence of conflict points caused by weaving maneuvers and the reduction of speed due to the increased deflection. The main advantages of the turbo roundabouts over the traditional one is, reduction in the accident points, decrease in the speed across the arrival, round, and departure lanes. Different kind of geometry can be explored in the same way and implement according to the traffic demand and site characteristics.

Many researchers have done the analysis on codes and guidelines of different countries. Research was done to revise the Italian standards by comparing the guidelines of other countries such as Australia, the USA, UK, France, and Switzerland. A detailed study has been carried out by Alfonso Montella et al. [1], and the main conclusions are shown in Table 1. Based on this, the changes can be adopted after reviewing IRC:65-2017 also. In some cases, mini- roundabouts might be a best option according to the traffic and environmental constraints. But IRC:65-2017 does not provide any specific design criteria for the same. The traditional design processes that we are using to design the roundabouts are iterative and time consuming. To avoid this, optimization model can be developed which directly gives the values geometry by considering the design consistence and operational efficiency. Atif Mehammood et al. [6], developed such a model which requires input data of approximate design parameter ranges, expected traffic data and side friction factors. Like that, it is possible to get optimized design values for the existing traffic conditions. Most of the capacity models are the function of ring width, circulating flow, incoming flow, outgoing flow, width of the central reserve island, and width of the entrance lane. Operational efficiency represents average delay in the roundabout and design consistency represents operating speeds for various conflicting paths. The input data required for optimization is expected traffic data at the field, and side friction factors. The design parameters ranges are acquired by the aerial photograph of selected site using GIS software. The expected traffic data can be acquired by the historical trends or transportation modeling which can ensure that the proposed design can satisfy the demand. Through, right, and left are the three primary vehicle paths considering in the design of roundabouts. Therefore, many factors are dependent on the operating speed along the curve followed by the vehicles such as side friction factor, super elevation, the radii of vehicle path and so on. In order to incorporate that, proper modeling of radii of each path has to be done corresponding to the geometric parameters. The minimization of average time delay and the mean difference between conflicting and consecutive speed along separate path taken by the vehicles can be performed by multi objective function. The primary output of the model comprises of radii corresponding to each vehicle path taken. It has been estimated based on the circulatory roadway width, entry widths, and both central and inscribed circle diameter. Along with that, certain other assessment factors such as details regarding queue length, capacity at each approach, average delay occurring at roundabouts in correspondence to the optimum design can be acquired. The significant parameters that affect the pedestrian safety also considered to get the results.

Srinath Mahesh et al. [13] found that the field entry flows in Indian condition is quite higher than the capacity given by HCM equation. The data supporting same is given in Figure 2 [13]. The difference in the capacity values can be explained in two factors. The first one is associated with the traffic heterogeneity present in Indian conditions as compared with the homogeneous existence of vehicles in US. The second one is the difference in driver's behavior present in two countries. In addition, the higher proportion of two wheelers in Indian traffic condition, the drivers observed to accept lower gap as compared to those in US. They have reviewed the critical gap and follow up time of both HCM and field results and found that there is a need to consider a multiplicative adjustment factor which can be used to estimate capacity using HCM equation in the Indian traffic condition. Even though the computed critical gap and follow up time is used in the HCM equations, it is not able to replicate the Indian traffic conditions. Therefore, an adjustment factor needs to be applied to satisfy the results.

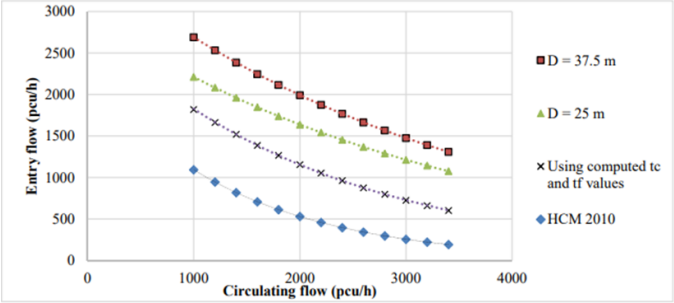

Fig. 2, Comparison of field entry capacity with HCM and adjusted HCM for Indian Condition [13]

And this adjustment factor depends on the circulating flow, central island diameter and the critical gap values. Two ranges of adjustment factors are proposed here, first set is based on the original HCM equation and the second is evaluated by considering the actual figures corresponding to the critical gap and follow up time likely to occur in India's traffic stream. The former one recommends critical gap as 4.5s and follow up time as 2.7s. The latter one suggested that the entry flow at roundabouts in developing countries can be found by calculating the adjustment factor considering a value of 2.2 s as critical gap and 1.2 s as follow up time.

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TABLE I. RECOMMENDED SUGGESTIONS FOR GEOMETRIC DESIGN (SOURCE: ALFONSO MONTELLA ET AL., 2012)

Topic	Recommended suggestions
Standard subject	Specific standard for each type roundabouts
Maximum ICD of mini roundabouts	20 m for flush mini-roundabouts 26 m for domed mini roundabouts
Truck apron	Allowed for roundabouts with ICD > 26 m Apron width = 2.00 – 4.00 m Cross slope = 2% Height= 40 – 100 mm
Splitter islands treatment	Raised with curbs (traversable) for roundabouts with ICD > 20 m
Number of exit lanes	provision of several exit lanes consistent with lane continuity through the roundabout
Deviation angle	≤ 55 m for single-lane roundabouts ≤ 85 m for two-lane roundabouts
Entry width	3.00 – 3.50 for ICD ≤ 26 m 4,00 for ICD > 26 m and 1 lane 7.00 – 8.00 for ICD > 26 m and 2 lanes

Sonu Mathew et al. also investigate the suitability of HCM equations for determining the capacity of roundabouts in Indian traffic conditions. The main limitation of using HCM is mixed traffic condition and lane discipline behavior in Indian conditions. So, it is necessary to estimate the critical gap and follow up time values for different categories of vehicles majorly available in India. In this study they have proposed different PCU values for each category of vehicles for the three major movements in roundabouts i.e., left turn movement, straight movement and right movement using time occupancy method. There are no guidelines in the IRC 65-2017 [15] which considers different PCU values for different turning movements. The values given by Sonu et al. [14], is given in Table 2. For each movement, difference in PCU factors can be seen in the case of big car, LCV, and heavy vehicle. They have suggested a value of 1.60 s for stream critical gap and 1.24 s for follow up time to calculate the capacity of roundabouts in developing countries like India. Also, 1.1 is recommended as an adjustment multiplicative factor to estimate the capacity in mixed traffic conditions.

TABLE II. PCU VALUE ADOPTED FOR DIFFERENT VEHICLE CATEGORIES (SONU ET AL., 2016)

Vehicle category	Left-turn movement	Straight movement	Right-turn movement
Two-wheeler	0.22	0.22	0.22
Three-wheeler	0.67	0.67	0.67
Small car	1	1	1
Big car	1.52	1.58	1.68
LCV	1.75	1.81	1.93
Heavy vehicle	4.04	4.43	4.64

Another main problem associated with Indian traffic condition is aggressive behavior of drivers in a congested network. The automobiles which are small in size constantly try to find headway between the other large vehicles in the roundabouts and move into the circulating traffic. Quantifying this behavior is a complex and challenging task for the researchers since India has heterogeneous traffic conditions. Ashish Kumar Patnaik et al. [18] used INAGA method to find the critical gap and follow up time in order to incorporate actual driver's behavior in mixed traffic condition. And it has been found that the critical gap values for India is nearly half of the values corresponding to the developed countries like USA and European countries. This is mainly due to the high proportion of two wheelers in India as it requires small gap compared to other vehicles. And it is suggested that the circulating path around the central island can be broaden so as to hold more heterogeneous traffic. The overall summary of IRC guidelines limitations and the corresponding approaches to rectify the same is given in Table 3.

TABLE III. IRC LIMITATIONS AND RESPECTIVE APPROACHES RECOMMENDED

IRC 65-2017 limitations	New approaches suggested by researchers
Restrained to the design of single geometry roundabout	• Turbo roundabouts • Two geometry roundabouts • Mega elliptical roundabouts • Modern roundabouts • Mini roundabouts
PCU factors for turning movements are not considered for the design	• Time occupancy method suggested by researchers can be used to find the PCU factors for turning movements.
Driver's behavior is not considered to carry out the design.	• INAGA method can be used to find the critical gap and follow up time to incorporate the driver's behavior and thus find out the multiplicative adjustment factor in order to use the HCM equations in Indian mixed traffic conditions.
Tedious and time-consuming design procedure	• Use of micro simulation software's and optimization techniques can be applied.

As these topics are covered by the researchers vastly, but the incorporation of pedestrian volume on the design of roundabout was not addressed in a detailed way. It is obvious that the entry capacity will get reduced if the pedestrian flow on that location is high. As different classification of vehicles is present, different behavior of pedestrians also can be seen. Vinod Vasudevan et al (2020) [21], concluded that the gap taken by pedestrians to cross the road is different based on several factors. For example, the time taking to cross the road is different for a pedestrian if they are crossing in group. Additionally, age of the pedestrian, whether they are distracted or not, especially abled or not, are they carrying an infant or not etc have an impact on the gap they are selecting to cross. Therefore, the gap accepted by the pedestrians will change based on the location whether there is a school, old age home, or any shopping mall nearby. Therefore, warrants for choosing control measures have to be done by incorporating pedestrian flow on that location too. It is found that the research papers are lack in this area.

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VI. CONCLUSION

Currently, IRC 65-2017 [15] is practicing in India for the design of roundabouts. Researcher's show that the designs of roundabout done by these conventional methods have certain limitations and time consuming too. Therefore, it is better to follow some advanced detailing so that the authenticity of the design can be ensured. The new innovative approaches from research all over the world were analyzed and presented here which is applicable in Indian conditions. From the study, the following suggestions and recommendations were made to carry out the same.

A. Critical Findings

1) In India, the roundabout design is done by using IRC 65-2017 [15] which has certain limitations. It only considers the PCU values based on the vehicle classification which is not enough to take the effect of heterogenous traffic conditions in India.
2) In Indian heterogeneous traffic condition, the driver's behaviour can be considered as a primary design factor for roundabouts. IRC 65-2017 [15] does not consider the effects of the same in the design part.
3) The design of roundabouts as per the IRC guidelines are stick to the basic conventional geometries.
4) In some cases, mini- roundabouts might be a best option according to the traffic and site constraints. But IRC:65-2017 does not provide any specific design criteria for the same.

B. Contributions of the study

The approach from researchers to resolve the limitations to some extent is listed below.

- In India, most of the roundabouts are circular in shape since IRC guidelines is only restrained to that shape which might not be appropriate according to the traffic and site characteristics. It is suggested to use new innovations in the roundabout's geometry using all over the world such as turbo roundabouts, two geometry roundabouts, mega elliptical roundabouts and other modern roundabouts according to the traffic and site characteristics. These geometries have certain advantages over the conventional one providing operational and safety benefits
- It is recommended to use simulation software's to accomplish the functioning of the roundabout design. It is possible to finalize the design of geometrical elements by performing several runs by analyzing the queue length, delay, and other performance indicators. Also, any minor change in the design will affect the performance of the roundabout in a great manner. To avoid this, optimization of geometric design can be done by developing a model so that the problems associated with the conventional method can be eliminated.
- Since the roundabouts are much depend on the turning movements, it is recommended to consider the PCU value respective to each of those movements. To work on the same, the researchers have found PCU values corresponding to each turning movement based on the vehicle classification by conducting time occupancy method.
- The suitability of using HCM has been studied and concluded that an adjustment multiplicative factor should be considered to carry out design in mixed traffic conditions. It is recommended to find the critical gap and follow up time of the study area as the capacity and adjustment multiplicative factor is primarily depends on these factors.
- INAGA method suggested by researchers can be used to determine the critical gap and follow up time considering drivers behavior in order to incorporate the effect as it is vital in a heterogeneous traffic conditions.
- The comparison of guidelines and norms of different countries according to the topographic condition has been studied by the researchers. Those guidelines can be adopted according to the Indian conditions.
- The pedestrian flow and behavior should be taken into account for choosing the control measures at an intersection.

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