Section A-Research Paper
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ASSESSMENT OF ROTARY INTERSECTION AND CAPACITY MODELLING UNDER MIXED TRAFFIC CONDITIONS: A CASE STUDY IN AFGHANISTAN

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Abstract

Intersections are playing an important role in the traffic network. as they are the greatest congested areas, which most of the delay, accidents, oil consumption, and noises occurring in intersections. with a smooth traffic flow can avoid these issues. It is a need to implement the roundabouts in the intersections as will decrease the conflict point. there is no procedure to analyze the capacity of rotary for Afghanistan traffic scenario. The data have been collected from 8 rotaries from different regions of Herat city of Afghanistan, which 5 rotaries used for development and 3 rotaries used for validation of the developed model. For the development of theoretical capacity model, the driver behavior is one of the main components which impact the entry capacity. Critical gap and follow-time are the gap acceptance parameters for driver behavior. One of the most important factor in the capacity modeling of the rotary intersectionis critical gap. Different methods are using for estimation of critical gap namely: Raff graphical method, maximum likelihood method, and Equilibrium of probabilities method. Finally, by utilizing the gap acceptance parameters an equation based on multi-regression analysis have been developed which is computable with site data and other existing capacity models. The model compared with both highway capacity manual (HCM 2010) and Germany capacity model, as the result shows both models underestimate/overestimate the entry capacity of roundabout.
Keywords: Traffic, rotary intersection, Gap acceptance, Capacity

Introduction

Roundabouts can accommodate a significantly greater volume of traffic than a sample intersection, especially due to their one-way circulatory operation. As the conflict points decreasing from 32 to 8 as per geometrical design, as shown in Fig (1). The delay probably maybe less than the signalized intersections.

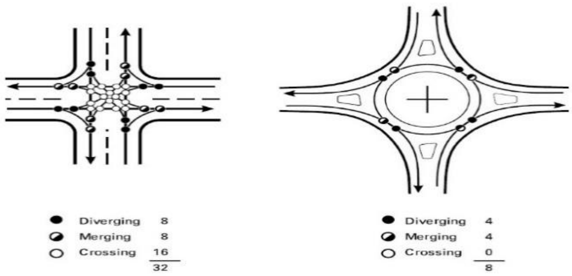

Fig 1. Roundabout versus sample intersection

Most of the studies related to capacity of capacity of roundabout have been conducted in developed countries. The basic methods are including an empirical model based on geometry of the roundabout like diameter, entry width, weaving length, exit width, etc. the Indian (IRC 65-1976)[5] model is an empirical model in the nature which using the Wardrop's equation. U.K method is based on a formula which proposed with transport and road research laboratory (TRRL). According to HCM 2000, the entry and circulating traffic flow showed a negative exponential model while HCM (2010)[6] the analytical model proposed which include the critical gap and follow-up time. NCHRP (572)[7] is a manual guidance for performance and calibrating the capacity of roundabouts in different geometrical aspects. Also, NCHRP (2010)[8] is the last update of that. Which includes the recent trends of rotary intersections worldwide. Like, level of services LOS, delay, driver behavioral gap acceptance parameters.

Basically, for the development of roundabout capacity model, there are two methods i.e., empirical, and theoretical (Gap acceptance). Various studies have been done since 1950 to utilize the behavior of driver characteristics. Raff (1950)[1] was the first to develop the method which used gap acceptance parameters. In this method the probabilities of accepted and rejected gap were used to find essential factors as gap parameters. The driver will decide as accepted or reject the gap in the entry of roundabout. this procedure will estimate the un-predictable behavioral parameters of drivers. because the critical gap is not possible to deduct from the site directly. Various changes were made in these methods offering to more correct estimations like Ashworth system (1969)[2], Maximum likelihood method by Trout beck (1992)[3], and Equilibrium of probabilities strategy by Ning Wu (2012)[4]. Among all these methods, Ning Wu technique is the most recent methodology and it beats the drawbacks of earlier methodologies by contemplating the probability distribution function (PDF) of gap acceptance and rejected gap for estimating critical gap. Since two decades, researchers carried out some related study to identify the capacity of roundabouts in different regions. Weiqi W. and X.Yangb (2012)[9], evaluate the modeling of roundabout weaving gap acceptance at weaving section. With utilizing the regression analysis based on gap acceptance theory new model for the capacity of roundabouts has been developed. Xuanwu C. and Ming S. Lee (2014)[10], verified the amount of queue length has an influence on the entry flow of traffic in roundabouts. Abdullah A. and Rajat R. (2016)[11], developed a regression roundabout capacity model for India. Used some factors i.e., entry flow, circulating flow and geometric elements. as this model shows overestimate which compare with the Malaysian model. Sonu Mathewa, et al., (2017)[12], investigated the highway capacity manual HCM in four-legged roundabouts, estimated a methodology for validation and calibration. The critical gap has been estimated by different methods. A mutilative adjustment factor 1.1 suggested for the use of HCM capacity model. Werner Brilon And R. K., et al. (1999)[13], suggested a different procedure for estimation of the critical gap. Observed two methods are most effective the maximum likelihood and Hewitt's. Harsh J. Amin And Akhilesh Kumar M., (2015)[14] observed different methods of critical gap such as i.e., Raff method, Green shield method, lag method, etc., the result shows except clearing behavior approach all methods describe the actual situation. Mostly, Raff method. Abdul Moqtader Y. et al. (2016)[15], investigated the capacity of a roundabout in mixed-traffic condition. used the TRRL tanner model. Estimate the queue length and PCUs. Abdullah A. and Rajat R. (2016)[16], found a procedure to convert traffic from heterogeneous to homogeneous in roundabouts (PCUs) passenger car unit and attempt to use the static parameters instead of dynamic parameters. According to Andyka Kusuma and Haris N. K., (2011)[17], there is a lognormal distribution among the driver population for critical gap. The maximum is used to estimate the critical gap. The result shows the critical gap depends on the target lane and size of vehicles. And compared with other existed methods. Janusz Chodur (2005)[18], developed a roundabout capacity model based on Poland traffic condition. The critical gap and follow-up time used for this purpose. And calibrating the models for local condition Also the HCM model adapted for the Polish traffic condition. Abdullah Ahmad, Srinath Mahesh, and Rajat Rastogi (2014)[19] overviewed the existing capacity models. and developed an empirical regression capacity model for the roundabouts. which the US model shows a good fit with the field data. Also, a calibration factor estimated to use the US model for Indian traffic condition. Chandrakant Patel and Dr. B.V. Khode (2016)[20] developed a capacity model based on the entry versus circulating flow. The capacity modeling of roundabout from these literatures have been studded suffer some drawbacks: One, the HCM 2010 capacity model evaluated capacity as per homogeneous traffic condition which assumes the critical gap in range of 3.6-4.1 seconds and follow-up time in range of 2.6-3.1 seconds which is not usable in all around the world because of the heterogeneity of traffic conditions. also, the HCM model estimates the capacity of single-lane approach roundabout. Two, there is not enough literature for traffic scenario of Afghanistan.

Objective of study

1. To develop the capacity model for the rotary intersection.
2. To discover the factors influences the capacity of rotary intersections.
3. To study the probable causes of congestion and possible solutions.
4. To meditate about the heterogeneity of traffic conditions at rotary intersection sites.
5. To Approve the developed model and contrasting outcomes and with other existing models.

Data collection and analysis

Data have been collected from eight roundabouts in Herat city of Afghanistan, namely, 29 Hamal, Share-e-Naw, Tanke-e-Markaz, Darb-e-Malik, Darb-e-Khosh, Mostofyat, chawk-e-Farhang, and chawk-e-Golha roundabouts, Table 1. Shows geometric details of selected roundabouts. All the roundabouts were four-legged. The (right-hand traffic condition) performed in this country. As per the shortage of personal videography technique is used to collect the traffic flow data from the sites. The data collected during the peak hours of traffic (8:00 a.m. to 10:00 a.m.) morning and (5:00 p.m. to 7:00 p.m.) evening. The HD camera was used, the camera installed on the tripod in a raised building near to the roundabouts which attend to record the traffic flows of all approachs of roundabouts in one time. For two hours. For the geometric elements of roundabouts, the Total-station have been used. after collecting Civil 3D software have been used to draw the geometry and topography of the roundabouts. The videos collected from the sites played on the screen of the computer, all needed data for the model development have been extracted carefully. For the selection of the roundabout, some criteria defined to choose it for this study.

1. The rotary intersection should un-controlled in case of traffic operation.
2. The rotary intersection is un-signalized.
3. Roundabout is on the ground level; the gradient is not more than the standard level.
4. The roundabout should free from the bus stop.
5. Roundabouts should free from the cross parking of vehicles.

Entry and circulating flows

Intersection is the location which vehicles change the direction, the traffic arriving from different directions of the roundabout is named minor stream, and vehicles circulating on curbed island anti-clockwise in (right-hand driving condition) are called major stream of traffic. These two types of traffic flow are establishment parameters of capacity modeling. These traffic data can be collected in two methods i.e., videography and intelligent traffic system. As mentioned earlier there is a mixed-traffic condition which using many types of vehicles i.e., Light commercial vehicles, buses, Tracks, Auto-Rickshaw, two-wheeler motorcycles, bikes, human-powered scooters, vehicles, and bicycles.

In this research, the IRC 65- 1976. To covert heterogenous traffic to the homogeneous traffic or to change vehicles per hour in PCU per hour. Fig 2. Shows the scatter plot of entry flow versus circulating flow in both, linear and exponential relationship, which the exponential is more correlated as compare to the linear relationship.

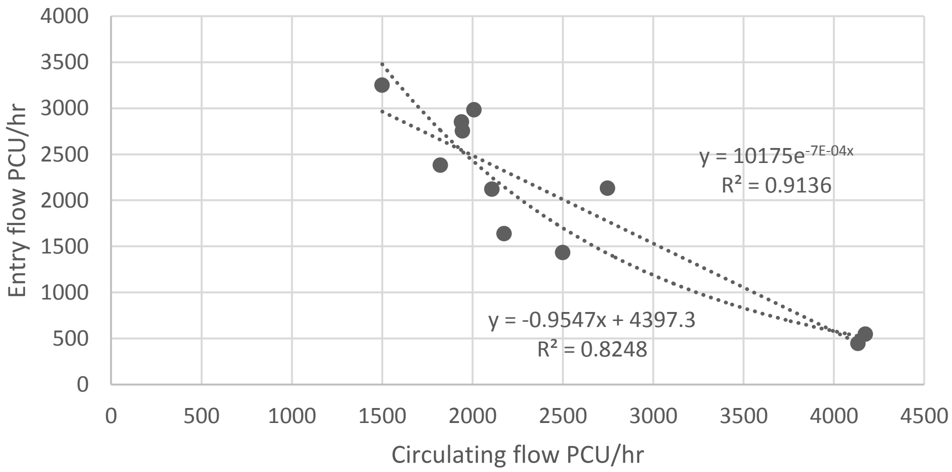

Fig 2. Scatter plot of Entry flow versus circulating flow

Follow-up time estimates

The follow-up time is the arrival of consecutive vehicles in the same gap. The follow-time shows the continues flow of traffic. For estimation of follow-up time, the videos divided into 15 minutes intervals for easy estimation. Procedure for estimation of follow-up time: assume one (Y1) imaginary line in the entry of approaching traffic flow direction as is shown in Fig. 2 And Fig. 3. when the back bumper of the first vehicle passes the imaginary line it is recorded the first-time stamp until the next vehicle comes and touch the imaginary line with the front bumper it is recorded second-time stamp. The difference between these two time stamps is estimated follow-up time.

Table. 1 shows the estimated result of follow-up time for all roundabouts which used for development capacity model. The estimated follow-up time shows in congested intersections lower volume as compared with others. The R1 and R2 located in the corner of the Herat city and traffic amount is fewer, and other three roundabouts located in the center of the city which has more traffic.

Critical Gap at Roundabouts

The minimum time in which a vehicle enters a major stream from minor stream safely and accepts the gap is known as the Critical Gap. The critical gap is not possible to estimate from the site directly. The principle of gap acceptance is applicable when the rejected gap is less than the critical gap and the accepted gap is more than the critical gap.
For estimation of the critical gap, there are many studies has been done as listed below:

1. Maximum likelihood method
2. Graphical of Raff method
3. Equilibrium of Probabilities Method

The procedure of gap estimation, for estimation of a critical gap there should assume two imaginary lines one (Y1) is in the entry of rotary (minor stream) and the second (Y2) is in the conflict of the rotary, as shown in Fig 5. and Fig 6. which the entry and circulating flow conflicted there. To estimate the critical gap two stamp watch has been used, the time which the front bumper of entry vehicles touch the imaginary line Y1 is it records T1 and when the front bumper of major of circulating flow touches the second Y2 imaginary line. Is recorded T2. Critical gap is the difference between the two time stamps. For every record of gap finally will check, is it accepted or rejected by driver.

Fig 3. First-time stamp (sec) **Fig 4.** Second-time stamp (sec)

Table 1. Follow-up time(sec)

Roundabouts	N	S	E	W
R1	4.66	4.42	5.9	4.98
R2	3.82	3.06	3.22	3.94
R3	2.59	3.0	2.6	3.18
R4	1.77	1.53	1.8	2.09
R5	2.27	2.99	2.56	2.5

Estimation of Critical gap (Raff Method)

The data for headways which was extracted from the videos of all approaches have been analyzed to estimate the critical gap using Raff graphical method. The probability of accepted and rejected gaps is calculated and defined for each headway. Then the cumulative probabilities were calculated and the graphs of the accepted gap and rejected gap drawn between those with the cumulative probabilities. Critical gap is estimated from the point of intersection of these two graphs and the amount of rejected probability and the acceptance probability is equal to the one. Fig. 7 shows the cumulative distribution function for the determination of the critical gap. The Table. 2 shows the critical gap of all roundabouts.

Fig 5. First critical gap time stamp (sec)

Fig 6. Second critical gap time stamp (sec)

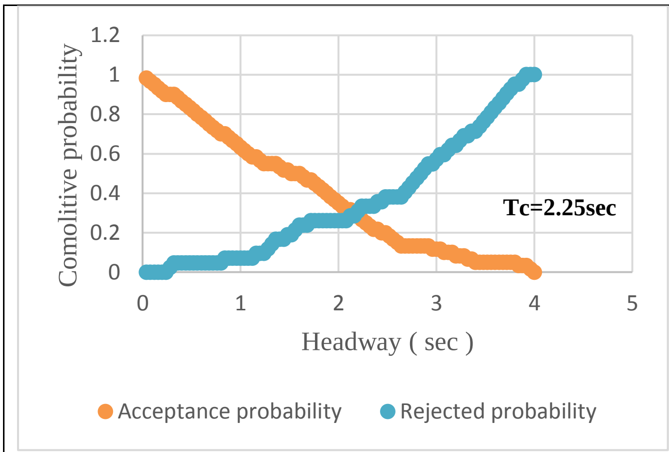

Fig 7. Plot of CDF's for estimation of critical gap

Roundabouts	N	S	E	W
R1	1.8	1.8	2.2	2.3
R2	2.1	1.9	1.6	1.8
R3	1.9	1.8	2	2.1
R4	2.3	1.7	0	2
R5	2.1	1.7	2	1.9

Table 2. Critical gap all approaches (sec)

Traffic composition Vehicles are classified as inclusive small motorized and non-motorized like bicycles, motorcycles Auto-rickshaws, passenger cars. And large vehicles like Bus, Track, LCV, light commercial vehicles. As observed in all the sites the amount of two-wheeler, passenger cars and Auto-rickshaws are more than other types of vehicles. The fig. 8 shows the entry number of vehicles in all roundabouts.

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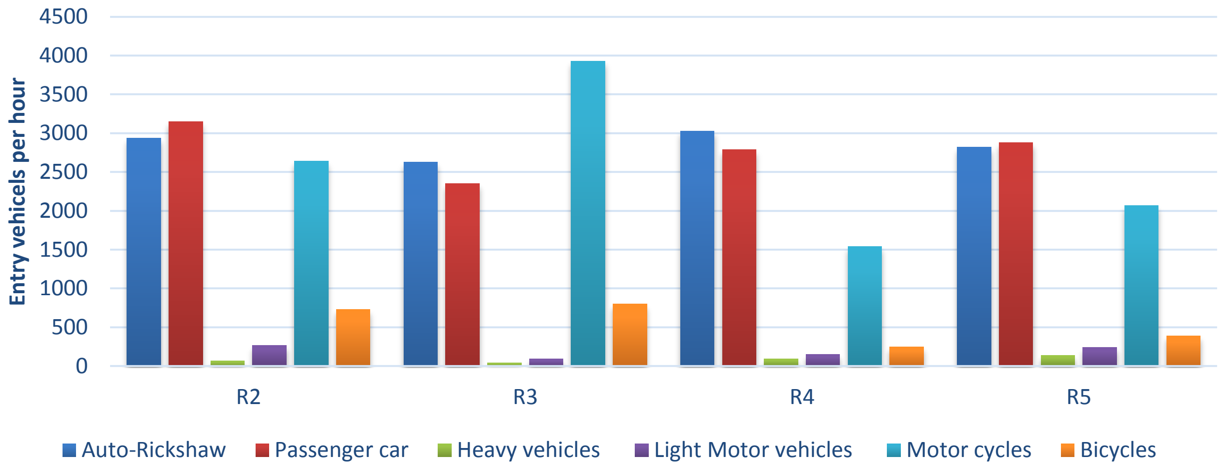

Fig 8. Entry vehicles per hour in all roundabout

Development of capacity model

In the recent past, lots of models for estimation of capacity for roundabouts have been developed by researcher in order the evaluate the functionality of roundabouts. The maximum number of vehicles which can enter the roundabout in the specific time period is known as the capacity of a roundabout. A correlation between dependent and independent variables is necessary before the development of a capacity model. Correlation is a statistical analysis which shows whether and how strongly the paired variables (dependent and independent) variables are related. After using the scatter plot for every approach of the roundabout for entry and circulating traffic, it shows for a negative exponential correlation of 0.91. with the use of these parameters as gap acceptance i.e., follow up time, critical gap, multi-linear regression used to develop the model as Shown in equation (1). The result shows which variables strongly fitted, as the R square of 0.901 and multiple R of 0.949. and it's good to be noted, the signs of the developed model are logical, which with the increase is circulating flow the entry capacity will decrease, also same for the critical gap and follow-up time these parameters have logical signs, by increases in both the capacity will decreases.

The equation has been developed for entry capacity of rotary intersection which using the parameters of gap acceptance i.e., critical gap, follow-up time, and the circulating flow of traffic. This model developed with investigation and collection of excessive data of five rotary intersections in Herat city of Afghanistan. Two methods are used for validation 1.Internal 2. External. To validate the developed equation as this equation has four parameters. We should check that whenever the developed equation can explain the traffic scenario of other rotary intersection or not. To achieve this theory, the predicted output data of the developed model should plot in scatter versus the observed data of the site which collected from the sites. After the plot of these two, if the plat equation stays in the middle we can decide that the developed equation is correct and win-win. And if the plot whether goes down and goes higher up that fails by overestimating and underestimate the site data. For external validation of the developed model, three roundabouts selected which not used for the development of the capacity model, namely, Mostofyat, Chawk-e-Farhang, and Chawk-e-Golha roundabouts. some statistical analysis has been done like i.e., percentage of error, RMSE root mean square error, and MAPE mean absolute percentage error. The result shows the maximum percentage error about 12% between developed model and field data, the RMSE is 242 and the MAPE is 8.5 which these parameters show the model is suitable to use in Afghanistan traffic scenario.

Qe= 7130-0.97Qc-1223Tc-135Tf (1)

Qe= Entry capacity PUC/hr

Qc= Circulating flow PCU/hr

Tc= Critical gap (sec)

Tf= Follow-up time (sec)

Table 3. Summary output

Regression Statistics	
Multiple R	0.949
R Square	0.901
Adjusted R Square	0.858
Standard Error	355.381
Observations	25

Table 4. Multi-regression result

Model variables	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	7129.311	1227.549	5.807	0.0006	4226.617	10032.005
Qc	-0.965	0.125	-7.681	0.0001	-1.263	0.668
Tc	-1222.929	539.864	-2.265	0.057	-2499.504	53.646
Tf	-135.048	142.242	-0.949	0.374	-471.398	201.301

Table 5. ANOVA

	df	SS	MS	F	Significance F
Regression	3	8067934.842	2689312	21.293	0.00067
Residual	7	884069.339	126295.6		
Total	10	8952004.182			

Validation of the Model

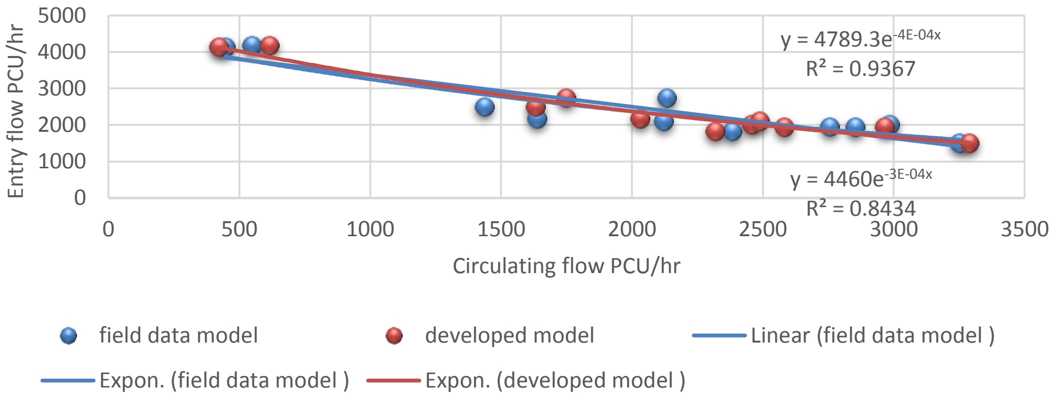

Fig 9. Field traffic data versus developed model data

Comparison of the Model

Comparison of the models giving two output one is the honesty of the developed model and second to shows a variety of data. As observed from the literature of the topic there are many models for

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entry capacity of a rotary intersection the most famous models are HCM highway capacity manual and German model. In this comparison tend to compare the developed model with these two models. Table 7. Shows all statistical result related to the compression of models.

Table 7. Comparison of models

Methods ⟹	*Developed model*	*German model*	*HCM model*
R^2	0.901	0.6	0.48
RMSE	242	480	1146
% error	12	22	37
MAPE	8.6	84	40.5

It's observed that the developed model has identical produce. As the high correlation range 0.901. and the error of 12%, less value of mean Absolut percentage error of 8.6 and root mean square error of 242 which shows reasonable. The Germany capacity model has been compared with the field data, which shows a better fit as compared with the highway capacity manual (HCM).

Conclusions

1. The behavior of the driver is different from nation to nation, with changes in traffic composition like, two-wheeler three-wheeler has a small dimension and the estimated critical gap is less as compared with other motorized vehicles.
2. The critical gap estimated with Raff method. As shows a good fit with Afghanistan traffic scenario.
3. From the study of traffic observed that the relationship of entry and circulating exponentially negative which show the entry of approach leg of roundabout decrease with an increase in the circulating traffic flow.
4. This research is the first instance study in Afghanistan which can be helpful for further study in this country.
5. For validation, the developed model has a good fit with site data, as the root mean square error RMSE is 242 and the mean absolute percentage error MAPE is 8.5, and the maximum average percentage error is 12%.
6. The comparative study shows the developed model with the existing model which the German model overestimates and HCM capacity model underestimate the capacity of the roundabout.
7. The highway capacity model (HCM) is developed for one-based approach roundabouts and homogenous traffic condition which is not useable in the traffic condition of Afghanistan.
8. The Germany capacity model has a better fit with field data, as in the Germany model can be used for multi-line approach roundabouts.
9. The critical gap estimated with Raff method in the range of 1.5-3 seconds, which is less than the purposed HCM model, because of abounding use of two-wheeler and Auto-Rickshaws.

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