Development a capacity model for Al-Turkmani roundabout

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Abstract. In this research, the main aim of this paper is to develop a statistical model for the total capacity of the roundabout as a function of influence traffic features and driver factors. The variables remain predicted to simulate the characteristics of the traffic that have most influence the capacity of the roundabout; classified as traffic conditions such as critical headway, follow-up headway, and driver behavior are involved in the building of the model by using SPSS statistical program. 30 samples have been taken, each sample representing an average of 15 readings for 15 minutes, equivalent to 450 readings for each of Critical Time Headway, follow up headway for each lane (Right, middle, Left) and Driver Factor for model one, for model 2 only Follow up time headway for the Middle lane and Driver Factor have been used. All tests for checking outliers, normality and correlation between independent variables with each other have been used for both models. Model 2 is the most significant with $R^2 = 91\%$. Validation of Observed and Theoretical Capacity is strongly liner with a Correlation coefficient $=0.938$, the statistical model proves that the Follow-up headway time and driver factor have been influenced effect on the total capacity of the roundabout.

1. Definition of the problem

The traffic congestion in the roundabouts has become a big problem especially in the peak hours in the morning and evening due to the obvious growth in the composition of vehicles, the lack of adherence to regulations and traffic laws. It will be difficult to get regular traffic flows, which is why traffic police need to intervene to regulate traffic and turn the roundabout into a signalized intersection, other elements affecting the roundabout capacity such as ineffective engineering design and consequences of bad development and lack of proper attention by the government to plan appropriate transport to solve congestion problems. Roundabout capacity is modeling to predict the capacity in different traffic conditions.

2. Introduction

In the development of the roundabout capacity model, the studies showed that the traffic condition (critical headway, follow up time headway) has been a significant effect on the total capacity of the intersection [1]. Figures 1 and 2 shown relation of critical gap and follow-up time with capacity.
Follow up time, was not emphasized much in previous studies. [2] concluded that when decreasing circulating traffic, the follow-up time was reduced. [3] mentioned that the follow-up time varies according to the type of vehicle that enters the intersection sequentially. It is only these two researchers who studied this effect the contributing factors of follow up-time. Actually, according to the Highway Capacity Manual [4], The effect of changes in the follow-up time higher than of the critical gap on roundabout capacities, particularly during especially in the absence of crowds (light traffic conditions). Therefore, it became clear the importance of studying and analyze the variability of follow up time and the factors affecting it, this effect reflects an inverse relationship between the value of the capacity obtained at different conditions to accept the gap, rate of gap acceptance vary according to several factors affecting driver behavior at the intersection, such as age, male or female, the familiarity of the driver for the roundabout intersection. Drivers of large ages need a larger gap when entering the intersection, which produces a negative impact on the capacity. In the case of an aggressive driver, the effect can be positive or negative depending on the periods (peak or nonpeak hours); for peak hours the effect is negative because of high traffic volumes, shown in Figure 3, while in the case of nonpeak the effect is positive and increased the roundabout capacity [5]. The driver often changes lane during the entry of the intersection in peak periods, changes in the direction of the movement during the entry to the roundabout can be reflected in the model in terms of the number of cases within a specified time.

3. Methodology and data collection
This Section describes the methodology of data collection and the procedures for analysis of the necessary data. A local roundabout was selected in Baghdad city (Al-Turkmani Roundabout). Many factors were considered in the roundabouts selection process (location, traffic volume, geometry, and other effects).

3.1. Al Turkmani roundabout
Is one of the greatest significant Roundabout in the city of Baghdad, due to its imperative position connected to Palestine arterial Street, which is a significant link between the areas of east Baghdad, the densely populated through the Palestinian street in the direction of the Bab Al-Moatham central station, which includes important government centers, the educational institutes (Al-Mustansiriya University), and many
commercial markets. This intersection has four entrances and exits, and the traffic density is high throughout official working hours, Plate 1 shows Al-Turkmani roundabout.

Plate 1. Al Turkmani roundabout.

3.2. Geometric design characteristics
The components of Geometric Design Involve of e.g., (no. of lanes/approach, lane designation, a width of the lane, the radius of entry, a diameter of the island and width of circulating), Figure 4 presented illustration of Elements Al-Turkmani Roundabout of a drawn with AutoCAD software.

Figure 4. Geometric elements for Al-Turkmani roundabout.

3.3. Peak hour time determination
The processes were conducted: field surveys, personal prosecutions, and interviews with traffic cop and drivers to obtain the data of traffic in the Al-Turkmani Roundabout in the time of crowded period (saturation flow conditions at rush hour). Through field observation. The peak hour traffic volumes were founded in the period range morning from (7:30-8:30 am) and afternoon from (1:00-2:00 pm).
4. Method of Data Collection
Traffic data at the intersection was recorded using AHD video cameras installed on the front of buildings opposite the intersection as shown in Plate 2. recording data on 12 mm videotapes and storing files within the hard drives in the camera's recording unit, the benefit of data collection in this way is the possibility of accessing and retrieving the data at any time, acting as a record to re-evaluate the results, in addition to reducing the human errors that result from the data collection manually.

The data collection equipment consists of:
1) Two video recording cameras (Aswar12-mm).
2) Hard Data storage unit (4*500 GB).

4.1. Traffic volume data
The videos taken by the cameras placed around the intersection area will be analyzed and the number of vehicles will be calculated in each entrance and exit. Then the traffic volume data (pcu) will be analysed in SIDRA Ver.8 Software to obtain the capacity of a roundabout. Subsequently, conversion factors have been used to convert the traffic volumes for various types of vehicles into PCU equivalents [6]. Table 1 shows the conversion factors.

| Class of vehicle                        | Flat Terrain |
|----------------------------------------|--------------|
| Motorcycle                             | 0.5          |
| Private car and taxi                   | 1.0          |
| Pick-up , van, and bus up to 24 passengers | 1.25        |
| Truck and trailer combination          | 2.0          |
| Heavy vehicle                          | 3.0          |

4.2. Follow-up headway
The minimum headway between two vehicles enters the intersection sequentially is define Follow-up headway. It is can be calculated by the average of the elapsed time for the two entering vehicles crossing the same mainstream headway under a crowded condition. The follow-up time for each lane was calculated during the morning peak hours from 7:30 am to 8:30 am and the evening peak from 1:00 pm to 2:00 pm.
4.3. Critical headway
Critical headway defined as "the minimum headway an entry driver will find acceptable" [7]. Therefore, the method used to calculate the Critical headway. It can be assessed by the entire approach, the total of internal lanes and lanes in the opposite direction for singular conflicting enter streams.

4.4. Driver behavior
The behavior of the driver is one of the most important factors affecting the traffic on roads and intersections in general and considered as one of the congestion caused in the streets of the capital cities. One of the most important behaviors of the driver is the change lane during the entry of the roundabout. This behavior leads to delay of vehicles in the backward and caused a negative impact on the capacity of the roundabout, these effects have depicted and analyzed using the follow-up time. Observation of field data through recording 30 average for 150 reading, 15 for every 15 minutes of sample size has been statistically analyzed and used to compare the total change in capacity with normal cases.

4.5. Linear regression
Linear regression is the most used method for data analysis and designs the models, practically, all regression methods checked how the linear regression works were implementing. As with most statistical analyses. Sometimes, there are dependent variables such as (Follow-up Time, Critical Headway, Driver Factor) and independent variable (Capacity) that can be found through a theory based on predictor's changes. The objective of the regression is to make the data collected more clear, brief and useful.

5. Checking for outliers
Outliers with significant observations have been checked by using Chauvenet's criterion [8] to test the outliers for applied data to confirm correctness. Table 2 output for this test. All results have been clearly below tabulated value, consequently, outlier not found. Also, the dependent variables for two models remained checked for outliers and over not any outlier can be observed.

| Model | Variable       | N  | Minimum | Maximum | Mean   | Std. Deviation | |Xmin-x'|/std  | Xmax-x'|/std |
|-------|----------------|----|---------|---------|--------|----------------|---------|---------|---------|
| 1     | Capacity       | 30 | 2610    | 5175    | 4029.4 | 661.36         | 2.146   | 1.732   |
|       | Critical Gap   | 30 | 2.6     | 4.3     | 3.20   | 0.48           | 1.257   | 2.265   |
|       | Follow Up      | 30 | 2.29    | 3.78    | 3.08   | 0.36           | 2.180   | 1.912   |
|       | Right Lane     | 30 | 2.34    | 3.98    | 2.98   | 0.44           | 1.444   | 2.223   |
|       | Follow Up      | 30 | 2.48    | 5       | 3.51   | 0.63           | 1.620   | 2.343   |
|       | Left Lane      | 30 | 0       | 12      | 4.26   | 3.45           | 1.235   | 2.239   |

(|Xmin-x'|/std) tabulated for the total number of observations equal to 30 is= 2.394 using the Table of Chauvenet's criterion values [8]. Since all calculated values in Table 2 above is less than the tabulated value (2.394), so there are no data point will be deleted (no outliers).
6. Normality test
Kolmogorov-Smirnov (or K-S test) can be hired to check the variables possess normally distributed. [9] state that the K-S Statistics D is made upon the maximum distance among $F(y)$ and $F_n(y)$, that is:

$$D = \text{Max} \ | F(y) - F_n(y) |$$

$F(y)$ = Normal of a cumulative probability. (From normal distribution table).

$F_n(y)$ = Sample of a cumulative distribution function.

Table 3. D-value and K-S test results for model 1.

| Kolmogorov-Smirnov Test | K-S Test, Lilliefors Probabilities |
|-------------------------|-----------------------------------|
| (Mean & standard deviation known) | (Mean & std.dev. estimated from data) |
| N  | max | D   | P     | Sig | N  | max | D   | p    | Sig |
|----|-----|-----|-------|-----|----|-----|-----|------|-----|
| Capacity | 30 | 0.161 | p < .05 | 0.016 | Capacity | 30 | 0.161 | p < .05 | 0.042 |
| Critical Gap | 30 | 0.199 | p < .05 | 0.004 | Critical Gap | 30 | 0.199 | p < .05 | 0.001 |
| Follow-up Right | 30 | 0.060 | p > .05 | 0.200 | Follow-up Right | 30 | 0.060 | p > .05 | 0.996 |
| Follow-up Throw | 30 | 0.211 | p < .01 | 0.011 | Follow-up Throw | 30 | 0.211 | p < .05 | 0.000 |
| Follow-up Left | 30 | 0.184 | p < .05 | 0.017 | Follow-up Left | 30 | 0.184 | p < .05 | 0.017 |
| Driver Factor | 30 | 0.276 | p < .05 | 0.000 | Driver Factor | 30 | 0.276 | p < .05 | 0.002 |

7. Multicollinearity
Multicollinearity (collinearity & intercorrelation) defines as a process using statistical methods to discover a relationship between independent variables with one another. The multicollinearity has an opposing effect is the regression coefficients that have been estimated a tendency to have a lot of the number of variabilities, [10] SPSS23 statistical analytical program is employed to develop the capacity models for the roundabout. A confidence level of 95%, (a significant level of 0.05) is applied. The inter-correlation analysis has been based, the independent variables have been removed one after another according to its significance. The process has been repeated until a significant predictor variable remained at that point of the interactions among the variables. The process has been repeated until a significant predictor variable remained at that point of the interactions among the variables. The choice of add or remove a variable is based upon that variable improves the model or not. Table 4 show the A binary variable relationship coefficients are detected to recognize the important form the connection within the dependent variable, critical gap, follow-up time (right lane, throw lane, left lane), driver factor and independent variable (capacity).
Table 4. Correlation coefficient matrix.

|                  | Capacity | Critical Gap | Follow-up Right | Follow-up Throw | Follow-up Left | Driver Factor |
|------------------|----------|--------------|-----------------|-----------------|----------------|---------------|
| Capacity         | 1        | -0.804       | -0.647          | -0.723          | -0.623         | -0.745        |
| Critical Gap     | -0.804   | 1            | 0.550           | 0.762           | 0.619          | 0.782         |
| Follow-up Right  | -0.647   | 0.550        | 1               | 0.763           | 0.709          | 0.561         |
| Follow-up Throw  | -0.723   | 0.762        | 0.763           | 1               | 0.792          | 0.720         |
| Follow-up Left   | -0.623   | 0.619        | 0.709           | 0.792           | 1              | 0.496         |
| Driver Factor    | -0.745   | 0.782        | 0.561           | 0.720           | 0.496          | 1             |

8. Multiple model of regression

With the 95% confidence level model, multiple regression was made to improve the model, as shown in the steps below:

1. Multiple equations contain five variables critical Gap, Follow-up headway (Right lane, Middle lane, left lane), Driver behavior, give R =0.956 and R² = 0.913 from the value of R² it is clear that the independent variables explain about 90.13 of the variance in capacity is significant presented in Table 5 below.

Table 5. Model 1 summary.

| Model | R   | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|-----|----------|-------------------|----------------------------|
| 1     | 0.956a | 0.913   | 0.895             | 213.92511                  |

The output results of ANOVA for variance analysis test are presented in Table (6).

Table 6. Results of ANOVA for model 1.

| Model          | Sum of Squares | df | Mean Square   | F    | Sig. |
|----------------|----------------|----|---------------|------|------|
| 1 Regression   | 11586550.30    | 5  | 2317310.061   | 50.636 | .000b|
| Residual       | 1098334.895    | 24 | 45763.954     |      |      |
| Total          | 12684885.20    | 29 |                |      |      |

The driver's behavior in Table 7 is the most significant variable with a level of significance 0.00 while the rest of the variables do not affect the regression equation because the significance level of these variables is more than 5%, this step is analyzed by the Enter method, without deleting the outliers. Figure 5 and 6 shown Normal P-P Plot, histogram and Scatter plot for Model 1, respectively.
Table 7. Coefficients for model 1.

| Model             | Unstandardized Coefficients | Standardized Coefficients | Correlations |
|-------------------|-----------------------------|---------------------------|--------------|
| (Constant)        | B 6075.230                  | Std. Error 494.699        | Beta -0.046  |
|                   |                             | t -0.415                 | Sig. 0.682   |
| Critical Gap      | -63.284                     | 152.514                  | -0.047       |
| Follow-up Right   | -49.583                     | 177.830                  | -0.027       |
| Follow-up Throw   | -281.673                    | 205.671                  | -0.190       |
| Follow-up Left    | -77.558                     | 110.134                  | -0.075       |
| Driver Factor     | -135.158                    | 20.143                   | -0.706       |

The regression equation of roundabout capacity will be:

\[ Y = 6075.23 - 135.158X_1 - 281.673X_2 - 63.284X_3 - 49.583X_4 - 77.558X_5 \]  

Where;

Y = Capacity (veh/hr).

Figure 5. Normal P-P plot and histogram for model 1.

Figure 6. Scatter plot for model 1.
\( X_1 \) = Driver factor.
\( X_2 \) = Follow-up headway (Middle lane) (sec).
\( X_3 \) = Critical Gap (sec).
\( X_4 \) = Follow-up headway (Right lane) (sec).
\( X_5 \) = Follow-up headway (Left lane) (sec).

2- The most influential variables will be dealt with to obtain a significant model reflecting the capacity. The most significant variables (follow-up headway, driver factor). Where the correlation coefficients among the variables and capacity are shown in Table 8, the ratio of the capacity correlation to the driver factor \( 93\% \), and the follow-up equals \( 81\% \).

| Table 8. Correlation for model 2. |
|----------------------------------|
|                                  |
| Pearson Correlation              |
| Capacity                         |
| Follow up headway                |
| Driver. Factor                   |
|                                  |
| Sig. (1-tailed)                  |
| Capacity                         |
| Follow up headway                |
| Driver. Factor                   |
| N                                |

The correlation coefficient for model 2 presented in Table 9, \( R \) is 95.4% and \( R^2 \) equal to 91%. The independent variables account for 91% variances in capacity, which are significant.

| Table 9. Model 2 summary. |
|----------------------------|
|                            |
| Model                      |
| R                          |
| R^2 Square                 |
| Adjusted R^2 Square        |
| Std. Error of the Estimate |
| R Square Change            |
| F Change                   |
| Sig. F Change              |

The value of \( F \) is equal to 136.09 with a level of significant 0.00, less than 5%, which indicated the rejection of the zero hypothesis and accept the alternative hypothesis, which is that the regression is significant and not equal to zero, and therefore a relationship between the variables constant and capacity exists.

| Table 10. Results of ANOVA for model 2. |
|----------------------------------------|
| Model                                  |
| Sum of Squares                         |
| df                                      |
| Mean Square                            |
| F                                        |
| Sig.                                    |

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Through the Coefficients Table 11 below, the driver's behavior is significant in Step 1 and Step 2, which is related to a linear inverse relationship, with a level of significant 0.00 and also follow-up headway, it is an effective variable in capacity model with a significance of 0.01. Figure 7 and 8 show the Normal P-P Plot, Histogram and Scatter plot for Model 2 respectively.

**Table 11. Coefficients for model 2.**

| Model    | Unstandardized Coefficients | Standardized Coefficients | 95.0% Confidence Interval for B |
|----------|-----------------------------|---------------------------|---------------------------------|
|          | B                           | Std. Error                | Beta                            | t     | Sig.  | Lower Bound | Upper Bound |
| I (Constant) | 5928.218 324.594             |                           |                                 | 18.263 | .000 | 5262.207    | 6594.230    |
| Follow up headway | -439.617 123.216            | -2.97                     | -3.568                          | .001  | -692.436 | -186.799    |
| Driver. Factor | -137.372 15.951             | -.717                     | -8.612                          | .000  | -170.101 | -104.643    |

The equation of capacity will be:

\[ Y = 5928.218 - 439.617X_1 - 137.372X_2 \]  
(3)

Where;

\( Y \) = Capacity (veh/hr).
\( X_1 \) = Follow-up headway (Middle Lane) (sec.)
\( X_2 \) = Driver factor.

**Figure 7.** Normal P-P plot and histogram for model 2.

**Figure 8.** Scatter plot for model 2.
9. Model validation

The validation procedure approved for examining if the predicted model is suitable for the specified situations then for the specified assignment; the predicted model has been associated with calculations or field data [11]. The purpose of the validation process to evaluate the sufficiency of the proposed predicted models and find the sufficiency or not of the prediction for validation time. Additional filed data for Follow-up headway and Driver factor were collected for the validation process. The data was input in equation (2) and a comparison between the observed capacity and theoretical capacity is shown in Figure 9.

![Figure 9. Observed and theoretical capacity for validation of model 2.](image)

10. T-Test

A T-Test has been conducted between the predicted capacity model and theoretical capacity values to check if there is an important difference between the mean of the values. Output indicates null hypothesis could not be rejected. In other words, there is no important difference among the mean of the observed capacity and theoretical capacity at a 95% confidence level. And results are expressed in Table 12 and Table 13.

|                          | N    | Minimum | Maximum | Mean   | Std. Deviation |
|--------------------------|------|---------|---------|--------|----------------|
| Theoretical Capacity     | 30   | 2610.000| 5175.000| 4029.40000| 661.369666     |
| observed capacity        | 30   | 2893.870| 4772.025| 4060.32231| 595.064874     |
| Valid N (listwise)       | 30   |         |         |        |                |

The null hypothesis (H0)

H0: $\mu_1 = \mu_2$ (There is no difference)

HA: $\mu_1 \neq \mu_2$
11. Conclusions

The following concluding remark can be recorded:

1. The most influential factors that effect on capacity are follow-up headway and driver factor in model 2.
2. Research has proved the significant effect of the follow-up time on the capacities of the roundabout more than the critical gap, according to the Highway Capacity Manual (HCM) models (TRS 2000; 2010),
3. The correlation coefficient for model R is 95.4%and R^2 equal to 91%. The independent variables account for 91% variances in capacity, which are significant.
4. Observed and Theoretical Capacity for Validation of Model 2 is strongly liner with R = 0.938.
5. T-Test results indicate the null hypothesis could not be rejected. In other words, there is no significant difference among the mean of observed capacity and theoretical capacity at 95% confidence level.

12. References

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[11] TRB, Transportation Research Board 2005. Highway Capacity Manual. (Washington D.C.)

Table 13. Paired samples test.

| Pair | Theoretical Capacity - observed capacity | Mean | Std. Deviation | Mean | Lower | Upper | t  | df | Sig. (2-tailed) |
|------|------------------------------------------|------|----------------|------|-------|-------|----|----|----------------|
| 1    | -30.922                                  | 170.690 | 31.163           | -94.65 | -3.1 | -3.8 | .992 | 29 | .329           |