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DEVELOPING AND VALIDATING REGRESSION MODELS TO PREDICT OPERATING SPEEDS FOR ROUNDABOUTS IN ABU DHABI, UNITED ARAB EMIRATES

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Abstract: Given the popularity of multi-lane roundabouts in the United Arab Emirates, it is necessary to develop models to predict the potential operating speed at a roundabout during its design stage to ensure that the expected operating speed and capacity of that roundabout will meet the design expectations. In this paper, regression models were developed to predict the 85th percentile operating speeds at multi-lane roundabouts in Abu Dhabi, the capital city of the United Arab Emirates. Three models were developed to predict the entering, circulating, and exiting speeds, respectively. The speeds are predicted based on hourly traffic volumes as well as the geometric characteristics of the roundabouts. The developed models were validated by using data not used in calibration, and the models were found to be stable and robust. Based on the observations collected in this research, it was found that the operating speeds at most roundabouts in Abu Dhabi exceed those suggested by design guides, which might be attributed to the large radii used when designing roundabouts in Abu Dhabi.

1 Introduction

Roundabouts are very common in the United Arab Emirates with more than 460 roundabouts located in Abu Dhabi – its capital city. An important function of a roundabout is to increase safety by reducing operating speeds (NCHRP 2010, NCHRP 2007, Flannery 2001). Therefore, predicting the potential operating speed at a roundabout, during its design stage, is vital to ensure that the expected operating speed will meet the design expectations of the given roundabout. Furthermore, the capacity of a roundabout is highly correlated with the entry gaps and vehicle spacing selected by drivers. Those attributes are both related to the operating speed of the given roundabout (NCHRP 2010, TRB 2010). Therefore, predicting the operating speed of a roundabout may also help in estimating the potential capacity of that roundabout and ensure that the capacity meets the design requirements and the expected traffic volume. Finally, precise prediction of operating speeds is also needed for different traffic simulation applications.

A speed prediction model for roundabouts in the United States was developed based on the assumption that the operating speed at any segment of the roundabout is correlated with the radius of the vehicle path at that segment (AASHTO 2011, NCHRP 2010). This approach is similar to an earlier speed prediction model for Australian roundabouts (Arndt, 1994). Džambas et al. (2016) found similar correlation between vehicle speeds at turbo roundabouts and the radius of vehicle path. Another approach for speed prediction models was developed for Italian roundabouts (Bassani and Sacchi 2011) where the predicted operating speed was assumed to be based on the diameter of the inscribed angle, the width of the circulatory roadway, and the width of the entry lane. Pilko et al. (2014) measured operating speeds at four single-lane roundabouts in the City of Zagreb, the capital city of Croatia, where they found correlation between entry speed and entry radius. Similar correlations were also observed between circulating speed and circulating radius and between exit speed and exit radius.

This paper contributes to the growing literature related to predicting operating speeds at roundabouts by developing regression models to predict the operating speeds at multi-lane roundabouts in the city of Abu Dhabi, the capital city of the United Arab Emirates. The developed regression models estimate the operating speeds at Abu Dhabi roundabouts based on the traffic hourly volumes and the geometric characteristics of the roundabouts. Radar guns were used to measure speeds of all vehicles, with different paths, at 12 multi-lane roundabouts in Abu Dhabi. Hourly traffic volumes and the geometric characteristics related to those roundabouts were all obtained from Abu Dhabi Department of Municipal Affairs and Transport. The following section provides details on data collection, followed by another section that provides details on how the developed models were calibrated and validated. Conclusions and recommendations for future research are also provided.

2 Data Collection

The 85^{th} percentile operating speeds of individual vehicles at 12 roundabouts were measured using Bushnell Velocity speed guns (Bushnell 2018), which are capable of measuring vehicle speeds from 16 km/h to 322 km/h at a range up to 457 m. All the roundabouts in the sample had flat grades (less than 2%) and three entry/circulatory/exit lanes. Those characteristics represent most roundabouts in Abu Dhabi and its surrounding suburban areas. For every possible vehicle path within the roundabout (turning right, turning left, going through, or making a U-turn), speeds were typically measured at the following three points as illustrated in Figure 1:

(a) The entering speed along the entry path arc, with the radius of the vehicle path is mainly determined by the entry radius R_1;

(b) The circulating speed around the central island, with the radius of the vehicle path is mainly determined by the radius of the central island, R_2; and

(c) The exiting speed along the exit path arc, with the radius of the vehicle path is mainly determined by the exit radius R_3.

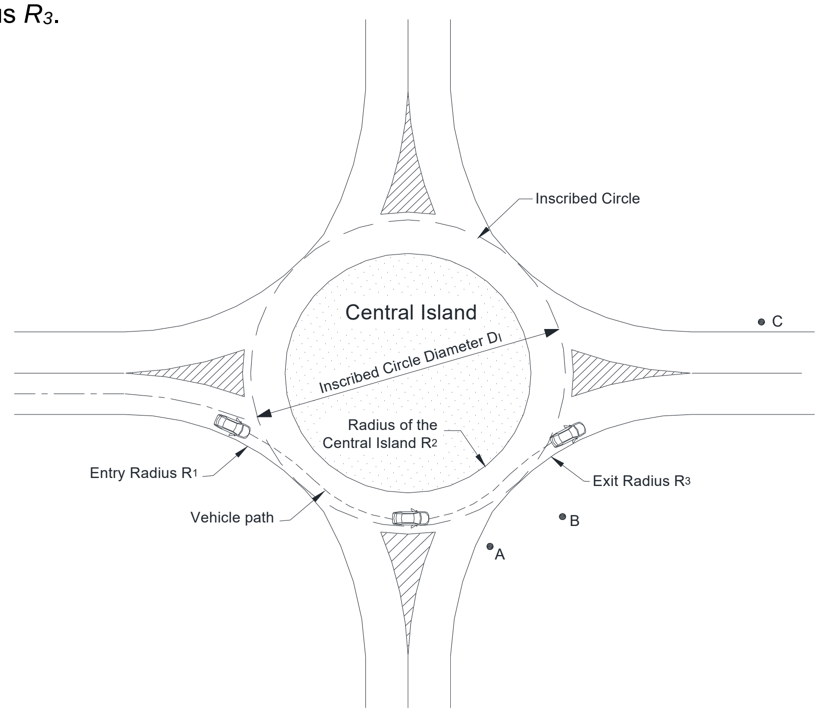

Figure 1: Example of speed measuring locations at a multi-lane roundabout

To ensure the highest level of precision in measuring the speeds, the speed guns were placed as close as possible at collision course with the target vehicles to minimize the angle of incidence and therefore eliminate the cosine effect (US DOT 2007). This is illustrated in Figure 1, which shows that the speed gun was placed at the following three typical points:

a. At point "A" to measure the entering speed;

b. At point "B" to measure the circulating speed; and

c. At point "C" to measure the exiting speed.

To avoid sampling bias, the speed of only the first vehicle was measured in cases when vehicles were traveling in platoons. For every roundabout, vehicle speeds were measured during four different weekdays. For each day, vehicle speeds were measured during one hour in the morning (between 7:30 AM and 9:30 AM), one hour in the afternoon (between 2:30 PM and 4:30 PM), and one hour in the evening (between 6:30 PM and 8:30 PM). Due to the weather and travel habits in Abu Dhabi, the hours during which speeds were measured are within the morning, afternoon, and evening peak periods as per the data provided by Abu Dhabi Department of Municipal Affairs and Transport. As per Table 1, there were 38,764 speed observations, from which 32,950 observations were used to calibrate the statistical models, and 5,814 observations were reserved to validate those models. Table 2 shows the minimum values, maximum values, mean values, and standard deviation of the traffic volumes, geometric characteristics, and observed speeds.

3 Model Calibration and Validation

Several combinations of independent variables were attempted to develop the regression models, and the final models that best fit the data are shown in Table 3 where:

(a) $SP_{entering}$ = predicted 85th percentile entering speed (km/h);

(b) $SP_{circulating}$ = predicted 85th percentile circulating speed (km/h);

(c) $SP_{exiting}$ = predicted 85th percentile exiting speed (km/h); and

(d) V = hourly traffic volume (vehicles per hour).

In all the developed models, the coefficients of all independent variables are significantly different from zero at 5% significance level. The residual plots of the independent variables exhibited random dispersion around the horizontal axis in all models, indicating a constant variance of errors. The models shown in Table 3 have logical explanations regarding the effect of different independent variables on the estimated speed. The positive sign associated with the curve radius coefficient suggests that the speed increases with the increase of the horizontal curve radius, which is consistent with most vehicle dynamics models found in literature and design guides (Mannering and Wahburn, 2013; AASHTO, 2011; Bassani and Sacchi, 2011; NCHRP, 2010; Arndt, 1994). The negative sign associated with the hourly traffic volume coefficient suggests that the speed decreases with the increase of the traffic volume due to the decrease in vehicle spacing and gaps, which is also consistent with most traffic flow models (TRB, 2010; May, 1990; TRB, 1975). It must be noted that the characteristics of vehicles and their drivers are not included in the developed models due to the lack of such microscopic data.

Table 1: Number of speed observations

Vehicle Location	Morning		Afternoon		Evening		Total	
	Cal.[(a)]	*Val.*[(b)]	*Cal.*[(a)]	*Val.*[(b)]	*Cal.*[(a)]	*Val.*[(b)]	*Cal.*[(a)]	*Val.*[(b)]
Along entry path arc	4,879	861	2,685	474	3,252	574	10,816	1,909
Around central island	5,057	892	2,926	516	3,965	700	11,948	2,108
Along exit path arc	4,632	817	2,418	427	3,136	553	10,186	1,797

Total	14,568	2,570	8,029	1,417	10,353	1,827	32,950	5,814

(a) Data used to calibrate the developed models

(b) Data used to validate the developed models

Table 2: Hourly traffic volumes, geometric characteristics, and observed speeds

Independent Variable	Min. Value	Max. Value	Mean	SD
Morning hourly volume (vph)	633	1936	1316.33	473.86
Afternoon hourly volume (vph)	301	1142	697.33	279.93
Evening hourly volume (vph)	362	1362	782.00	319.96
Entry radius R_1[a] (m)	24.15	48.63	35.35	7.60
Radius of inscribed circle R_2[a] (m)	28.14	72.14	45.54	13.41
Exit Radius R_3[a] (m)	29.61	68.21	44.20	12.69
Observed entering speed (km/h)	17.7	73.5	48.3	11.5
Observed circulating speed (km/h)	19.8	105.2	62.4	17.7
Observed exiting speed (km/h)	24.1	114.8	71.1	18.4

(a) As shown in Figure 1

Table 3: Developed speed models

Parameter	Coefficient	t-stat
Predicting entering speed:		
Intercept	24.55	58.99
$(R_1)^{0.65}$	6.134	139.97
$(V)^{0.5}$	-1.245	-146.54
Coefficient of determination (R^2)	0.783	-
Significance of *f* statistic	0.000	-
Standard error	6.018	-
Predicting circulating speed:		
Intercept	24.83	63.58
$(R_2)^{0.65}$	7.494	224.44
$(V)^{0.5}$	-1.691	-161.79
Coefficient of determination (R^2)	0.821	-
Significance of *f* statistic	0.000	-
Standard error	5.771	-
Predicting exiting speed:		
Intercept	28.00	57.96
$(R_3)^{0.65}$	8.145	186.52
$(V)^{0.5}$	-1.708	-132.01
Coefficient of determination (R^2)	0.816	-
Significance of *f* statistic	0.000	-
Standard error	5.490	-

Table 4 shows the predicted operating 85th percentile speeds corresponding to different geometric and traffic characteristics. As shown in Table 4, operating speeds corresponding to the mean values of geometric characteristics, as found in Table 2, exceed those suggested by design guides (AASHTO, 2011; NCHRP, 2010). More strict design standards may be needed to be implemented for roundabouts in

Abu Dhabi to ensure that drivers will select their operating speeds from within the range suggested by design guides (AASHTO, 2011; NCHRP, 2010).

The reserved observations, shown in Table 1, were used to validate the developed models. The validation statistics of all the models are shown in Table 5. The statistics shown include the residual sum of squares, *SSE*, the mean squared error, *MSE*, and the root mean squared error, *RMSE*. As shown in Table 5, the mean squared errors, *MSE*, for all the models are insignificant given the large number and high values of the observed operating speeds. Furthermore, the root mean squared errors, *RMSE*, of all models are also small with values close to the standard errors associated with model calibration shown in Table 3. Based on these statistical measures, it could be concluded that the developed models are stable and robust when being validated with data not used in calibration.

Table 4: Predicted operating speeds (in km/h) corresponding to different radii

Segment Speed	Min. [(a)]	Mean[(a)]	Max. [(a)]
Hourly traffic volume 600 vehicles per hour:			
Entering speed (km/h)	42.7	56.3	70.7
Circulating speed (km/h)	49.0	73.1	104.3
Exiting speed (km/h)	59.8	81.8	112.9
Hourly traffic volume 900 vehicles per hour:			
Entering speed (km/h)	35.8	49.5	63.8
Circulating speed (km/h)	39.7	63.8	95.0
Exiting speed (km/h)	50.4	72.4	103.5
Hourly traffic volume 1,200 vehicles per hour:			
Entering speed (km/h)	30.0	43.7	58.0
Circulating speed (km/h)	31.8	55.9	87.2
Exiting speed (km/h)	42.5	64.4	95.6
Hourly traffic volume 1,500 vehicles per hour:			
Entering speed (km/h)	24.9	38.6	52.9
Circulating speed (km/h)	24.9	49.0	80.3
Exiting speed (km/h)	35.5	57.4	88.6
Hourly traffic volume 1,800 vehicles per hour:			
Entering speed (km/h)	20.3	34.0	48.3
Circulating speed (km/h)	18.7	42.8	74.0
Exiting speed (km/h)	29.2	51.1	82.3

(a) Corresponding to the minimum, mean, and maximum values shown in Table 2

Table 5: Validation statistics of the speed prediction models

Statistical Measure	Entry Speed	Circulating Speed	Exit Speed
Residual sum of squares (*SSE*)	81557.8	120484.5	185329.5
Mean squared error (*MSE*)	38.690	57.156	87.917
Root mean squared error (*RMSE*)	6.220	7.560	9.376

4 Conclusions

In this paper, regression models were developed to predict the 85th percentile operating speeds at multi-lane roundabouts in Abu Dhabi, the capital city of the United Arab Emirates. Three models were developed to predict the entering, circulating, and exiting speeds, respectively. The speeds are predicted based on the hourly traffic volume as well as the geometric characteristics of the roundabout. Other variables related to the characteristics of vehicles and their drivers were not included in the developed models due to the lack of such microscopic data. The models were validated by data not used in calibration and the models were found to be stable and robust. The developed models will help roundabout designers adjust their designs to ensure that the expected operating speeds will meet the design intent. The developed models will also help in predicting the potential capacities of multi-lane roundabouts that are being designed to ensure that the capacities meet the design requirements and the expected traffic volumes. Finally, the developed models will also help developers of traffic simulation applications by providing realistic estimates of operating speeds that may be implemented in those applications. Based on the observations collected in this research, it was found that most multi-lane roundabouts in Abu Dhabi are overly designed, which resulted in operating speeds that exceed those suggested by design guides. More strict design standards may be needed to be implemented for multi-lane roundabouts in Abu Dhabi to reduce the operating speeds to the range suggested by design guides. It should be noted that the developed models are based on the unique characteristics and attitudes of drivers in the United Arab Emirates. Further research may be needed to develop other models for other countries where driver characteristics and attitudes are different from those found in the United Arab Emirates.

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