Statistical Analysis of Two-lane Roundabout Data for Traffic Control Decision-Making in an Urban Area

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Abstract

Researches using existing statistics and data collected from the area of study help officials at decision-making, to improve the region's problems, like the problem of the high rate of accidents in the region, despite the low volume of daily service. The uses of roundabouts in many parts of the world have many advantages over intersections, amongst them are increased safety and capacity and reduced cost. To improve the roundabout function, roundabout traffic control and vehicle safety, decision-making fromer studies carried out is required. Roundabout design for capacity and safety are inseparable components, due to the conditions of roundabout geometry, traffic sign, pavement conditions and patterns of driver's behavior change. The aim of this study was to evaluate the importance and influence of these parameters on the behavior of drivers. In this research, the effect of Pavement Condition Index (PCI), contrast of roundabout lane lines color and volume-to-capacity ratio on the value of obeying the rules of the road for drivers (using turn signals and avoiding unnecessary lane change at roundabout) were evaluated. Data was gathered through field research of seven roundabouts in the city of Yazd, Iran. Statistical methodologies (t-test method and bivariate regression) and the CART model were used for data analysis. Results show when Pavement Condition Index (PCI) improves, unnecessary lane changes by drivers at the roundabout decrease. Similarly, the use of turn signal increases with an increase in the volume-to-capacity ratio, so in the roundabouts with a higher volume-to-capacity ratio of 0.58, 47.5% of drivers use turn signals, while with a less volume-to-capacity ratio of 0.58, the rate of using turn signal will be less than this amount (11.7%).This suggests the need for policy-making at roundabout with low volume-to-capacity ratio, to encourage the use of turn signals by drivers. The results of this research can help city managers and traffic police to prioritize traffic control and reform municipal roundabouts.

Keywords: Decision-making, two-lane roundabout, pavement condition index, contrast of traffic lane lines color, CART model.

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1. Introduction

Road traffic management is considered a complex issue. Road traffic laws and policies depend on several factors. Making a proper decision for traffic management can be difficult because decision-makers need to analyze and absorb a large quantity of information [Almejalli Dahal and Hossain, 2006; Dell'Acqua , Luca and Mauro., 2011]. Nowadays decision-makers and transportation specialists widely use the data analysis relating to accidents, infrastructure status and vehicles [Pande and Abdel-Aty, 2009; Dell'Acqua , Luca and Mauro, 2011; Fanga and Guo, 2013], and data related to road safety used by different agencies such as the police, transport departments, Insurance Companies and politicians [WHO, 2015]. Road transport needs improvement, to improve the mobility of the people and goods, access to education, health care, jobs and economic locations [WHO,2015]. In recent studies, transportation decision-making process has been done using traffic statistics data. In previous studies, several methods of collecting and analyzing data were used [Dell'Acqua , Luca and Mauro, 2011]. In this study, data collection was conducted by field study research and data analysis by statistical methods using SPSS software (Statistical Package for Social Sciences). Intersections are a small part of the road but crash rates at intersections are significantly high in the total number of crashes recorded. Recently, most intersections are being converted to roundabouts [Montella et al., 2012] because it reduces crash rates and increases roadway capacity. Also roundabouts are better alternatives for increase in traffic-flow at intersections compared to other options [Kusuma and Koutsopoulos, 2011].

Roundabouts have been classified into three basic categories according to size of inscribed circle diameter and number of entering lanes: mini-roundabouts, single-lane roundabouts and multilane roundabouts. These categories based on their location can be divided into smaller groups e.g. rural, suburban and urban. Table 1 compares the different categories of roundabouts.

The types of pavement markings for roundabouts delineate the entries, exits, and the circulatory roadway, providing guidance and information for pedestrians and vehicle operators. The Manual on Uniform Traffic Control Devices (MUTCD) contains the standards for traffic control devices including color, size and pavement markings [U.S. DOT MUTCD, 2009].

Table.1 Roundabout Category Comparison [Mills et al. 2011]

Design element	Maximum number of entering lanes per approach	Typical inscribed circle diameter	Typical daily service volumes on 4-leg roundabout below which may be expected to operate without requiring a detailed capacity analysis (Veh/day)
mini-roundabout	1	13 to 27 m	Up to approximately 15,000
single-lane roundabout	1	27 to 55 m	Up to approximately 25,000
multi-lane roundabout	2+	46 to 91 m	Up to approximately 45,000 for two-lane roundabout

Pavements marking at roundabouts have different types, color and application. Yellow edge lines along splitter islands are placed at the left edge of the approach to help drivers recognize the changing roadway. White lane lines markings are used on multilane approaches to provide the following benefits; at signalized intersections, solid lane lines on approaches reduce the likelihood of sideswipe crashes by preventing last-minute lane changes. Solid lane lines on approaches and departures can discourage drivers from cutting across, unnecessary lane change and deflection through the roundabout [NCHRP report 672, 2010]. Examples of circulatory roadway pavement markings including lane lines, edge lines and arrows are shown in Figure 1.

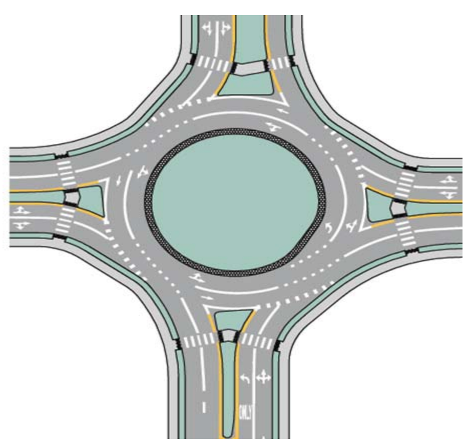

Figure.1 Examples of circulatory roadway pavement markings [FHWA, 2010]

Increasing visibility of pavement markings is provided at safe environment for drivers, the width of pavement lines is one of the factors that increase the visibility, so a wider longitudinal line has positive impact on vehicle safety [Park et al., 2012]. Scott McKnight et al. (1998) studied the effect of lane line width and contrast upon lane keeping. They found that lane line width and contrast have negligible impact on lane-keeping, except when the contrast is so extreme [Mcknight and Tippetts 1998].The study of Yong Cao (2004) on the effect of lane line color contrast on driving safety, showed that the driver's response time drops when the contrast was increased [Cao, 2004].

The condition of the pavement is yet another effective parameter on driving quality. In the study of Yinfeng, Li et al. "Impact of Pavement Conditions on Crash Severity", it was shown that pavement with poor condition is one of the contributing factors to crash rates. However, this study shows that poor pavement condition reduces crash severity while good pavement condition increases crash severity [Li, Liu, and Ding, 2013]. Chan et al. investigated the effect of pavement on traffic safety. In this study the effects of rut depth, international roughness index (IRI), pavement serviceability index (PSI) on the number of accidents was studied. The results showed that the depression depth is effective on crash rates only at night and in rainy conditions [Chan et al., 2008]. As a result of the wide range of factors affecting the performance of drivers, further research in this field is required to help decision makers improve transportation conditions.

Many countries are concerned with the low level of safety in multi-lane roundabouts. If the number of collisions (conflict) is decreased, the concern would be less. One point that will reduce the number of collisions is the use of appropriate geometric designs in roundabouts. One possible solution from those countries with behavior patterns comparable to Iran was used with conditions in Iran. The study showed that considering the traffic parameters that affect a roundabout's capacity, such as flow and gap, is essential. However, further investigation into the behavior pattern of drivers was highly recommended. It was indicated that geometric corrections and little traffic can ensure a safer situation in the roundabout. Diah et al. also focused on improving driver behavior under traffic and geometry conditions [Diah et al., 2011].

The aim of this study was to investigate the effect of pavement conditions and traffic signs and the rate of traffic congestion on the driver's performance in the small roundabouts of city. The performance of driver in the study refers to risky driving (Unnecessary lane change) and not using the turn signals (of Automobile). According to objectives of research for priority of immunization urban roundabouts can firstly measure the parameters path, the pavement lane lines color quality and volume of traffic. It can also be used for expertise decisions and traffic control management.

2. Research Methodology

In this study, data collection was conducted by field studies, and the performance of the drivers (turn signals and unnecessary lane change regarding approaches and departures of road way) was gathered using a recorder (Fig.2). Data analysis was performed using SPSS IBM statistics 22.

2.1 Data Collection

In this paper, seven roundabouts in Yazd, Iran were studied to assess the effect of Pavement Condition Index (PCI), Contrast in the color of roundabout lane lines and volume-to-capacity ratio, on the value of obeying the rules of the road for drivers (using turn signals and not having unnecessary lane change at roundabout). The location of roundabouts which there are 7 of them is shown in Figure 3. For collecting information and data, camera and observation were used by statistician.

The performance of drivers was assessed during the day and at off-peak hours, so that the low-light parameter at night and the existence of other vehicles did not have an impact on the targeted vehicles. The drivers' performance was recorded by the recorder. After selecting the vehicle (randomly), the first parameter was recorded when the drivers were using turn signals and when they were not using turn signals. Thereafter, with respect to vehicle direction (origin and destination), unnecessary lane change was also recorded. With regard to the figure.4, when every vehicle enters to roundabout, if it passes in the green lines, it does not need to change the lane, if it passes in the red line or blue line, it can only change the lane twice, if it changes more than twice, it is unnecessary lane change. Statisticians, according to the standard width of traffic lines, traced the movements of vehicles in a hypothetical area in the roundabouts which did not have marking or in other words, were not clear (Fig.4). Accordingly, if the driver had lane changes more than the above mentioned numbers; they were recorded and counted as unnecessary lane changes.

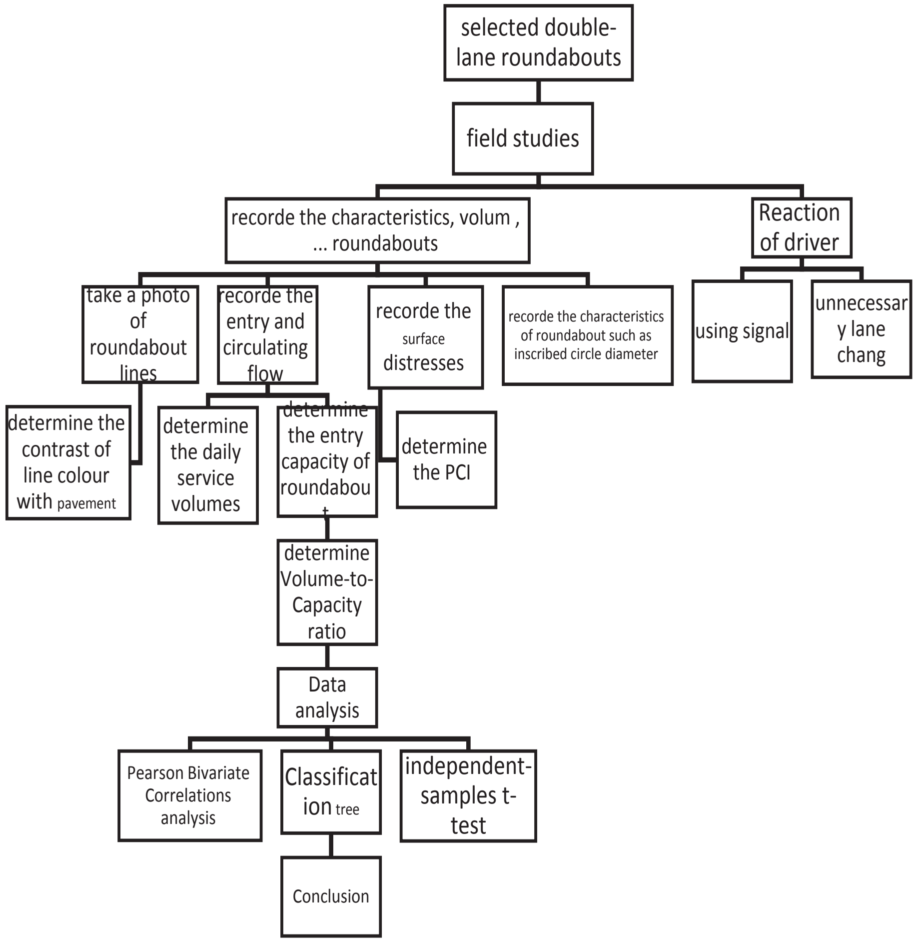

Figure 2. Flowchart, data collection and research methodology

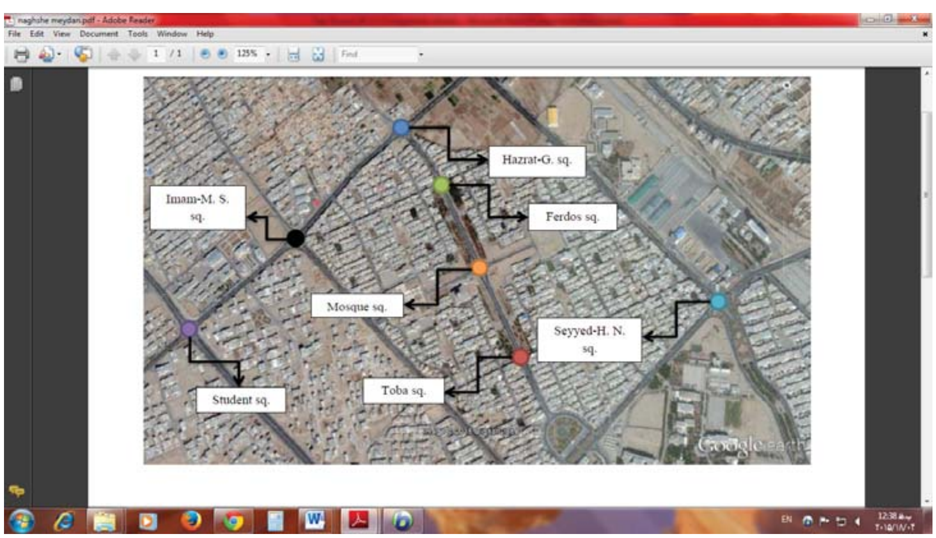

Figure 3. The location of the seven selected roundabouts, [source: Google Earth, 2015]

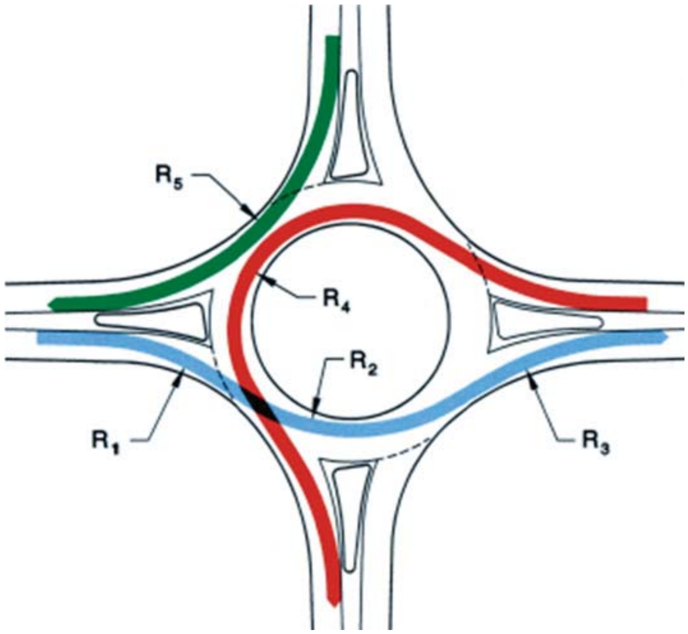

Figure 4. Vehicle path radii [Mills et al., 2011]

Table 2. Characteristics of these roundabouts

Roundabout Element	Inscribed circle diameter (m)	Typical daily service Volumes on 4-leg roundabout (veh/day)
Toba sq.	34	3312
Mosque sq.	30	3072
Ferdos sq.	37	5232
Hazrat-G. sq.	57	10824
Imam-M. S. sq.	62	10296
Student sq.	30	23688
Seyyed-H. N. sq.	35	24384

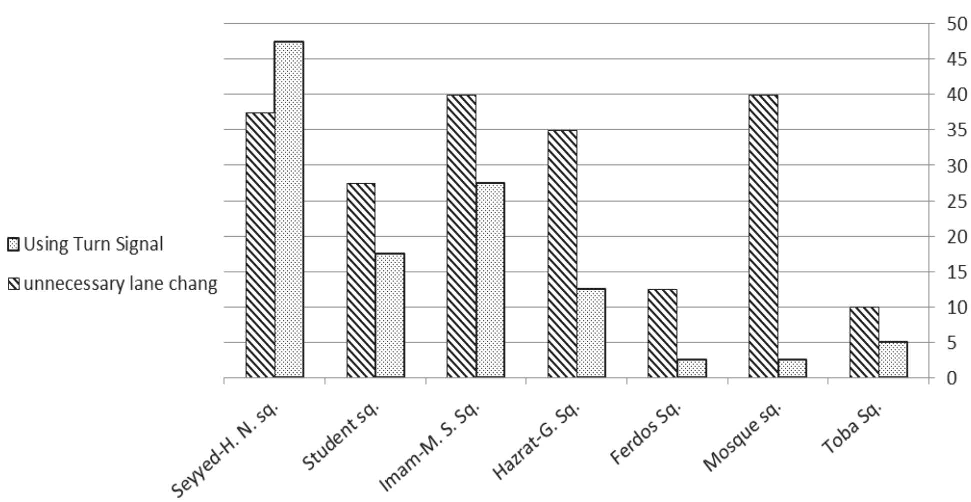

Figure 5. Percentage of vehicles which use turn signals with unnecessary lane change

Table 3. The information of the most recorded distress of roundabout pavement.

Name of roundabout / area of roundabout's pavement (m2)	Distress types	Severity Level	Area / Length / Count distress	Number of sample unit
Toba / 593	block cracking	L / M	m^2 6 / 1.5	2
	Long & Trans cracking	L	18.2 m	
	Alligator cracking	L	m^2 2.5	
	Patching	L	m^2 9	
	Potholes	L	One number	
Ferdos / 761	block cracking	L	m^2 18	2
	Patching	L / M	m^2 24.25 / 6	
	Bumps and Sags	L	m^2 1	
Mosque / 1256	Long & Trans cracking	L / M	m 64 / 55	4
	Patching	M	m^2 5.75	
	Weathering and Raveling	L	m^2 7	
Hazrat-G. / 1421	block cracking	L / M	m^2 22 / 18	4
	Long & Trans cracking	L	36.5 m	
	Alligator cracking	L / M	m^2 14.5 / 6.2	
	Patching	L	m^2 28.7	
Imam-M. S. / 1943	block cracking	L / M	m^2 18 / 2	4
	Long & Trans cracking	L / M	9 / 56.3 m	
	Potholes	L	One number	
	Patching	L / M	m^2 30.3 / 48	
Student / 2119.5	block cracking	M	m^2 40	4
	Long & Trans cracking	L / M	70 / 20 m	
	Potholes	M	One number	
	Patching	L	m^2 32	
	Weathering and Raveling	M	m^2 12	
Seyyed-H. N. / 1413	block cracking	L	m^2 50	4
	Alligator cracking	L	m^2 6	
	Patching	L / M	m^2 38 / 9	
	Potholes	L	One number	

Table.2 displays the location of "the seven roundabouts" in this study and they can be classified according to Table 1, on the two-lane roundabout. Most of the roundabouts are in areas with low traffic flow, therefore typical daily service volumes is low.The results of 280 vehicles are shown in Figure 5.It was assumed that the vehicles did not have impact on each other; hence the survey was conducted during off-peak hours.

2.2 Pavement Condition Index Calculation

To determine the PCI by roundabout supervision, surface distresses were recorded from the pavement area, it is used from existing standard forms for collecting data of pavement. Table 3 indicates the type and severity level of each roundabout. Pavement Condition Index (PCI) calculation has a standard method which is referred to it's in handbook and standard ASTM D6433-11 [ASTM D6433-11, 2011].

The roundabouts were divided into 2 and 4 sample units, then pavement distresses of all sample units were recorded and the PCI was determined by averaging the PCI of the sample units. The following four steps are involved in the calculation of the PCI for a sample unit; the computational steps are described briefly below:

Step 1: Determine deduct -values.

For each by distress type, density and severity level within a sample unit and by the existing charts, a deduct value is determined.

Step 2: Determine the maximum allowed deduct value (m).

For roads with asphalt surface, the allowed deduct value was calculated using Eq. (1).

$$m_i = 1 + \frac{9}{98}(100 - HDV_i) \tag{1}$$

Where

m_i is the number allowed deduct value, including the decimal value for the sample unit i. HDV_i is the maximum individual deduct value for the sample unit i.

Step3: Determine the maximum corrected deduct value (The maximum CDV).

Using the number of deduct values greater than two for roads with asphalt surface (q).The Total Deduct Value(TDV) was determined by trial and error method. Parameter The Total Deduct Value (TDV) is extracted from the current charts in the standard ASTM D6433 - 11.

Step4: Determine PCI

PCI was calculated by subtracting the maximum CDV from 100 [Shahin, 2002]. The value of PCI for Toba, Ferdos, Mosque, Hazrat-G, Imam-M.S, Student Seyed-H N. is 86, 89, 80, 81, 82, 85, 86 respectively)

2.3 Roundabout Volume-to-Capacity Ratio Calculation

There are several ways to determine roundabout capacity such as Highway Capacity Manual [HCM, 2000], British method for the analysis of roundabout capacity [Robinson, 2000] etc. Computer software can also be used to analyze roundabout capacity, such as British-based RODEL and ARCADY software, which are designed according to British driving behavior and British roundabout designs and Australian-based SIDRA software which are estimated capacity, delay, queue, fuel and environmental measures [Robinson, 2000].

Equation (3), based on Equation (2) with current assumptions is obtained in the Roundabout, shows the expected capacity of a double-lane roundabout based on the design of templates for the urban/rural double-lane roundabouts. The capacity forecast is based on simplified British regression relationships, which may also be derived with a gap-acceptance model by incorporating limited priority behavior [Robinson, 2000].

The traffic volume in each roundabout during peak-off hours per working week circulating and entering traffic volume at each approach for vehicles (cars, motorcycles and buses) was recorded by a recorder. Using the data obtained and by converting the traffic volume to passenger car equivalent and averaging, circulating and entering traffic volume of each approach was determined in terms of passenger car equivalent per hour. The capacity of each approach was calculated using Eq. (3) as well as the volume of the circulating traffic. With hourly traffic volume of the entering roundabout approaches, the volume-to-capacity ratio was determined for each approach and by having the average of values obtained for each approach; the volume-to-capacity ratio for the roundabout was obtained, the value for Toba, Ferdos, Mosque, Hazrat-G., Imam-M.S., Student, Seyed-H. N roundabouts are 0.098, 0.06, 0.105, 0.395, 0.485, 0.565, and 0.595 respectively).

$$\begin{aligned} Q_e &= K(F - f_c Q_c), & f_c Q_c \le F \\ &= 0, & f_c Q_c \succ F \end{aligned} \tag{2}$$

$$K = 1 - 0.00347(\phi - 30) - 0.978(\frac{1}{r} - 0.05) \tag{2-1}$$

$$F = 303x_2 \tag{2-2}$$

$$f_c = 0.210 t_D (1 + 0.2 x_2) \quad (2\text{-}3)$$

$$t_D = 1 + \frac{0.5}{1 + \exp(\frac{D - 60}{10})} \quad (2\text{-}4)$$

$$x_2 = v + \frac{e - v}{1 + 2S} \quad (2\text{-}5)$$

$$S = \frac{1.6(e - v)}{l'} \quad (2\text{-}6)$$

Where

e = entry width, m

v = approach half width, m

l' = effective flare length, m

S = sharpness of flare, m/m

D = inscribed circle diameter, m

ϕ = entry angle, degrees

R= entry radius, m

For double-lane roundabout:

$$Q_e = 2424 - 0.7159 Q_c \ldots\ldots \quad (3)$$

Where

Q_e = entry capacity (pce/h),

Q_c = circulating flow (pce/h)

2.4 Calculating the Contrast of Pavement Lane Lines Color at Roundabout

Pavement markings were used to avoid confusion at the roundabout and to direct drivers, to clearly show the intended direction of travel [Robinson, 2000]. The intensity of pavement lane lines colour, can be achieved by using generated geo-referenced intensity image [Guan et al., 2014].

In this study, to determine the intensity of the colours on the pavement, the picture of roundabout lines were taken vertically. For uniformity of conditions of shots, all of them were prepared in a distance of 50 cm from the pavement surface and the camera was fully horizontal and the light in the time of shooting was morning light and all the shots were prepared in a period of less than 1 hour.Using Colour Contrast Checker software, the contrast of line colour with pavement was determined by calculating the mean, for each roundabout one number was considered. So the ratios larger than 1.0 indicated more intense contrast .The contrast of line colour with pavement at three rounabouts, Hazrat-G., Imam-M. S. and Ferdos are respectively, 1.597, 1.325 and 1.13. The lining on four other roundabouts were washed off. An example of the image of pavement lanes and adjustment with the contrast checker is shown in Figure 6 [CCSoftware,2013].

3. Data Analysis

In this study, a non-parametric classification tree and statistical methods were used for data analysis. In a research by Attiyah M. Al-Atawi, independent-samples t-test was used to analyze data [Al-Atawi, 2014]. Also, this study used independent-samples t-test to determine the presence or absence of a significant difference between average lane change and use of turn signals at different types of roundabouts, the studied roundabouts were classified into two groups to measure the influence of roundabout properties (inscribed circle diameter and volume-to-capacity ratio) on driver behavior, and explore reliable answer to the question of whether the roundabout properties have an effect on driver behavior (using turn signals and the number of unnecessary lane change at the roundabout).

With regard to the use of volume calculation relation and capacity of the roundabout in traffic studies in Iran, in this study, the relationship to the United Kingdom were used [Shahi, 2010].Toba, Ferdos and Mosque square, because of similarity in geometry and the volume-to-capacity ratio were classified as type 1 and Hazrat-G. , Imam-M. S., Student and Seyed-H.N as type 2. In independent t-test, it is assumed that the variances of two groups of data are equal. If the assumption of homogeneity of variances is rejected, then the second row t would be reported. Assuming homogeneity of variances, Levene's Test of Equality of Variances using SPSS software can be investigated.

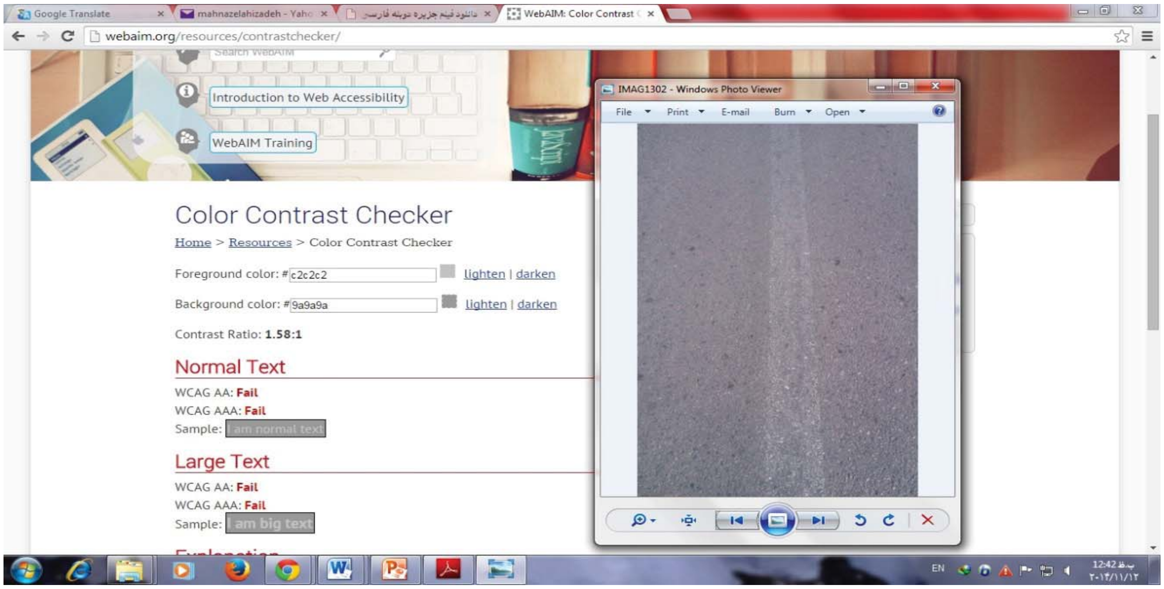

Figure 6.The outputs of Color Contrast Checker Software [CCSoftware,2013]

Table 5. Results of T -Test between type 1 and type 2 for the dependent variables of unnecessary lane change and the use of turn signals

		Independent-samples T Test								
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Using signal	Equal variances assumed	256.628	.000	-5.849	278	.000	-.250	.043	-.334	-.166
	Equal variances not assumed			-6.546	207.781	.000	-.250	.038	-.325	-.175
Unnecessary lane chang	Equal variances assumed	7.530	.006	-1.977	278	.049	-.177	.090	-.353	-.001
	Equal variances not assumed			-2.002	267.100	.046	-.177	.088	-.351	-.003

If the significance level is greater than a pre-set critical value of significance (for example 0.05); the two groups' variances can be treated as equal. However, if p < the defined critical p-values, the variances will be unequal.

The t-test results are shown in Table 5, a significance value (p-value) can be seen in less than the critical p-values (p <o.o5).Therefore, it can be said that the variances of the two groups are not equal and also between unnecessary lane change and use of signals, in type 1 and type 2, there is significant difference. The results of Table 5 show the parameters of volume-to-capacity ratio and inscribed circle diameter, which based on roundabouts are divided into two types 1 and 2, have an impact on the driver's performance. The results of another study on Driver Behavior Characterization passing through double-lane roundabouts in an arterial road were also revealed that roundabout geometric characteristics have an impact on driver behavior [Bastos et al., 2014].

3.1 Pearson Bivariate Correlations Analysis

The correlation coefficient communicates both the strength and the direction of the linear relationship between two variables. The sign of the correlation coefficient indicates whether the direction of the relationship is positive (direct) or negative (inverse).

Variables which have a direct relationship (a positive correlation) increase together and decrease together. Using SPSS, the correlation between the independent variables and the dependent variable, using the turn signals and unnecessary lane change was determined. The values of the correlation coefficient and P Value are shown in Tables 6 and 7. Significance value (p-value) less than the critical p-values (p <o.o5), shows the obvious correlation between two variables.

The correlation coefficient of Table 6 shows the volume-to-capacity ratio and Pavement Condition Index have a relationship with the dependent variable number of unnecessary lane change. The parameter volume-to-capacity is directly related to the unnecessary lane change, it means that in roundabouts with a greater volume-to-capacity ratio, drivers showed a higher number of unnecessary lane change. The Pavement Condition Index is inversely related to the unnecessary lane change. It means that with the decline in Pavement Condition, the number of unnecessary lane change increases.

Table 6. Results of Pearson Bivariate Correlations analysis on the dependent variable number of unnecessary lane change

independent variable	Correlation	*P Value
volume-to-capacity ratio	157.	008.
Pavement Condition Index	179.-	003.
Pavement color contrast	080.-	182.

***according to Pearson Bivariate Correlations**

Table 7. Results of Pearson Bivariate Correlations analysis on the dependent variable the use turn signals

independent variable	Correlation	P Value*
volume-to-capacity ratio	.360	.000
Pavement Condition Index	-.015	.802
Pavement color contrast	.030	.619

***according to Pearson Bivariate Correlations**

The correlation coefficient of Table 7, shows that the volume-to-capacity ratio is directly related to using a turn signal, it means that with increase in the volume-to-capacity ratio, the drivers use more turn signals. The results of another study by Sullivan et al. tested the factors that influence the use of turn signals at the intersection, and showed the effect of entry traffic volume on turn signals, such that if there is a forward vehicle, the possibility of using turn signals increases to 1.5 [Sulliva et al., 2015].

3.2 Classification Tree

Classification and Regression Tree (CART) is a robust tool for data mining [Beshah et al. 2013]. The Classification and Regression Tree (CART) model can be used to classify factors affecting the dependent variables, for example, determine the factors influencing driving behavior, modeling travel demand and traffic accident analysis. Also, CART is a powerful tool for the prediction and classification of problems [Chang, 2013]. In Figure 7 using CART model, the effective variables on using turn signals were determined.

As shown in Figure 7, most of the vehicles (83.2%) did not use turn signals at the roundabout. As can be seen, tree branches based on tree parameters, the volume-to-capacity ratio, PCI and inscribed circle diameter have been divided. This reflects the importance of these variables and their impact on the use of turn signals.

Figure 5 shows that at the roundabout with the greater ratio of volume-to-capacity, 0.58 drivers used more turn signal. Also, at the roundabout with inscribed circle diameter of more than 61 m and Pavement Condition Index of less than 87.5, drivers used more turn signal. Therefore, in roundabouts with volume –to-ratio capacity of 0.58, 47.5% of drivers use traffic signals, but this value for the roundabouts with capacity less than 0.58, is 11.7%. Using turn signal increases vehicle safety and reduces car crashes [Sullivan and Flannagan, 2012].

4. Conclusions

This study focused on the decision-making of multi-lane roundabout safety improvement. The results of the analysis show that one of the reasons for unnecessary lane change by drivers at the roundabout is low Pavement Condition Index Information Guide and Correlation coefficient between changes of additional lines and pavement index -0.179 was obtained. Policy makers can increase safety and reduce accidents through pavement repair and maintenance. Also, volume-to-capacity ratio has a significant impact on the use of turn signals, which means drivers tend to use turn signals at roundabouts with high traffic flow. The results of this paper revealed that the importance of pavement condition parameters with a ratio of volume to low traffic capacity (more privacy or a V/c ratio of less than 0.25) is greater than with other roundabouts. The results also indicated that, on average, only 15% of drivers used turn signals on small roundabouts, and more than 25% of drivers made unnecessary lane changes.

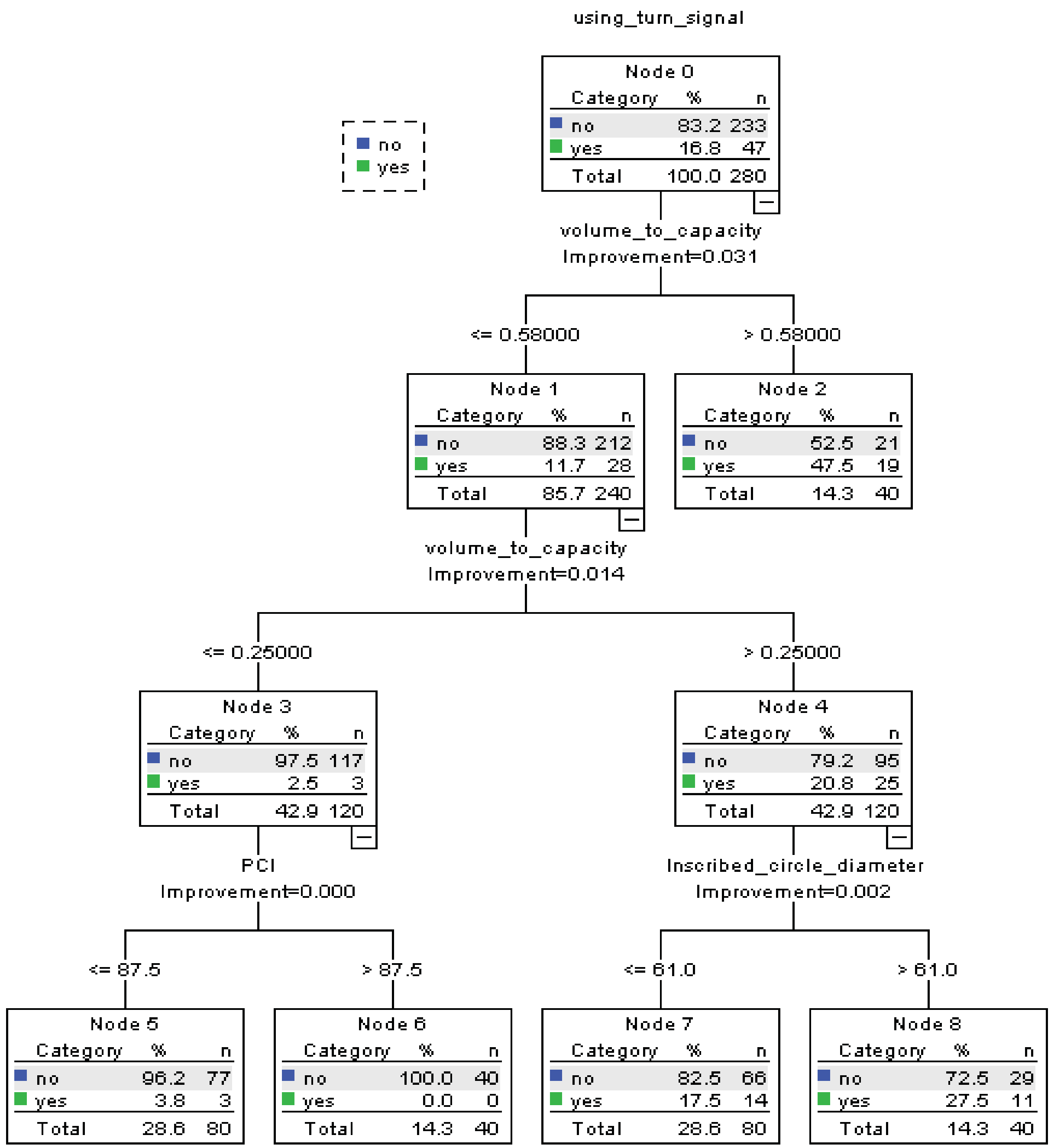

Figure 7. Classification tree generated by using CART model to determine the effective variables on using turn signals at roundabout

The study of samples from small roundabouts determined that the ratio of volume to capacity is often less than 6.0 and more than 70% of drivers in these roundabouts exhibit unsafe behavior (unnecessary lane changes without using a turn signal).

A study of small, local roundabouts was performed. For the area under study, pavement quality was in excellent condition, and pavement maintenance was not a current priority. The lines (horizontal traffic signs), however, were in poor condition. A renewal lane, or improvement lane, is essential to all roundabouts. In the cited study, only one roundabout had an appropriate lane situation, and lane contrast was more than 1.5. Based on the results of this research and the importance of turn signals, training drivers and enforcement of laws to encourage the use of turn signals, is required.

It is recommended that driver behaviors could be observed in other countries and the roundabouts in industrial areas can be examined, rather than roundabouts in residential areas which were surveyed in this study.

5. Acknowledgement

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6. List of abbreviations

SPSS: Statistical Package for Social Sciences
IRI: International Roughness Index
PSI: Present Serviceability Index
PCI: Pavement Condition Index
HDV: highest individual deduct value
CDV: corrected deduct value
TDV: Total Deduct Value
HCM: Highway Capacity Manual

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