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EVALUATING THE SAFETY PERFORMANCE OF ROUNDABOUTS

Summary. The use of roundabouts is well recognized for sustaining an efficient and safe intersection. However, the safety results may vary based on the prevailing conditions. Therefore, this study assesses the safety performance of roundabouts in Jordan. This study developed a predictive model by collecting and analyzing all accident records of 12 major urban roundabouts in the country over 3 years. For developing the model, this study employed an accident frequency analysis. The model calculated the rate of accidents and incorporated the geometric and operational characteristics of roundabouts. This was followed by ranking the safety performance of the roundabouts. It was concluded that driver behavior of violating the traffic rules, lack of clear lane markings in the circulating area and inadequate signage at the roundabouts entries are the main causes of roundabout accidents. The research recommends including the developed predictive model in future traffic control and planning studies, for identifying hazardous locations, or for prioritizing roundabout improvements based on safety performance.

1. INTRODUCTION

Roundabouts are an alternative intersection control method that is used to improve road safety and convey traffic without widening roadways [1]. Initially, the concept of roundabouts first emerged in the United Kingdom for resolving the problems of traffic circles [2]. The modification of the driving rule, such as yielding of the entering traffic to circulate traffic, set the bases for the formation of the circulatory lanes, leading to the successful implementation of contemporary roundabouts. This has improved the roundabout safety and operations in contrast to the signalized intersection with rotaries.

Given the current dynamic, road accidents are an increasing public health concern, which has cost the lives of more than 1.24 million people and resulted in almost 20–50 million non-fatal impairments. The World Health Organization [3] listed road accidents as the ninth leading cause of disability-adjusted life years (DALYs) lost, accounting for over 38 million DALYs lost or 2.6% of the global burden of disease. Low-income and middle-income countries account for 91.8% of the DALYs lost to road traffic injuries worldwide [4].

Compared to neighboring Middle Eastern countries, Jordan has one of the highest rates of traffic accidents [5]. The majority of the road accidents in Jordan were observed in the capital, Amman, where the population density is highest, the street network is saturated, and roundabouts are very common. The annual growth of registered vehicles in Jordan was 5.5% over the period 2012-2015 [6]. The total number of accidents has increased to 75% from 2004 to 2009 [7], roughly following the parallel increase of registered vehicles [7]. In 2015 alone, around 9,712 accidents took place in the region, which caused 608 deaths, 2,021 critical injuries as well as 12,000 minor injuries as stated by the Central Traffic Department [8]. Moreover, the increased number of road accidents, in 2010 alone, cost the country about US$ 440 million [4].

AASHTO [9] highlights that there are many factors that affect roundabouts' performance, namely, operational factors, human factors and geometric design factors. Various studies have highlighted the impact of these factors, although no study has specifically studied these all together, particularly in Jordan, such as Al-Suleiman el al. [10] and AlShannaq [11]. This study aims to provide a reliable model for forecasting traffic accidents at roundabouts in Jordan. It integrates a group of models, a capacity model, a speed model and the geometric characteristics of the roundabout, to build an accident-prediction model. The assumption is that this model will be adopted by traffic engineers, planners and decision-makers to assist them in the management of traffic at existing roundabouts or in predicting traffic accidents during the design process for future facilities. The importance of this research is that this model could be used for evaluating existing roundabouts or in planning future roundabouts.

2. LITERATURE REVIEW

Previous research has demonstrated the substantial contribution of roundabouts in the enhancement of safety and efficiency while comparing it with various other intersection types [12]. Tang [13] indicated that the severity of the accidents and the conflicting intersectional points decline due to the roundabout. However, the performance of the roundabout has been found to be better when the traffic is intermediate as compared to high traffic [2]. Despite this, various researches have confirmed that the modification of the signalized intersection to roundabouts offers an effective way to overcome the frequency of accidents as well as its associated severity [14, 15].

The fundamental design of roundabouts is inclusive of the geometric layout, operational as well as safety evaluation. Small changes in roundabout geometry cause significant changes in its performance related to safety and operations [16]. Roundabouts are evaluated operationally in terms of capacity, delays and Level of Service (LOS); however, these factors were found to impact the safety performance of roundabouts [17]. In this respect, the study by Uddin [18] assessed the operational performance of roundabouts in terms of traffic parameters. The study found that roundabouts reduce the delay by 24%, along with a decline of 77% in idle time, and a 67% increase in average speed. Similarly, Akçelik [19] elaborated on the NCHRP Report 572 findings on roundabout capacities and LOS. They conducted an assessment of the adequacy of roundabout geometric features using the volume (v) to capacity (c) ratio (v/c). Al-Omari et al. [20] established an empirical model for the estimation of roundabout delay based on 15-minute intervals. The results of their study showed that geometric parameters have an effect on the roundabout capacity [21].

The HCM identifies control delay as a measure to determine the LOS for signalized and non-signalized intersections [22]. Control delay is the time that a driver spends slowing to a queue, queuing, waiting for a gap in the circulating flow or speeding up out of the queue [22]. The HCM describes LOS as the performance of a transportation feature from the point of view of a user [22]. LOS is used for quantifying the performance using the control delay. The study by Polus and Shmueli [23] evaluated the geometric data and the flow of traffic from a small- to medium-sized roundabout using the individual and aggregated entry-capacity models. The study substituted the conflicting flow with the circulating flow, where it found a consensus between the developed as well as a model of Highway Capacity Manual. Persaud and Lyon [24] explained the rationality and appeal of the Empirical Bayes (EB) approach. Cameron and Windmeijer [25] applied Poisson and Gamma modeling for crash prediction of roundabouts in a study sample of 148 roundabouts. The models recognized different types of road users and showed that the accident rates are proportional to traffic exposure. The most common accidents predicting models are described in the Highway Safety Manual [9]. The predictive models estimate the expected average accident rate of a roundabout for a certain period of time, given its specific geometric parameters and traffic volumes. They were developed from a number of similar sites and could be adjusted for specific local conditions.

3. RESEARCH METHODOLOGY

3.1. Data collection and Method of Analysis

Traffic data were collected from the Traffic Police Department, Greater Amman Municipality and Jordan Traffic Institute. Descriptive analysis included GIS mapping of the accidents recorded by the

Traffic Police Department of Amman at the 12 roundabouts in Amman. The geometric and operational parameters of the 12 roundabouts are provided in Appendix (1).

3.2. Geometric and Operational Analysis

Geometric data were obtained through field measurements during off-peak periods. The geometric characteristics included central diameter (W_e), circulatory roadway width (W_c), entry width (D_i), exit width, entry deviation angle and drive curve. The stopped delay model used in this study is presented in Eq. (1) and Eq. (2) integrating the stopped delay [20] and control delay [20].

$$\mathrm{D_s} = 2.89 + 0.00199\mathrm{V_s} + 0.00535\mathrm{V_c} - 0.153\mathrm{D_i} + 0.582\mathrm{W_c} - 0.325\mathrm{W_e} \qquad (1)$$

where:
D_s= stopped delay; V_s= subject approach volume; V_c = circulating traffic volume.

$$\text{Control Delay} = 1.3 \times \mathrm{D_s} \qquad (2)$$

The capacity model of Masaeid and Faddah [26] was used as shown in Eq. 3:

$$q_e = 168.2 \times D^{0.312} \times S^{0.219} \times e^{0.071W+0.019RW} \times e^{-5.602q_c/10,000} \qquad (3)$$

where:
q_e = entry capacity; q_c = circulating traffic flow; W= entry width; RW= roundabout roadway width; D = central island diameter; S = entry/exit distance.

The speed model of Al-Omari et al. [21] was used in this research as presented by Eq. 4:

$$\mathrm{V_c} = 14.321 + 0.196\mathrm{V_a} + 0.048\mathrm{DC} + 0.107\mathrm{D_i} - 11.964\mathrm{A_e} + 0.655\mathrm{W_e} \qquad (4)$$

where:
DC= drive curve; D_i = internal circle diameter; A_e = entry derivation angle; W_e = entry width;
V_a = Flee Flow Speed (FFS) of the upstream approach.

FFS is taken as the posted speed on the streets within the Greater Amman Municipality jurisdiction. Drive curve (DC) was calculated using Eq. 5 [21].

$$\mathrm{DC} = \left(\frac{(\mathbf{0.25}\times\mathbf{L})+\left(\mathbf{0.50}\times(\mathbf{U}+\mathbf{2})\right)^2}{\mathbf{U}+\mathbf{2}}\right) \qquad (5)$$

where:
U= the roundabout shift measured from the plan and
L = the distance between the entry and proceeding exit.

The accident rate for each roundabout was calculated using the Highway Safety Manual [9] according to Eq. (6) as follows:

$$AR_{sp} = \frac{A\times 1,000,000}{365\times T\times V} \qquad (6)$$

where:
AR = accident rate per million vehicles; A = number of accidents; T = period of study in years;
V = Average Daily Traffic (ADT).

3.3. Accidents Mapping

The influence areas of roundabouts were determined based on accident data for three years (2012, 2013 and 2014) with a total of 4155 accidents. Mapping of the accidents was conducted to determine the location of the accidents and prepare the datasheets for accidents' attributes for each circle. The ArcMap Version 10.1 software was used for this purpose. Polygons were used to define the locations of the accidents. The datasheets for each roundabout were developed containing the following information: the location of accidents, date of the accident and cause of the accident at a confidence level of 95 %, with a 0.02 margin of error for all roundabouts. The accidents outside the roundabout center and entries/exits were eliminated. 300m distance upstream of the roundabout entry and 300m downstream of the roundabout exit were selected as boundaries of the assessments [21, 22].

3.4. Accidents Prediction Model

To identify the Accident Modification Factors (AMF), the relationship between individual independent variables and accident rate (AR) for each roundabout was explored. Linear correlations were considered between the Accident Rate and the geometric and operational parameters (as independent variables) as previously done by Muskaug [27]. There was no linear correlation between the AR and Central Island Diameter (D), since the correlation coefficient R^2 was equal to 0.37, as illustrated in Fig. 1(a). According to the HSM [9], the correlations between AR and the AMFs are not necessarily linear, as sometimes, the correlation could be expressed as an exponential function. Therefore, further analysis was carried out to evaluate whether a non-linear exponential regression model is applicable for the purpose of this research. Thereafter, the correlation between the AR and D was found to be a strong non-linear exponential relationship with an R^2 value of 0.85, as shown in Fig. 1(b).

Based on the collected traffic data and historical data on accidents for the 3-year period, the AR was calculated and is provided in Tab.1 for each roundabout. The AR is expressed per million entering vehicles (MEV).

The Accidents Prediction Model was developed as a multi-variable exponential regression model as expressed in Eq. (7).

$$AR_p = AR_a + X_1 \times e^{(T+X_2+0.207)} \text{ , R2 = 0.903} \tag{7}$$

where:
AR_p= Predicted accident rate; AR_a= Current accident rate estimated by Eq. 6; X_1 = Average annual increase in AR (%); T = Number of years; X_2= Average annual increase in traffic (%).

The prediction model and all the regression parameters were found to be statistically significant at the 95% confidence level, with the coefficient of multiple determination (R^2) equal to 0.903.

Table 1

Accident Rates for the 12 Roundabouts

Roundabout	Number of Accidents	ADT	MEV	Accident Rate (veh/MEV)
R1	60	150,698	165	0.364
R2	153	170,332	187	0.820
R3	431	390,282	427	1.009
R4	299	339,186	371	0.805
R5	175	305,784	335	0.523
R6	392	481,429	527	0.744
R7	651	563,571	617	1.055
R8	771	482,791	529	1.458
R9	593	415,568	455	1.303
R10	173	123,568	135	1.279
R11	314	438,189	480	0.654
R12	159	230,716	253	0.629

4. ANALYSIS AND RESULTS

The main characteristics of the accidents' sample in the study were evaluated in terms of the main causes of the accidents and the locations of the accidents within the roundabouts' vicinity.

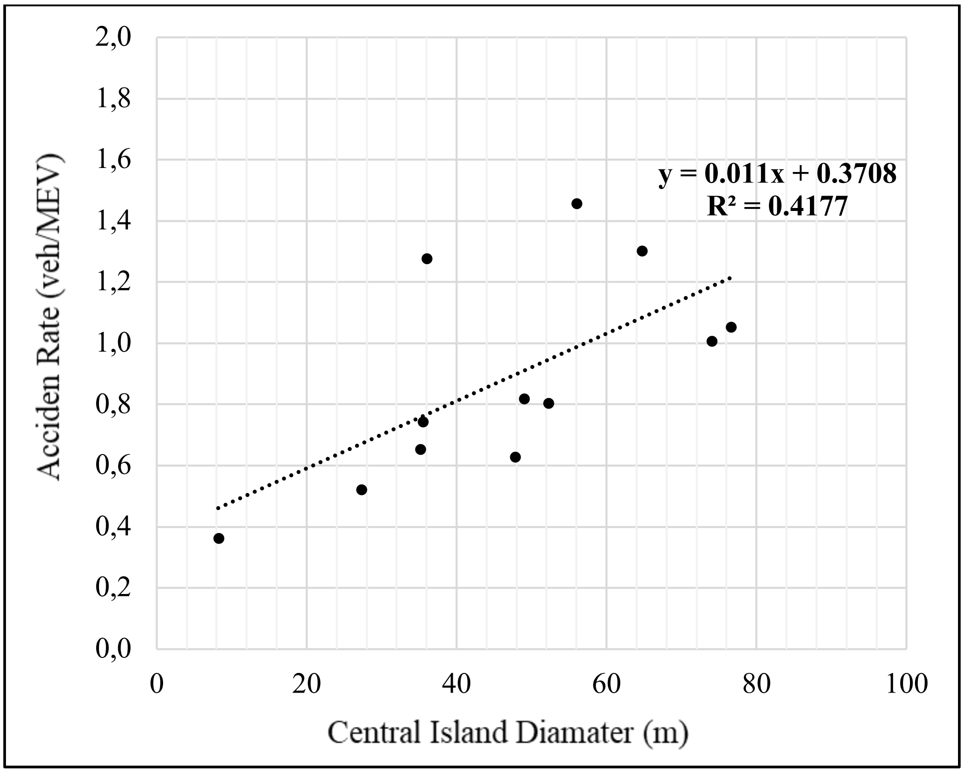

Fig. 1(a). Linear Correlation between AR and Central Island Diameter

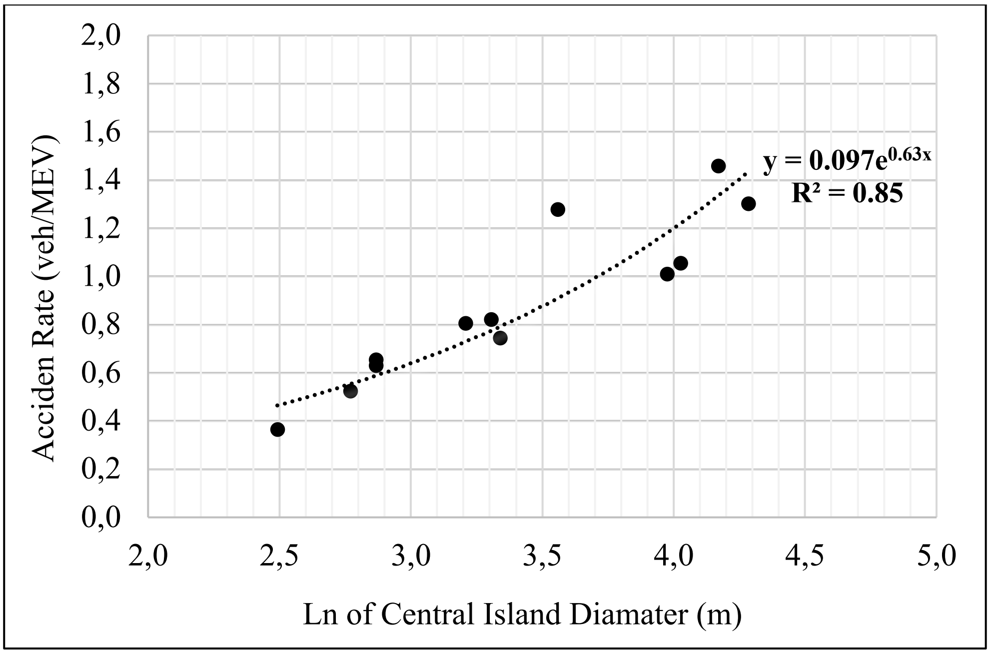

Fig. 1(b). Non-linear Correlation between AR and Central Island Diameter

4.1. Main Causes of Accidents

All of the causes of the accidents were related to the drivers' behavior one way or another. Factors such as age, judgment, driving skills, attention, fatigue, experience, etc. were all found to be contributing factors to the occurrence of accidents. Among the causes of accidents, the highest percentage was "violation of traffic rules" at 42%, followed by "violation of safety distance" at 18%, and finally "abrupt/sudden lane change" at 11%. Fig. 2 shows the distribution of the most common accident causes for the 12 roundabouts. The possible reason for the high number of violations of rules may be the lack of understanding of roundabout rules, where driving training or the licensing process has not provided adequate information about roundabouts. Similar findings have been reported in the study by Ramisetty-Mikler and Almakadma [28], which focused on the risky driving behavior of Saudi Arabian adolescents. Their study also highlighted factors such as young age, deficiency in training, and poor driving skills contributing to vehicle accidents. The study by Bener et al. [29] on driver behavior in Qatar and Turkey endorses the current findings and highlights that the drivers' socio-economic conditions, driving style and skills, cultural factors, education, as well as ethnicity, contribute to traffic rule violations.

4.2. Distribution of Accidents according to the Location

Another important characteristic of the accidents is the location within the roundabout. The majority of the accidents in the studied sample occurred in the center – traffic circulating the central island of the roundabout, as shown in Figure 3. The distribution of accidents locations was 42% for circulating traffic; 24% for entering traffic; and 34% for existing traffic. The study identified that a significant number of accidents, 42%, occur at the center of the roundabout. These findings parallel the research outcomes of Zhao et al. [31], who highlighted that this may be due to less space and fewer markings. Further analysis revealed that all roundabouts examined in the study had no clear lane markings in the circulating area, whereas signage at the entries of the roundabouts was somewhat inadequate. Similar reasoning has been reported in the study of Jaisawal et al. [32], who studied roundabout safety in India.

4.3. Estimating AR from the Prediction Model

The Predicted Accident Rates were calculated using the developed accident prediction model and compared to the Actual Accident Rates. The results are presented in Tab. 2, where the model predicted the accident rate accurately, as the percentage difference between actual AR and predicted AR was less than 10% for all the roundabouts.

4.4. Performance Evaluation

In general, the roundabouts evaluated had a good overall safety performance. Performance depends on the design, operational and safety characteristics of the roundabout. Therefore, an overall performance evaluation of the roundabouts was conducted incorporating the geometric (central island diameter) and operational (capacity) parameters, combined with the safety (accident rate) parameter of the roundabouts. A ranking matrix was created where each roundabout was scored according to the weights described in Table 3 for each parameter. Furthermore, the overall safety performance of the roundabouts was ranked according to the assigned weights in comparison to the total study sample (12 roundabouts). The ranking scale is ascending from 1 to 12, where 1 is assigned to the best overall performance and 12 represents the poorest performance.

Using the accident rates as well as the operational and geometric parameters of roundabouts, the performance evaluation of the roundabouts was carried out. Nevertheless, an accident prediction model was proposed in this research that was able to accurately predict the accident rates. Finally, the results revealed that roundabouts R7, R5 and R3 were the lowest ranking amongst the 12 studied roundabouts, which translates to the poorest overall safety performance. The best overall safety performance in the study has been observed for roundabouts R8, R9 and R7, respectively.

Table 2

Predicted vs. Actual Accident Rate

Roundabout	Actual Accident Rate (veh/MEV)	Predicted Accident Rate (veh/MEV)	Percentage Difference
R1	0.364	0.372	2.20%
R2	0.82	0.834	1.71%
R3	1.009	1.045	3.57%
R4	0.805	0.834	3.60%
R5	0.523	0.542	3.63%
R6	0.744	0.793	6.59%
R7	1.055	1.104	4.64%
R8	1.458	1.587	8.85%
R9	1.303	1.396	7.14%
R10	1.279	1.357	6.10%
R11	0.654	0.701	7.19%
R12	0.629	0.637	1.27%

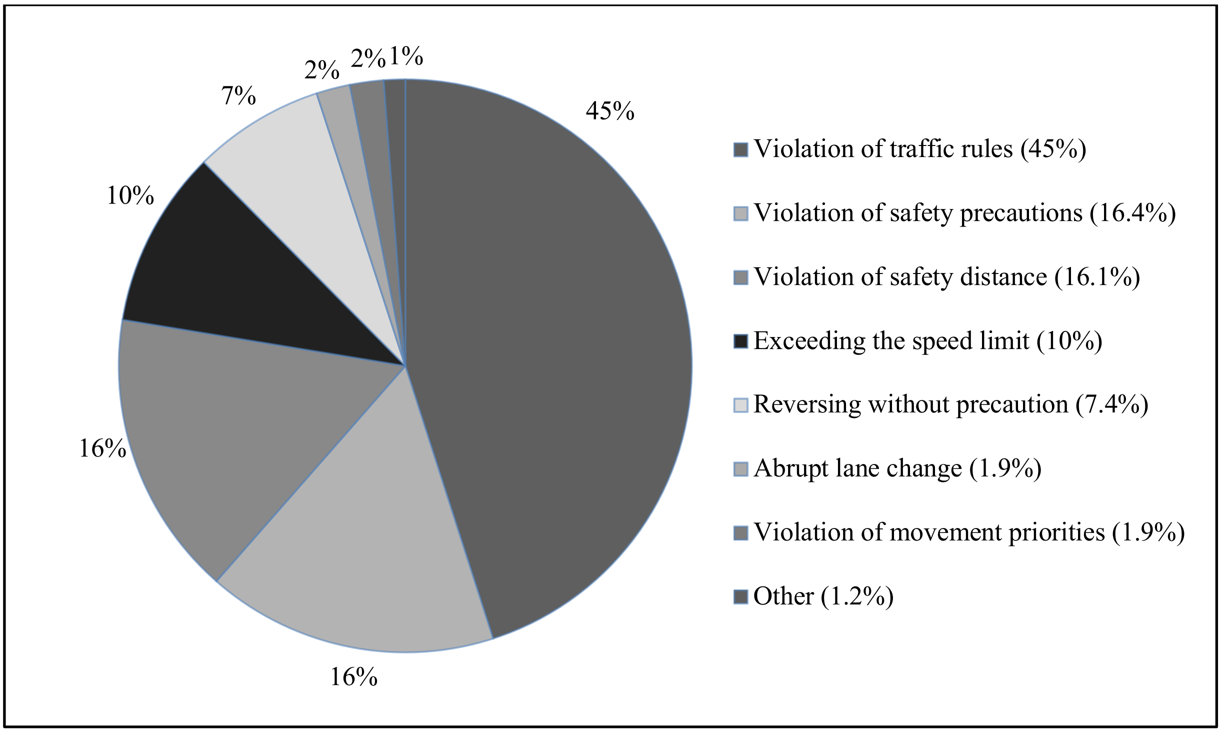

Fig. 2. Distribution of Accident Causes

The results show that the highest-ranking roundabouts were R8, R9 and R7, scoring 14, 13 and 11, respectively. On the other hand, roundabouts R7, R5 and R3 scored the least and were the lowest ranked in the study sample. The ranking of all 12 roundabouts is presented in Tab. 4.

5. CONCLUSIONS AND RECOMMENDATIONS

The improved safety performance of roundabouts is attributed to the elimination or alteration of conflict points, reduction in speed differences and the need for drivers to slow down as they approach or proceed through the intersection. The study identified the main causes of roundabout accidents in

Amman, where the main cause is related to driver behavior in the form of violations of either the traffic rules, safety precautions or safety distance at about 72%. This finding highlights an inadequacy in the recording procedure of traffic accidents by the Traffic Police Department, as several causes are grouped under "violation of traffic rules" without specifying the exact violation committed by the driver. Other factors affecting the safety performance of roundabouts were unclear circulating area lane markings and inadequate signage at the roundabouts' entries. In terms of the location of roundabout accidents, the study identified that the majority of accidents (42%) occur at the center of the roundabout, as opposed to the entrance or the exit of the roundabout.

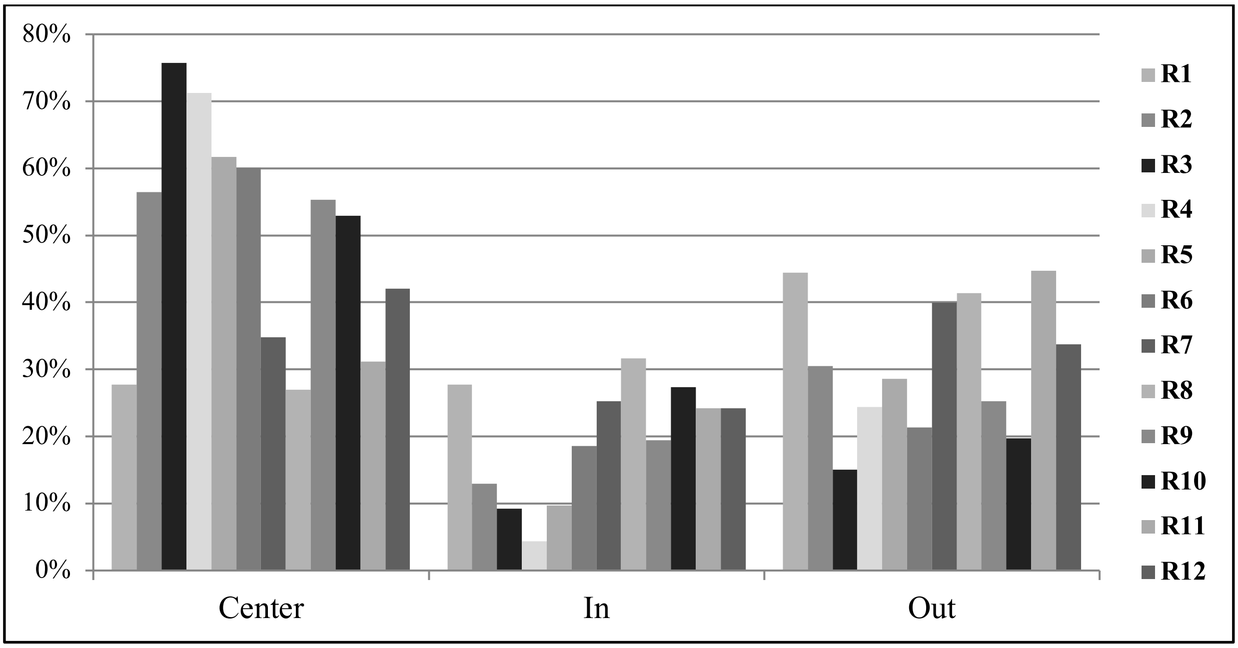

Fig. 3. Distribution of Accident Locations for all 12 roundabouts

Table 3

Parameters and Assigned Weights

Parameter	Category	Range	Weight
Safety Percentage Annual Increase in Accident Rate (%)	Very low	1 – 2.5	1
	Low	2.5 – 4	2
	Medium	4 – 6.5	3
	High	6.5 – 9	4
	Very High	>9	5
Geometric Center Island Diameter (D in m)	Small	8-25	1
	Small to Medium	25 – 35	2
	Medium	35 – 45	3
	Medium to Large	45 – 55	4
	Large	>55	5
Operational Capacity (q_e in veh/h)	Small	1000-2000	1
	Small to Medium	3000-2000	2
	Medium	2000-3000	3
	Medium to Large	4000-3000	4
	Large	>4000	5

Table 4

Ranking Matrix

Roundabout	Safety	D	q_e	Total Score	Ranking
R1	1	1	1	3	12
R2	1	4	2	7	10
R3	2	5	3	10	4
R4	2	4	2	8	7
R5	2	2	1	5	11
R6	4	3	2	9	5
R7	3	5	3	11	3
R8	5	5	4	14	1
R9	4	5	4	13	2
R10	3	3	2	8	7
R11	4	3	2	9	5
R12	1	4	3	8	7

An exponential regression accident prediction model was proposed for predicting accident rates. A safety performance evaluation framework of roundabouts was developed and applied on 12 roundabouts in Amman, Jordan. It included the accident rates as a safety parameter, the central island diameter as a geometric parameter and the capacity of the roundabout as the operational parameter.

The study suggests providing adequate training to drivers and enhancing their knowledge of roundabout driving regulations and priorities. Future research could investigate the role of the human factor in the risk perception of roundabouts, and the decisive role that it plays in conditioning driving behavior. This understanding is essential for defining new design criteria and/or for improving the existing ones.

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Appendix (1): Geometric and Operational Parameters of the 12 Roundabouts

No.	No. of Accidents	ADT	Land use*	No. of legs	CID (m)	Circulating width (m)	Entry angle	Entry/Exit width (m)	Entry/Exit Distance	FFS (Km/h)	Capacity (veh/h)	Delay (sec/vsh)	Speed Km/h	v/c	Queue length (m)	Location**
R1	4	27,409	3	4	8.2	11	0	4	31	50	1,119	12	33	1.034	240	1
R1	9	19,219	3	4	8.2	12	48	6.3	55	50	1,530	11	25	0.146	19	1
R1	6	3,721	3	4	8.2	10.5	0	6.3	40	50	1,387	7	30	0.279	1	1
R1	6	6,429	3	4	8.2	10	48	4	30	50	1,096	8	19	3.119	5	1
R1	16	56,777	3	4	8.2	11		3.2		50	3,000		50	0.121		2
R1	13	6,047	3	4	8.2	11		4		50	1,400		50	0.568		3
R1	9	13,206	3	4	8.2	12		6.3		50	1,400		50	0.326		3
R1	0	7,591	3	4	8.2	10.5		6.3		50	1,400		50	0.443		3
R1	3	10,299	3	4	8.2	10		4		50	1,400		50	1.075		3
R2	7	25,000	3	5	49	12	48	6.3	40	60	2,465	20	28	0.194	7	1
R2	3	7,957	3	5	49	12	64	6.3	26	60	2,268	18	24	0.330	1	1
R2	4	12,425	3	5	49	12	34	4	44	60	2,162	19	43	0.410	3	1
R2	6	14,718	3	5	49	12	50	4	37	60	2,081	19	38	0.150	4	1
R2	87	65,282	3	5	49	12	45.8	4.84	34.4	60	3,500	27	32	0.478		2
R2	14	27,774	3	5	49	12		6.3		60	2,800		60	0.015		3
R2	11	681	3	5	49	12		6.3		60	2,800		60	0.074		3
R2	15	3,455	3	5	49	12		4		60	2,800		60	0.048		3
R2	14	2,209	3	5	49	12		4		60	1,400		60	0.243		3
R2	10	5,648	3	5	49	12		3.6		60	1,400		60	1.719		3
R3	9	39,967	3	5	74	12	47	9	31	60	3,194	38	33	0.374	10	1
R3	3	19,817	3	5	74	12	50	10	44	60	3,765	35	46	0.394	1	1
R3	9	24,635	3	5	74	12	52	9.8	60	60	3,972	35	34	0.402	2	1
R3	8	26,545	3	5	74	12	45	8	48	60	3,329	36	33	0.346	3	1
R3	13	19,120	3	5	74	12	44	8	67	60	3,581	35	37	2.187	1	1
R3	322	130,100	3	5	74	12		3.2		60	2,389		31	0.934		2
R3	3	37,060	3	5	74	12		9		60	2,800		60	0.451		3
R3	13	20,963	3	5	74	12		10		60	2,800		60	0.707		3
R3	13	32,890	3	5	74	12		9.8		60	2,800		60	0.525		3
R3	32	24,419	3	5	74	12		8		60	2,800		60	0.318		3
R3	6	14,767	3	5	74	12		0		60	2,800		60	0.753		3
R4	6	35,033	3	4	52.2	10.8	25	8	38	60	2,712	39	33	0.653	12	1
R4	1	29,419	3	4	52.2	10.8	25	8	38	60	2,773	38	33	0.178	7	1
R4	5	8,223	3	4	52.2	10.8	29	7.7	32	60	2,614	34	32	0.975	1	1
R4	1	42,342	3	4	52.2	10.8	27	7.7	40	60	2,745	40	33	2.444	28	1
R4	209	111,462	3	4	52.2	10.8		3.2		60	1,995		30	0.374		2
R4	5	12,392	4	4	52.2	10.8		8		60	2,800		60	0.938		3
R4	26	43,638	4	4	52.2	10.8		8		60	2,800		60	0.242		3
R4	37	11,262	4	4	52.2	10.8		7.7		60	2,800		60	0.976		3
R4	6	45,415	4	4	52.2	10.8		7.7		60	2,800		60	0.523		3
R5	13	19,770	1	4	27.30	8.2	21	8	18	60	1,781	51	66	0.801	22	1
R5	10	19,270	1	4	27.3	8.2	19	8	17	60	1,808	51	65	1.454	19	1
R5	2	35,541	1	4	27.3	8.2	5	8	20	60	1,874	54	67	1.106	200	1
R5	7	28,014	1	4	27.3	8.2	19	8	20	60	1,874	53	65	3.972	83	1
R5	108	100,581	1	4	27.3	8.2	16	8	20	60	1,874	67	66	0.787		2
R5	8	19,919	1	4	27.3	8.3		8		60	2,800		60	0.523		3
R5	1	19,797	1	4	27.3	8.3		8		60	2,800		60	1.067		3
R5	11	40,378	1	4	27.3	8.3		8		60	2,800		60	0.595		3
R5	8	22,514	1	4	27.3	8.3		8		60	2,800		60	0.550		3
R6	30	25,581	1	4	35.5	12	25	10	20	60	2,436	45	34	1.151	7	1
R6	16	46,578	1	4	35.5	12	17	10	19	60	2,491	49	37	1.127	83	1
R6	12	46,628	1	4	35.5	12	35	10	19	60	2,491	49	32	1.008	83	1
R6	15	41,694	1	4	35.5	12	18	10	20	60	2,519	48	35	3.835	43	1
R6	237	160,482	1	4	35.5	12	23.75	10	19.5	60	2,505	66	34	0.592		2
R6	11	24,651	1	4	35.5	12		10		60	2,800		60	1.313		3
R6	58	61,080	1	4	35.5	12		10		60	2,800		60	1.246		3
R6	5	57,940	1	4	35.5	12		10		60	2,800		60	0.361		3
R6	0	16,794	1	4	35.5	12		10		60	2,800		60	1.076		3
R7	25	50,050	4	5	76.6	8.3	10	12.8	17	60	3,380	59	45	0.457	19	1
R7	21	25,664	4	5	76.6	8.3	30	13.5	25	60	4,020	55	43	0.330	2	1
R7	34	22,043	4	5	76.6	8.3	26	11	17	60	3,093	55	42	0.697	3	1
R7	14	35,831	4	5	76.6	8.3	27	11	34	60	3,600	57	40	0.907	4	1

No.	No. of Accidents	ADT	Land use*	No. of legs	CID (m)	Circulating width (m)	Entry angle	Entry/Exit width (m)	Entry/Exit Distance	FFS (Km/h)	Capacity (veh/h)	Delay (sec/vsh)	Speed Km/h	v/c	Queue length (m)	Location**
R7	74	54,252	4	5	76.6	8.3	31	14	41	60	4,641	59	43	2.437	5	1
R7	224	187,857	4	5	76.6	8.3		12.5		60	3,802	80	42	0.906		2
R7	43	57,209	4	5	76.6	8.3		12.8		60	3,500		60	0.252		3
R7	51	14,651	4	5	76.6	8.3		13.5		60	3,500		60	1.303		3
R7	89	75,781	4	5	76.6	8.3		11		60	3,500		60	0.434		3
R7	34	25,216	4	5	76.6	8.3		11		60	3,500		60	0.258		3
R7	41	15,017	4	5	76.6	8.3		14		60	3,500		60	0.707		3
R8	86	41,113	3	4	56	12	22	13.4	19.5	60	3,515	58	41	0.561	7	1
R8	52	42,292	3	4	56	11	15	12	23	60	3,386	58	66	0.788	9	1
R8	21	44,302	3	4	56	11	26	15	11	60	3,565	58	40	0.561	8	1
R8	86	33,223	3	4	56	11	13	16	30	60	4,768	56	49	2.032	2	1
R8	207	160,930	3	4	56	11		14.1		60	3,848		44	0.510		2
R8	67	32,608	3	4	56	11		13.4		60	3,500		60	0.629		3
R8	48	36,561	3	4	56	12		12		60	3,500		60	0.771		3
R8	99	44,850	3	4	56	11		15		60	3,500		60	0.807		3
R8	102	46,910	3	4	56	11		16		60	3,500		60	0.753		3
R9	42	35,595	3	4	64.7	12.5	40	10	10	60	2,505	60	35	0.974	58	1
R9	20	32,986	3	4	64.7	11.5	31	15	20	60	4,291	58	46	0.674	3	1
R9	27	39,081	3	4	64.7	13	33	10	19	60	3,061	61	42	0.749	28	1
R9	25	31,000	3	4	64.7	11.5	25	13	21	60	3,763	58	41	2.727	4	1
R9	327	138,662	3	4	64.7	12		12	17.5	60	3,400		40	0.853		
R9	37	39,176	3	4	64.7	12.5		10		60	2,800		60	0.975		3
R9	61	36,878	3	4	64.7	11.5		15		60	2,800		60	1.090		3
R9	43	41,230	3	4	64.7	13		10		60	2,800		60	0.554		3
R9	11	20,959	3	4	64.7	11.5		13		60	2,800		60	0.234		3
R10	1	8,838	3	4	36	12	27	12	42	60	3,243	17	44	0.143	1	1
R10	34	6,284	3	4	36	11	53	13	37	60	3,515	15	46	0.259	0	1
R10	10	12,297	3	4	36	12	31	10	27	60	2,702	18	37	0.377	2	1
R10	2	13,757	3	4	36	11	58	11	33	60	2,974	17	46	0.487	2	1
R10	7	19,554	3	4	36	12		12		60	2,800		60	0.104	4	3
R10	10	3,919	3	4	36	11		13		60	2,800		60	0.064		3
R10	5	2,432	3	4	36	12		10		60	2,800		60	0.404		3
R10	13	15,284	3	4	36	11		11		60	2,800		60	1.089		3
R10	90	41,203	3	4	36	12	42	11.5	34.8	60	3,176	23	43	1.222		2
R11	0	64,485	3	4	35.1	11	37	12.8	19	60	2,794	65	56	0.901	188	1
R11	26	41,794	3	4	35.1	10	0	13	17	60	2,886	60	54	0.830	19	1
R11	21	39,767	3	4	35.1	9	0	12.8	20	60	2,893	59	41	0.835	15	1
R11	7	40,150	3	4	35.1	11	37	12.8		60	2,800		31	1.303	19	3
R11	30	60,598	3	4	35.1	10	0	13		60	2,800		60	0.694		3
R11	31	32,259	3	4	35.1	9	0	12.8		60	2,800		60	0.281		3
R11	27	13,056	3	4	35.1	10	0	13		60	2,800		60	3.141		3
R11	95	146,080	3	4	35.1	10	0	12.9		60	2,925		45	0.602		2
R12	3	23,784	2	4	47.8	10	13	8	26	60	2,287	31	48	0.267	14	1
R12	3	8,243	2	4	47.8	10	26	8.7	33	70	2,708	28	43	0.645	1	1
R12	11	23,608	2	4	47.80	10	29	7.8	42	70	2,678	31	37	0.547	7	1
R12	8	19,797	2	4	47.80	10	28	8	41	70	2,702	30	37	0.456	5	1
R12	10	16,635	2	4	47.80	10	13	8		70	3,500		70	0.522		3
R12	2	24,689	2	4	47.80	10	26	8.7		70	3,500		70	0.490		3
R12	23	23,189	2	4	47.80	10	29	7.8		70	3,500		70	0.324		3
R12	24	15,324	2	4	47.80	10	28	8		70	3,500		70	1.595		3
R12	66	75,446	2	4	47.80	10	24	8		70	2,618		41	2.132		2

* The land uses are coded as follows: 1 for Mixed use, 2 for Residential, 3 for Commercial, 4 for Business/Fffice.

** The locations of the accidents are coded as follows: 1 for in (entry); 2 for center (middle); and 3 for out (exit).

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