Traffic safety at roundabouts in Urban Areas - Case Study in Jordan

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ABSTRACT: The main objectives of this research were to investigate traffic accidents problem at roundabouts in Jordan, and to explore possible relationships between traffic accidents and traffic, geometric and planning variables. Thirty roundabouts were selected from different cities as a case study. Traffic and geometric variables were measured through field survey. The results indicated that vehicle-vehicle accidents constitute the major portion of accidents pattern (94.2%). The analysis showed that roundabouts with three or four legs resulted in lower accidents rate than roundabouts with five legs. Traffic accidents at roundabouts were found strongly correlated with peak-hour volume, land-use type and presence of traffic calming measures. The correlation coefficients between geometric variables and traffic accidents were found relatively small. The developed statistical regression models can be used by traffic engineers to assess the impact of implementation of roundabouts on reducing traffic accidents at intersections.

BACKGROUND

Roundabout is a form of intersection at which traffic moves around a central island in one direction. Also, they can be defined as small raised island placed in the middle of an intersection. They are typically landscaped with ground cover and street trees. Roundabouts require drivers to slow to a speed that allows them to comfortably maneuver around them. Roundabouts are widely used in Europe, Australia, Arabic countries, and recently they received more acceptances in the United States and other countries. They are used to reduce conflicts points at intersections, accidents severity, traffic speeds, traffic delay, air pollution, fuel consumption, and construction costs. Although roundabouts work better than traffic signals at intersections with low to medium traffic volumes, they require large spaces, which may cause confusion for drivers who are not familiar with roundabouts capacities.

(Arndt 1998) investigated the relationship between geometry and accident rates on 100 roundabouts in Queensland. His accident prediction models included estimated speed variables, which interestingly, were found to be more significant than traffic volumes. Approach curvature, central island diameter, and separation between legs were all found to have a major impact on accident rates.

Harper and Dunn 2003) developed more advanced prediction models that enable more accurate evaluation of urban roundabout accidents. These models were developed to predict vehicle accidents on urban roundabouts in relation to traffic volumes and geometric variables. They found that entering and circulating accidents are the most common crash type. (Haycock and Hall 1984) found that at 4-arm roundabouts in the UK, the risk of single vehicle accidents increased with wider entries and with greater entry path curvature, but decreased where there was greater approach curvature.

In Jordan, roundabouts are widely used in urban and suburban areas, not only at low or medium traffic volumes but also at high volume of traffic. Although, traffic accidents problem is growing and becoming more serious over the years, safety experience at roundabouts is not well documented. According to the statistics of (Jordan Traffic Institute 2004), it was found that 70,266 traffic accidents occurred during the year of 2004, which have resulted in 818 fatalities, 2451 sever injuries and 14,276 slight injuries. Roundabouts involved during the same year in 663 traffic accidents (0.94% of total traffic

accidents and 17% of traffic accidents at intersections) with one fatality, 34 slight injuries and 2 sever injuries.

In Jordan, safety performance at roundabouts is not well documented, efforts were concentrated on evaluating capacities and delay at roundabouts. (Al-Masaied and Fedda 1998) developed an empirical model for the geometric effect on capacities of 10 roundabouts in Jordan. They found that the estimated entry capacity is mainly influenced by entry width and island diameter. In addition, (Al-Omari, Al-Masaied, and Al-shawabkah 2004) used an empirical approach to develop delay models. They found that geometric variables have significant effect on roundabout entry delay. The entry width had the greatest influence over other variables such as circulating lane width and roundabouts diameter. Performance of roundabouts and the relationship between accidents and traffic and geometric factors need further investigation in Jordan.

The main objectives of this research effort were to:

1. Explore possible relationship between traffic accidents and traffic, geometric and planning characteristics of roundabouts in Jordan based upon the available accident data.
2. Develop regression models that can be used to predict traffic accidents at roundabouts in urban areas.

DATA COLLECTION

To fulfill the needs of this research, data have been collected for 30 main roundabouts in Jordan as shown in Table 1. The selected locations were visited during different periods to determine peak-hours of traffic flow and traffic operational conditions. In addition, geometric design and planning were investigated and measured in the field.

Traffic Accident Data

Data on traffic accidents were collected from Traffic Directorates and Public Security Headquarter in the related cities. After reviewing accidents reports for three years (2003-2005) with a total of 2620 accidents, the influence areas of roundabouts were determined based on accidents reports. The following detailed accidents information was obtained from these reports:

1. Location of the accident.
2. Accident type.
3. Accident severity.

4. Time of day.
5. Day of week.
6. Week of month.
7. Drivers faults.

Table 2 show accidents experience of each roundabout in the study area. This table lists the total number of accidents for three years, the average number of accidents, and the accidents rate.

Traffic Operational Data

Traffic volume is one of the major factors that influence safety condition at roundabouts as well as any other road segments. Traffic volumes were estimated during the peak-hours based on manual traffic counts. The counting process were conducted during spring months (March and April) of 2006 and sunny working days in the mid of week (Monday, Tuesday and Wednesday).

Pedestrian counting covered pedestrians who were crossing the legs of the roundabouts in addition to those who walk around the area and in direct conflict with traffic. The counting process was conducted during the same period of traffic volume counting. Pedestrian volume was used in this study as a descriptive variable and classified into three levels:

- Low: pedestrian volume per hour <100.
- Medium: pedestrian volume per hour 100 - 200.
- High: pedestrian volume per hour >200.

Traffic speed was measured using hand gun-radar within 50 m away from the roundabouts in a random way. It was found that all roundabouts had average speed less than 40km/hr. It was found that speed had weak correlation with safety at roundabouts and based on these results, average speed variable was omitted from the analysis. This interesting finding can be explained by the fact that roundabouts traffic movement obliges drivers to slow their speed a distance before merging the circulating traffic.

Geometric Design and Planning Data

Geometric design variables for each selected roundabout were measured using tapes, in addition to direct measurements from maps, design and surveying drawings that were available in the municipalities of the selected cities. The collected data are presented below:

Table 1: The Selected Roundabouts and their Locations.

Roundabout ID	Roundabout Name	Location
R1	The First Circle	Amman
R2	The Second Circle	Amman
R3	The Third Circle	Amman
R4	The Seventh Circle	Amman
R5	Jamal Abed Al-Naser	Amman
R6	Sport City	Amman
R7	Badea'a	Irbid
R8	Zabda	Irbid
R9	Sal Al-Sagheer	Irbid
R10	Sal Al-Kabeer	Irbid
R11	Al-Jamal	Irbid
R12	Abd Al-Gader Al-Husaiene	Irbid
R13	Industrial City	Irbid
R14	Wasfe Al-Tal	Irbid
R15	Fouara	Irbid
R16	Al-Byadda	Irbid
R17	Fathel Al-Dalgamune	Irbid
R18	Electricity Company	Irbid
R19	Muhammad Al-Durra.	Irbid
R20	Shafeeg Irsheidat	Irbid
R21	Queen Nour	Irbid
R22	Engineering Association	Irbid
R23	Al –Qubba	Irbid
R24	Al-Nuaime	Al-mafraq
R25	Al-Jumruk	Al-mafraq
R26	Ahmed Al-Husban	Al-mafraq
R27	Idon	Al-mafraq
R28	Queen Zain Al-Sharaf	Al-Ramtha
R29	Al-Wakaleh	Al-Ramtha
R30	Al-Turra	Al-Ramtha

Table 2: Accidents Experience of Each Roundabout.

Roundabout	No. of accidents	No. of acid/yr.	Accidents Rate*
R1	6.9	2.3	0.05
R2	21.99	7.33	0.13
R3	73.98	24.66	0.34
R4	133.98	44.66	0.66
R5	957	319	3.39
R6	720	240	2.45
R7	8.01	2.67	0.10
R8	12.99	4.33	0.20
R9	12.99	4.33	0.11
R10	9	3	0.15
R11	2.01	0.67	0.03
R12	12.99	4.33	0.12
R13	24.99	8.33	0.21
R14	29.01	9.67	0.23
R15	18.99	6.33	0.16
R16	51.99	17.33	0.36
R17	5.01	1.67	0.04
R18	15.99	5.33	0.14
R19	9	3	0.07
R20	47.01	15.67	0.34
R21	75	25	0.46
R22	17.01	5.67	0.14
R23	125.01	41.67	0.74
R24	17.01	5.67	0.16
R25	24	8	0.23
R26	24	8	0.20
R27	15.99	5.33	0.22
R28	48	16	0.34
R29	9	3	0.17
R30	0.99	0.33	0.02

***Accidents Rate = average no. of accidents/($PHV^{0.5}$)**

1. Circulating lane width (A): This is measured from the outer edge of the central island to the center of the curbed edge of the splitter island.
2. Central island diameter (B).
3. Average entry width (C).

4. Entry angle (Φ): Which represents the conflict angle between entering and circulating streams of traffic; it was classified into 3 classes: (>30◦, 30-60◦, >60◦).
5. Number of roundabout legs.
6. Presence of calming measures: Humps and pedestrians crossing.
7. Land use type: Commercial, residential, and mixed.

Table 3 shows the collected operational, geometric and planning variables for the selected roundabouts. The statistical characteristics of the measured variables included in this study are shown in Table 4.

DATA ANALYSIS

Roundabout accidents can be categorized into vehicle-vehicle collision, pedestrians-vehicle accidents, and collision with fixed objects. The analysis showed that the majority of accidents were vehicle-vehicle collisions (94.21%), followed by pedestrian-vehicle collisions (3.84%), and the rest of the accidents were collisions with fixed objects (1.85%).

The high percentage of vehicle-vehicle collisions referred to rapid growth of car ownership in Jordan, which resulted in extra traffic volumes and extra conflicts. Pedestrians are in direct conflict with vehicle during crossing roundabout legs or walking around the roundabout area especially when pedestrian facilities are insufficient and combined with bad driver's behavior. Collision with fixed object, such as trees or sidewalk, referred to improper geometric design and construction or to bad behavior of drivers.

The results of this study indicated a remarkable reduction in accident severity at roundabouts locations. 92.87% of the accidents were classified as property damage only, 7.09% injury and only 0.04% fatality accidents. The reduction in accident severity comes from the unique shape of roundabouts, which forces drivers to slow their speeds to merge with circulating traffic. Also, severity reductions come from the reduction of conflicting points of vehicles at roundabouts, where the traffic circulates around the central island.

The most common driver faults were not giving priority for vehicles at roundabouts (58.78%), close following (9.13%), failure in changing lane (8.90%) and wrong stopping (6.53%). Other types of faults included not following traffic regulation or traffic signals and not taking care during merging.

Table 3 shows the collected operational, geometric and planning variables for each roundabout.

NO.	PHV	NO. of ARMS	ISLAND DIAMETER	LANE WIDTH	ENTRY WIDTH	ENTRY ANGLE	PED. LEVEL
R1	1756	4	82	12.2	6.2	>60	L
R2	3117	5	49	14.5	7.03	>60	H
R3	5248	5	74	15.6	10.3	>60	H
R4	4589	4	60	11	11.5	30-60	M
R5	8856	5	76.6	13	13.2	30-60	L
R6	9594	4	56	12.3	14.5	30-60	H
R7	730	3	17.8	12.2	12.5	30-60	L
R8	470	6	15	11.3	11.2	<30	H
R9	1615	5	12.85	11.8	10.4	>60	L
R10	397	4	80	13.2	16.7	>60	M
R11	665	4	51	12.3	10.1	>60	M
R12	1280	4	5.5	14	10.9	>60	H
R13	1513	4	62	11	15	30-60	L
R14	1825	5	14.5	12.7	8.9	<30	H
R15	1577	4	52	12.8	16.2	30-60	L
R16	2376	5	116	10.2	13.6	30-60	M
R17	1835	4	40	17.3	11	<30	M
R18	1543	4	17.5	13.2	9	<30	H
R19	1947	4	60	12.7	15	<30	H
R20	2110	3	14.5	17.3	12.8	30-60	H
R21	2954	4	30.6	19.3	14	30-60	L
R22	1537	3	19.9	8.4	13.7	30-60	H
R23	3206	5	20	17	11.7	30-60	H
R24	1333	4	17.1	15.5	12.2	30-60	L
R25	1175	4	33.8	14.3	10.1	30-60	M
R26	1570	4	31.8	13.9	10.2	30-60	L
R27	585	3	19.4	10.2	12.15	30-60	M
R28	2275	5	22.2	15.2	12	30-60	H
R29	304	4	23.8	11.5	9	<30	H
R30	234	4	5	13	12.9	30-60	H

Table 4: Statistical Characteristics of the Measured Variables.

Variable	Mean	Standard Deviation	Minimum Value	Maximum Value
Accidents Rate	0.39	0.72	0.02	3.39
PHV (V/H)	2273	2218	234	9594
Number of Legs	4.20	0.71	3.00	6.00
Central Island Diameter (m)	39.33	27.61	5.00	116.00

Circulating Lane Width (m)	13.29	2.40	8.40	19.30
Average Entry Width (m)	11.79	2.49	6.20	16.70

Roundabouts are considered as an efficient measure of traffic calming. However, in order to reduce the speed of approaching vehicles, calming measures such as speed humps are introduced. The presence of calming measures showed fewer accidents during crossing and walking around roundabout area. This study revealed that the presence of humps, pedestrians crossing and other calming measures increased driver's attention to excessive speeds and aggressive driving behavior. Clearly, the presence of calming measures would improve both vehicle and pedestrian safety. This result is compatible with the results of previous research (Suleiman 2004).

The analysis showed that roundabouts with more than four legs would not be a good choice to handle traffic safety. Also, traffic accidents decreased when the designers used entry angles between 30-60° and avoided lower or higher angles.

MODELING OF TRAFFIC ACCIDENTS AT ROUNDABOUTS

The main objective of this section is to investigate the effect of operational, geometric and planning variables on traffic safety at roundabouts, and to explore the possible relationships between these variables and traffic accidents. The variables included in this study are listed below:

- Operational variables (peak hour volume and pedestrian volume level).
- Geometric variables (number of roundabout legs, central island diameter, circulating lane width, average entry width, and entry angle).
- Planning variables (land uses).
- Presence of traffic calming measures.

Table 5 shows the symbols of variables and the related units. General linear regression analysis was conducted to develop accident prediction models for accident rate and number of accidents at roundabouts. Step wise regression analysis is the most suitable technique to develop the best prediction models when the number of independent variables is relatively high.

Table 5: The Symbols of Variables and the Related Units.

Symbol	Variable	Unit
Y	Accidents rate	Acc. / VPH
X	Number of accidents/year	Acc./year
X1	Peak hour volume	VPH
X2	No. of legs	Number
X3	Central island diameter	Meter
X4	Circulating lane width	Meter
X5	Average entry width	Meter
X6	Entry angle (Φ)	Degree
X7	Presence of calming measures	-
X8	Land use type	-
X9	Pedestrian volume level	-

- X6: Dummy variables equals 1 if Φ< 30º and 0 otherwise.
- X8: Dummy variables equals 1 if commercial and 0 otherwise
- X9: Dummy variables equals 1 if pedestrian volume is low (<100 ped./ hr.) and 0 otherwise.

Modeling of Accidents Rate

The following exponential model was found the best to predict accidents rate:

$$Y = 0.00041\, X1^{0.747} e^{(0.107X5 - 0.690X7 - 0.553X9)} \quad (1)$$

The prediction model and all regression parameters were found to be statistically significant at 90% confidence level, with coefficient of multiple determination equals to 0.67(R^2=0.67, Adj-R^2=0.62, F- value=12.906). The statistical characteristics of the model in Equation 1 are presented in Table 6.

Modeling of Number of Accidents

The following exponential model was found the best to predict the number of accidents:

$$X = 0.0023X1^{0.978} e^{(0.158\ X5 - 1.525X7)} \quad (2)$$

The prediction model and the regression parameters were found to be statistically significant at 90% confidence level, with coefficient of determination equals to 0.75 (R^2= 0.75, Adj-R^2= 0.72, F-value=26.244). The statistical characteristics of the model in Equation 2 are presented in Table 7.

The peak hour volume (X1) appears in the two models (Equations 1 and 2) indicating the influence of this variable on the occurrence of traffic accidents. Also, the effect of both the entry width (X5) and presence of traffic calming measures (X7) was found significant in predicting the number of accidents and accidents rate.

The developed exponential form of accident prediction model in this study is consistent with many previous studies (Haycock and Hall 1984 and Harper and Dunn 2003). However, the developed models are distinguished by their simplicity and abilities in showing the effects of new variables that were not discussed in most of similar international studies such as entry width, presence of calming measures and pedestrian volume. More details about data collection, data analysis, and prediction models of traffic accidents are presented elsewhere (Abu Al-Bandoura, 2006).

CONCLUSIONS AND RECOMMENDATIONS

The main objectives of this study were to investigate the safety performance of roundabouts in Jordan and to explore possible relationships between traffic accidents and traffic, geometric and planning characteristics of

Table 6: Statistical characteristics of prediction model in Equation 1

Variable	Unstandardized Coefficients		Standardized Coefficients	T-Value	Sig. Level (α)
	B	Std. Error	β		
Constant	-7.794	1.282		-6.080	0.000
Ln X1	0.747	0.146	0.598	5.104	0.000
X5	0.107	0.053	0.240	2.018	0.054
X7	-0.690	0.267	-0.305	-2.588	0.016
X9	-0.553	0.282	-0.232	-1.959	0.061

Table 7: Statistical characteristics of prediction model in Equation 2

Variable	Unstandardized Coefficients		Standardized Coefficients	T-Value	Sig. Level (α)
	B	Std. Error	β		
Constant	-6.063	1.373		-4.415	0.000
X1	0.978	0.162	0.599	6.043	0.000
X5	0.158	0.058	0.272	2.740	0.011
X7	-1.525	0.298	0.515	-5.120	0.000

Roundabouts. To accomplish these objectives, data on traffic accidents for three years (2003-2005) were obtained from traffic departments and data on traffic, geometric and planning characteristics were measured through field surveys for 30 roundabouts in Jordan.

Based on linear regression analysis, two prediction models were developed using accidents rate and number of accidents as dependent variables. Based on the analysis in this study, the following points were concluded:

- The majority of roundabouts accidents resulted in property damage only (92.87%), (7.09%) and (0.04%) of accidents were injury and fatality accidents, respectively.
- Vehicle-vehicle accidents had a significant proportion of the total accidents (94.21%).
- Not giving priority for circulating vehicles was found the most common driver`s fault (58.78%), and was greater than other common faults: following too closely, wrong stopping, and not giving priority for pedestrians.
- Roundabouts with three or four legs resulted in lower accidents rate and number than roundabouts with five legs.
- Presence of humps, pedestrian's crossing and other traffic calming measures at roundabouts had strong impact on reducing both the traffic accidents rate and accidents number.
- The peak hour volume and the average entry width have significant effect on safety at roundabouts.

Based on the previous findings, the following recommendations can be stated:

- Improving safety at urban roundabouts requires consideration of driver behavior, pedestrian behavior, roadway characteristics and land use planning.
- More attention should be given to pedestrian safety at roundabouts by providing traffic calming measures according to the standards and clearly mark the crosswalk at each entry.
- It is recommended to use entry angle of (30^{o}- 60^{o}) range for design purposes.
- More comprehensive well-documented accidents reports that include detailed data on all approaches of roundabouts are necessary to improve the predictability of traffic safety models.

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