

# **Evaluation of Traffic Safety at Urban Roundabouts**

**(Case study Addis Ababa)**



**MENG Project**

Submitted to Addis Ababa Science and Technology University in partial fulfillment of the requirement for the degree of Masters of Engineering in road and transport Engineering

**BY**

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# APPROVAL PAGE

This **Meng** Project entitled with “*Evaluation of traffic safety at urban roundabouts*” has been approved by the following examiners in partial fulfillment of the requirement for the degree of Master of Engineering **Meng** in **road and transport Engineering**.

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## ABSTRACT

This paper presents a brief overview of current road accident fatality statistics at urban roundabouts under mixed traffic. It discusses worrying trends, under-reporting, socioeconomic aspects of road accidents, and also common practices in safety improvement. Its main focus, however, is the importance of establishing a reliable road accident database and analysis system; road accidents being the fundamental measure of safety. Access to the database is thus an essential part of identifying, and hence targeting, specific safety problems and in evaluating the effectiveness of any measures introduced. Five roundabouts were selected from different locations as a case study. Traffic accidents at roundabouts were found strongly correlated with peak-hour volume, land-use type and presence of traffic calming measures.

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## 1. BACKGROUND

Roundabout is a form of intersection at which traffic moves around a central island in one direction. Also, it 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 many 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.

The entry width had the greatest influence over other variables such as circulating lane width and roundabouts diameter. Performance of roundabouts is mainly influenced by traffic accidents and geometric factors.

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Evaluation of junction capacity is very important since it is directly related to delay, level of service, accident, operation cost, and environmental issues. For more than three decades modern roundabouts have been used successfully throughout the world as a junction control device. Addis Ababa also has its share of roundabouts. There are three legs; four legs; five legs and six legs roundabouts in Addis Ababa. Therefore, road authorities and other concerned bodies need to conduct a comprehensive capacity and delay study of every roundabout so that they can come up with solutions for the traffic congestions, traffic delays, and level of services, accidents and operating costs.

## 1.1 Statement of the Problem

Now days, it is common to see traffic congestion at junctions in Addis Ababa at peak hours in the morning and afternoon. Hence, the traffic police need to intervene in the situation to regulate the traffic flow by over-riding the traffic control devices. Otherwise, it would be practically impossible to have normal traffic flows, especially at roundabout junctions, which is more dependent on driver behavior and balanced traffic flow between the approaches. This problem will continue and it may worsen in the future due to the rapid growth of population and vehicle numbers in Addis Ababa. Poor road planning and sub-standard geometric conditions of roundabouts have a significant effect on roundabout capacity and traffic congestion. Therefore, it is vital to evaluate the capacity of roundabouts for proper traffic operation, and to give a clear picture for the planners and traffic engineers involved in highway junction design and traffic operation tasks.

Some of the problems related to capacity of roundabouts are:

- Necessarily geometric features of roundabouts such as flare and apron do not exist.
- In some roundabouts, there are visibility problems caused by plants or elevated masonry. This causes the entering driver to hesitate on entering the circulating traffic; affecting the capacities of the roundabouts.
- Roundabouts' central islands are accessed by pedestrians.
- Absence of road marking signs and lights.

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## 2. Objectives

### 2.1. General objective

The main objective of this research is in general to know, solve and develop the traffic safety requirement of roundabouts under mixed traffic.

### 2.2. Specific objectives

The research has the following specific objectives:

- ✚ To compile available information regarding capacity analysis of roundabouts through critical literature review;
- ✚ To evaluate the capacities of roundabout junctions in Addis Ababa;
- ✚ To investigate possible causes of road accidents on roundabouts; and
- ✚ To propose low cost engineering counter measures.

## 3. Literature Review

Transport Research Laboratory of England first introduced modern roundabout facilities in the early 1960s, United Kingdom Mark (2003). These facilities were introduced in order to solve the problems of the existing rotaries and traffic circles; using the principle that entering traffic yields to circulating traffic, or the "give way" rule. And almost all city planners soon accepted it. Above all, improvement in safety is the most distinct advantage of roundabouts; most areas that implement roundabouts rules experience an impressive impact on their accident numbers. Because of this reputation, some countries have converted many ordinary intersections into roundabouts. Norway and Ireland were the first countries to follow England; the first roundabout in Norway was built in 1971. For instance, France is building almost 1500 roundabouts a year Thaweesak, (1998). In the Netherlands, since the late 1980s, approximately 400 roundabouts have been built over a period of only six years Thaweesak, (1998).

Road accidents are not reliably and regularly published by all countries of the world but accidents of the most severe form, those involving a fatality, are normally more reliably recorded than the other types. Recent research by Jacobs et al, (2000) has estimated that in 1999 about 750,000 people were killed in road accidents globally. Of most concern is that about 640,000 of these, that is, 85 per cent occur in developing countries or emerging nations. Hence there is a great need to focus efforts in developing countries.

The World Health Organization produced a report in (Murray & Lopez, 1996) which reviewed the main causes of death and disability throughout the world. 'Fatalities due to road accidents' were then ranked as the ninth most important factor. Based on a detailed analysis, the WHO made predictions of the situation for the year 2020 and the various changes in position are predicted to rise to third place (after ischaemic heart disease and unipolar major depression). Thus the need to attempt to prevent road accidents by whatever means are effective and will become increasingly important. A survey of hospitalized road accident victims in seven developing countries Ghee et al, (1997) has indicated that children up to the age of 15 constitute



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about 15 to 20 per cent of accident victims with boys in the majority in most of the 7 countries studied. However, it is young economically active males in the age range 26-45 that were the largest accident casualty group, being well over-represented when compared with their proportion of the population distribution in all countries surveyed. The majorities of these victims were married and, most were either the main earner or major contributor to the family income.

Road traffic accidents occur as a result of several factors associated with the traffic system, namely: road users, road environment and vehicles. Road accidents are concentrated in the capital city, with fatal accidents and injuries. Pedestrian accidents and multiple-vehicle accidents were dominated in urban areas. Single vehicle non-pedestrian and rollover accidents were higher in non-built-up (rural) areas. The main causes of accidents at black spots were identified to be unavailability of proper pedestrian facilities, high volume of pedestrian traffic, drivers' fatigue, lack of awareness of traffic rules and regulations, and violation of speed limit.

## 3.1 Basic Concepts and Definitions of Roundabouts

Roundabout is a form of intersection at which traffic moves around a central island in one direction. Also, it 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. A roundabout is a channelized intersection at which all traffic moves anticlockwise around a central traffic island. Yield signs control the approaching traffic and the driver can only make a right turn onto the circulating roadway. The only decision the entering motorist needs to make once they reach the yield line is whether or not a gap in the circulating traffic is large enough for them to enter. The vehicles then exit the circulating roadway by making a right turn toward their destination FHWARD- 00-067, (2000).

Roundabouts are often confused with traffic circles or rotaries and it is important to be able to distinguish between them. According to FHWA-2000 information guide, roundabouts have five main characteristics that identify them when compared to traffic circles:

-  Traffic control: Yield control is used on all entries at roundabouts. The circulatory roadway has no control.
-  Priority to circulating vehicles: Circulating vehicles have the right of way in roundabouts. Some traffic circles require circulating traffic to yield to entering traffic.
-  Pedestrian access: Pedestrian access is allowed only across the legs of the roundabout, behind the yield line. Some traffic circles allow pedestrian access to the central island.
-  Parking: No parking is allowed within the circulatory roadway or at the entries. Some traffic circles allow parking within the circulating roadway.
-  Direction of Circulation: All vehicles circulate counter-clockwise and pass to the right of the central island of the roundabout. Some neighborhood traffic circles allow left-turning vehicles to pass to the left of the central island. A case in point can be in countries like In United Kingdom, Japan, India, Australia, New Zealand, South Africa, Kenya, Uganda, Tanzania, Zambia, Zimbabwe, and Malawi.

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Besides to those five mentioned above, Thaweesak (1998) included additional features of roundabout, which distinguish them from other traffic circles.

**Approach Flare:** Most roundabout approaches flare out at the entries and allow more vehicles to enter the circulating roadway at a more obtuse angle. This improves capacity, and allows entering vehicles to enter at similar speeds as the circulating vehicles unless a queue has developed at the entry. The size and angle of the flare is generally controlled by a raised traffic island that separates the entering and exiting traffic at an approach. This island also gives pedestrians a safe location to cross the approach in two stages. This is the old English principle and gives high capacity, but low safety due to high speed in some countries.

**Deflection:** This characteristic is the geometry of the facility that requires vehicles to slow down as they maneuver through the roundabout. The size of the Center Island and angle of approach determine the deflection and potential speeds of entering and circulating vehicles. Generally, the effect of the roundabout is that traffic is required to slow down to negotiate the curve around the central island, but unlike full stop and signal controlled intersections, vehicles entering a roundabout are not required to stop completely. This makes the facility more efficient under a wide range of traffic volumes, as motorists only need to find an acceptable gap for entrance.

## 3.2 Major Geometric Features of a Modern Roundabouts

Since some methodologies (like the UK's - regression capacity analysis) depend totally on roundabout geometric features or elements, it is necessary to identify and clearly understand the geometric features or elements of roundabouts. According to the capacity study of roundabouts in the UK, geometric elements of roundabouts play an important part in the efficiency of roundabouts operational performance. Good geometric design will improve not only capacity but also safety, which is a major concern for road design.

Basic elements for design consideration of roundabouts are

- |                             |                                |
|-----------------------------|--------------------------------|
| ❖ Design of vehicles        | ❖ Entry and exit design        |
| ❖ Design speed              | ❖ Splitter island              |
| ❖ Sight distance            | ❖ Super elevation and drainage |
| ❖ Deflection                | ❖ Pavement markings            |
| ❖ Central island            | ❖ Signage                      |
| ❖ Circulating width         | ❖ Lighting                     |
| ❖ Inscribed circle diameter | ❖ Landscaping                  |

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## 3.3 Some Description on Basic Elements of Roundabouts

**Central Island:** A raised, no mountable curb usually delineates the central island, and its size is determined by the width of the circulatory roadway and the diameter of the inscribed circle.

**Truck Apron:** A truck apron is a traversable portion of the raised center island to accommodate the wheel path of oversized vehicles.

**Splitter Island:** The splitter island is placed within the leg of a roundabout to separate entering and exiting traffic and provide vehicle deflection prior to entering the roundabout.

**Bypass Lane:** A bypass lane may be warranted for heavy right turn vehicles as it allows traffic to bypass the roundabout.

**Approach Width:** The approach width refers to the width of the entering lanes before flaring or any other influence from the roundabout.

**Exit Width:** The exit width is the perpendicular distance from the right curb line of the exit to the intersection of the left edge line and the inscribed circle.

**Departure Width:** The departure width refers to the width of the lanes departing from the roundabout at a point where the width is no longer influenced by the roundabout.

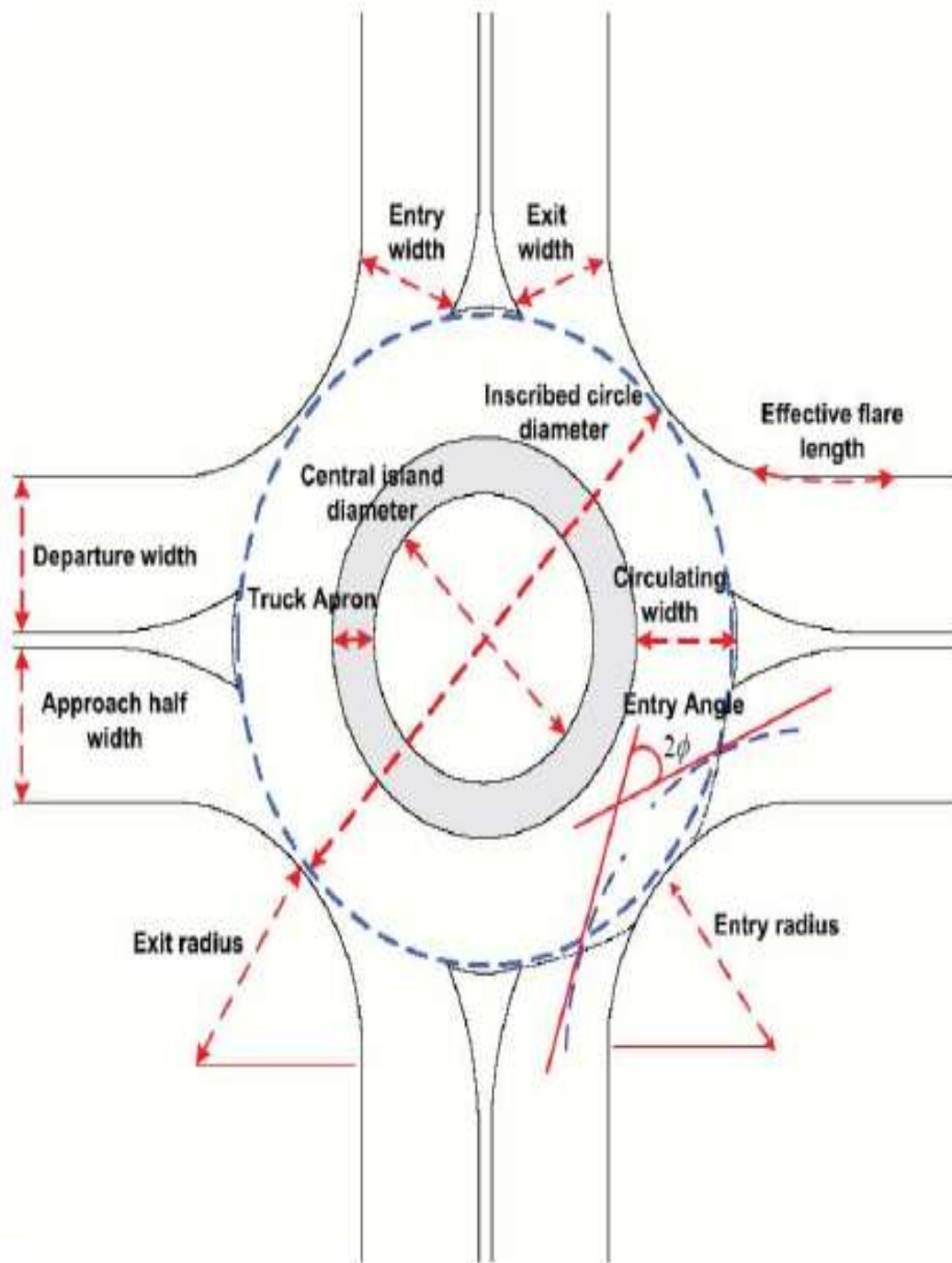
**Effective Flare Length:** The effective flare length is equal to the distance from the entry width to a point where the approach width is equal to half the sum of the entry width and the approach traveled way width prior to influence from the roundabout.

**Entry Radius:** The entry radius is the minimum radius of curvature for the compound curve measured along the right curb at entry beginning before the yield line.

**Approach Stopping Sight Distance:** The approach stopping sight distance is the minimum stopping sight distance to the back of queue or yield line at the roundabout entry.

**Circulating Roadway Width:** The width of the circulatory roadway depends mainly on the number of entry lanes and the radius of vehicle paths.

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**Fig 3-1 Major Geometric Features of Modern Roundabout**

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## 4. Materials and Methodology

### 4.1 Description Of The Study Area

To fulfill the needs of this research, data have been collected for 5 roundabouts in Addis Ababa 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.

**Table 1: The Selected Roundabouts and their Locations.**

Roundabout ID	Roundabout Name	Location
R1	German Adebabay	Addis Ababa
R2	Merat Hail	Addis Ababa
R3	Abo Adebabay	Addis Ababa
R4	Kadisco	Addis Ababa
R5	Bole Michael	Addis Ababa

### 4.2 Traffic Accident Data

Traffic movements of vehicle and vehicles' volume classification are important parameters to predict accident rate and number of accidents at roundabouts. High pedestrian volume also has a significant effect on accident. Because of this, vehicle and pedestrian volume data were needed at peak hours with their direction of movements. The vehicles and pedestrians counted are summarized as shown in Table 3. The data is collected for one hour or 60 minutes duration. For detailed information on the movement of vehicles Data on traffic accidents were collected from Traffic Directorates and Addis Ababa traffic police commission Headquarter by observing the documented data in the related roundabouts. 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.

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**Table 2: Accidents Experience of Each Roundabout.**

Roundabout ID	No. of accidents	No. of acid/yr	% of collisions		
			vehicle-vehicle	pedestrian-vehicle	vehicle-with fixed objects
R1	4	30	90.35	7.08	2.57
R2	3.2	25			
R3	2.5	20			
R4	2.5	20			
R5	3	22			

## 4.3 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 would be estimated during the peak-hours based on manual traffic counts. 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 must be 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.

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.

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**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	3222	4	65	3.5	15	30-60	9547
R2	3421	4	60	3.5	15	30-60	11239
R3	2856	4	30	3.5	13	30-60	10237
R4	2387	4	30	3.5	13	30-60	5812
R5	2984	4	30	3.5	13	30-60	8112

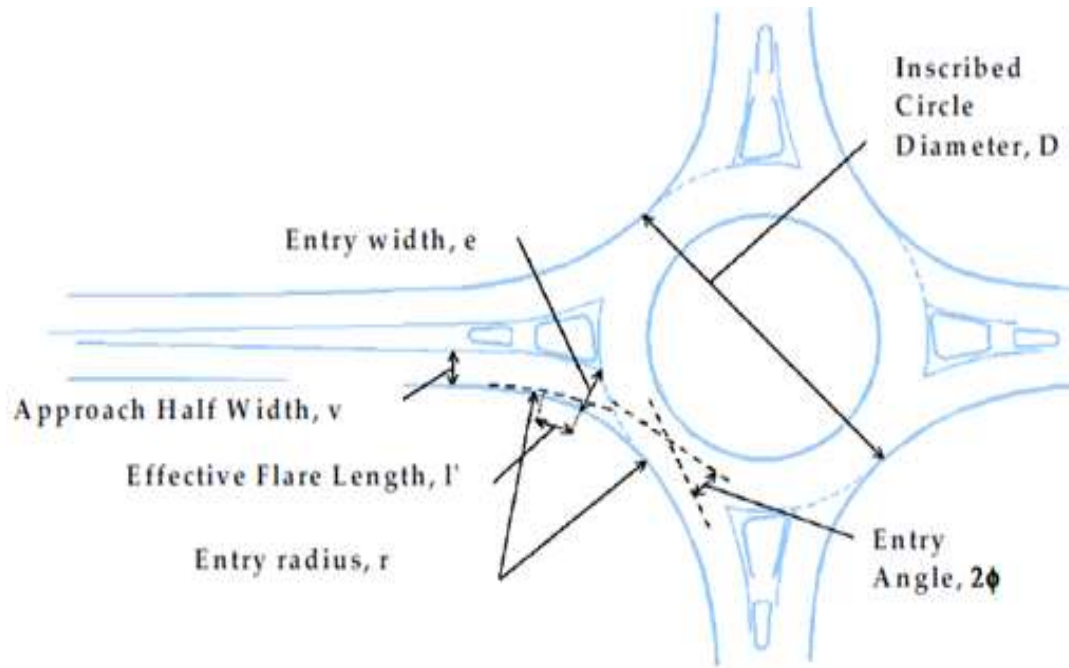
## 4.4 Geometric Design and Planning Data

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 Roundabouts. The collected data are presented below:

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 ( $\Phi$ ): Which represents the conflict angle between entering and circulating streams of traffic; it was classified into 3 classes: ( $>30^\circ$ ,  $30-60^\circ$ ,  $>60^\circ$ ).
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.

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**Figure 4-1 Geometric Parameters used for Capacity Analysis**

## Modeling of Accidents Rate

The following exponential model was found the best to predict accidents rate: (Abu Al-Bandoura, 2006).

$$Y = 0.00041 X_1^{0.747} e^{(0.107X_5 - 0.690X_7 - 0.553X_9)} \quad (1)$$

The statistical characteristics of the model in Equation 1 are presented in Table 5.

## Modeling of Number of Accidents

The following exponential model was found the best to predict the number of accidents: (Abu Al-Bandoura, 2006).

$$X = 0.0023 X_1^{0.978} e^{(0.158 X_5 - 1.525 X_7)} \quad (2)$$

The statistical characteristics of the model in Equation 2 are presented in Table 6.



# Evaluation of Traffic Safety at Urban Roundabouts

**Table 4: 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 ( $\Phi$ )	Degree
X7	Presence of calming measures	-
X8	Land use type	-
X9	Pedestrian volume level	-

- X6: Dummy variables equals 1 if  $\Phi < 30^\circ$  and 0 otherwise.
- X8: Dummy variable equals 1 if commercial and 0 otherwise
- X7: Dummy variable equals 1 if presence of calming measures 0 otherwise
- X9: Dummy variables equals 1 if pedestrian volume is low ( $< 100$  ped./ hr.) and 0 otherwise.

## 4.5 Result and Discussion

Roundabout accidents can be categorized into vehicle-vehicle collision, pedestrians-vehicle accidents, and collision with fixed objects. The analysis from table 2 showed that the majority of accidents were vehicle-vehicle collisions (90.35%), followed by pedestrian-vehicle collisions (7.08%), and the rest of the accidents were collisions with fixed objects (2.57%).

The high percentage of vehicle-vehicle collisions referred to rapid growth of car ownership 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 roundabout locations. 90.87% of the accidents were classified as property damage only, 7.09% injury and only 2.04% 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,

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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 4: Statistical Characteristics of the Measured Variables.**

Variable	Mean	Minimum Value	Maximum Value
Accidents Rate	0.488	0.37	0.529
PHV ( V/H )	2974	2387	3421
Number of Legs	3	3	3
Central Island Diameter (m)	43	30	65
Circulating Lane Width (m)	22	20	25
Average Entry Width (m)	13.8	13	15

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 drivers' attention to excessive speeds and aggressive driving behavior. Clearly, the presence of calming measures would improve both vehicle and pedestrian safety.

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.

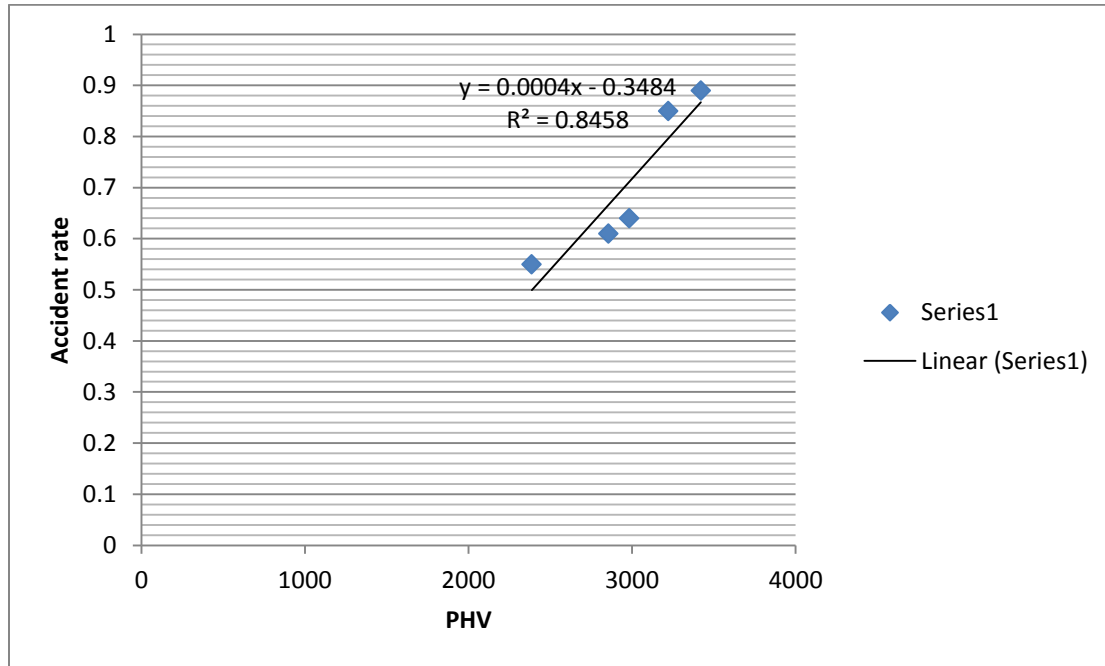
## MODELING OF TRAFFIC ACCIDENTS AT ROUNDABOUTS

Modeling of traffic accidents is used 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.

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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.



**Figure 4.2: Regression line**

## Modeling of Accidents Rate

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

$$Y = 0.00041 X_1^{0.747} e^{(0.107X5 - 0.690X7 - 0.553X9)}$$

The statistical characteristics of the model in Equation 1 are presented in Table 5.

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**Table 5: Statistical characteristics of prediction model in Equation 1**

Roundabout ID	X <sub>1</sub>	X <sub>5</sub>	X <sub>7</sub>	X <sub>9</sub>	Y
R1	3222	15m	No	0	0.85
R2	3421	15m	No	0	0.89
R3	2856	13m	No	0	0.61
R4	2387	13m	No	0	0.55
R5	2984	13m	No	0	0.64

## Modeling of Number of Accidents

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

$$X = 0.0023X_1^{0.978} e^{(0.158 X_5 - 1.525 X_7)}$$

The statistical characteristics of the model in Equation 2 are presented in Table 6.

**Table 6: Statistical characteristics of prediction model in Equation 2**

Roundabout ID	X <sub>1</sub>	X <sub>5</sub>	X <sub>7</sub>	X
R1	3222	15m	No	65
R2	3421	15m	No	68.9
R3	2856	13m	No	42.45
R4	2387	13m	No	35.62
R5	2984	13m	No	44.3

The peak hour volume (X<sub>1</sub>) 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 (X<sub>5</sub>) and presence of traffic calming measures (X<sub>7</sub>) 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. (Abu Al-Bandoura, 2006).

## 5. Conclusions

Samples of the Addis Ababa roundabouts capacity analysis results indicate that most of the roundabouts are in serious problems or over saturation. Based on observed actual field conditions, it is common to see that at peak hours, the traffic police have to regulate the traffic at these roundabouts since traffic control devices cannot function or regulate the traffic. As the study revealed, the major problems are related to inadequacy of number of entry lanes, number of circulatory lanes, high traffic flow, high volume of pedestrians and unbalanced traffic on the approaches which, in fact, are not recommended for roundabouts.

Even if modern roundabouts driving (traffic) rules are to be applied to Addis Ababa roundabouts, some of the important Geometric elements don't exist at some roundabouts, such as deflection and island splitters. Deflection is the most important geometric feature, which forces drivers to reduce their speeds and to avoid collision between neighboring leg entering vehicles. The aprons of the central islands also are not properly mounted to serve heavy vehicles.

The traffic entry flows at the roundabouts are found to be very high. Regarding the traffic volumes of the pedestrians at some roundabout intersections, it is more than expected, adversely affecting normal traffic flow and endangering their safety. According to modern roundabout traffic rules the central island should not be accessed by the pedestrians. However, the central islands are accessed by pedestrians almost all roundabouts in Addis Ababa.

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## 6. Recommendations

The Geometric elements of all Addis Ababa roundabouts should be revised and built properly as stated in design manuals of modern roundabouts since they are very helpful to have reasonable capacity and traffic safety. After additional study or peak hour data collection for the roundabouts that have high and unbalanced traffic flow, their replacement with other junction type is recommended. The roundabouts, which are located at the ring road, are not providing the intended services since this device connects high-speed primary road and access road. Therefore, replacement of these roundabouts by other junction type is recommended after careful study.

It is better to separate the pedestrians from vehicular traffic at the roundabouts where high pedestrian flows were observed since they affect normal traffic flows and the capacities of the roundabouts. Besides, this action is necessary for the safety of the pedestrians.

Since the collected data for the analysis was limited, especially regarding peak hour traffic the chart developed by this researches only insight on the theme of my research. In this respect, further study is recommended with more data collection in order to refine the chart and for use in the improvement of roundabout traffic services. The refined chart can assist the Addis Ababa City Road Authority when taking measures to improve roundabout intersections.

They can also use it in forecasting traffic capacity pertaining to land use. Thus, if more traffic is generated because of new land use, the charts can be used to easily forecast traffic in respect of each roundabout. 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:

- 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.
- 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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