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MEDIA RELEASE

Study Establishes Influence of Driver Site Distance at Modern Roundabouts

Publication from the Institute of Transportation Engineers (ITE)

Haddonfield, NJ – A study about driver site distance to be published in the July 2010 issue of *ITE Journal* was researched to predict passenger vehicle speeds and vehicle crash rates at modern roundabouts. "The Influence of Driver Site Distance on Crash Rates and Driver Speed at Modern Roundabouts in the United States," was written by Michael Angelastro, PE, PTOE, Associate of Remington & Vernick Engineers, for professionals involved in the design and safety evaluation of modern roundabouts. Mr. Angelastro is currently pursuing a Ph.D. degree at Rutgers University.

Data was collected at 26 single-lane modern roundabouts in the United States. The models developed in conjunction with this research produced statistically significant results utilizing only driver site distance as the single independent variable. The models established in the study can be used to estimate the speeds at the approach and entrance to a roundabout, and certain crash rates at modern roundabouts. Although human factors, such as driver age and gender, were not included in the research, the models presented are valid for the range of factors used to develop the models. The overall conclusion was too much site distance results in a higher crash rate since it leads to higher speeds and thus reduces roundabout safety.

Mr. Angelastro serves as a Transportation Engineer and is responsible for the completion of traffic impact studies, traffic signal analyses and design, site plan reviews, parking lot design, parking studies, NJDOT highway access permits and other related transportation engineering services. With a working knowledge of NJDOT, PennDOT, AASHTO, MUTCD and other related transportation policy standards, he has designed and managed a variety of capital improvement projects for State, County and local government agencies. Mr. Angelastro was also the co-author of "Synthesis and Evaluation of Automated Enforcement Programs in the United States," published in the Red-Light Camera Seminar held at the ITE International Meeting in March 1999.

Remington & Vernick Engineers is one of the oldest engineering firms in the country, founded in 1901 by J.C. Remington. The firm provides full survey, engineering and planning services, as well as inspection and contract administration services. The firm operates 11 offices in the tri-state region, including corporate headquarters in Haddonfield, NJ; and regional offices in Bordentown, NJ; Pleasantville, NJ; Wildwood, NJ; Toms River, NJ; Old Bridge, NJ; East Orange, NJ; Conshohocken, PA; Mechanicsburg, PA; Pittsburgh, PA and Newark, DE.

FOR IMMEDIATE RELEASE

REMINGTON & VERNICK ENGINEERS AND AFFILIATES

The Influence of Driver Sight Distance on Crash Rates and Driver Speed at Modern Roundabouts in the United States

Michael Angelastro, P.E., PTOE

Abstract. This paper investigated the driver sight distance as an independent variable to predict passenger vehicle speeds and vehicle crash rates at roundabouts in the United States based on data collected at twenty-six (26) single-lane roundabouts. Six (6) linear regression models indicate driver sight distance is a statistically significant predictor of 85^{th} percentile approach speeds, 85^{th} percentile entrance speed and the difference between the 85^{th} percentile approach speed & the 85^{th} percentile entrance speeds at the entrance to a roundabout. The speed models are found to explain between 68% and 88% of the variability in the 85^{th} percentile approach speeds, 85^{th} percentile entrance speed and the difference between the 85^{th} percentile approach speed & the 85^{th} percentile entrance speeds. The three (3) crash rate models presented in this paper have R^2 values between 0.33 to 0.48. The models developed in conjunction with this research produced statistically significant crash models utilizing only driver sight distance as the single independent variable. This paper showed that vehicle speeds and crash rates at modern roundabouts in the United States are related to driver sight distance.

INTRODUCTION

The objective of this paper was to establish that vehicle speeds and crash rates at modern roundabouts in the United States are related to driver sight distance. This paper investigated the relationship between driver sight distance and passenger vehicle speeds and vehicle crash rates at roundabouts in the United States based on data collected at twenty-six (26) single-lane roundabouts.

The 85th percentile speed parameter was selected as an analysis technique because the current operating speed models for other roadway elements evaluate design consistency using this parameter. Models were developed which predict the 85^{th} percentile approach speed, 85^{th} percentile entrance speed and the difference between the 85^{th} percentile approach and 85^{th} percentile entrance speeds. Models were developed to predict vehicle crash rates at roundabouts considering driver sight distance. The models presented in this paper can be used to estimate the speeds at the approach and entrance to a roundabout, and crash rates at modern roundabouts in the United States.

LIMITATIONS OF STUDY MODELS

The models developed in this research do not include human factors which may have significant influence on vehicle speeds and crash rates at roundabouts, including but not limited to driver age and gender. The impact human factors have on vehicle speeds and crashes at roundabouts are beyond the scope of this research and could be the subject of future research. Additionally, the models presented in this paper are valid for the range of values utilized to develop the models.

DATA COLLECTION

A portion of the data set that was used in this paper was collected at roundabouts throughout the United States under the research project funded by the National Cooperative Highway Research Program project #3-65 *Applying Roundabouts in the United States* (NCHRP 3-65). A primary objective of NCHRP 3-65 is to develop new models to estimate the safety and operational impacts of roundabouts and to enhance the criteria for the design of modern roundabout in the United States.[1] To support this effort, a key component of NCHRP 3-65 was the data collection and the development of a database on facility operation and safety for a variety of roundabout sites in the United States.[1] NCHRP 3-65 was the first nationwide research project to develop a dataset concerning roundabouts in America, and to investigate the implications of roundabout design with respect to operational and safety performance.[1]

NHCRP contracted with a private consultant and three major universities in the year 2003 to complete a nationwide roundabout data collection project. The NHCRP 3-65 project involved onsite field data collection of roundabout operations and geometric elements.[1] The data was collected through onsite measurements via video camcorders, speed data through radar guns, and the measurement of geometric design elements.[1] Additionally, police crash reports were obtained to determine the crash frequency and severity at roundabouts.[1]

The following are geometric information that was taken/measured directly from the design plans and the various horizontal elements are illustrated in Figure 1.[1]

- Inscribed circle diameter
- Entry width
- Approach half width
- Effective flare length
- Entry radius
- Entry angle
- Exit width
- Departure width
- Exit radius
- Angle to the next entry leg
- Type of pedestrian crosswalk

- Splitter island width
- Splitter island length
- Circulating roadway width
- Truck apron width
- Central island diameter
- Striping on the circulating roadway
- Lane configuration (lane 1, lane 2, lane 3, bypass lane)
- Type of vertical geometry (entering, exiting, circulating)

The dataset was supplemented by additional speed data and sight distance measurements collected at each of the study roundabouts. The minimum of 15 speed observations were collected along each arm of the study roundabouts. A majority of the roundabout locations were supplemented with an additional 50 speed observations along each approach to the study roundabouts. The data was collected during daylight and dry conditions. Speed data was collected via RADAR guns. Table 1 indicates the study roundabouts.

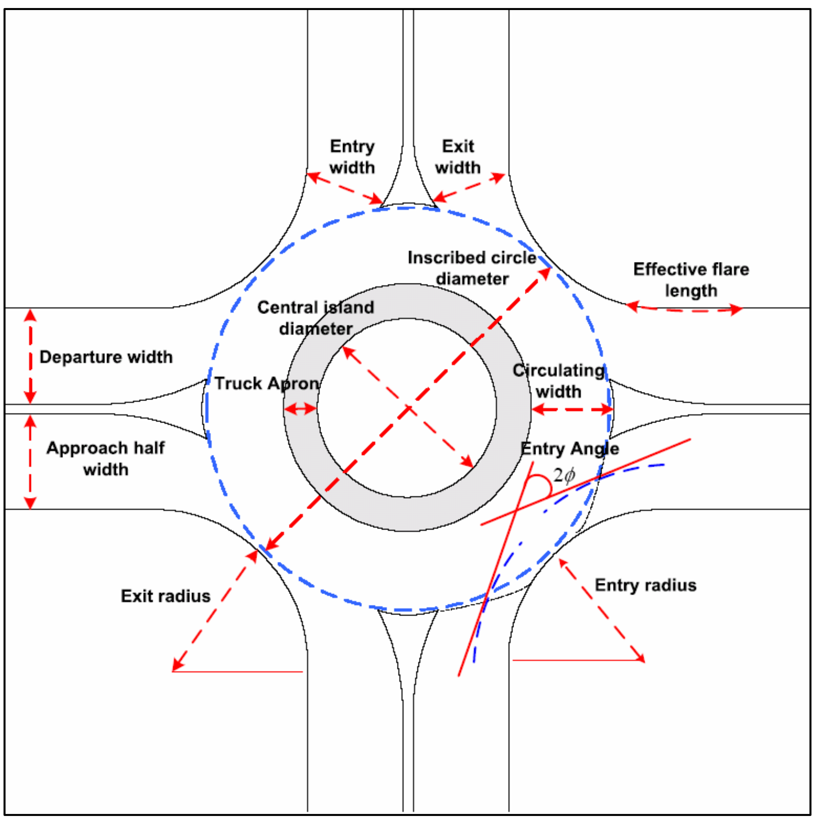

Figure 1 - Data extracted from engineering documents
(Source: *NCHRP 3-65: Data Collection and Extraction*)

Sight distance measurements were obtained at the study locations and the collection procedures were in accordance with AASTHO standards.[2] Measurements were collected by a two-person crew using measuring tapes and measuring wheels.

Additionally, sight distance measurements were also obtained via photogrammetry methods. Sight distance data was collected at four locations along each approach as shown in Figure 2.

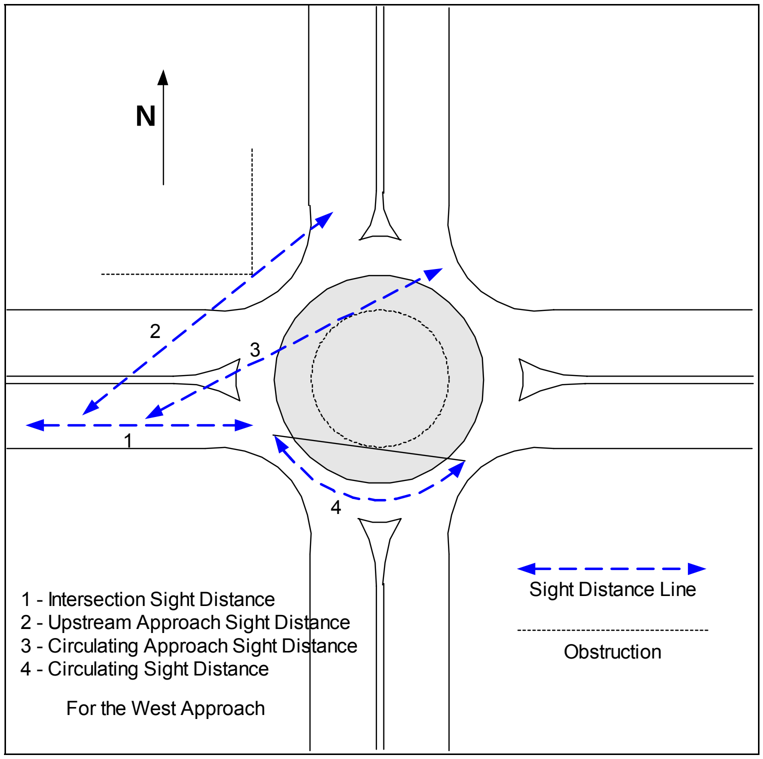

Figure 2 - Sight Distance Measurements
(Source: *NCHRP 3-65: Data Collection and Extraction*)

Intersection sight distance, d_1, is the distance at which an approaching vehicle can visibly detect the upcoming roundabout.[1] The upstream approach sight distance, d_2, is the distance measured on the approaching roadway in which a vehicle can detect another vehicle on the upstream approach.[1] Circulating approach sight distance, d_3, is distance measured on the approaching roadway in which an approaching vehicle can detect another vehicle present on the circulating roadway and the circulating sight distance, d_4, is the distance along the centerline of the circulating lane in which a vehicle that entered from the subject approach can detect another vehicle on the circulating roadway.[1]

The supplement speed data was collected approximately 250 feet upstream from the entry yield line of the roundabout and speeds at this location represent speeds prior to vehicle decelerating to travel through the roundabout[1] and entering speeds were recorded as vehicles entered the roundabout and speeds were recorded as the front of the vehicle crossed the yield line.[1] Vehicle's speeds were only recorded when the vehicles were traveling under a free flowing condition. Vehicles at location 2 were not recorded if they were yielding to other vehicles entering the roundabout or yielding to other vehicles circulating through the roundabout.[1]

DATA ANALYSIS

The data base utilized in this paper consisted of the variables shown in Table 1 and these variables were used to develop the models presented later in this paper.

Sight Distance Data	
Intersection sight distance, ft	Circulating approach sight distance, ft.
Upstream approach sight distance, ft.	Circulating sight distance, ft.
Vehicle Speed Data	
Approach 85th percentile speed	
Entrance 85th percentile speed	
Difference 85th approach - 85th entrance speed, mph	
Approach mean speed	
Entrance mean speed	
Difference mean approach - entrance speed, mph	
Geometric Data	
Entry width, ft	Truck apron, ft
Departure width, ft	Lanes per approach
Circulating width, ft	Entry radius, ft
Approach half width, ft	Entry angle, degrees
Effective flare length, ft	Exit width, ft
Inscribed Diameter, ft	Exit radius, ft
Crash Data	
Entry rear end crashes, crashes/year	
Entry rear-end severe Injury, crashes/year	
Approach rear-end crashes, crashes/year	
Approach rear-end severe injury, crashes/year	
Entry/circulating crashes, crashes/year	
Entry/circulating severe injury, crashes/year	
Circulating/exiting severe injury, crashes/year	
Circulating/exiting, crashes/year	
Circulating/exiting/rear-end, crashes/year	
Circulating/exiting/rear-end severe injury, crashes/year	
Loss of control crashes, crashes/year	
Loss of control severe injury, crashes/year	
Vehicle/pedestrian crashes, crashes/year	
Vehicle/ pedestrian severe Injury, crashes/year	
Vehicle/bike crashes, crashes/year	
Vehicle/bike severe injury, crashes/year	
Traffic Data	
Annual average daily traffic	Posted speed limit on approach, mph

Table 1 - Data Base Parameters for Statistical Analysis

DESCRIPTIVE STATISTICS

The 85th percentile vehicle speeds and vehicle crash rates were the dependant variables chosen for this analysis. A descriptive statistical analyses was performed on the speed, geometric and operational variables. Data was collected at 26 roundabouts located throughout the United States. The study roundabouts consisted of four (4) approaches and three (3) approaches. A total of 98 approaches were used in the speed model development and 80 approaches were used for the crash model development. Table 2 provides a portion of the descriptive statistics associated with the independent variables utilized in the paper.

Variable	n	Mean	Std. Dev.	Minimum	Maximum
Sight Distance Data					
InterSD	98	1128.70 ft	401.37 ft	528.00 ft	1850.00 ft
UpStrSD	98	426.96 ft	376.03 ft	117.00 ft	1584.00 ft
CirAppSD	98	355.48 ft	390.86 ft	97.00 ft	1500.00 ft
CirSD	98	124.19 ft	55.15 ft	75.00 ft	259.00 ft
Vehicle Speed Data					
AppSpd	98	33.56 mph	4.66 mph	22.00 mph	44.00 mph
EntSpd	98	21.67 mph	2.45 mph	18.00 mph	26.00 mph
DiffSpd	98	11.85 mph	4.29 mph	3.00 mph	23.00 mph
MeanAppSpd	98	30.28 mph	4.66 mph	16.00 mph	40.20 mph
MeanEntSpd	98	18.63 mph	1.85 mph	16.00 mph	22.00 mph
DiffMeanSpd	98	11.63 mph	4.18 mph	0.00 mph	21.20 mph
Geometric Data					
EW	98	15.96 ft	1.83 ft	13.00 ft	20.00 ft
DW	98	13.31 ft	2.63 ft	10.00 ft	20.00 ft
CW	98	18.59 ft	1.47 ft	16.00 ft	21.00 ft
AHW	98	14.27 ft	4.30 ft	10.00 ft	28.00 ft
EFL	98	82.98 ft	110.38 ft	0.00 ft	499.00 ft
IDia	98	114.81 ft	17.18 ft	100.00 ft	150.00 ft
TRkapp	98	11.85 ft	3.06 ft	10.00 ft	20.00 ft
Lane	98	1.00	0.00	1.00	1.00
ERad	98	69.63 ft	24.60 ft	50.00 ft	162.00 ft
EAng	98	13.76 deg	5.59 deg	5.00 deg	22.00 deg
ExitW	98	17.59 ft	1.08 ft	16.00 ft	20.00 ft
Exitrad	98	89.65 ft	31.36 ft	50.00 ft	162.00 ft
Crash Data*					
EntRear	80	0.17 crash/yr	0.39 crash/yr	0.00 crash/yr	1.31 crash/yr
EntRearSevInj	80	0.06 crash/yr	0.16 crash/yr	0.00 crash/yr	0.67 crash/yr
AppRear	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr

AppRearSevInj	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
EnCir	80	0.05 crash/yr	0.12 crash/yr	0.00 crash/yr	0.48 crash/yr
EnCirSInj	80	0.01 crash/yr	0.04 crash/yr	0.00 crash/yr	0.18 crash/yr
CirExit	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
CirExitSInj	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
CirExRe	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
CirExReSInj	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
Loss	80	0.23 crash/yr	0.28 crash/yr	0.00 crash/yr	0.79 crash/yr
LossSInj	80	0.05 crash/yr	0.12 crash/yr	0.00 crash/yr	0.49 crash/yr
VehPed	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
VehPedSInj	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
VehBik	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
VehBikeSinj	80	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr	0.00 crash/yr
Traffic Data					
AADT	98	2821.68	1982.28	434.00	7301.00
Post	98	37.78 mph	6.25 mph	30.00 mph	50.00 mph

* crash rates were determined by dividing the total number of crashes by the time period for which data was available.

Table 2 Descriptive Statistics for Database

where:

InterSD	=	intersection sight distance, ft.
UpSSd	=	upstream approach sight distance, ft.
CirASd	=	circulating approach sight distance, ft.
CirSD	=	circulating sight distance, ft.
AppSpd	=	approach 85th percentile speed, mph
EntSpd	=	entrance 85th percentile speed, mph
DiffSpd	=	difference 85th approach - 85th entrance speed, mph
MnASd	=	approach mean speed
MnESd	=	entrance mean speed
MnDSd	=	difference mean approach - entrance speed, mph
EW	=	entry width, ft
DW	=	departure width, ft
CW	=	circulating width, ft

CID	=	central island diameter, ft
AHW	=	approach half width, ft
EFL	=	effective flare length, ft
IDia	=	inscribed diameter, ft
Tkapp	=	truck apron, ft
Lane	=	lanes per approach
ERad	=	entry radius, ft
EAng	=	entry angle, degrees
ExitW	=	exit width, ft
Exitrad	=	exit radius, ft
EntRear	=	entry rear end crashes, crashes/year
EntRInj	=	entry rear-end severe Injury, crashes/year
AppRear	=	approach rear-end crashes, crashes/year
AppRInj	=	approach rear-end severe injury, crashes/year
EnCir	=	entry/circulating crashes, crashes/year
EnCirInj	=	entry/circulating severe injury, crashes/year
CirExit	=	circulating/exiting severe injury, crashes/year
CirExitSInj	=	circulating/exiting, crashes/year
CirExRe	=	circulating/exiting/rear-end, crashes/year
CirExReInj	=	circulating/exiting/rear-end severe injury, crashes/year
Loss	=	loss of control crashes, crashes/year
LossSInj	=	loss of control severe injury, crashes/year
VehPed	=	vehicle/pedestrian crashes, crashes/year
VehPedInj	=	vehicle/ pedestrian severe Injury, crashes/year
VehBik	=	vehicle/bike crashes, crashes/year
VehBikeinj	=	vehicle/bike severe injury, crashes/year
TCrash	=	total crashes, crashes/year
AADT	=	annual average daily traffic
Post	=	posted speed limit on approach, mph

SPEED DATA TEST FOR NORMALITY

The speed distributions at each speed measurement point were first tested for normality. A Kolmogorov-Smirnov (K-S) test was performed to establish whether the observed speeds follow the normal distribution at each of the locations observed. The K-S test was chosen instead of the Chi-square test because the speed samples are from a continuous distribution.

The Kolmogorov-Smyrnov (K-S) test is a technique for evaluating how well a measured distribution can be represented by a mathematical distribution (goodness of fit). The test does not assume a shape for the population from which the samples are taken. The test is based on the measurement of the maximum vertical difference between the two cumulative distributions. The K-S statistic "d" is the maximum absolute difference between two cumulative density functions (observed and hypothesized). This is compared to the K-S table of D_o's, for a specified α and sample size. The 26 sites consisted of 98 K-S tests of the following hypothesis for normality:

Ho: Speeds (on approach or entrance) are normally distributed
Ha: Speeds (on approach or entrance) are not normally distributed

The tests resulted in three (3) of the 98 tests (approximately 4%) concluding: reject the null hypothesis, therefore the speed data can be represented by a normal distribution at a 95 percent confidence level. It was thus concluded that the data can be assumed to be normally distributed and therefore conventional statistical procedures are valid in order to analyze this data. Each arm of the roundabout was analyzed individually for normality.

MODEL SPECIFICATION

The preliminary data analysis used standard statistical correlation methods to identify the relationships between potential independent variables and the dependent variables (vehicles, crashes, and 85th percentile driver speed at the approach and entrance to the roundabouts). The linear regression model is given in the following general form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots\dots\dots\dots + \beta_i X_i \qquad (1)$$

where:

Y = Dependent variable
β_0 = Constant
X_i = Independent variable "*i*"
β_i = Respective parameter of independent variable "*i*"

The models were estimated using Minitab and *Statgraphics - Centurion* statistical software package and these software packages were selected because of their straightforwardness in model estimation. The *best subsets regression* module was utilized to achieve the best possible combination of independent variables. Forward/backward stepwise regression procedure was used and this routine is probably the most widely used automatic search methods.[3] This procedure develops a sequence of regression models, at each step adding or deleting an independent variable. The criterion for adding or deleting an independent variable is stated in terms of error sum of squares reduction coefficient of partial correlation, or F* statistic.[3] The following section provides a detailed review of regression modeling procedures.

MODEL ESTIMATION RESULTS

The models formulated in this paper predict 85th percentile approach and entrance speeds of passenger cars and certain crashes at modern roundabouts in the United States. Models were developed to predict the 85^{th} percentile vehicle speed difference (85^{th} percentile approach speed - 85^{th} percentile entrance speed) at the entrance to a roundabout as a function of driver sight distance. Sight distance was the independent variable that was found to be statistically significant in following predictive models. The following sections describe the models in detail.

85^{TH} PERCENTILE APPROACH SPEED

A regression analysis was conducted to predict the 85th percentile speeds of passenger cars at the approach tangent to a roundabout. As previously indicated, the point of interest is 250 feet from the yield line located at the entrance to the roundabout. The analysis reviewed the ability of intersection sight distance as the only independent variable to predict approach speeds. Model 2 yielded an R^2 value of 0.84 and the independent variable, intersection sight distance has a p-value of 0.000.

$$AppSpd = 0.0334 \times InterSD \quad (2)$$

where:

AppSpd = 85^{th} percentile approach speed, mph

InterSD = Intersection sight distance, ft.

A linear model describes the relationship between approach 85th percentile approach speed and intersection sight distance. The p-value is less than 0.05 indicating there is a statistically significant relationship between the approach 85th percentile speed and intersection sight distance at the 95.0% confidence level.

The model explains 84% of the variability in approach speed utilizing only one independent variable. The correlation coefficient indicates a very strong correlation between the independent and dependent variable. The remaining variability in the data may be explained by human factors such as age or gender. Other variables such as weather conditions, and time of day could assist in explaining vehicle speeds when approaching roundabouts. Based on the results of the regression analysis, as intersection sight distance increases vehicle speeds also increase. Conversely, as sight distance decreases vehicle speeds also decrease. This relationship is reasonable given that when drivers have an unobstructed view of the roadway vehicle speed increases.

85TH PERCENTILE ENTRANCE SPEED

The regression analysis developed a model that will predict the 85th percentile entrance speed at the entrance to a roundabout based on the intersection sight distance. The various geometric elements associated with the entrance to a roundabout were also reviewed and the analysis revealed that the intersection sight distance was a statistically significant independent variable. Model 3 yielded an R^2 value of 0.85 and the independent variable, intersection sight distance has a p-value of 0.0000.

$$EntSpd = 0.0212 \times InterSD \qquad (3)$$

where:

EntSpd	=	85th percentile entrance speed, mph
InterSD	=	Intersection sight distance, ft.

The linear regression model explains 85% of the variability in entrance speed utilizing only one independent variable. The correlation coefficient indicates a very strong correlation between the independent and dependent variable.

A second regression model was developed to predict the 85th percentile entrance speed at the entrance to a roundabout based on the circulating sight distance. Model 4 yielded an R^2 value of 0.80 and the independent variable, circulating sight distance has a p-value of 0.0000.

$$EntSpd = 0.1429 \times CirSD \qquad (4)$$

where:

EntSpd	=	85th percentile entrance speed, mph
CirSD	=	Circulating sight distance, ft.

The linear regression model explains 80% of the variability in entrance speed data utilizing only one independent variable.

A third model was developed to predict entrance speeds at roundabouts utilizing intersection sight distance and circulating sight distance. Model 5 yielded an R^2 value of 0.88 and the independent variables, intersection sight distance and circulating sight distance have p-values of 0.0000.

$$EntSpd = 0.0112 InterSD + 0.0553 CirSD \qquad (5)$$

where:

EntSpd	=	85th percentile entrance speed, mph
InterSD	=	Intersection sight distance, feet
CirSD	=	Circulating sight distance, ft.

Based on the results of the regression analysis, as intersection sight distance and circulating sight distance increases vehicle speeds also increases. Conversely, as sight distance decreases vehicle speeds also decrease. This relationship was reasonable and appropriate given that when drivers have an unobstructed view of the roadway vehicle speeds appears to increase.

DIFFERENCE 85TH PERCENTILE APPROACH SPEED AND 85TH PERCENTILE ENTRANCE SPEED

The regression analysis yielded a linear model that will predict the difference between the 85th percentile approach speed and 85th percentile entrance speed at the entrance to a roundabout. The analysis indicated that intersection sight distance is a significant independent variable. As indicated in the following regression equation, intersection sight distance was found to be statistically significant with a p-value of 0.000.

$$DiffSpd = 0.01204 \times InterSD \quad (6)$$

where :

DiffSpd	=	Difference between 85th Percentile Approach Speed and 85th Percentile Entrance Speed at roundabout entrance, mph
InterSD	=	Intersection sight distance, ft.

This model has an R^2 of 0.68 @ p = 0.05 which explains 68% of the variability in the difference between the 85th percentile speed difference and the 85th percentile entrance speed utilizing only one independent variable, intersection sight distance. The correlation coefficient equals 0.84 indicating a very strong correlation between the independent and dependent variable.

A second regression model was developed to predict the difference between the 85th percentile approach speed and the 85th percentile entrance speed based on the circulating sight distance. Model 7 yielded an R^2 value of 0.52 and the independent variable, circulating sight distance has a p-value of 0.0000.

$$DiffSpd = 0.0071 \times CirSD \quad (7)$$

where:

DiffSpd	=	Difference 85th Percentile Approach Speed and 85th Percentile Entrance Speed at roundabout entrance, mph
CirSD	=	Circulating sight distance, ft.

This model has an R^2 of 0.52 @ p = 0.05 which explains 52% of the variability in the difference between the 85th percentile approach speed and the 85th percentile entrance speed utilizing only one independent variable, circulating sight distance.

The models explain 68% and 52% of the variability in speed difference utilizing only one independent variable. The correlation coefficients indicate a strong correlation between the independent and dependent variable. The remaining variability in the data may be explained by human factors such as age or gender. Other variables such as geometric elements, weather conditions, and time of day could assist in explaining vehicle speeds when entering roundabouts. Based on the results of the regression analysis, as driver sight distance increases vehicle speeds also increase. Conversely, as sight distance decreases vehicle speeds also decrease. This relationship is reasonable given that when drivers have an unobstructed view of the roadway vehicle speeds appear to increase.

VEHICLE CRASHES

Three (3) models were developed to predict vehicle crashes at modern roundabouts in the United States utilizing driver sight distance. The types of crashes analyzed in this paper are as follows:

Crash Type	
Entry, rear end crashes	Circulating/exiting/rear-end
Entry rear-end severe Injury	Circulating/exiting/rear-end severe injury
Approach rear-end crashes	Loss of control crashes
Approach rear-end severe injury	Loss of control severe injury
Entry/circulating crashes	Vehicle/pedestrian crashes
Entry/circulating severe injury	Vehicle/ pedestrian severe Injury
Circulating/exiting severe injury	Vehicle/bike crashes
Circulating/exiting	

Table 3 - Crash Types

Upon completion of the correlation analysis, several crash types were identified as crashes that could yield successful regression models. The identified crashes were entry rear-end, loss of control and total crash rates. Previous research has indicated that crashes are correlated with average annual daily traffic volumes (AADT)[4] and this independent variable is usually found to be a statistically significant predictor of crash rates.

The author recognizes that AADT is the primary independent variable to predict vehicle crashes. These models were developed to validate the statement in the FHWA's publication Roundabout: Information Guide: *"Providing more than the minimum required intersection sight distance can lead to higher speeds that reduce intersection safety".*[4] The crash models are valid for AADT between 434 vehicles per year and 7,300 vehicles per year. Future models will include driver sight distance and AADT as independent variables.

ENTRY REAR-END CRASHES

The regression analysis developed a model to predict entry rear-ends crash rates that utilized a single independent variable. Model 8 yielded an R^2 value of 0.37 and the independent variable circulating sight distance has a p-value of 0.0000.

$$EntRear = 0.0031 \times CirSD \quad (8)$$

where :

EntRear	=	Entry, rear-end crashes, crashes per year
CirSD	=	Circulating sight distance, ft.

The p-value indicates a moderately strong correlation between the dependent variable and the single independent variable and the model explains 37% of the variability in entry rear end crash rate. The results of the analysis indicate that entry rear-end crash rate increases as circulating sight distance increases. The results seem counter intuitive however the results of the regression analysis seem to correspond to the results the effect sight distance has on vehicle speed. Upon review of the previous presented speed models when drivers approach a roundabout with more sight distance they are more likely to enter the roundabout at a higher speed resulting in a higher crash rate. This theory seems to be validated by speed prediction models presented in this paper that indicates that vehicle speeds increase with increased sight distance. The results are consistent with research conducted in Britain that determined too much sight distance results in higher crash rates.[4]

This crash model presented in this paper explains a greater portion of the variability in entry rear-ends crashes than other models developed to predict crash rates at modern roundabouts which utilized five or more independent variables.[5]

LOSS OF CONTROL CRASHES

The evaluation of the data revealed that intersection sight distance was a statistically significant independent variable to predict loss of control crash rate at modern roundabouts. Model 9 yielded an R^2 value of 0.33 and the single independent variable, intersection sight distance has a p-value of 0.0000.

$$Loss = 0.002 \times InterSD \quad (9)$$

where :

Loss	=	Loss of control, crashes/year
InterSD	=	Intersection sight distance, feet

The p-value indicates a moderately strong correlation between the dependent variable and the single independent variable and the model explains 33% of the variability in the data. This is a relatively high percentage considering a single independent variable explains one-third of variability in loss of control crash rate. The results of the analysis indicate that loss of control crash rate increases as circulating sight distance increases. The results are consistent with the previously presented crash models. It appears that the portion of the loss of control crashes occur at the entrance to the roundabouts. This finding indicates as drivers approach a roundabout with more sight distance they are more likely to enter the roundabout at a higher speed resulting in higher crash rate.

The crash model presented in this paper explains a greater portion of the variability in the data than other models developed to predict crash rates at modern roundabouts which utilized five or more independent variables.[5] Again the results are consistent with previous research conducted in Britain that determined that too much sight distance results in higher crash rates.[4]

TOTAL CRASHES

The regression analysis yielded a linear model that will predict the total crash rate at modern roundabouts. Model 10 yielded an R^2 value of 0.48 and the independent variable circulating sight distance, has a p-value of 0.0000.

$$TCrash = 0.0058 \times CirSD \qquad (10)$$

where :

TCrash	=	Total crashes, crashes/year
CirSD	=	Circulating sight distance, ft.

The p-value indicates a strong correlation between the dependent variable and the single independent variable and the model explains 48% of the variability in the total crash rates. Sight distance was evaluated as an independent variable and circulating sight distance that was found to be a statistically significant predictor of total crash rates at modern roundabouts in the United States.

The majority of the crashes at the study locations occurred at the entrance to the roundabouts. The results of the analysis indicate that the total crash rate increases as circulating sight distance increases. Again, the results seem counter intuitive however the outcome of the regression analysis seems to correspond to the results the affect sight distance has on vehicle speed. The speed models presented in this paper indicate the circulating sight distance is related to vehicle entrance speed. When drivers that enter a roundabout with more sight distance they are more likely to enter the roundabout at a higher speed resulting in a higher crash rate. This theory seems to be validated by the previously presented models that indicate that the speed difference is higher for more sight distance resulting in more crashes. These results are consistent with research conducted in Britain that determined too much sight distance results in a higher crash rates.[4]

CONCLUSIONS

This paper established that vehicle speeds and crashes at modern roundabouts in the United States are related to driver sight distance. The study yielded nine (9) models that utilized sight distance to predict vehicle speeds and crashes at modern roundabouts in the United States. Six of these developed models indicate that sight distance is a statistically significant predictor of 85th percentile approach speeds, 85th percentile entrance speed and the difference between the 85th percentile approach speed & the 85th percentile entrance speeds. The p-value of the speed models indicates a very significant correlation between the dependent variable and the independent variable(s) and the models explain between 68% and 88% of the variability in the 85th percentile approach speeds, 85th percentile entrance speed and the difference between the 85th percentile approach speed & the 85th percentile entrance speeds.

This paper also developed models to predict entry rear-end crashes, loss of control crashes and total crashes at modern roundabouts with sight distance as the single statistically significant variable. The three (3) crash models presented in this paper have R^2 values between 0.33 to 0.48. Generally, crash prediction models rely on average daily traffic volume (AADT) to successfully predict vehicle crash rates on roadway elements. The models developed in conjunction with this research produce statistically significant crash models utilizing only driver sight distance as the single independent variable. These models explain a greater portion of the variability in the data than other models developed to predict crash rates at modern roundabouts which utilized five or more independent variables.[5] As indicated in the FHWA's publication Roundabout: Information Guide: *"Providing more than the minimum required intersection sight distance can lead to higher speeds that reduce intersection safety."*[4] The research conducted in the paper corroborates that providing more that the minimum required sight distance will result in reduced safety at modern roundabouts. Additionally, the crash prediction models presented in this paper are consistent with research conducted in Britain that determined that too much sight distance results in higher crash rate.[4]

This paper has presented useful and constructive predictive models for estimating the 85th percentile approach speeds; 85th percentile entrance; the difference between the 85th percentile approach speed and the 85th percentile entrance speed for passenger vehicles and rates of certain vehicle crashes at modern roundabouts in the United States.

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