Modeling Traffic Flows Through a Modern Roundabout Based on Video Data

GREG LUTTRELL, EUGENE R. RUSSELL, AND MARGARET RYS

In 1997, the City of Manhattan installed the first modern roundabout in the state of Kansas. Field study of the operation of the roundabout has been conducted by a Kansas State University research team. Comparison to comparable traffic flows at stop controlled intersections have been made. Using the measured field conditions as a starting point, the SIDRA computer model was used to evaluate a range of traffic conditions. Field traffic conditions and measured delays were used to check output from the models and assist in model validation. SIDRA was used to replicate field conditions to test the projected roundabout operation at increasing traffic levels. The model results of the roundabout and other intersection traffic control are compared. The comparison yields information usable by other jurisdictions when evaluating the installation of new intersection controls versus a roundabout. The methodology should be valuable to any community desiring to consider roundabouts as a viable, cost-effective intersection traffic control device. Key words: roundabout, capacity, safety, intersection.

INTRODUCTION

This study examined the operation of a roundabout compared to other intersection control scenarios. Traffic counts were observed by way of a specially designed 360° view video camera. The camera was linked to video recording equipment. The collected traffic counts became inputs into the computer intersection and roundabout evaluation program: Signalized and Unsignalized Intersection Design and Research Aid, version 5.20b (SIDRA). SIDRA is based on gap acceptance theories adopted by the Australian Road Authority *(1)*. Six of the SIDRA outputs were selected as measures of effectiveness (MOEs) for analysis and comparison of intersection operation; 1.) 95% queue, 2.) average delay, 3.) maximum approach delay, 4.) proportion stopped, 5.) maximum approach stopped, and 6.) degree of saturation. These MOEs were statistically analyzed to determine how the four intersection control scenarios compared with one another.

The Manhattan Roundabout

The Manhattan roundabout was the first modern roundabout built in the state of Kansas. It is located at the intersection of two collector roads adjacent to a residential area. For three years prior to 1997, the intersection had an average of three crashes per year. Citizens were concerned and wanted additional traffic control devices. The city engineer considered four-way stop control, but decided to construct a roundabout instead. The roundabout was completed in the fall of 1997.

The Manhattan roundabout controls a four-leg intersection. All legs are two lanes—one entering and one exiting,—parking is allowed on both sides of all approach roads. There is one circulating lane. All approaches are YIELD controlled, and have raised splitter islands and marked crosswalks (see FIGURE 1). The central island is 16.7 meters (54 feet) in diameter and the approach lane width ranges from 4.0 to 4.9 meters (13 to 16 feet).

FIGURE 1 Manhattan roundabout

Hourly Traffic Volumes

Jacquemart summarized existing US roundabouts in relation to entering traffic volumes. Entering traffic volumes ranged from a high of around 4,700 (Long Beach) to 300 (Los Vegas) *(2)*.

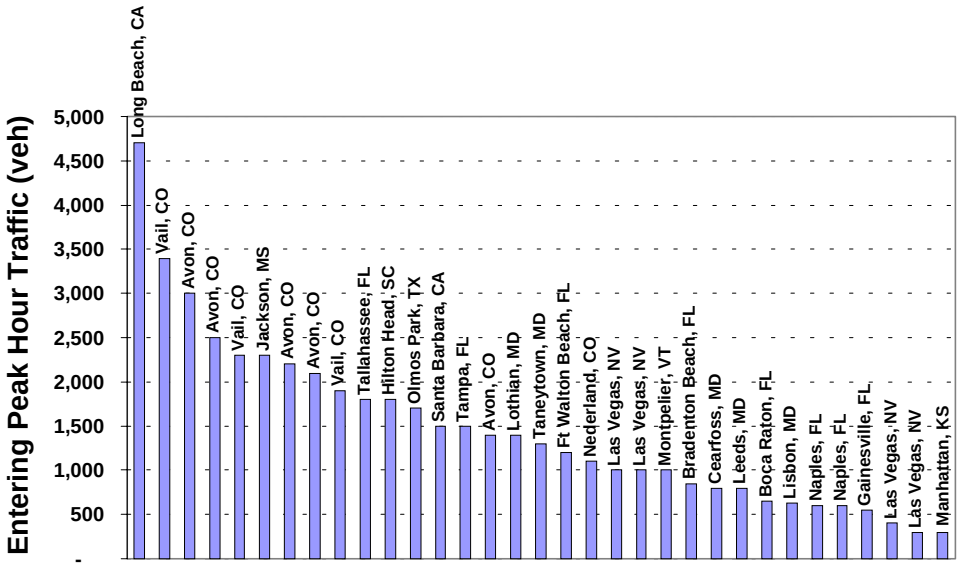
The Manhattan roundabout carries traffic at the bottom end of the range for existing roundabouts in the United States (see FIGURE 2). Twenty-two hourly entering volumes recorded at the Manhattan roundabout for study analysis ranged from 224 to 402 vehicles. The average hourly entering volume for the Manhattan roundabout was 310 vehicles.

Statistical testing indicated that the hourly samples were normally distributed. This was important in that the statistical analysis was based on an assumption of having normally distributed data.

This analysis examined the operation of the roundabout intersection under four operational scenarios:

1. two-way STOP control with single lane approaches (2S);
2. four-way STOP control with single lane approaches (4S);
3. four-way STOP control with multi-lane approaches, i.e., each

G. Luttrell and E. Russell, Department of Civil Engineering, Kansas State University, Seaton 119, Manhattan, Kansas 66506-2905. M. Rys, Department of Industrial & Manufacturing Systems Engineering, Kansas State University, Durland 237, Manhattan, Kansas 66506.



(Source: Jacquemart, modified to also show the Manhattan roundabout)

FIGURE 2 United States roundabouts and entering peak hour traffic volumes

approach modeled with a separate left turn lane and shared through/ right lane (4SL); and

4. roundabout intersection control (RA).

The traffic control prior to construction of the roundabout is represented by 2S. Alternative configurations suggested by the neighborhood residents are represented by 4S and 4SL. The city engineer opted to install a roundabout (RA).

DATA COLLECTION

Each vehicle must be tracked through the roundabout to determine what turn is made. Traditional traffic counting techniques were not considered feasible for this study, as resources were not adequate. The City of Manhattan obtained and installed a specially designed video camera and recording equipment for data collection. Intelligent Highway Systems, Inc. *(3)* supplied the camera, which provided a full 360º view of the intersection. Videotape records allowed the data to be collected and viewed for later examination.

The camera was installed on an existing street light pole at the intersection (see FIGURE 3). Video images were fed down the pole to a VCR assembly inside a weather tight cabinet (see FIGURE 4). The camera was mounted at a height of approximately 6.5 meters (20 feet) which provided ample sight of the entire intersection.

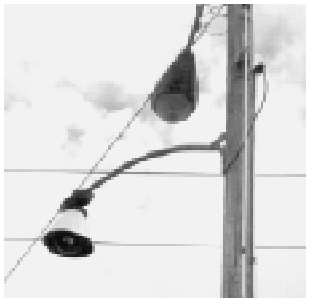


FIGURE 3 Omnidirectional camera mounted on power pole

Once the videotapes were collected, they were viewed, and traffic counts recorded in 15-minute intervals. This allowed the heaviest traffic flows from each tape to be used for analysis.

FIGURE 4 VCR assembly inside signal controller cabinet

SIDRA ANALYSIS

The data were input into the computer program SIDRA to obtain values for the six MOEs selected for the analysis of the intersection under the four operational scenarios described above. (See TABLE 1). The roundabout geometric features required for SIDRA were based on measurements taken from the construction plans.

SIDRA evaluates the operation of an intersection using the maximum hourly flow as calculated by the equation: Vol_{SIDRA} = Vol_{hour} / Peak Hour Factor. Therefore, the SIDRA analysis hour volumes are higher than the actual hourly volumes counted.

TABLE 1 Intersection Measures of Effectiveness

Measure of Effectiveness	Description
95% Queue	Total Length of the queue for all approaches at the 95% confidence level[a]
Average Delay	Average vehicle delay for all entering vehicles
Maximum Approach Delay	Average vehicle delay for the approach with the highest average vehicle delay
Proportion Stopped	Proportion of entering vehicles that are required to stop due to vehicles already in the intersection
Maximum Proportion Stopped	Proportion of entering vehicles that are required to stop due to vehicles already in the intersection on the approach with the highest proportion stopped value
Degree of Saturation	Amount of capacity that is consumed by the current traffic loading (referred to as v/c ratio)

[a]Queue lengths were based on a vehicle length of 8 meters (25 feet)

STATISTICAL ANALYSIS

The output from SIDRA was analyzed to determine how the operation of the roundabout compared to the three other intersection control scenarios. Statistical tests (*4, 5*) were performed using the Statistical Analysis Software, version 6.12 (SAS), on the Kansas State University Unix operating system.

Two base assumptions exist for the use of most statistical tests: normality and equal variances. These two data assumptions were tested prior to determining what specific statistical tests to use to evaluate the intersection operation (see TABLE 2). The first test of normality was an evaluation of the interquartile range divided by the standard deviation. The interquartile range is the difference between the 25th and 75th percentile values. A normal distribution was indicated if this ratio was within +/- 50% of the desired 1.3 value. The Shapiro-Wilk test was used as the second method for evaluating normality. This test is sensitive to small samples. Therefore, to lessen the possibility of a false rejection, a small alpha value of 0.01 was chosen. Equal variances between the four data sets were tested using the Levene's test. This test is sensitive to normality assumptions; therefore, the null hypothesis was rejected only if the test p-value was less than 0.01 (value).

One of three different statistical paths was chosen to test for statistically significant differences of the six MOEs based on the results of the normality and equal variance tests, i.e., IIIA, IIIB, or IIIC (see TABLE 2).

Comparison of the four operational scenarios analyzed is presented below for each MOE.

TABLE 2 Statistical Test Summary - Overview

Test	Comment
I. Normality	
- IQR/S ≈ 1.3	Interquartile divided by standard deviation
- Shapiro-Wilk P-value	H_o: 'have a normal distribution', $\alpha = 0.01$
II. Equal Variances	
Levene's test	H_o: $\sigma^2_{2S} = \sigma^2_{RA} = \sigma^2_{4S} = \sigma^2_{4SL}$, $\alpha = 0.01$
III.A. Normal w/ Equal Variances	
Analysis of Variance F-test	H_o: $\mu_{2S} = \mu_{RA} = \mu_{4S} = \mu_{4SL}$, $\alpha = 0.05$
- Fail to reject – means considered equal, analysis stops	
- Reject – perform multiple comparisons	Tukey's and Duncan tests
III.B. Normal w/ Unequal Variances	
Welch's test	H_o: $\mu_{2S} = \mu_{RA} = \mu_{4S} = \mu_{4SL}$, $\alpha = 0.05$
- Fail to reject – means considered equal, analysis stops	
- Reject – perform multiple comparisons	Fisher Least Significant Difference test
III.C. Not normal	
Kruskal-Wallis test	H_o: 'Population distributions are the same', $\alpha = 0.05$
- Fail to reject – distributions considered equal, analysis stops	
- Reject – Observe data plots to determine rank order	

95% Queue

The 95% queue values ranged as shown in TABLE 3 and FIGURE 5. The data was found to be normally distributed with unequal variances. Data groupings were found to be 4S≠4SL= S≠RA. Based on the mean values, the roundabout produced the lowest level of 95% queue followed by the two-way STOP, four-way STOP and four-way STOP with turn lanes.

TABLE 3 95% Queue

Intersection Control	2-way STOP (2S)	Roundabout (RA)	4-way STOP (4S)	4-way STOP w/ Turn Lanes (4SL)
Minimum	11 m (35 ft)	8 m (26 ft)	15 m (49 ft)	10 m (34 ft)
Maximum	24 m (78 ft)	17 m (54 ft)	34 m (110 ft)	28 m (92 ft)
Mean (μ)	16 m (53 ft)	11 m (37 ft)	23 m (75 ft)	18 m (58 ft)
Standard Deviation (σ)	3.6 m (11.8 ft)	7.9 m (2.4 ft)	4.8 m (15.6 ft)	4.9 m (15.9 ft)

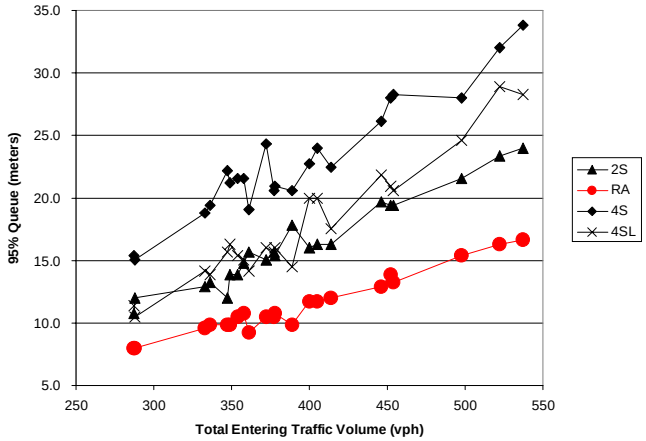


FIGURE 5 95% queue

Average Delay

The average intersection delay values are shown in TABLE 4 and FIGURE 6. The average delay values were found to be not normally distributed. Using mean values and the non-parametric statistical test, the roundabout can be said to operate with the same average vehicle delay as the two-way STOP control and with less average vehicle delay than either of the four-way STOP scenarios RA=2S<4S<4SL.

TABLE 4 Average Vehicle Delay

Intersection Control	2-way STOP (2S)	Roundabout (RA)	4-way STOP (4S)	4-way STOP w/ Turn Lanes (4SL)
Minimum	6.3	7.5	14.4	18.5
Maximum	10.2	8.1	23.1	21.7
Mean (μ)	8.2	7.9	16.8	19.8
Standard Deviation (σ)	1.2	0.2	1.7	0.9

Note: Average vehicle delay is measured in sec/veh.

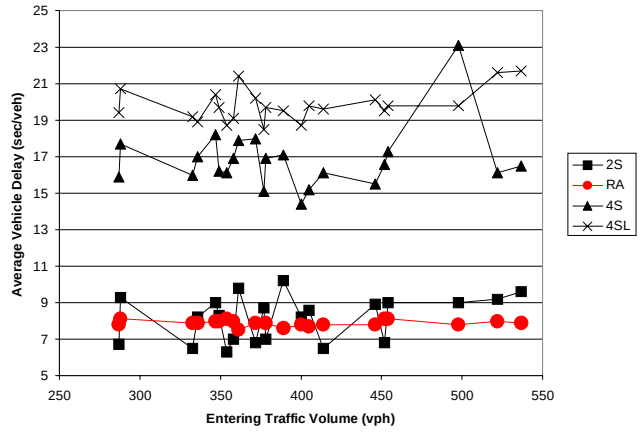


FIGURE 6 Average vehicle delay

Maximum Approach Delay

The maximum approach delay values are shown in TABLE 5 and FIGURE 9. These values were found to be not normally distributed. All distributions were found to be different. Based on the mean values, the roundabout was found to operate with the lowest maximum average vehicle delay, followed in order by the two-way STOP, four-way STOP and four-way STOP with turn lanes (RA< 2S <4S<4SL).

TABLE 5 Maximum Approach Average Vehicle Delay

Intersection Control	2-way STOP (2S)	Roundabout (RA)	4-way STOP (4S)	4-way STOP w/ Turn Lanes (4SL)
Minimum	11.3	8.4	19.7	24.2
Maximum	14.6	9.2	65.0	40.1
Mean (μ)	12.9	8.8	27.9	31.5
Standard Deviation (σ)	1.0	0.2	9.1	4.7

Note: Maximum approach average vehicle daily measured in sec/veh.

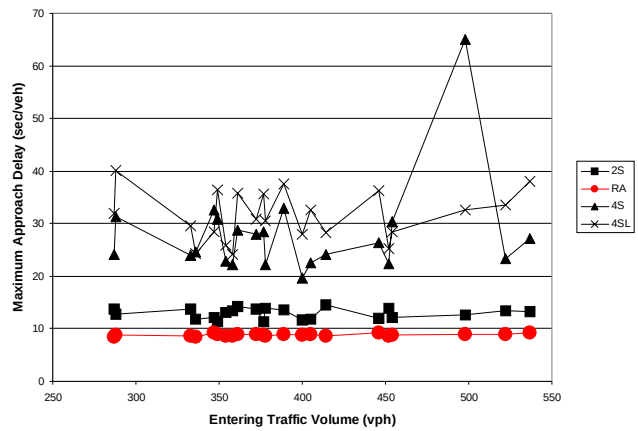


FIGURE 7 Maximum approach average vehicle delay

Proportion Stopped

The proportion stopped is a measure provided in SIDRA and represents the proportion of vehicles stopped by other traffic already in the intersection. The values for proportion stopped can range from 0.0 to 1.0 (see TABLE 6 and FIGURE 8). The proportion stopped values were found to be normally distributed with equal variances. Tukey and Duncan's multiple comparison tests both concluded that all four means could be considered statistically different and that the roundabout experienced the lowest value for proportion stopped, followed by the two-way STOP, four-way STOP with turn lanes and the four-way STOP (RA<2S<4SL<4S).

TABLE 6 Proportion Stopped

Intersection Control	2-way STOP (2S)	Roundabout (RA)	4-way STOP (4S)	4-way STOP w/ Turn Lanes (4SL)
Minimum	0.17	0.13	0.78	0.69
Maximum	0.31	0.23	0.87	0.79
Mean (μ)	0.24	0.18	0.83	0.76
Standard Deviation (σ)	0.04	0.02	0.02	0.02

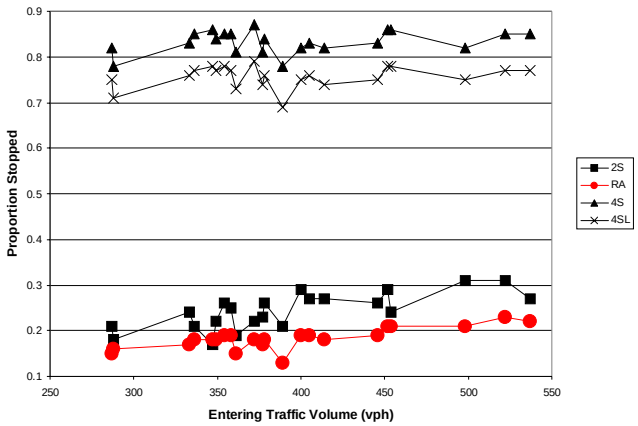


FIGURE 8 Proportion of vehicles stopped

Maximum Proportion Stopped

The maximum proportion stopped values can range from 0.0 to 1.0 (see TABLE 7 and FIGURE 9). The maximum proportion stopped values were found to be normally distributed with unequal variances. The Fisher's groupings found RA≠2S≠4SL≠4S. Based on the mean values, the roundabout can be said to operate best for this MOE.

TABLE 7 Maximum Approach Proportion Stopped

Intersection Control	2-way STOP (2S)	Roundabout (RA)	4-way STOP (4S)	4-way STOP w/ Turn Lanes (4SL)
Minimum	0.21	0.21	0.89	0.82
Maximum	0.44	0.32	0.99	0.91
Mean (μ)	0.31	0.25	0.94	0.87
Standard Deviation (σ)	0.06	0.03	0.03	0.03

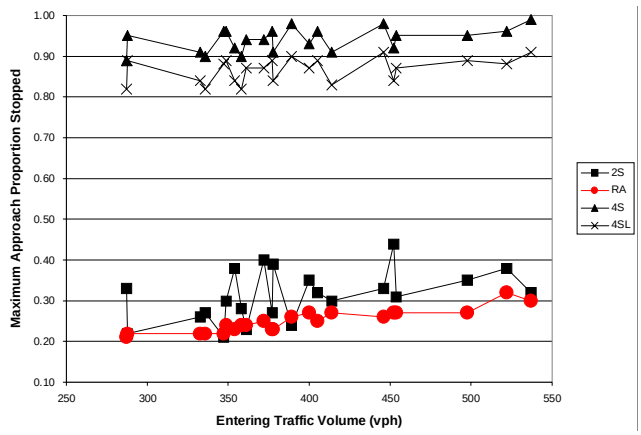


FIGURE 9 Maximum approach proportion stopped

Degree of Saturation

The degree of saturation (volume to capacity (v/c) ratio) values (see TABLE 8 and FIGURE 10) were found to be normally distributed with unequal variances. All four means were determined to be statistically different from one another. The roundabout operates at a lower degree of saturation value than the other three scenarios, followed by the two-way STOP, the four-way STOP and the four-way STOP with turn lanes (RA<2S<4S< 4SL).

TABLE 8 Degree of Saturation

Intersection Control	2-way STOP (2S)	Roundabout (RA)	4-way STOP (4S)	4-way STOP w/ Turn Lanes (4SL)
Minimum	0.107	0.061	0.176	0.251
Maximum	0.280	0.150	0.402	0.575
Mean (μ)	0.168	0.095	0.260	0.362
Standard Deviation (σ)	0.052	0.023	0.059	0.085

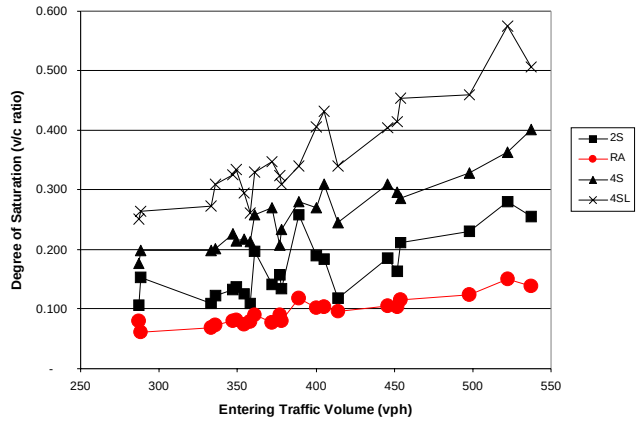


FIGURE 10 Degree of saturation

STUDY SUMMARY

This study evaluated the operation of an existing modern roundabout located in Manhattan, Kansas. The Manhattan roundabout was completed in the fall of 1997. The roundabout operates with approximately 4,600 daily and 310 peak hour entering vehicles. The operation of the roundabout was evaluated relative to three alternatives: two-way STOP, four-way STOP with, and four-way STOP without separate left turn lanes.

Intersection operation was evaluated using six measures of effectiveness (MOEs). Values for these MOEs were obtained from the computer program SIDRA. The results of the MOE evaluation (see TABLE 9) found that the roundabout operates better than the other three intersection control scenarios in all but one case—in that case, it is equal to the two-way STOP alternative.

This study evaluated the operation of the roundabout in Manhattan, Kansas versus three other intersection control scenarios. The conclusions may apply to other locals only if the overall conditions are similar to that found in this study.

Summary of Statistical Analysis for Intersection Scenarios

The purpose of analyzing the MOE data was to determine if and how the four intersection control scenarios differed operationally under similar levels of traffic flows. The summary of the statistical analyses of the four intersection scenarios studied are shown in TABLE 9.

TABLE 9 Summary of MOE Statistical Results

Measure of Effectiveness	Statistical Result	Leading Traffic Control[a]
95% Queue	RA < 4SL = 2S < 4S	Roundabout
Average Delay	RA = 2S < 4S < 4SL	Roundabout/ 2-WAY stop (tie)
Maximum Approach Delay	RA < S2 < 4S < 4SL	Roundabout
Proportion Stopped	RA < 2S < 4SL < 4S	Roundabout
Maximum Approach Stopped	RA < 2S < 4SL < 4S	Roundabout
Degree of Saturation	RA < 2S < 4S < 4SL	Roundabout

[a]based on having the best performance on each MOE. All statistical testing yielded results at the 95% confidence level.

Safety

In the 2½ years since the roundabout has been in operation, there have been no crashes. This has been determined to be a significant reduction.

CONCLUSIONS

Under all conditions except one, the roundabout performed statistically better than the previous intersection control—two-way STOP. Under all measures of effectiveness, the roundabout was found to operate statistically better than the two, four-way STOP alternatives tested. In regard to safety, there have been no crashes in the approximately 2½ years since the roundabout was completed—a statistically significant reduction. The decision to build the roundabout was a good decision.

ACKNOWLEDGEMENTS

Funding for this study was supplied by the Mack Blackwell Transportation Center (MBTC) with matching funds from the Kansas Department of Transportation (KDOT) and an in-kind contribution and assistance, from the City of Manhattan. The authors are solely responsible for all statements and conclusions in this paper.

REFERENCES

1. Troutbeck, R. The Guide to Traffic Engineering Practice Roundabouts. *Austroads*, Sidney, Australia, 1993.
2. Jacquemart, G. *Modern Roundabout Practice in the United States, Synthesis of Highway Practice 264*. Transportation Research Board, National Research Council, Washington, D.C., 1998.
3. List, G. and E. Waldenmaier. Omnidirectional Video Instrumentation for Unsignalized Intersections and Roundabouts. *Third International Symposium on Intersections Without Traffic Signals*, Portland, Oregon, 1997.
4. Mendenhall, W. *Statistics for Engineering and the Sciences*. 4th edition. Prentice Hall, New Jersey, 1998.
5. Ott, L. An Introduction to Statistical Methods. 4th edition, Duxlaury Press, California, 1993.