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Safety and Design Improvements at Rural Expressway Median Crossovers - Phase II

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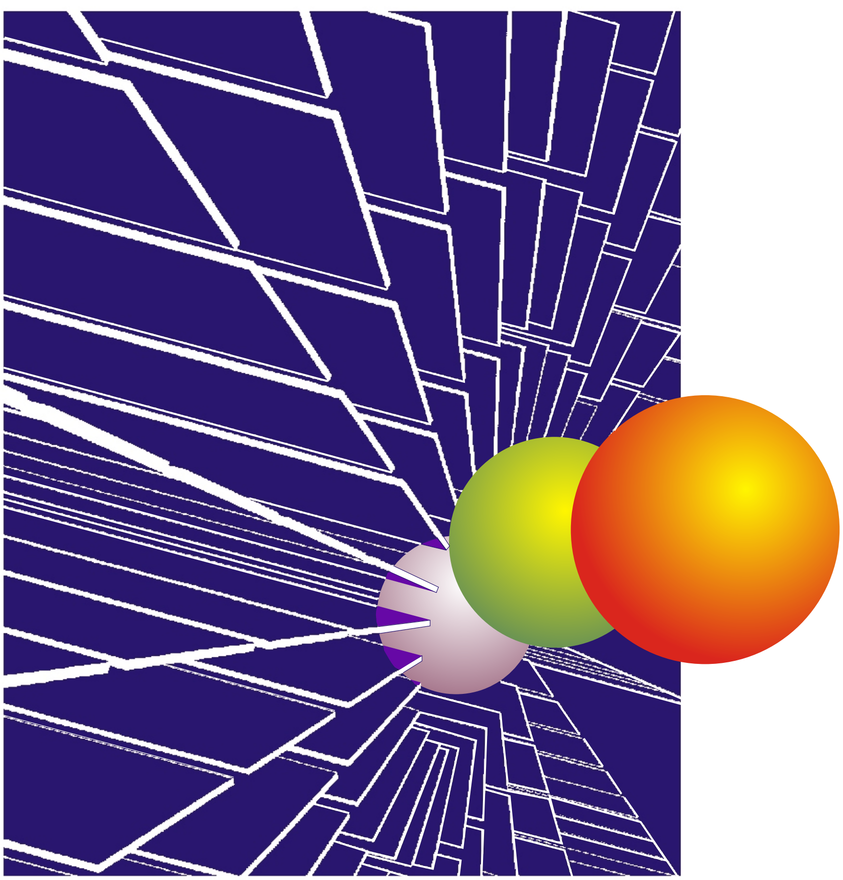

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Safety and Design Improvements at Rural Expressway Median Crossovers (Phase II)

MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY

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16. Abstract Expressway medians separate opposing lanes of traffic. Crossovers in medians provide protection and control for cross and turning traffic. This study provides a means for the Missouri Department of Transportation to determine whether particular high-speed rural expressway crossovers are performing satisfactorily and, if not, to assess alternatives for crossover design. Design practices of other states were examined and alternative design options were identified. The *Highway Capacity Manual* (HCM) approach and the CORSIM simulation technique were compared to determine how best to identify appropriate alternatives. A procedure was then developed to assist district traffic and design engineers in selecting improvements for existing crossovers as they become congested. The procedure includes a diagram showing the combinations of highway volumes compatible with specific design alternatives.			
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EXECUTIVE SUMMARY

Expressway medians provide a separation area between opposing lanes of traffic. Crossovers in medians provide protection and control for cross and turning traffic. The objective of this study was to provide a means for MoDOT engineers to determine whether particular high-speed rural expressway crossovers are performing satisfactorily and, if not, to assess alternatives for crossover design.

Design practices of other states were examined and alternative design options were identified. The *Highway Capacity Manual* (HCM) approach and the CORSIM simulation technique were compared to determine how best to identify appropriate alternatives. A procedure was then developed to assist MoDOT district traffic and design engineers in selecting improvements for existing crossovers as they become congested. That procedure is described directly below.

RECOMMENDED PROCEDURE FOR SELECTING IMPROVEMENTS

1. Identify potential problems at Type II rural crossovers. It is expected that MoDOT Districts are aware of possible congestion and safety problems at their crossovers through their normal procedures of observation and through citizen comments.

2. Observe the specific crossover during likely time periods of concern to identify congestion problems. If problems are observed, continue to step 3.

3. Examine the list of potential alternative treatments (see Ch. 2). Identify feasible treatments and appropriate performance measures (see Ch. 3). If the principle problem is a demand for left turns from the expressway that is greater than the capacity for that movement (i.e., the left turns are causing a queue to spill back into the expressway through lanes) then consult Chapter 7. Figure 7-4 is a simple tool to help identify the design alternatives that could be appropriate for the left turn demand.

4. Apply the CORSIM simulation tool to existing condition and to feasible treatments (see Ch. 4). Input data will include geometric, operations, demand, and control data. Outputs will include performance measures to compare alternatives.

5. Estimate costs of treatments (see Ch. 6).

6. Identify the best alternative, based upon selected performance measures.

7. Implement and monitor the solution.

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INTRODUCTION TO THE PROBLEM AND PROCEDURE

Expressway medians provide a separation area between opposing lanes of traffic. The normal purpose of a crossover is to provide access for crossing traffic, left-turning traffic, and U-turning movements. Crossovers in those medians provide protection and control for cross and turning traffic. MoDOT only considers Type-II median crossovers at State Routes, county roads, and major streets.

This report describes the results of the first phase of a study of rural median crossovers. The immediate following sections describe the objectives, present condition, technical approach used. This is followed by a lengthy section describing results and conclusions.

Within the section on Results and Discussion, Chapter 1 describes introductory information. Chapter 2 describes a wide range of treatments that can be considered for crossovers experiencing or expected to experience congestion. Chapter 3 summarizes various performance measures (measures of effectiveness) that a MoDOT engineer might wish to use in examining the alternatives for improvement. Chapter 4 provides a description of how to apply the CORSIM model to simulate crossovers and examine improvement strategies. Similarly, Chapter 5 describes the HCM approach and why it was found to be a inferior to CORSIM for analyzing the problem of rural crossovers. Chapter 6 provides information on estimating costs. Appendix 1 provides a summary of some of the research and design literature relevant to the problem of rural crossovers. Appendix 2 summarizes recent state design, operations and safety experience.

OBJECTIVE

The objective of this study was to provide a means for MoDOT engineers to determine whether particular high-speed rural expressway crossovers are performing satisfactorily and, if not, to assess alternatives for crossover design.

PRESENT CONDITIONS

MoDOT only considers Type-II median crossovers at State Routes, county roads, and major streets. There is currently no procedure to determine the conditions under which alternative treatments should be considered.

TECHNICAL APPROACH

The design practices of other states were examined, as well as design alternatives that have been suggested in traffic and highway design references. Two alternative tools to evaluate potential improvements, the *Highway Capacity Manual* [3] (HCM) approach and the CORSIM simulation technique, were compared to determine how best to identify appropriate alternatives. A procedure was then developed to assist MoDOT district traffic and design engineers in selecting improvements for existing crossovers as they become congested with increasing crossing and left turn movements. A generalized tool to indicate alternative designs appropriate for various combinations of highway volumes was also developed.

RESULTS AND DISCUSSION

I. INTRODUCTION TO THE PROBLEM AND THE PROCEDURE

As described in the Missouri Department of Transportation's (MoDOT's) *Policy, Procedure and Design Manual* [1], expressway medians provide a separation area between opposing lanes of traffic. Crossovers in those medians provide protection and control for cross and turning traffic. MoDOT only considers Type-II median crossovers at State Routes, county roads, and major streets. A simplistic sketch of a Type-II median crossover is shown in Figure 1-1. Detailed sketches are available in MoDOT's design manual and through its web site [2].

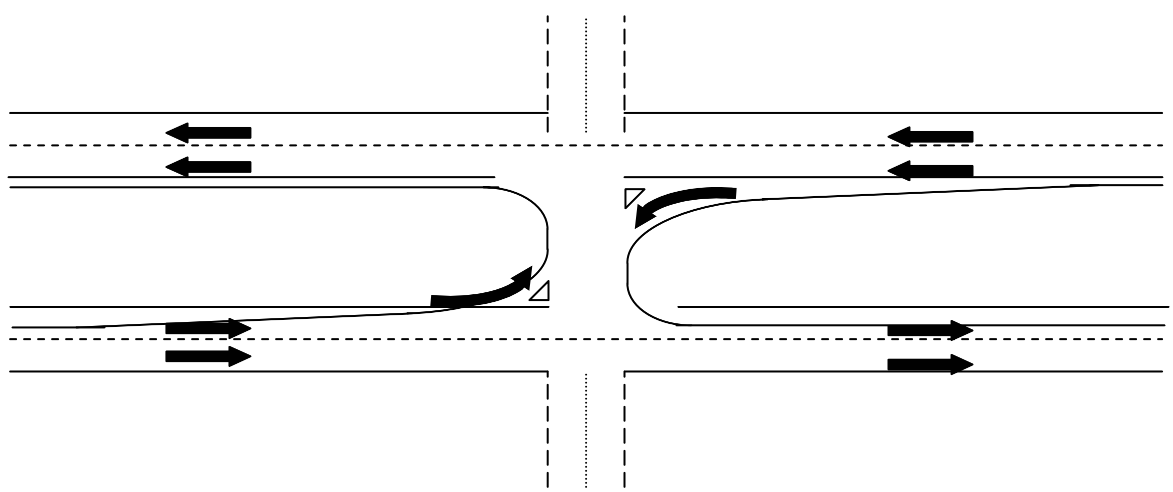


Figure 1-1: Type II Median Crossover

The normal purpose of a crossover is to provide access for crossing traffic, left-turning traffic, and U-turning movements. Each of these three movements can be complex for the following reasons:

- While the expressway speed is high, speeds of crossing and turning vehicles are low.
- The lengths and required turning paths of the various design vehicles making these movements must be accommodated within the median width.
- Crossing, left-turning, and U-turning drivers must find gaps in conflicting traffic before they leave the crossover.
- The presence of other waiting vehicles can block a driver's view of conflicting traffic.
- The combination of crossing, left-turning, and U-turning traffic and the conflicting traffic to which these movements must yield can lead to a situation in which through lanes of the expressway may be blocked.

The objective of this study was to provide a means for MoDOT engineers to determine whether particular high-speed rural expressway crossovers are performing satisfactorily and, if not, to assess alternatives for crossover design.

The design practices of other states were examined, as well as design alternatives that have been suggested in traffic and highway design references. Two alternative tools to evaluate potential improvements, the *Highway Capacity Manual* [3] (HCM) approach and the CORSIM simulation technique, were compared to determine how best to identify appropriate alternatives. A procedure was then developed to assist MoDOT district traffic and design engineers in selecting improvements for existing crossovers as they become congested with increasing crossing and left turn movements. That procedure is described directly below.

RECOMMENDED PROCEDURE FOR SELECTING IMPROVEMENTS

1. Identify potential problems at Type II rural crossovers. It is expected that MoDOT Districts are aware of possible congestion and safety problems at their crossovers through their normal procedures of observation and through citizen comments.

2. Observe the specific crossover during likely time periods of concern to identify congestion problems. If problems are observed, continue to step 3.

3. Examine the list of potential alternative treatments (see Ch. 2). Identify feasible treatments and appropriate performance measures (see Ch. 3). If the principle problem is a demand for left turns from the expressway that is greater than the capacity for that movement (i.e., the left turns are causing a queue to spill back into the expressway through lanes) then consult Chapter 7. Figure 7-4 is a simple tool to help identify the design alternatives that could be appropriate for the left turn demand.

4. Apply the CORSIM simulation tool to existing condition and to feasible treatments (see Ch. 4). Input data will include geometric, operations, demand, and control data. Outputs will include performance measures to compare alternatives.

5. Estimate costs of treatments (see Ch. 6).

6. Identify the best alternative, based upon selected performance measures.

7. Implement and monitor the solution.

ORGANIZATION OF THIS SECTION

Chapter 2 describes a wide range of treatments that can be considered for crossovers experiencing or expected to experience congestion. Chapter 3 summarizes various performance measures (measures of effectiveness) that a MoDOT engineer might wish to use in examining the alternatives for improvement. Chapter 4 provides a description of how to apply the CORSIM model to simulate crossovers and examine improvement strategies. Similarly, Chapter 5 describes the HCM approach and why it was found to be inferior to CORSIM for analyzing the problem of rural crossovers. Chapter 6 provides information on estimating costs. Chapter 7 describes the development of a relatively simple tool to identify design treatments for the expressway left turn problem.

Appendix 1 provides a summary of some of the research and design literature relevant to the problem of rural crossovers. Appendix 2 summarizes recent state design, operations and safety experience.

II. ALTERNATIVE TREATMENTS TO ADDRESS PROBLEMS

There are several kinds of problems related to the Type II median crossover. NCHRP Synthesis 281: *Operational Impacts of Median Width on Larger Vehicles* [4] and NCHRP Report 375: *Median Intersection Design* [5] provide comprehensive analyses of median opening operations for urban, suburban, and rural highways. The rural highways problems and alternative treatments applicable to Type II median crossovers described in these reports are summarized below. The identified problems are [4]:

1. Undesirable driving behavior, including:
   - Encroachment on through lanes by vehicles in the median opening,
   - Side-by-side queuing in the median opening, and
   - Angle stopping in the median opening.
2. Collisions between left-turning vehicles and vehicles stopped in the median opening.
3. Collisions between vehicles turning left from the divided highway and other same-direction vehicles.
4. Collisions between vehicles turning left from the divided highway and opposing through vehicles.
5. Collisions between vehicles making U-turns and opposing through vehicles.

The task of choosing particular mitigation techniques is based on the types of collisions to be prevented. Mitigation techniques, described in NCHRP Synthesis 281 [4] and NCHRP Report 375 [5], for each of the above five problem types are described below. The reader is referred to the above references for more detailed discussion of specific measures.

Undesirable Driving Behavior and Collisions Involving Vehicles in the Median Opening Area

(1) Reconstruct rural highways with wider median.

The width of median should be able to store safely at least one of the largest vehicles using the intersection most often. In some cases, several vehicles may need to be stored. The width of the median should not attract an additional vehicle to enter if the added vehicle would encroach on the through lanes.

(2) Prohibit left-turn maneuvers.

(3) Close median opening.

(4) Reconfigure median to prohibit crossing maneuvers while still permitting left turns.

For the above three techniques, consideration must be given to the alternate routes that will be used by the diverted traffic and the traffic operational and safety impacts on other locations.

(5) Provide median acceleration lanes.

It was indicated by NCHRP Report 375 [5] that, on the basis of the guidelines used by state highway agencies, acceleration lanes for left-turning vehicles from a crossroad onto the divided highway should be considered at locations where adequate median width is available and:

(a) limited gaps are present in the major-road traffic;
(b) the low-speed turning traffic merges with high-speed through traffic;
(c) rear-end or sideswipe accidents crashes are prevalent;
(d) required intersection sight distance is not present; and
(e) there are high volumes of trucks turning into the divided highway from the median opening.

(6) Extend edgelines to better define median opening area.

(7) Mark double yellow centerline on roadway in the median opening to discourage angle stopping.

(8) Remove STOP signs in median. NCHRP Report 375 [5] states that most highway agencies use no control in the median opening area for median widths up to 9m (30ft). Most use YIELD control for median widths from 9 to 25m (30 to 82ft). Most use STOP control for median widths greater than 25m (82ft).

(9) Install traffic signals. Traffic signals are seldom used in rural areas. Traffic signals at median openings should be considered only when the signal warrants of the *Manual on Uniform Traffic Control Devices* [6] are met [4].

Collision Between Vehicles Turning Left from the Divided Highway and Other Same-Direction Vehicles

These collisions are often caused by turning conflicts that are not expected by through motorists on the divided highway. The large speed differences between the turning and thorough vehicles contribute to crash frequency and severity [4]. Mitigation techniques include:

(1) Install advance intersection signing.

Intersection advance warning sign or advance guide signs, with the name of the intersecting road, or both, can be used [4].

(2) Install bigger signs.

(3) Install better delineation.

This method can include:

(a) marking channelizing islands with reflective paint,
(b) creating obvious breaks in delineator spacing at the crossover, and
(c) creating obvious breaks in pavement markings at the crossover [4].

(4) Implement lower speed limits.

A speed limit change should only be considered on the basis of an engineering study [6].

(5) Implement advisory speeds on major road [4].

(6) Increase the deceleration and storage length of existing left-turn lanes.

AASHTO gives guidance on lengths for left-turn lanes, based upon the appropriate distances for deceleration and storage [7].

(7) Prohibit left turns from the major road.

(8) Close the median opening.

Alternate routes must be considered for the last two options.

Collisions between Vehicles Turning Left and Opposing Through Vehicles

Limited sight distance is the primary cause of this kind of problems. Mitigation techniques include:

(1) Prohibit left turns from the major road.

(2) Close the median opening.

Consideration must be given to the alternate routes for both of these options.

Collisions Between Vehicles Making U-Turns and Opposing through Vehicles

U-turn maneuvers have potentially higher safety risks than comparable left-turn maneuvers. Mitigation techniques for the accident pattern involving U-turn collisions include:

(1) Increase width of paved/stabilized shoulder to allow trucks to swing wider.

(2) Reconstruct highway with wider median or reconstruct at selected intersections.

(3) Provide a different median crossover or indirect routes for U-turns.

(4) Prohibit U-turn maneuver or U-turn maneuvers by larger vehicles.

(5) Close the median opening.

Consideration must be given to the alternate routes for these options.

NCHRP Synthesis 281 [4] indicates many highway agencies have problems with medians that are too narrow. While only some of these medians would serve the same purposes as Type II median crossovers, Table 2-1 is included below to show use of some general countermeasures to address problems.

TABLE 2-1: HIGHWAY AGENCY USE OF SPECIFIC MITIGATION MEASURES FOR TRAFFIC OPERATIONAL PROBLEMS RELATED TO LARGER VEHICLES AND NARROW MEDIANS [4]

Mitigation Measures	Agencies Using This Measure*
Reconstruct highway with wider median	4 (15.4)
Reconstruct highway with wider median only at selected intersections	7 (26.9)
Provide left-turn lanes	19 (73.1)
Prohibit left turns	9 (34.6)
Close median opening	15 (57.7)
Reconfigure median to prohibit crossing maneuvers while still permitting left turns	6 (23.1)
Provide median U-turn roadways	4 (15.4)
Provide median acceleration lanes	7 (26.9)
Improve signal timing at adjacent signals	11 (42.3)

* Percentages (shown in parentheses) are based on the total of 26 highway agencies that report traffic operational and safety problems related to larger vehicles and narrow medians.

III. ALTERNATIVE PERFORMANCE MEASURES

The performance measures most often used to analyze intersection operations are volume-to-capacity ratio, delay, level of service, queue length, fuel consumption, and stops. For the specific problem of congested rural Type II crossovers, another important performance measure is the proportion of time a through lane on the expressway is blocked (closely related to queue length) by vehicles waiting to use the crossover.

The tools examined in this report are simulation, through the NETSIM program within CORSIM [8], and the *Highway Capacity Manual* [3] (HCM), as applied through the *Highway Capacity Software* [9] (HCS). The ability of each of these two approaches to provide relevant performance measures is presented below.

CORSIM PERFORMANCE MEASURES

The CORSIM program provides a range of performance measures, based upon a summary of traffic conditions present during its simulation runs. There are two different ways to view the output. One option is to view an animation of the simulation. This can be useful in identifying obvious traffic problems that would result from a particular design.

The other option is to view tables and graphs summarizing results. This latter option can prove useful in evaluating alternatives quantitatively. CORSIM provides the following system-wide measures of effectiveness:

- Average total delay (vehicle-minutes)
- Average delay per vehicle (seconds)
- Average percent stops
- Average queue length

- Average maximum queue length
- Average fuel consumption (gallons)
- Average fuel consumption (mpg)
- Total Emissions of HC (grams/mile)
- Total Emissions of CO (grams/mile)
- Total Emissions of NO (grams/mile)

CORSIM can also describe for each link:

- Time spent moving
- Time spent stopped
- Average queue by lane
- Maximum queue by lane
- Number of lane changes
- Average vehicle occupancy

Importantly, CORSIM allows one to place a simulated detector at a location of interest. Since it is desirable that median crossover traffic not block expressway through lanes, an obvious location for detectors is in the through lanes at the crossover.

HCM/HCS PERFORMANCE MEASURES

The HCM (and HCS) provides a smaller number of measures, based upon the expected average flow conditions predicted from its analytical approach. The principle measures output by the HCS program are average control delay (in seconds) and the level of service resulting from that average delay. The HCS output can be manually manipulated to estimate average queue length and maximum (actually 95th percentile) queue length. In theory, one should be able to determine the maximum queue length expected in the crossover. However, as described in Chapter 5, the researchers were unable to adapt the HCS to provide that desired result.

RECOMMENDED PERFORMANCE MEASURES

A principle performance measure should be the proportion of time a through lane on the expressway is blocked (closely related to queue length) by vehicles waiting to use the crossover. It would also be desirable to provide the performance measures estimated by CORSIM for use as additional measures of effectiveness.

IV. USING SIMULATION TO EVALUATE ALTERNATIVES

Simulation models are often used to augment Highway Capacity Manual [3] (HCM) results or in some cases to address issues that cannot be effectively resolved using the Manual. Existing tools for the analysis of highway operations contained in the HCM are based upon deterministic models that simply execute known relations efficiently [10]. In many situations this approach works well. In others, where there exist significant random components, such as vehicle arrivals and queuing, a stochastic approach may be more efficacious. Interrupted flow simulation models, such as CORSIM [8], attempt to incorporate randomness in a system explicitly. They use traditional statistical techniques to represent complex systems thus allowing inferences to be made about system behaviour. These types of models have many strengths. They allow:

- Explicit treatment of the randomness which is innate to the crossover situation,
- Study of the effects of changes on the operation of a system,
- Experimenting with new situations that do not currently exist,
- Modeling of queuing processes.

Other features relevant to rural crossovers, which are currently not available in the HCM but which CORSIM provides, are [11]:

- Oversaturated conditions
- Bus and truck activity
- Special lane use
- Geometrically offset intersections

- Explicit actuated control
- Alternating arrival characteristics
- Two stage gap acceptance - especially applicable for analysis of rural crossovers

CORSIM is a microscopic simulation model for an integrated urban network freeway network, or corridor analysis. CORSIM consists of FRESIM, a microscopic model of freeway traffic, and NETSIM, a microscopic model of urban streets, as well as a traffic assignment model. CORSIM was chosen for this study for several reasons. It was developed for the Federal Highway Administration, has many qualities that recommend its use, as described later, and is commonly used in the industry and is the software of choice at MoDOT.

As indicated in previous sections of this report, rural expressway facilities can generate hazardous crossing situations and confusing vehicle operations at rural median crossovers. As volumes increase through a crossover area, multiple vehicles can be positioned in the median so they actually block each other and impede visibility to oncoming vehicles. The AASHTO *Green Book* [7] does not provide a complete solution to the problem. No guidance is provided on how to solve the problem of crossing vehicles stacking up in the median area, or the hazard that can be created by long vehicles protruding into the through lane. Further, AASHTO does not provide a solution for those crossovers which have been placed in a median that is narrower than 60 feet. The purpose of this chapter is to explain the use of simulation software, which may be used to address these issues, for evaluating alternative rural crossover designs.

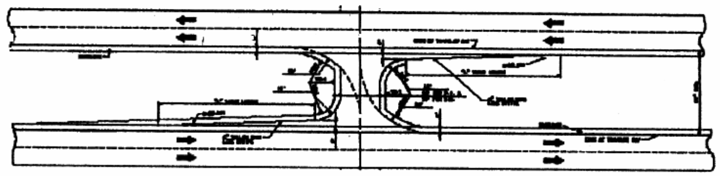
Five designs were chosen as illustrative of what may be used in Missouri. They are depicted in Figure 4.1. The CORSIM software was used to evaluate two of these configurations for two different operational and control situations described later. This exercise provides information about the use of simulation software for this purpose. The information will be used in the following pages to evaluate that use.

INPUT REQUIREMENTS

There exist four general categories of inputs and outputs: geometrics, operations, demand and control. Geometrics describe the physical network over which vehicles travel. Details include number of lanes, turn bays, lane lengths, lane use and grade as well as topology. CORSIM uses the link-node concept to represent networks where a link represents a road section and a node represents either an intersection or a change in road geometry. Creation of the five alternative cases as shown in Figure 4.1 required approximately 45 minutes to one hour each. Operational data are link specific - for example, capacities, lane use, lane restrictions, free flow speed, HOV lanes, parking, lane blockages, and so on.

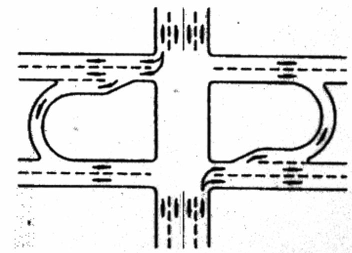
Demand data may be entered in two different ways in CORSIM, either by using O-D data at the entrance and exit points of the network with turn proportions specified at intersections, or by entering explicit volumes on links and turn volumes at intersections. Up to sixteen different time periods may be defined which are used to divide the simulation into periods of similar character such as pre-peak hour, peak hour and post peak hour. Control data include the full array of signage and signals. Entry of volume data requires fairly significant manipulation in order to put it into a useful form. Total time per site took about 1 hour which includes data entry and reduction, and reallocating volumes under the alternative scenarios (these would need to be done regardless of tool used). Schematic drawings of the two alternatives are provided in Figure 4.2.

The TRAF suite of software includes a graphical interface, called ITRAF, a simulation algorithm called CORSIM and a graphics generator called TRAFVU. ITRAF allows creation of a transportation system relatively quickly and easily along with the entry of the other data types, and TRAFVU provides animation of individual runs in addition to more familiar modes of data output as described below. TRAF is a Windows-based software and provides very useful features that are common to this type of software, namely, button-pad commands, on-line help facility, of course all menu driven, point and click inputs for nodes and links in a network. It also allows a great deal of flexibility in the choices of other variables to use. For example, the user may specify volumes entering the system with turn percentages at intersections, or he/she may enter turn volumes explicitly at intersections. Lanes may be designated as being blocked if one has interest in the effects of incidents on traffic.

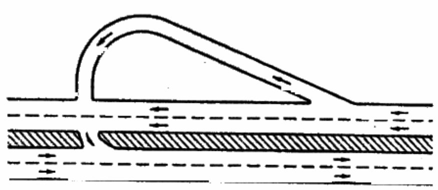


a) Ty. I Crossover (Existing Condition)

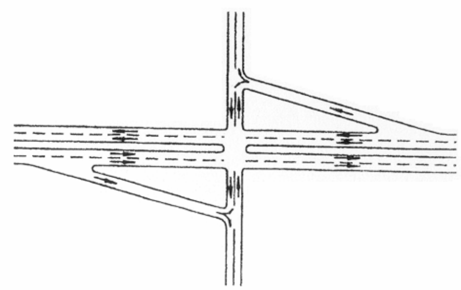
b) Ty. II Crossover (Existing condition)



c) Case 3 Crossover



d) Case 4 Crossover



e) Case 5 Crossover

Figure 4.1 Rural Crossover Alternatives

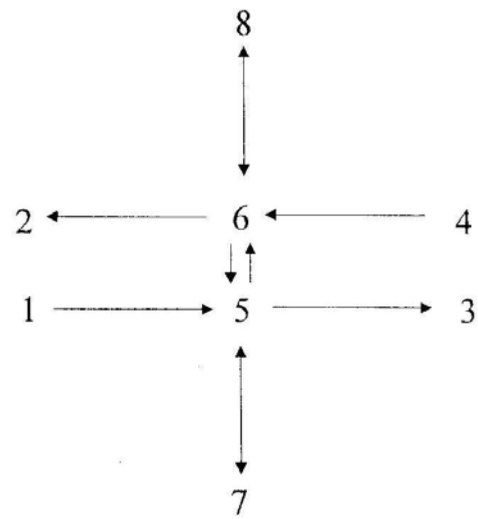


Figure 4.2a Schematic for Existing Conditions

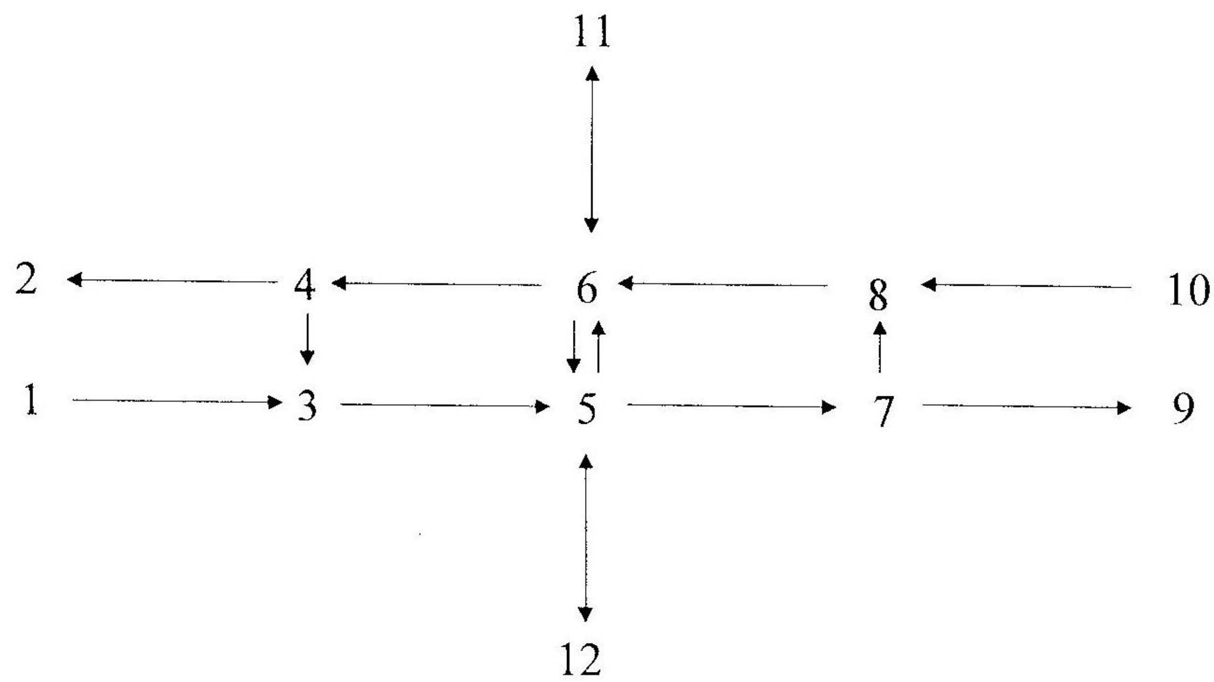


Figure 4.2b Schematic for Improved Conditions

PERFORMANCE MEASURES

Outputs from simulation are provided in two very different forms. The user may opt to view an animation of the actual implementation of his/her designs using specified geometrics, operation and control information. This form of output allows one to identify gross problems with the intersection. It provides an excellent means to eliminate problem configurations very quickly and to view alternative scenarios also very quickly. The second form of output is the more familiar tables and graphics. This, for analytical purposes is far superior. Tables 4.1 through 4.4 (shown at the end of this Chapter) provide a sample listing of outputs obtained from CORSIM. These numerical outputs are crucial for assessing alternatives quantitatively. Additionally, for each link a table or graph may be generated which tracks a variable of interest over time - see Figure 4.3. As the Tables show, the software can be used to model all of the five design options quite precisely.

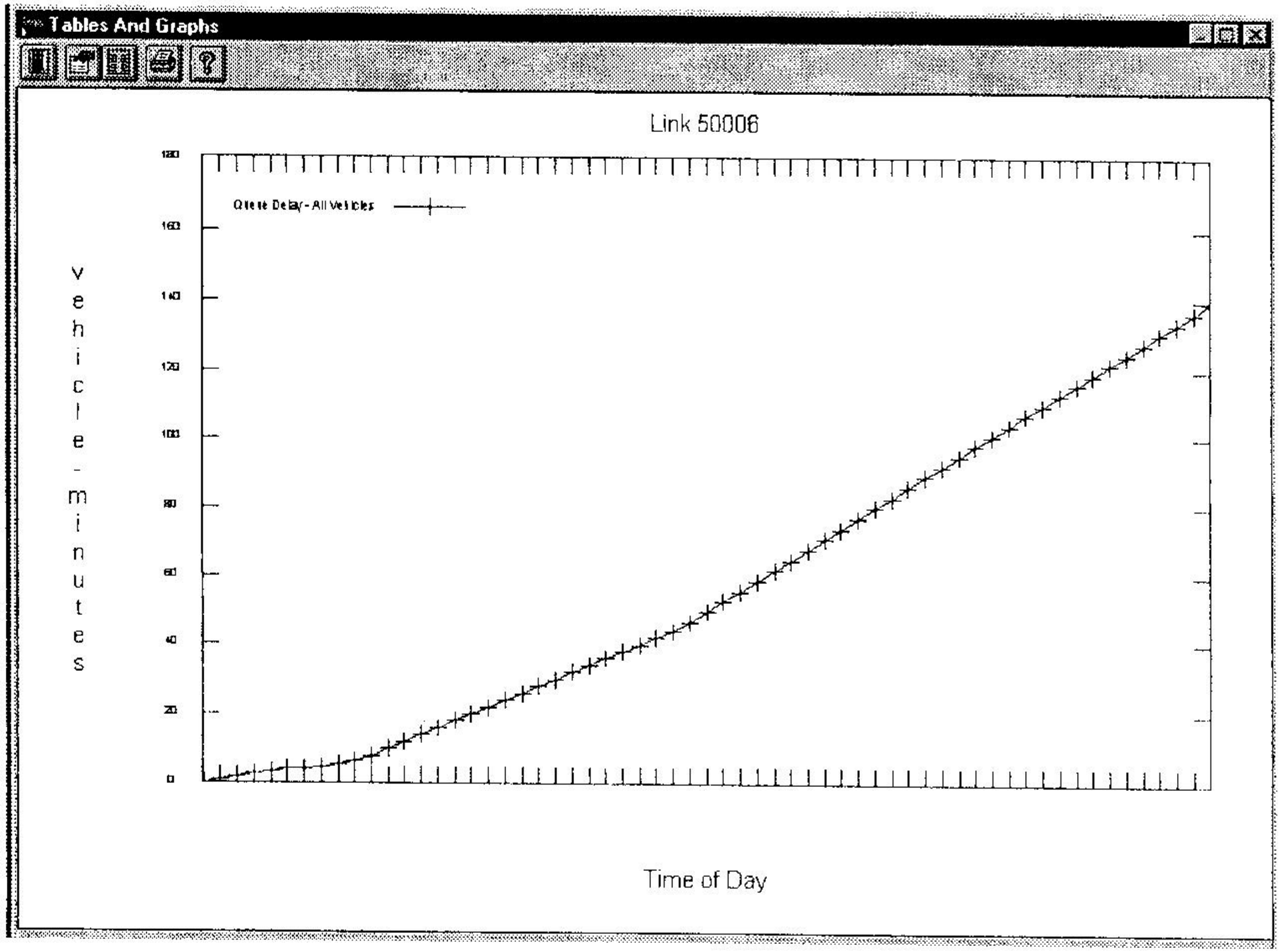


Figure 4.3 Time Plot of Total Vehicle Delay

CASE STUDIES

Data for six type II median crossovers were obtained from MoDOT District 8. The two sites selected for analysis are Route 13 at Route O and Route 160 at Farm Road 157 both in Greene County. The sites were examined under existing conditions and under one alternative geometry - case 3 depicted in Figure 4.1. Case 3 was chosen due to its simplicity and for its relative low cost (see Chapter 6).

Route 13 is a 4 lane divided highway with 12 foot lanes, 6 foot inside shoulders, 10 foot outside shoulders and a 60 foot median. There are no traffic signals at or near this location. Route 160 has the same geometrics as Route 13 except for a 40 foot median. Data from the two locations were entered into the TRAF software via ITRAF and were used to simulate operation at the sites. For the purpose of illustrating the use of simulation software, each site's existing conditions and one alternative design were examined. Simulation outputs allow both link-specific and system-level assessments. Both are useful in evaluating alternatives. With regard to the former, the output tables were used to identify problem links at the sites under existing conditions. Key performance measures were then compared for the two alternatives: existing versus case 3. Table 4.5 depicts the comparisons. Table 4.6 compares selected system-wide outputs as well for each scenario. As both tables illustrate quite dramatically, the alternative design significantly improves most measures. The prime exception is fuel consumed which makes sense given the requirement for vehicles to travel further to navigate through the intersection. The gains in delay reductions, decreased queue lengths (with potentially lowered conflicts) and emissions levels all recommend the alternative design.

EVALUATION

When evaluating software it becomes necessary to establish its operating goals. What features do we want it to have and what do we want it to be able to do? Features that are desirable for simulation software as it is applied here include accuracy and ease of use - both of which are discussed in detail in the paragraphs that follow. It should be noted that these features are often product specific. With regard to the second question, as always, one has interest in safety and efficiency. Efficiency measures include individual delay, queue length, fuel consumption and emissions. CORSIM provides all of these, as Tables 4.1 to 4.4 show. With regard to safety, CORSIM is similar to the HCM in its lack of safety outputs. However, the wide variety and very detailed operational outputs allow for more accurate assessments of safety.

ACCURACY AND PRECISION OF THE MODEL

There are two sources at issue here: assumptions that must be made (and their accuracy as they pertain to rural crossovers), and the limitations of the tool selected. Since CORSIM is a stochastic model, it is assumed to be as random as the real world. Consequently, its resulting performance measures are samples from a population. That is, each measure is a random variable with a mean and variance. Several runs for a given situation are therefore needed. For a specified confidence level, a considerable number of runs may be necessary. In addition to confidence level, the number depends upon the variable of interest, its variance and its required precision. For example, if queue length were the variable of interest, assuming a variance of 4 and a required precision of 1 vehicle, the required number of runs would be around 16. The appropriate number of runs derives from specification of a time interval duration which is used to control the requirements for frequency of output in CORSIM. An appropriate interval must be assumed since the variance of each variable is not known.

Other notable limitations of the software include its inability to accept separate lane width for median turn lanes. Thus, all lanes on a link must have the same width (e.g. left turn bays must be 12 feet in this case); enter median acceleration lanes; specify link lengths less than 50 feet. While this last means the software would not be directly usable for median widths of 50 feet or less, the software does give queue lengths and so could be used even for narrow medians for this purpose.

EASE OF USE

Elefteriadou et al. [11] established two criteria for assessing the ease of use of a simulation model, namely how the software handles input data (preprocessing) and how it presents results (post processing).

The preprocessor, or input unit, used by the TRAF software package, as stated previously, is ITRAF. It is a windows-based graphical user interface akin to a geographic information system style of entry. It allows both graphical and numerical input of node and link positions, topology, and characteristics via a map of the network and a series of dialogs. This of course is a subjective evaluation but the software is fairly friendly. Indeed, it required a graduate student with fairly recent knowledge of the software only 15 minutes to enter all geometric data for each of the 5 configurations described before. Subsequent input, essentially to revise volumes and some geometrics, requires perhaps 5 minutes on average.

The postprocessor or output unit which generates files for subsequent analysis is the CORSIM component. CORSIM processes the input data from ITRAF and generates text output files with all of the variables listed in Tables 4.1 through 4.5. This may then be viewed using the TRAFVU module which allows tabular and graphical displays of the output data. The module also uses the output to simulate the operation of the network in a graphical display. A "run" requires approximately 5 minutes. Generation of graphics is fairly interactive, although the software is somewhat cumbersome in this regard.

CONCLUSIONS ON SIMULATION

Simulation software addresses several problems, listed in this report, that cannot be addressed by the HCM model. It allows detailed analysis of wide medians and two stage gap acceptance situations. It provides very detailed estimates of expected queue lengths and other critical performance measures that are not provided by the HCM - in addition to delay measures, which are provided by both tools. Further, it is stochastic in nature and therefore thought to be more appropriate for this type of analysis. Given the relative low level of time required to use the software, its appropriateness for this application, its relative ease of use, minimal data requirements, high levels of precision, and the richness of its outputs, the simulation software seems an excellent tool for evaluating rural crossover alternatives.

Table 4.1a: Site 1 Delay Measures

EXISTING			VEHICLE MINUTES			RATIO	MINUTES/MILE		SECONDS/VEHICLE			AVERAGE VALUES			
	VEHICLE		MOVE	DELAY	TOTAL	MOVE/	TOTAL	DELAY	TOTAL	DELAY	QUEUE*	STOP*	STOPS	VOLUME	SPEED
LINK	MILES	TRIPS	TIME	TIME	TIME	TOTAL	TIME	TIME	TIME	TIME	TIME	TIME	(%)	VPH	MPH
(8001,1)		398.0												398.0	
(1,5)	149.2	394.0	138.2	13.7	151.9	0.9	1.0	0.1	34.6	13.6	11.8	11.8	4.0	394.0	58.9
(5,3)	151.5	400.0	140.4	7.8	148.2	1.0	1.0	0.1	22.2	1.2	-	-	-	400.0	61.3
(8006,4)		1,932.0												1,932.0	
(4,6)	702.3	1,854.0	650.5	1,340.9	1,991.4	0.3	2.8	1.9	109.7	89.0	69.1	64.7	27.0	1,854.0	21.2
(6,2)	685.2	1,809.0	634.7	110.3	745.0	0.9	1.1	0.2	24.6	3.6	-	-	-	1,809.0	55.2
(8002,7)		92.0												92.0	
(7,5)	3.7	13.0	4.9	5.8	10.7	0.5	2.9	1.6	1,422.4	1,409.7	1,404.2	1,403.7	100.0	13.0	20.7
(5,7)	9.6	34.0	12.8	2.2	15.0	0.9	1.6	0.2	26.5	3.9	0.1	0.1	-	34.0	38.4
(5,6)	0.1	7.0	0.1	8.3	8.4	0.0	126.0	124.6	846.6	846.1	837.6	836.5	85.0	7.0	0.5
(6,5)	0.3	32.0	0.4	3.2	3.7	0.1	12.1	10.7	173.6	172.8	171.1	170.4	40.0	32.0	5.0
(6,8)	11.9	44.0	15.9	2.1	18.0	0.9	1.5	0.2	24.5	2.9	-	-	-	44.0	39.7
(8,6)	7.9	29.0	10.5	31.0	41.6	0.3	5.3	3.9	1,231.3	1,217.6	1,211.8	1,210.8	100.0	29.0	11.4
(8004,8)		102.0												102.0	

CASE 3			VEHICLE MINUTES			RATIO	MINUTES/MILE		SECONDS/VEHICLE			AVERAGE VALUES			
	VEHICLE		MOVE	DELAY	TOTAL	MOVE/	TOTAL	DELAY	TOTAL	DELAY	QUEUE*	STOP*	STOPS	VOLUME	SPEED
LINK	MILES	TRIPS	TIME	TIME	TIME	TOTAL	TIME	TIME	TIME	TIME	TIME	TIME	(%)	VPH	MPH
(8001,1)		398.0												398.0	
(1,3)	188.0	397.0	174.1	4.4	178.5	1.0	1.0	0.0	26.8	0.7	-	-	1.0	397.0	63.2
(3,5)	144.3	508.0	133.7	39.8	173.5	0.8	1.2	0.3	20.5	4.7	0.8	0.7	7.0	508.0	49.9
(5,7)	125.9	443.0	116.6	19.7	136.3	0.9	1.1	0.2	18.4	2.7	0.1	-	-	443.0	55.4
(7,9)	192.7	407.0	178.5	4.6	183.1	1.0	1.0	0.0	27.0	0.7	-	-	-	407.0	63.1
(8004,10)		1,932.0												1,932.0	
(10,8)	915.7	1,934.0	848.2	52.6	900.9	0.9	1.0	0.1	27.8	1.6	-	-	-	1,934.0	61.0
(8,6)	561.1	1,975.0	519.7	88.4	608.1	0.9	1.1	0.2	18.4	2.7	0.2	0.2	3.0	1,975.0	55.4
(6,4)	576.4	2,029.0	533.9	108.8	642.7	0.8	1.1	0.2	18.9	3.2	-	-	-	2,029.0	53.8
(4,2)	911.9	1,926.0	844.7	109.1	953.8	0.9	1.1	0.1	29.7	3.4	-	-	-	1,926.0	57.4
(4,3)	1.3	111.0	2.5	1.6	4.1	0.6	3.3	1.3	2.2	0.9	1.1	1.0	25.0	111.0	18.5
(7,8)	0.4	39.0	0.9	23.5	24.4	0.0	54.9	52.9	37.5	36.1	34.7	34.5	92.0	39.0	1.1
(8005,11)		123.0												123.0	
(11,6)	45.2	123.0	60.3	33.5	93.7	0.6	2.1	0.7	45.2	16.1	11.1	10.9	100.0	123.0	28.9
(6,11)	29.8	81.0	39.7	5.3	45.0	0.9	1.5	0.2	33.3	3.9	0.1	-	-	81.0	39.7
(6,5)	0.3	26.0	0.4	8.2	8.6	0.1	29.1	27.8	19.8	18.9	17.2	15.5	34.0	26.0	2.1
(5,6)	0.4	39.0	0.6	28.8	29.4	0.0	66.3	65.0	44.5	43.6	43.5	42.0	84.0	39.0	0.9
(5,12)	58.0	153.0	77.3	9.8	87.1	0.9	1.5	0.2	34.0	3.8	0.1	-	-	153.0	39.9
(12,5)	37.5	99.0	50.0	15.9	65.9	0.8	1.8	0.4	39.5	9.5	4.1	3.9	100.0	99.0	34.2
(8006,12)		98.0												98.0	
	3,788.9	2,567.0	59.7	9.2	68.9	0.9	1.1	0.2	1.6	0.2	0.0	0.0	16.9		55.0

Table 4.1b: Site 2 Delay Measures

EXISTING	VEHICLE		VEHICLE MINUTES			RATIO	MINUTES/MILE		SECONDS/VEHICLE			AVERAGE VALUES			
			MOVE	DELAY	TOTAL	MOVE/	TOTAL	DELAY	TOTAL	DELAY	QUEUE*	STOP*	STOPS	VOLUME	SPEED
LINK	MILES	TRIPS	TIME	TIME	TIME	TOTAL	TIME	TIME	TIME	TIME	TIME	TIME	(%)	VPH	MPH
(8001,1)		1,681.0												1,681.0	
(1,5)	611.7	1,615.0	566.7	623.0	1,189.6	0.5	1.9	1.0	79.3	58.4	49.1	47.6	25.0	1,615.0	30.9
(5,3)	608.0	1,605.0	563.2	99.7	662.8	0.9	1.1	0.2	24.7	3.7	-	-	-	1,605.0	55.0
(8006,4)		612.0												612.0	
(4,6)	229.6	606.0	212.6	16.8	229.5	0.9	1.0	0.1	36.1	15.1	13.5	13.5	1.0	606.0	60.0
(6,2)	218.2	576.0	202.1	9.1	211.2	1.0	1.0	0.0	21.9	1.0	-	-	-	576.0	62.0
(8002,7)		72.0												72.0	
(7,5)	3.1	11.0	4.2	3.7	7.8	0.5	2.5	1.2	1,241.6	1,226.7	1,220.8	1,220.3	100.0	11.0	23.9
(5,7)	4.2	15.0	5.6	0.6	6.3	0.9	1.5	0.2	25.1	2.5	0.1	-	-	15.0	40.5
(5,6)	0.1	5.0	0.1	0.1	0.2	0.4	3.2	1.8	1,123.1	1,122.7	1,122.5	1,122.4	40.0	5.0	18.9
(6,5)	0.0	4.0	0.1	1.5	1.5	0.0	40.0	38.7	1,102.0	1,101.5	1,100.8	1,099.5	100.0	4.0	1.5
(6,8)	8.9	33.0	11.9	1.5	13.4	0.9	1.5	0.2	24.3	2.6	-	-	-	33.0	40.1
(8,6)	1.4	5.0	1.8	0.7	2.6	0.7	1.9	0.6	1,892.8	1,881.6	1,876.2	1,875.8	100.0	5.0	31.9
(8004,8)		79.0												79.0	

CASE 3	VEHICLE		VEHICLE MINUTES			RATIO	MINUTES/MILE		SECONDS/VEHICLE			AVERAGE VALUES			
			MOVE	DELAY	TOTAL	MOVE/	TOTAL	DELAY	TOTAL	DELAY	QUEUE*	STOP*	STOPS	VOLUME	SPEED
LINK	MILES	TRIPS	TIME	TIME	TIME	TOTAL	TIME	TIME	TIME	TIME	TIME	TIME	(%)	VPH	MPH
(8001,1)		1,681.0												1,681.0	
(1,3)	793.1	1,675.0	734.6	37.9	772.5	1.0	1.0	0.1	27.6	1.4	-	-	-	1,675.0	61.6
(3,5)	502.8	1,770.0	465.8	68.0	533.8	0.9	1.1	0.1	18.1	2.3	0.1	-	-	1,770.0	56.5
(5,7)	507.7	1,787.0	470.3	67.9	538.2	0.9	1.1	0.1	18.0	2.3	-	-	-	1,787.0	56.6
(7,9)	818.2	1,728.0	757.9	79.5	837.4	0.9	1.0	0.1	29.0	2.8	-	-	-	1,728.0	58.6
(8004,10)		612.0												612.0	
(10,8)	289.3	611.0	268.0	10.5	278.5	1.0	1.0	0.0	27.3	1.1	-	-	-	611.0	62.3
(8,6)	188.9	665.0	175.0	26.0	201.0	0.9	1.1	0.1	18.1	2.4	0.2	0.2	2.0	665.0	56.4
(6,4)	196.0	690.0	181.6	34.6	216.2	0.8	1.1	0.2	18.8	3.0	0.1	-	-	690.0	54.4
(4,2)	279.8	591.0	259.2	13.0	272.2	1.0	1.0	0.1	27.5	1.3	-	-	-	591.0	61.7
(4,3)	1.1	97.0	2.2	22.5	24.7	0.1	22.4	20.4	15.3	13.9	14.1	13.9	63.0	97.0	2.7
(7,8)	0.7	57.0	1.3	1.8	3.1	0.4	4.8	2.8	3.3	1.9	2.3	2.2	45.0	57.0	12.5
(8005,11)		118.0												118.0	
(11,6)	43.0	117.0	57.3	17.1	74.4	0.8	1.7	0.4	37.8	8.7	3.8	3.7	100.0	117.0	34.7
(6,11)	33.4	91.0	44.6	4.8	49.4	0.9	1.5	0.1	32.3	3.2	-	-	-	91.0	40.6
(6,5)	0.1	11.0	0.2	7.3	7.5	0.0	60.0	58.7	39.2	38.3	38.8	37.8	72.0	11.0	1.0
(5,6)	0.1	8.0	0.1	3.3	3.4	0.0	37.2	35.9	25.4	24.5	23.1	21.1	50.0	8.0	1.6
(5,12)	18.9	50.0	25.3	3.0	28.3	0.9	1.5	0.2	33.8	3.6	0.1	-	-	50.0	40.2
(12,5)	26.9	71.0	35.9	17.6	53.4	0.7	2.0	0.7	44.3	14.5	10.0	9.9	100.0	71.0	30.2
(8006,12)		72.0												72.0	

Table 4.2a: Site 1 Queue Measures

EXISTING	VEH MINUTE		AVERAGE	CONGESTION		QUEUE LENGTH															NUMBER
	QUEUE	STOP	OCCUPANCY	STORAGE	PHASE	AVERAGE QUEUE BY LANE							MAXIMUM QUEUE BY LANE								OF LANE
LINK	TIME	TIME	(VEHICLE)	(%)	FAILURE	1	2	3	4	5	6	7	1	2	3	4	5	6	7		CHANGE
(1,5)	78.8	78.6	4.4	2.1	-	-	-	-	-	-	-	1.0	1.0	2.0	-	-	-	-	2.0		121.0
(5,3)	0.1	0.1	3.0	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		49.0
(4,6)	2,238.8	2,097.2	59.4	28.3	-	4.0	33.0	-	-	-	-	6.0	28.0	68.0	-	-	-	-	9.0		756.0
(6,2)	-	-	12.9	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		848.0
(7,5)	2,199.9	2,199.1	37.7	50.2	-	37.0	-	-	-	-	-	-	81.0	-	-	-	-	-	-		-
(5,7)	0.1	0.1	0.4	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
(5,6)	139.6	139.4	3.0	118.8	-	2.0	-	-	-	-	-	-	3.0	-	-	-	-	-	-		-
(6,5)	97.0	96.5	1.7	67.2	-	2.0	-	-	-	-	-	-	2.0	-	-	-	-	-	-		-
(6,8)	-	-	0.5	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
(8,6)	2,100.4	2,098.8	36.1	50.2	-	35.0	-	-	-	-	-	-	75.0	-	-	-	-	-	-		-

CASE 3	VEH MINUTE		AVERAGE	CONGESTION		QUEUE LENGTH														NUMBER
	QUEUE	STOP	OCCUPANCY	STORAGE	PHASE	AVERAGE QUEUE BY LANE							MAXIMUM QUEUE BY LANE							OF LANE
LINK	TIME	TIME	(VEHICLE)	(%)	FAILURE	1	2	3	4	5	6	7	1	2	3	4	5	6	7	CHANGE
(1,3)	0.1	0.1	3.7	1.5	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-	8.0
(3,5)	6.7	6.1	3.3	2.2	-	-	-	-	-	-	-	-	2.0	2.0	-	-	-	-	-	102.0
(5,7)	0.5	-	2.7	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67.0
(7,9)	-	-	3.5	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42.0
(10,8)	-	-	15.3	6.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	367.0
(8,6)	8.1	6.9	10.6	7.0	-	-	-	-	-	-	-	-	3.0	6.0	-	-	-	-	-	374.0
(6,4)	1.7	1.3	11.1	5.9	-	-	-	-	-	-	-	-	4.0	2.0	-	-	-	-	-	409.0
(4,2)	-	-	16.4	6.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	552.0
(4,3)	2.0	1.9	0.1	4.0	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	-
(7,8)	22.5	22.4	0.6	20.3	-	-	-	-	-	-	-	-	3.0	-	-	-	-	-	-	-
(11,6)	23.1	22.6	2.1	2.2	-	-	-	-	-	-	-	-	3.0	-	-	-	-	-	-	-
(6,11)	0.1	-	1.1	1.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(6,5)	7.5	6.7	0.3	9.3	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-	-
(5,6)	29.0	28.0	0.8	27.0	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	-
(5,12)	0.3	0.1	1.9	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(12,5)	6.8	6.5	1.8	1.8	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	-	-

Table 4.2b: Site 2 Queue Measures

EXISTING	VEH MINUTES		AVERAGE	CONGESTION		QUEUE LENGTH														NUMBER
	QUEUE	STOP	OCCUPANCY	STORAGE	PHASE	AVERAGE QUEUE BY LANE							MAXIMUM QUEUE BY LANE							OF LANE
LINK	TIME	TIME	(VEHICLE)	(%)	FAILURE	1	2	3	4	5	6	7	1	2	3	4	5	6	7	CHANGE
(1,5)	1,383.1	1,340.5	37.4	15.0	-	1.0	10.0	-	-	-	-	14.0	9.0	31.0	-	0	-	-	31.0	680.0
(5,3)	-	-	11.6	5.8	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	734.0
(4,6)	139.1	138.8	6.7	2.7	-	-	-	-	-	-	-	2.0	1.0	3.0	-	0	-	-	5.0	53.0
(6,2)	-	-	4.0	2.0	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	77.0
(7,5)	1,485.3	1,484.7	25.7	34.3	-	25.0	-	-	-	-	-	-	61.0	-	-	0	-	-	-	-
(5,7)	-	-	0.2	0.3	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-
(5,6)	149.7	149.6	3.3	130.8	-	2.0	-	-	-	-	-	-	3.0	-	-	0	-	-	-	-
(6,5)	110.1	109.9	1.9	76.0	-	2.0	-	-	-	-	-	-	2.0	-	-	0	-	-	-	-
(6,8)	-	-	0.4	0.5	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-
(8,6)	2,501.6	2,501.0	42.7	59.3	-	42.0	-	-	-	-	-	-	75.0	-	-	0	-	-	-	-

CASE 3	VEH MINUTES		AVERAGE	CONGESTION		QUEUE LENGTH														NUMBER
	QUEUE	STOP	OCCUPANCY	STORAGE	PHASE	AVERAGE QUEUE BY LANE							MAXIMUM QUEUE BY LANE							OF LANE
LINK	TIME	TIME	(VEHICLE)	(%)	FAILURE	1	2	3	4	5	6	7	1	2	3	4	5	6	7	CHANGE
(1,3)	0.2	0.2	13.2	5.3	-	-	-	-	-	-	-	-	1.0	-	-	0	-	-	-	303.0
(3,5)	1.8	1.4	9.4	6.3	-	-	-	-	-	-	-	-	2.0	5.0	-	0	-	-	-	321.0
(5,7)	0.3	-	9.4	5.0	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	369.0
(7,9)	-	-	14.5	5.8	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	524.0
(10,8)	-	-	5.1	2.0	-	-	-	-	-	-	-	-	1.0	-	-	0	-	-	-	11.0
(8,6)	2.5	2.3	3.9	2.6	-	-	-	-	-	-	-	-	1.0	2.0	-	0	-	-	-	89.0
(6,4)	1.2	0.2	4.1	2.2	-	-	-	-	-	-	-	-	-	-	-	0	-	-	1.0	110.0
(4,2)	-	-	5.0	2.0	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	107.0
(4,3)	22.9	22.4	0.6	21.0	-	-	-	-	-	-	-	-	3.0	-	-	0	-	-	-	-
(7,8)	2.2	2.1	0.1	3.7	-	-	-	-	-	-	-	-	2.0	-	-	0	-	-	-	-
(11,6)	7.5	7.3	1.8	1.9	-	-	-	-	-	-	-	-	1.0	-	-	0	-	-	-	-
(6,11)	0.1	-	1.3	1.3	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-
(6,5)	7.8	7.6	0.2	8.0	-	-	-	-	-	-	-	-	2.0	-	-	0	-	-	-	-
(5,6)	3.1	2.8	0.1	3.7	-	-	-	-	-	-	-	-	1.0	-	-	0	-	-	-	-
(5,12)	0.1	-	0.7	0.7	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-
(12,5)	12.2	12.1	1.6	1.6	-	-	-	-	-	-	-	-	2.0	-	-	0	-	-	-	-

Table 4.3a: Site 1 Fuel Consumption Measures

EXISTING	FUEL CONSUMPTION					
	Gallons			MPG		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(5,3)	2.69	4.22	6.6	14.82	22.38	2.58
(6,8)	0.21	0.47	0.59	9.96	17.92	1.8
(6,2)	13.59	24.81	35.41	10.72	18.49	2.36
(5,7)	0.16	0.34	1.08	10.33	16.2	1.9
(6,5)	0.01	0.4	0.78	5.85	0.49	0.02
(4,6)	18.4	41.4	34.68	8.06	11.43	2.47
(8,6)	3.11	14.05	1.18	1.23	0.95	0.46
(5,6)	0.37	0.7	0	0.02	0.03	0
(1,5)	3.05	5.09	7.35	12.63	17.86	2.43
(7,5)	7.11	10.75	0.37	0.78	0.86	0.26

CASE 3	FUEL CONSUMPTION					
	Gallons			MPG		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(7,9)	2.47	4.57	8.15	19.43	26.8	2.71
(5,12)	1.29	1.94	1.95	11.28	19.57	2.15
(4,2)	11.71	24.04	33.05	17.13	25.27	3.17
(6,11)	0.43	1.09	0.98	11.89	20.01	2.53
(6,4)	9.04	17.05	21.8	13.9	22.48	3.03
(5,6)	0.04	0.21	0.01	0.83	0.8	0.13
(5,7)	2.64	4.16	5.5	11.88	19.05	2.58
(3,5)	2.69	4.8	6.13	13.34	19.01	2.79
(6,5)	0.02	0.06	0.01	3.98	1.6	0.77
(8,6)	6.49	13.87	17.74	18.3	26.92	3.81
(4,3)	0.01	0.03	0.02	9.18	13.01	3.1
(7,8)	0.05	0.13	0.01	0.95	0.79	1.8
(12,5)	0.48	1.12	0.19	16.33	25.14	3.97
(11,6)	0.93	1.27	0.37	15.27	23.09	2.96
(10,8)	11.58	24.04	39.98	16.33	25.08	2.71
(1,3)	3.15	4.93	9.27	15.4	23.19	2.41

Table 4.3b: Site 2 Fuel Consumption Measures

EXISTING	FUEL CONSUMPTION					
	Gallons			MPG		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(5,3)	13.84	23.96	27.17	9.96	17.08	2.28
(6,8)	0.23	0.38	0.57	8.19	14.97	1.85
(6,2)	2.37	5.64	9.33	19.5	26.05	2.68
(5,7)	0.06	0.18	0.29	9.92	17.16	1.93
(6,5)	0.01	0.44	0.86	0.47	0.04	0
(4,6)	3.68	7.43	12.14	12.98	20.51	2.23
(8,6)	4.24	15.36	1.36	0.66	0.54	0.25
(5,6)	0	1.16	0	10.49	0.02	0
(1,5)	12.59	28.44	25.18	10.99	14.69	2.47
(7,5)	4.85	7.44	0.44	0.96	1.17	1.14

CASE 3	FUEL CONSUMPTION					
	Gallons			MPG		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(7,9)	10.73	21.64	26.53	17.32	25.61	3.01
(5,12)	0.32	0.62	0.82	11.83	20.93	2.67
(4,2)	3.22	7.06	10.76	18.96	27.01	2.69
(6,11)	0.72	1.04	1.67	11.99	19.76	2.17
(6,4)	3.44	6.24	6.87	12.17	21.21	2.88
(5,6)	0	0.03	0	0.32	2.02	0
(5,7)	7.22	14.38	15.29	15.74	23.98	3.19
(3,5)	6.81	13.75	14.43	16.45	24.81	3.49
(6,5)	0.01	0.05	0	1.07	0.48	0
(8,6)	2.24	5.29	7.49	17.69	24.15	3.02
(4,3)	0.03	0.17	0.03	3.8	1.83	1.32
(7,8)	0.01	0.02	0	10.95	8.49	5.86
(12,5)	0.27	0.83	0.19	20.47	24.72	4.01
(11,6)	0.79	1.03	0.16	17.35	27.34	4.67
(10,8)	3.82	8.01	15.94	15.68	23.67	2.24
(1,3)	10.76	21.73	31.15	16.04	24.4	2.53

Table 4.4a: Site 1 Emissions Measures

EXISTING	EMISSIONS OF HC (GRAMS/MILE)			EMISSIONS OF CO (GRAMS/MILE)			EMISSIONS OF NO (GRAMS/MILE)		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(5,3)	0.2	0.2	14.9	11.9	12.4	288.9	1.0	1.0	34.9
(6,8)	0.3	0.3	19.1	25.2	26.3	341.2	1.2	1.0	49.9
(6,2)	0.3	0.3	15.5	25.6	25.0	292.1	1.3	1.1	38.1
(5,7)	0.3	0.4	18.0	20.0	30.2	321.7	1.1	1.1	46.8
(6,5)	0.2	0.1	1,228.8	6.3	34.2	*******	1.0	0.3	733.1
(4,6)	0.3	0.3	14.4	21.2	25.0	263.3	1.3	1.2	31.1
(8,6)	0.4	0.5	59.3	44.3	55.3	783.6	1.7	1.4	66.0
(5,6)	0.7	0.1	-	1,089.4	467.5	-	3.7	0.4	-
(1,5)	0.3	0.3	16.6	19.4	21.9	333.2	1.1	1.1	36.9
(7,5)	0.4	0.5	101.7	51.4	55.7	1,259.9	1.6	1.3	91.5

CASE 3	EMISSIONS OF HC (GRAMS/MILE)			EMISSIONS OF CO (GRAMS/MILE)			EMISSIONS OF NO (GRAMS/MILE)		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(7,9)	0.1	0.1	14.0	4.7	4.4	270.9	0.8	0.8	33.1
(5,12)	0.2	0.3	15.9	19.8	21.3	283.3	1.0	0.8	41.3
(4,2)	0.2	0.2	11.7	10.2	11.0	220.7	0.8	0.7	27.8
(6,11)	0.2	0.2	13.4	17.6	20.4	236.7	0.9	0.8	34.8
(6,4)	0.2	0.2	12.1	15.9	15.9	228.0	1.0	0.8	29.2
(5,6)	0.4	0.4	197.1	33.5	36.0	2,283.6	2.2	1.9	112.6
(5,7)	0.3	0.3	14.6	20.2	21.6	281.3	1.2	1.1	34.7
(3,5)	0.2	0.3	13.1	15.7	22.4	247.2	1.1	1.1	31.9
(6,5)	0.2	0.1	33.8	7.9	13.4	400.3	1.1	0.5	24.9
(8,6)	0.1	0.1	9.4	8.9	9.1	172.8	0.7	0.6	22.8
(4,3)	0.1	0.0	8.5	3.8	3.0	110.4	0.5	0.1	11.2
(7,8)	0.1	0.1	14.7	19.1	21.8	186.9	0.2	0.3	17.7
(12,5)	0.2	0.2	8.6	12.5	13.7	150.9	0.6	0.5	20.9
(11,6)	0.2	0.2	11.5	13.1	14.4	204.0	0.6	0.5	28.2
(10,8)	0.2	0.2	14.7	12.2	13.1	293.0	0.8	0.8	32.9
(1,3)	0.2	0.2	16.7	11.7	13.0	336.2	0.9	0.9	37.3

Table 4.4b: Site 2 Emissions Measures

EXISTING	EMISSIONS OF HC (GRAMS/MILE)			EMISSIONS OF CO (GRAMS/MILE)			EMISSIONS OF NO (GRAMS/MILE)		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(5,3)	0.4	0.4	16.1	28.4	29.0	301.9	1.4	1.3	39.5
(6,8)	0.4	0.4	18.7	32.5	35.8	333.5	1.6	1.3	48.3
(6,2)	0.1	0.1	14.3	4.8	6.4	277.7	0.8	0.8	33.6
(5,7)	0.3	0.3	17.8	23.8	28.4	316.4	1.2	1.0	46.0
(6,5)	-	0.1	6,207.3	36.2	362.3	*******	-	0.5	3,547.1
(4,6)	0.2	0.2	18.4	15.1	16.1	376.6	1.0	0.9	39.9
(8,6)	0.4	0.5	105.2	53.9	72.3	1,316.0	1.6	1.5	94.2
(5,6)	-	-	-	1.9	692.8	-	-	-	-
(1,5)	0.2	0.3	15.6	16.6	20.1	305.0	1.0	0.9	33.7
(7,5)	0.4	0.4	25.3	49.0	47.9	360.5	1.6	1.2	38.0

CASE 3	EMISSIONS OF HC (GRAMS/MILE)			EMISSIONS OF CO (GRAMS/MILE)			EMISSIONS OF NO (GRAMS/MILE)		
LINK	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck	Avg. Auto	Aggressive Auto	Truck
(7,9)	0.1	0.2	12.6	9.5	10.4	242.3	0.8	0.7	29.4
(5,12)	0.2	0.2	12.7	19.0	18.6	224.2	1.0	0.7	33.0
(4,2)	0.1	0.1	14.5	6.0	5.6	285.7	0.8	0.7	33.3
(6,11)	0.2	0.3	15.8	18.8	21.4	279.4	1.0	0.8	40.8
(6,4)	0.3	0.2	13.2	19.4	17.2	254.6	1.2	1.0	31.0
(5,6)	-	0.1	-	51.0	11.6	-	-	0.6	-
(5,7)	0.2	0.2	11.6	12.4	13.1	219.9	0.8	0.8	27.7
(3,5)	0.2	0.2	10.5	11.0	11.6	196.1	0.8	0.7	25.2
(6,5)	0.3	0.4	-	24.4	51.3	-	1.6	1.6	-
(8,6)	0.1	0.2	12.4	7.8	10.9	235.9	0.8	0.8	29.6
(4,3)	0.1	0.1	19.8	7.0	13.8	241.7	0.4	0.6	17.8
(7,8)	0.0	0.0	4.5	2.1	2.6	55.1	0.1	0.0	4.4
(12,5)	0.1	0.2	8.0	7.4	12.1	135.4	0.4	0.5	19.9
(11,6)	0.2	0.1	7.1	11.7	10.5	120.8	0.5	0.4	17.1
(10,8)	0.2	0.2	18.3	11.5	12.4	371.2	0.9	0.9	40.2
(1,3)	0.2	0.2	16.0	12.2	13.7	322.4	0.8	0.8	35.4

Table 4.5a: Link Specific Comparisons of Performance Measures - Site 1

LINK		DELAY PER VEHICLE (SEC)		QUEUE		FUEL CONSUMPTION (GAL)		HC EMISSIONS (GRAMS/MILE)	
EXISTING	CASE 3	EXISTING	CASE 3	EXISTING	CASE 3	EXISTING	CASE 3	EXISTING	CASE 3
(4,6)	(8,6)	109.7	2.7	19	-	29.9	10.2	0.6	0.3
(7,5)	(12,5)	1,409.7	9.5	19	-	9.0	0.8	0.9	0.4
(5,6)	(5,6)	846.1	43.6	1	-	0.5	0.1	0.8	0.3
(6,5)	(6,5)	172.8	18.9	1	-	0.2	0.0	0.3	0.1
(8,6)	(11,6)	1,217.6	16.1	18	-	8.6	1.1	0.9	0.4

Table 4.5b: Link Specific Comparisons of Performance Measures - Site 2

LINK		DELAY PER VEHICLE (SEC)		QUEUE		FUEL CONSUMPTION (GAL)		HC EMISSIONS (GRAMS/MILE)	
EXISTING	CASE 3	EXISTING	CASE 3	EXISTING	CASE 3	EXISTING	CASE 3	EXISTING	CASE 3
(4,6)	(8,6)	15.1	2.4	13	-	5.6	3.8	0.2	0.2
(7,5)	(12,5)	2.5	14.5	-	-	6.1	0.6	0.4	0.2
(5,6)	(5,6)	1,122.7	24.5	1	-	0.6	0.0	-	0.1
(6,5)	(6,5)	1,101.5	38.3	1	-	0.2	0.0	0.1	0.4
(8,6)	(11,6)	1,881.6	2.4	21	-	9.8	0.9	0.5	0.2

Table 4.6a: System-wide Comparisons of Performance Measures - Site 1

MOE	EXISTING	CASE 3	% REDUCTION
Average total delay in vehicle minutes	152.5	34.6	77%
Average delay per vehicle in seconds	376.0	9.5	97%
Average percent stops	35.6	43.5	-22%
Average queue length	5.7	-	100%
Average maximum queue length	13.0	1.0	92%
Average fuel consumption (gallons)	8.0	11.8	-48%
Average fuel consumption (mpg)	6.5	11.2	-72%
Total Emissions of HC (grams/mile)	1,494.4	415.7	72%
Total Emissions of CO (grams/mile)	5,952.1	6,387.4	-7%
Total Emissions of NO (grams/mile)	1,153.1	568.1	51%

Table 4.6b: System-wide Comparisons of Performance Measures - Site 2

MOE	EXISTING	CASE 3	% REDUCTION
Average total delay in vehicle minutes	75.7	25.9	66%
Average delay per vehicle in seconds	541.6	7.8	99%
Average percent stops	36.6	27.0	26%
Average queue length	4.1	-	100%
Average maximum queue length	9.3	0.7	92%
Average fuel consumption (gallons)	7.0	11.1	-59%
Average fuel consumption (mpg)	7.0	11.7	-67%
Total Emissions of HC (grams/mile)	6,443.7	195.9	97%
Total Emissions of CO (grams/mile)	5,161.2	3,941.3	24%
Total Emissions of NO (grams/mile)	3,939.7	441.3	89%

V. USING THE HCM/HCS TO EVALUATE ALTERNATIVES

The Highway Capacity Software [9] implements Part A of the *Highway Capacity Manual* (HCM) [3] Chapter 10 (Unsignalized Intersections). Part A of the HCM chapter deals with two-way stop-controlled intersections. It provides an analytical approach to estimate average conditions. The results can be adapted to apply, to a limited extent, to Type II Crossovers. However, as described in this chapter, the HCM approach was found to be inferior to the CORSIM approach (described earlier in Chapter 4).

INTRODUCTION

The HCM method for two-way stop-controlled intersections assumes that:

- vehicles yield to other movements in priority accorded by normal traffic law,
- gaps used by lower priority vehicles are randomly distributed, however the arrival pattern within a particular time interval may be affected by nearby (within ¼ mile) signals,
- the first waiting vehicle requires a "critical gap" in conflicting traffic to make its movement, and
- additional vehicles behind the first vehicle require additional "follow-up time" to use that same gap.

To illustrate critical gap and follow-up time, see Figure 5-1 below. Vehicle 1 must wait for a critical gap in the conflicting flow. If that gap equals the critical gap plus the follow-up time, then both Vehicle 1 and Vehicle 2 can make their maneuver in the same gap.

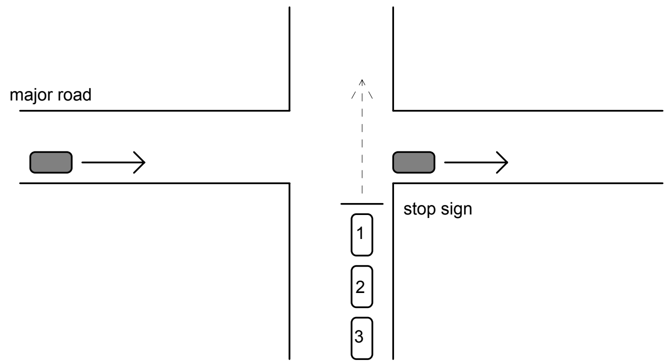


Figure 5-1: Critical Gap and Follow-up Time

As mentioned above, it is assumed that vehicles yield to other movements in priority accorded by normal traffic law. The priority is shown in Table 5-1 and Figure 5-2.

TABLE 5-1: PRIORITY OF STREAMS

Rank	Movement	Subordinate to:
r = 1	• through traffic on major road • right turning traffic from major road	-
r = 2	• left-turning traffic from major road • right turning traffic onto major road from minor	Rank 1
r = 3	• through traffic on minor road • left-turning traffic from minor road (if a T-intersection)	Ranks 1 and 2
r = 4	• left-turning traffic from minor road (if a 4-leg intersection)	Ranks 1, 2, and 3

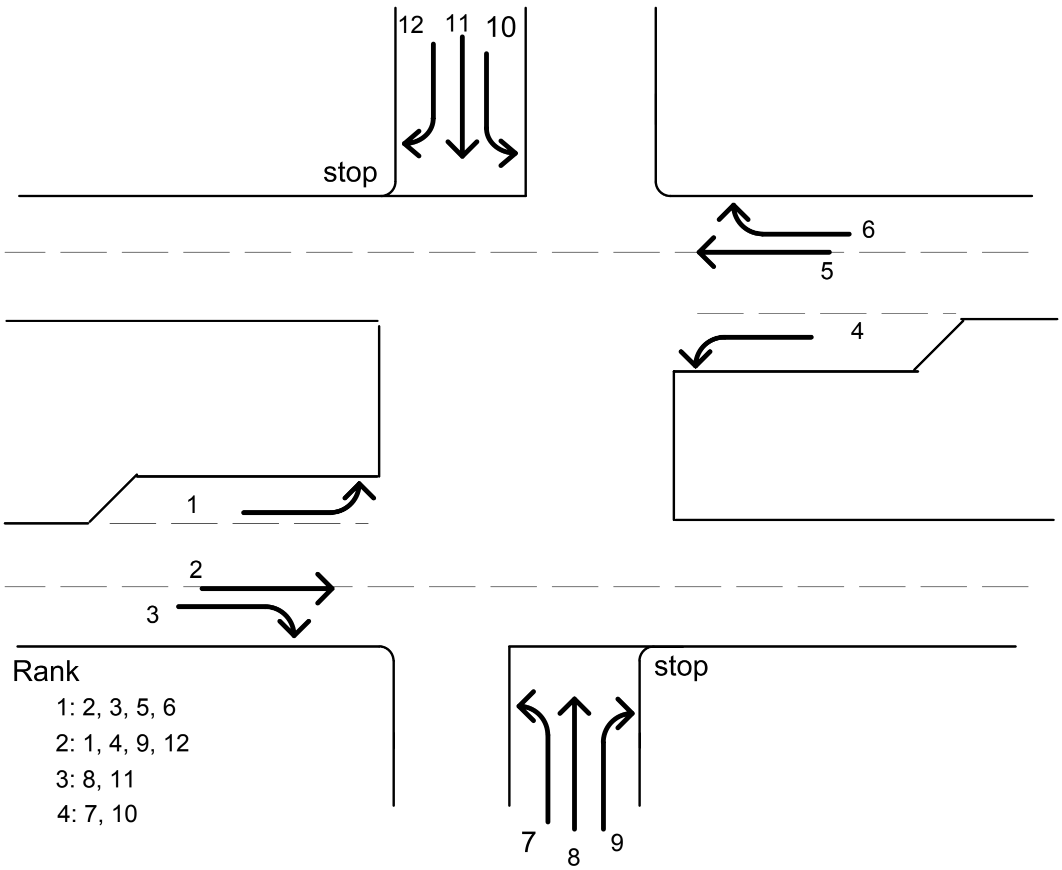


Figure 5-2: Priority of Streams at Crossover

TWO-STAGE GAP ACCEPTANCE

To analyze traffic movements at a crossover, a special procedure called two-stage gap acceptance is used. For example, a minor road left-turning vehicle (Movement 7 in Figure 5-2) might first find a gap in major road traffic coming from the left and then wait for a gap in major road traffic coming from the right (also see Figure 5-3).

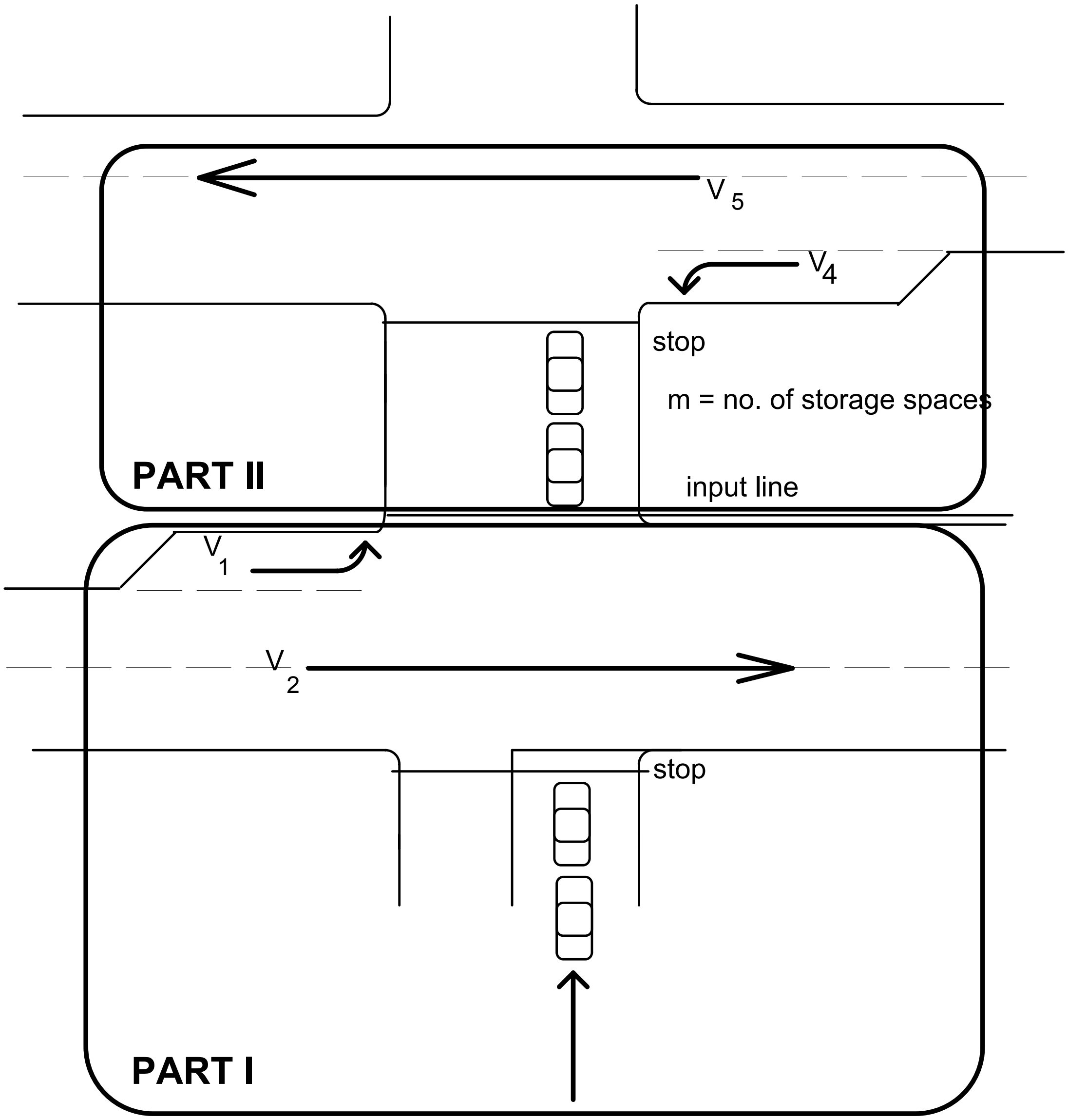


Figure 5-3: Two-stage Gap Acceptance

FLARED MINOR-ROAD APPROACHES

When the minor road approach is flared or channelized so that two vehicles can wait side-by-side at the stop line (e.g., a right-tuning vehicle and a through vehicle), the capacity of this approach is greater than if only one vehicle can wait at the stop line. This is generally the case at a crossover. The magnitude of this increase in capacity depends on the turning movement flow rates and the storage length to feed the "second position."

The resulting capacity will be between that of a single lane approach and that of a two-lane approach.

INPUT REQUIREMENTS

The input requirements consist of geometric data and traffic flow data. Geometric data include:

- Number and use of lanes – On major road, this may include a left-turn lane (really a deceleration lane with perhaps some storage space) plus two through lane plus a right-turn lane or a left-turn lane (really a deceleration lane with perhaps some storage space) plus one through lane plus a shared through/right-turn lane;
- Channelization – all locations where right turns are channelized should be noted;
- Raised or striped median storage – Crossovers by their nature have median storage. When using the HCS, this storage space is indicated by selecting “raised median. Generally about 30 ft. is needed to store a passenger car;
- approach grade – downgrades increase capacity while upgrades decrease capacity; and
- flared approaches on minor roads.

Traffic data include:

- vehicular volumes by movement during the peak hour must be indicated. Note that the “peak hour” is the consecutive 60 minute period with the highest volumes. However, if the minor road traffic peaks at a different time than the major road traffic, one should consider any time period that might be congested;
- PHF – The 15 minute flows during the peak hour should be examined to determine one peak hour factor for the crossover traffic. PHF = peak hour volume/(4x Peak 15-minute volume);
- traffic composition – the % heavy vehicles (i.e., trucks and buses) for each traffic movement should be entered;
- upstream signal data – needed if a signal on the major road is within 0.25 miles of the crossover. Required information includes cycle length, green time for major road traffic, progression speed, arrival type, saturation flow rate, and progressed flow; and

- pedestrian volumes – generally equal to zero for rural crossovers.

PERFORMANCE MEASURES

The performance measures output by the HCS include delay and level of service. The results can be manually manipulated to also produce average queue length and 95th percentile queue length.

Delay and Level of Service

The HCS estimates average control delay. Note also that this delay can be directly measured in the field. The LOS criteria are given in the HCM are shown in Table 5-2.

TABLE 5-2: LEVEL-OF-SERVICE CRITERIA

LOS	AVERAGE CONTROL DELAY, D (sec/veh)
A	D ≤ 10
B	10 < D ≤ 15
C	15 < D ≤ 25
D	25 < D ≤ 35
E	35 < D ≤ 50
F	50 < D

Note that we can calculate control delay, and therefore level of service, for:

- a single yielding movement
- a minor road approach
- average intersection total delay

Average Queue Length and Maximum (95th percentile) Queue Length

Average Queue Length must be calculated manually. The average queue length will be equal to the average delay per vehicle times the flow rate of the movement (both available from the HCS output). To visualize the units, think of average delay in <u>hours</u> times <u>vehicles per hour</u> (hr x veh/hr = veh-hr/hr = veh = vehicles).

The expected maximum queue length (also called the 95th percentile queue length or the queue length that will not be exceeded except for 5% of the time) is found through a nomograph in the HCM. One must manually enter the volume/capacity ratio and the hourly approach volume (available from the HCS output) to find the expected maximum queue length. Unfortunately, the maximum queue length is calculated by the HCS only for minor road flared approaches, which does not address the issue of congestion in the median opening.

CASE STUDY

The HCS was applied to the same base condition for that used in the CORSIM simulation (Route 13 at Route O in MoDOT's District 8) described in Chapter 4. The HCS application demonstrated both the strengths and weaknesses of the HCM approach. The delay and level of service for each turning movement were estimated with little effort. However, since results are reported by movement, some critical information was absent. For example, the delay experienced by a minor road crossing vehicle consists of delay when waiting for expressway traffic coming from the left (before the minor road vehicle reaches the median) and delay while in the median and waiting for a gap in expressway traffic coming from the right. This division of delay is due to two-stage gap acceptance.

To overcome this problem, the data were manipulated to analyze the crossover location as two separate intersections. While this is mathematically appropriate, it may seem to be an uncomfortable burden to an engineer responsible for the analysis. Unfortunately, no method was found to force the HCS to correctly identify the capacities, delays, or levels of service for the flows. The reason for this flaw in the application was not determined. Due to these problems, the case study was ended.

EVALUATION

The HCM and HCS can be used to estimate the capacities, delays, or levels of service for the flows at a crossover. Unfortunately, no means was found to apply the HCS to accurately identify the capacities, delays, or levels of service for the flows and queuing vehicles within the median crossover (stage II of the two-stage gap acceptance procedure). However, the expected accuracy and usefulness of this type of approach are discussed below.

ACCURACY ISSUES AND LIMITATIONS

The HCM assumes a constant vehicle length. At many rural crossovers, problems arise when long trucks are present. Since the HCM deals with average conditions, vehicle length is not explicitly addressed.

The HCM also assumes that critical gap is a constant. If expected queue lengths are long then average delays may also be long. When minor road or major road left-turning traffic experiences long delays, drivers will often accept shorter (and perhaps dangerously short) gaps.

EASE OF USE

The HCS generally can be applied in a relatively short time. A graduate student who was just learning to apply the HCS found that learning to apply the software required several hours. However, once some experience was gained, he could take a plan view of an intersection and 15-minute count data and, within 15 minutes, have the intersection analyzed by the HCS.

CONCLUSIONS

The HCM and HCS can be used to describe average flow conditions for individual movements (i.e., lefts, throughs, and rights) at a crossover. One can usually take HCS results and manually estimate 95th percentile queue lengths. However the analysts were unable to force the HCS to accurately estimate the delays taking place within the median crossover. For this reason, the HCS proved to be a weaker tool than needed for analyzing crossovers.

VI. COST ESTIMATES FOR EVALUATION

There exist several approaches to evaluating alternative improvements. All require some sort of cost information. The purpose of this brief chapter is to propose one method for estimating capital costs using the Case 3 alternative described in Chapter 4. MoDOT construction cost data were used to develop the costs of improvements.

COST ESTIMATES

The "big cost" items were assumed to be those listed in Table 6.1 and were the only ones included in cost estimates.

Table 6.1 MoDOT Unit Costs

Item Number	Description	Unit cost	Unit
201-10.00	Clearing	$ 2,340.72	ACRE
201-20.00	Grubbing	$ 1,807.37	ACRE
203-50.00	Unclassified Excavation	$ 2.69	CY
403-81.30	AC PG64-28	$ 117.80	TON
304-00.43	Aggregate base	$ 2.61	SY
310-50.01	Gravel (for sub-base)	$ 26.54	CY
620-55.18	Thermoplastic 8" lines	$ 1.14	LF
620-55.19	Thermoplastic ONLY	$ 124.25	EA
903-50.09	Stop Sign (36")	$ 161.71	EA
903-50.04	Signage	$ 22.71	SF
903-12.40	Breakaway assembly	$ 55.33	EA

All calculations are based upon the following assumptions:

- Width of repair zone between improved and existing pavements equals 5 ft.,
- Depth of excavation equals 1.5 ft.,
- Pavement structure consists of 4 in. AC, 4 in. granular base, 12 in. gravel sub-base,

- New median opening is a Type I crossover design as indicated in MoDOT's standard drawings, and
- Maintenance costs are equal for all of the alternative designs presented in Figures 4.1.

Areas upon which costs are based are shown in Tables 6.2 and 6.3 below and derive from MoDOT's standard drawings for Types I and II crossovers. The following terms are used in the subsequent tables:

Terms

Lj = Length of jug handle

N = number of lanes on jug handle

Length = length of storage lane

L_j = 450 (storage in jug approximately 50 ft.)

N = 1

Table 6.2 Case 3

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	2,239	2,311	2,383	2,455	2,527	2,599	2,671	2,743	2,815
55	2,300	2,372	2,444	2,516	2,588	2,660	2,732	2,804	2,876
60	2,360	2,432	2,504	2,576	2,648	2,720	2,792	2,864	2,936
65	2,421	2,493	2,565	2,637	2,709	2,781	2,853	2,925	2,997
70	2,482	2,554	2,626	2,698	2,770	2,842	2,914	2,986	3,058
75	2,542	2,614	2,686	2,758	2,830	2,902	2,974	3,046	3,118
80	2,603	2,675	2,747	2,819	2,891	2,963	3,035	3,107	3,179
85	2,663	2,735	2,807	2,879	2,951	3,023	3,095	3,167	3,239
90	2,724	2,796	2,868	2,940	3,012	3,084	3,156	3,228	3,300
95	2,785	2,857	2,929	3,001	3,073	3,145	3,217	3,289	3,361
100	2,845	2,917	2,989	3,061	3,133	3,205	3,277	3,349	3,421

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	992	1,020	1,048	1,075	1,103	1,130	1,158	1,185	1,213
55	1,015	1,043	1,070	1,098	1,125	1,153	1,180	1,208	1,235
60	1,038	1,065	1,093	1,120	1,148	1,175	1,203	1,231	1,258
65	1,060	1,088	1,115	1,143	1,170	1,198	1,226	1,253	1,281
70	1,083	1,110	1,138	1,165	1,193	1,221	1,248	1,276	1,303
75	1,105	1,133	1,160	1,188	1,216	1,243	1,271	1,298	1,326
80	1,128	1,156	1,183	1,211	1,238	1,266	1,293	1,321	1,348
85	1,151	1,178	1,206	1,233	1,261	1,288	1,316	1,343	1,371
90	1,173	1,201	1,228	1,256	1,283	1,311	1,338	1,366	1,394
95	1,196	1,223	1,251	1,278	1,306	1,333	1,361	1,389	1,416
100	1,218	1,246	1,273	1,301	1,329	1,356	1,384	1,411	1,439

c) Total Costs for Alternative

Width (ft)	Length (ft)								
	50	75	100	125	150	175	200	225	250
50	$ 51,635	$ 52,919	$ 54,204	$ 55,488	$ 56,772	$ 58,057	$ 59,341	$ 60,625	$ 61,910
55	$ 52,656	$ 53,940	$ 55,224	$ 56,509	$ 57,793	$ 59,077	$ 60,362	$ 61,646	$ 62,930
60	$ 53,677	$ 54,961	$ 56,245	$ 57,530	$ 58,814	$ 60,098	$ 61,383	$ 62,667	$ 63,951
65	$ 54,697	$ 55,982	$ 57,266	$ 58,550	$ 59,835	$ 61,119	$ 62,403	$ 63,688	$ 64,972
70	$ 55,718	$ 57,003	$ 58,287	$ 59,571	$ 60,856	$ 62,140	$ 63,424	$ 64,708	$ 65,993
75	$ 56,739	$ 58,023	$ 59,308	$ 60,592	$ 61,876	$ 63,161	$ 64,445	$ 65,729	$ 67,014
80	$ 57,760	$ 59,044	$ 60,328	$ 61,613	$ 62,897	$ 64,181	$ 65,466	$ 66,750	$ 68,034
85	$ 58,781	$ 60,065	$ 61,349	$ 62,634	$ 63,918	$ 65,202	$ 66,487	$ 67,771	$ 69,055
90	$ 59,801	$ 61,086	$ 62,370	$ 63,654	$ 64,939	$ 66,223	$ 67,507	$ 68,792	$ 70,076
95	$ 60,822	$ 62,106	$ 63,391	$ 64,675	$ 65,959	$ 67,244	$ 68,528	$ 69,812	$ 71,097
100	$ 61,843	$ 63,127	$ 64,412	$ 65,696	$ 66,980	$ 68,265	$ 69,549	$ 70,833	$ 72,118

Table 6.3.1 Case 4 - Lj = 450 ft., N = 1 lane

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	13,595	13,667	13,739	13,811	13,883	13,955	14,027	14,099	14,171
55	13,679	13,751	13,823	13,895	13,967	14,039	14,111	14,183	14,255
60	13,762	13,834	13,906	13,978	14,050	14,122	14,194	14,266	14,338
65	13,845	13,917	13,989	14,061	14,133	14,205	14,277	14,349	14,421
70	13,928	14,000	14,072	14,144	14,216	14,288	14,360	14,432	14,504
75	14,011	14,083	14,155	14,227	14,299	14,371	14,443	14,515	14,587
80	14,095	14,167	14,239	14,311	14,383	14,455	14,527	14,599	14,671
85	14,178	14,250	14,322	14,394	14,466	14,538	14,610	14,682	14,754
90	14,261	14,333	14,405	14,477	14,549	14,621	14,693	14,765	14,837
95	14,344	14,416	14,488	14,560	14,632	14,704	14,776	14,848	14,920
100	14,427	14,499	14,571	14,643	14,715	14,787	14,859	14,931	15,003

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	12,349	12,376	12,404	12,431	12,459	12,486	12,514	12,542	12,569
55	12,394	12,421	12,449	12,477	12,504	12,532	12,559	12,587	12,614
60	12,439	12,467	12,494	12,522	12,549	12,577	12,604	12,632	12,659
65	12,484	12,512	12,539	12,567	12,594	12,622	12,650	12,677	12,705
70	12,529	12,557	12,584	12,612	12,640	12,667	12,695	12,722	12,750
75	12,575	12,602	12,630	12,657	12,685	12,712	12,740	12,767	12,795
80	12,620	12,647	12,675	12,702	12,730	12,757	12,785	12,813	12,840
85	12,665	12,692	12,720	12,748	12,775	12,803	12,830	12,858	12,885
90	12,710	12,738	12,765	12,793	12,820	12,848	12,875	12,903	12,930
95	12,755	12,783	12,810	12,838	12,865	12,893	12,921	12,948	12,976
100	12,800	12,828	12,855	12,883	12,911	12,938	12,966	12,993	13,021

c) Total Costs for Alternative

Width (ft)	Length (ft)								
	50	75	100	125	150	175	200	225	250
50	$ 524,131	$ 525,415	$ 526,699	$ 527,984	$ 529,268	$ 530,552	$ 531,837	$ 533,121	$ 534,405
55	$ 526,077	$ 527,361	$ 528,646	$ 529,930	$ 531,214	$ 532,499	$ 533,783	$ 535,067	$ 536,352
60	$ 528,024	$ 529,308	$ 530,592	$ 531,876	$ 533,161	$ 534,445	$ 535,729	$ 537,014	$ 538,298
65	$ 529,970	$ 531,254	$ 532,539	$ 533,823	$ 535,107	$ 536,392	$ 537,676	$ 538,960	$ 540,245
70	$ 531,916	$ 533,201	$ 534,485	$ 535,769	$ 537,054	$ 538,338	$ 539,622	$ 540,907	$ 542,191
75	$ 533,863	$ 535,147	$ 536,431	$ 537,716	$ 539,000	$ 540,284	$ 541,569	$ 542,853	$ 544,137
80	$ 535,809	$ 537,094	$ 538,378	$ 539,662	$ 540,947	$ 542,231	$ 543,515	$ 544,800	$ 546,084
85	$ 537,756	$ 539,040	$ 540,324	$ 541,609	$ 542,893	$ 544,177	$ 545,462	$ 546,746	$ 548,030
90	$ 539,702	$ 540,986	$ 542,271	$ 543,555	$ 544,839	$ 546,124	$ 547,408	$ 548,692	$ 549,977
95	$ 541,649	$ 542,933	$ 544,217	$ 545,502	$ 546,786	$ 548,070	$ 549,355	$ 550,639	$ 551,923
100	$ 543,595	$ 544,879	$ 546,164	$ 547,448	$ 548,732	$ 550,017	$ 551,301	$ 552,585	$ 553,870

Table 6.3.2 Case 4 - Lj = 450 ft., N = 2 lanes

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	50	75	100	125	150	175	200	225	250
50	24,425	24,497	24,569	24,641	24,713	24,785	24,857	24,929	25,001
55	24,509	24,581	24,653	24,725	24,797	24,869	24,941	25,013	25,085
60	24,592	24,664	24,736	24,808	24,880	24,952	25,024	25,096	25,168
65	24,675	24,747	24,819	24,891	24,963	25,035	25,107	25,179	25,251
70	24,758	24,830	24,902	24,974	25,046	25,118	25,190	25,262	25,334
75	24,841	24,913	24,985	25,057	25,129	25,201	25,273	25,345	25,417
80	24,925	24,997	25,069	25,141	25,213	25,285	25,357	25,429	25,501
85	25,008	25,080	25,152	25,224	25,296	25,368	25,440	25,512	25,584
90	25,091	25,163	25,235	25,307	25,379	25,451	25,523	25,595	25,667
95	25,174	25,246	25,318	25,390	25,462	25,534	25,606	25,678	25,750
100	25,257	25,329	25,401	25,473	25,545	25,617	25,689	25,761	25,833

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	50	75	100	125	150	175	200	225	250
50	23,179	23,206	23,234	23,261	23,289	23,316	23,344	23,372	23,399
55	23,224	23,251	23,279	23,307	23,334	23,362	23,389	23,417	23,444
60	23,269	23,297	23,324	23,352	23,379	23,407	23,434	23,462	23,489
65	23,314	23,342	23,369	23,397	23,424	23,452	23,480	23,507	23,535
70	23,359	23,387	23,414	23,442	23,470	23,497	23,525	23,552	23,580
75	23,405	23,432	23,460	23,487	23,515	23,542	23,570	23,597	23,625
80	23,450	23,477	23,505	23,532	23,560	23,587	23,615	23,643	23,670
85	23,495	23,522	23,550	23,578	23,605	23,633	23,660	23,688	23,715
90	23,540	23,568	23,595	23,623	23,650	23,678	23,705	23,733	23,760
95	23,585	23,613	23,640	23,668	23,695	23,723	23,751	23,778	23,806
100	23,630	23,658	23,685	23,713	23,741	23,768	23,796	23,823	23,851

c) Total Costs for Alternative

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	$ 968,547	$ 969,831	$ 971,116	$ 972,400	$ 973,684	$ 974,969	$ 976,253	$ 977,537	$ 978,822
55	$ 970,493	$ 971,778	$ 973,062	$ 974,346	$ 975,631	$ 976,915	$ 978,199	$ 979,484	$ 980,768
60	$ 972,440	$ 973,724	$ 975,009	$ 976,293	$ 977,577	$ 978,862	$ 980,146	$ 981,430	$ 982,715
65	$ 974,386	$ 975,671	$ 976,955	$ 978,239	$ 979,524	$ 980,808	$ 982,092	$ 983,377	$ 984,661
70	$ 976,333	$ 977,617	$ 978,901	$ 980,186	$ 981,470	$ 982,754	$ 984,039	$ 985,323	$ 986,607
75	$ 978,279	$ 979,564	$ 980,848	$ 982,132	$ 983,417	$ 984,701	$ 985,985	$ 987,269	$ 988,554
80	$ 980,226	$ 981,510	$ 982,794	$ 984,079	$ 985,363	$ 986,647	$ 987,932	$ 989,216	$ 990,500
85	$ 982,172	$ 983,456	$ 984,741	$ 986,025	$ 987,309	$ 988,594	$ 989,878	$ 991,162	$ 992,447
90	$ 984,119	$ 985,403	$ 986,687	$ 987,972	$ 989,256	$ 990,540	$ 991,824	$ 993,109	$ 994,393
95	$ 986,065	$ 987,349	$ 988,634	$ 989,918	$ 991,202	$ 992,487	$ 993,771	$ 995,055	$ 996,340
100	$ 988,011	$ 989,296	$ 990,580	$ 991,864	$ 993,149	$ 994,433	$ 995,717	$ 997,002	$ 998,286

Table 6.3.3 Case 4 - Lj = 550 ft., N = 1 lane

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	15,995	16,067	16,139	16,211	16,283	16,355	16,427	16,499	16,571
55	16,079	16,151	16,223	16,295	16,367	16,439	16,511	16,583	16,655
60	16,162	16,234	16,306	16,378	16,450	16,522	16,594	16,666	16,738
65	16,245	16,317	16,389	16,461	16,533	16,605	16,677	16,749	16,821
70	16,328	16,400	16,472	16,544	16,616	16,688	16,760	16,832	16,904
75	16,411	16,483	16,555	16,627	16,699	16,771	16,843	16,915	16,987
80	16,495	16,567	16,639	16,711	16,783	16,855	16,927	16,999	17,071
85	16,578	16,650	16,722	16,794	16,866	16,938	17,010	17,082	17,154
90	16,661	16,733	16,805	16,877	16,949	17,021	17,093	17,165	17,237
95	16,744	16,816	16,888	16,960	17,032	17,104	17,176	17,248	17,320
100	16,827	16,899	16,971	17,043	17,115	17,187	17,259	17,331	17,403

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	14,749	14,776	14,804	14,831	14,859	14,886	14,914	14,942	14,969
55	14,794	14,821	14,849	14,877	14,904	14,932	14,959	14,987	15,014
60	14,839	14,867	14,894	14,922	14,949	14,977	15,004	15,032	15,059
65	14,884	14,912	14,939	14,967	14,994	15,022	15,050	15,077	15,105
70	14,929	14,957	14,984	15,012	15,040	15,067	15,095	15,122	15,150
75	14,975	15,002	15,030	15,057	15,085	15,112	15,140	15,167	15,195
80	15,020	15,047	15,075	15,102	15,130	15,157	15,185	15,213	15,240
85	15,065	15,092	15,120	15,148	15,175	15,203	15,230	15,258	15,285
90	15,110	15,138	15,165	15,193	15,220	15,248	15,275	15,303	15,330
95	15,155	15,183	15,210	15,238	15,265	15,293	15,321	15,348	15,376
100	15,200	15,228	15,255	15,283	15,311	15,338	15,366	15,393	15,421

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 622,731	$ 624,015	$ 625,299	$ 626,584	$ 627,868	$ 629,152	$ 630,437	$ 631,721	$ 633,005
55	$ 624,677	$ 625,961	$ 627,246	$ 628,530	$ 629,814	$ 631,099	$ 632,383	$ 633,667	$ 634,952
60	$ 626,623	$ 627,908	$ 629,192	$ 630,476	$ 631,761	$ 633,045	$ 634,329	$ 635,614	$ 636,898
65	$ 628,570	$ 629,854	$ 631,139	$ 632,423	$ 633,707	$ 634,992	$ 636,276	$ 637,560	$ 638,844
70	$ 630,516	$ 631,801	$ 633,085	$ 634,369	$ 635,654	$ 636,938	$ 638,222	$ 639,507	$ 640,791
75	$ 632,463	$ 633,747	$ 635,031	$ 636,316	$ 637,600	$ 638,884	$ 640,169	$ 641,453	$ 642,737
80	$ 634,409	$ 635,694	$ 636,978	$ 638,262	$ 639,547	$ 640,831	$ 642,115	$ 643,399	$ 644,684
85	$ 636,356	$ 637,640	$ 638,924	$ 640,209	$ 641,493	$ 642,777	$ 644,062	$ 645,346	$ 646,630
90	$ 638,302	$ 639,586	$ 640,871	$ 642,155	$ 643,439	$ 644,724	$ 646,008	$ 647,292	$ 648,577
95	$ 640,249	$ 641,533	$ 642,817	$ 644,102	$ 645,386	$ 646,670	$ 647,954	$ 649,239	$ 650,523
100	$ 642,195	$ 643,479	$ 644,764	$ 646,048	$ 647,332	$ 648,617	$ 649,901	$ 651,185	$ 652,470

Table 6.3.4 Case 4 - Lj = 550 ft., N = 2 lanes

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	29,225	29,297	29,369	29,441	29,513	29,585	29,657	29,729	29,801
55	29,309	29,381	29,453	29,525	29,597	29,669	29,741	29,813	29,885
60	29,392	29,464	29,536	29,608	29,680	29,752	29,824	29,896	29,968
65	29,475	29,547	29,619	29,691	29,763	29,835	29,907	29,979	30,051
70	29,558	29,630	29,702	29,774	29,846	29,918	29,990	30,062	30,134
75	29,641	29,713	29,785	29,857	29,929	30,001	30,073	30,145	30,217
80	29,725	29,797	29,869	29,941	30,013	30,085	30,157	30,229	30,301
85	29,808	29,880	29,952	30,024	30,096	30,168	30,240	30,312	30,384
90	29,891	29,963	30,035	30,107	30,179	30,251	30,323	30,395	30,467
95	29,974	30,046	30,118	30,190	30,262	30,334	30,406	30,478	30,550
100	30,057	30,129	30,201	30,273	30,345	30,417	30,489	30,561	30,633

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	27,979	28,006	28,034	28,061	28,089	28,116	28,144	28,172	28,199
55	28,024	28,051	28,079	28,107	28,134	28,162	28,189	28,217	28,244
60	28,069	28,097	28,124	28,152	28,179	28,207	28,234	28,262	28,289
65	28,114	28,142	28,169	28,197	28,224	28,252	28,280	28,307	28,335
70	28,159	28,187	28,214	28,242	28,270	28,297	28,325	28,352	28,380
75	28,205	28,232	28,260	28,287	28,315	28,342	28,370	28,397	28,425
80	28,250	28,277	28,305	28,332	28,360	28,387	28,415	28,443	28,470
85	28,295	28,322	28,350	28,378	28,405	28,433	28,460	28,488	28,515
90	28,340	28,368	28,395	28,423	28,450	28,478	28,505	28,533	28,560
95	28,385	28,413	28,440	28,468	28,495	28,523	28,551	28,578	28,606
100	28,430	28,458	28,485	28,513	28,541	28,568	28,596	28,623	28,651

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 1,165,633	$ 1,166,917	$ 1,168,202	$ 1,169,486	$ 1,170,770	$ 1,172,055	$ 1,173,339	$ 1,174,623	$ 1,175,908
55	$ 1,167,579	$ 1,168,864	$ 1,170,148	$ 1,171,432	$ 1,172,717	$ 1,174,001	$ 1,175,285	$ 1,176,570	$ 1,177,854
60	$ 1,169,526	$ 1,170,810	$ 1,172,094	$ 1,173,379	$ 1,174,663	$ 1,175,947	$ 1,177,232	$ 1,178,516	$ 1,179,800
65	$ 1,171,472	$ 1,172,757	$ 1,174,041	$ 1,175,325	$ 1,176,610	$ 1,177,894	$ 1,179,178	$ 1,180,463	$ 1,181,747
70	$ 1,173,419	$ 1,174,703	$ 1,175,987	$ 1,177,272	$ 1,178,556	$ 1,179,840	$ 1,181,125	$ 1,182,409	$ 1,183,693
75	$ 1,175,365	$ 1,176,649	$ 1,177,934	$ 1,179,218	$ 1,180,502	$ 1,181,787	$ 1,183,071	$ 1,184,355	$ 1,185,640
80	$ 1,177,312	$ 1,178,596	$ 1,179,880	$ 1,181,165	$ 1,182,449	$ 1,183,733	$ 1,185,018	$ 1,186,302	$ 1,187,586
85	$ 1,179,258	$ 1,180,542	$ 1,181,827	$ 1,183,111	$ 1,184,395	$ 1,185,680	$ 1,186,964	$ 1,188,248	$ 1,189,533
90	$ 1,181,204	$ 1,182,489	$ 1,183,773	$ 1,185,057	$ 1,186,342	$ 1,187,626	$ 1,188,910	$ 1,190,195	$ 1,191,479
95	$ 1,183,151	$ 1,184,435	$ 1,185,720	$ 1,187,004	$ 1,188,288	$ 1,189,572	$ 1,190,857	$ 1,192,141	$ 1,193,425
100	$ 1,185,097	$ 1,186,382	$ 1,187,666	$ 1,188,950	$ 1,190,235	$ 1,191,519	$ 1,192,803	$ 1,194,088	$ 1,195,372

Table 6.3.5 Case 4 - Lj = 650 ft., N = 1 lane

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	18,395	18,467	18,539	18,611	18,683	18,755	18,827	18,899	18,971
55	18,479	18,551	18,623	18,695	18,767	18,839	18,911	18,983	19,055
60	18,562	18,634	18,706	18,778	18,850	18,922	18,994	19,066	19,138
65	18,645	18,717	18,789	18,861	18,933	19,005	19,077	19,149	19,221
70	18,728	18,800	18,872	18,944	19,016	19,088	19,160	19,232	19,304
75	18,811	18,883	18,955	19,027	19,099	19,171	19,243	19,315	19,387
80	18,895	18,967	19,039	19,111	19,183	19,255	19,327	19,399	19,471
85	18,978	19,050	19,122	19,194	19,266	19,338	19,410	19,482	19,554
90	19,061	19,133	19,205	19,277	19,349	19,421	19,493	19,565	19,637
95	19,144	19,216	19,288	19,360	19,432	19,504	19,576	19,648	19,720
100	19,227	19,299	19,371	19,443	19,515	19,587	19,659	19,731	19,803

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	17,149	17,176	17,204	17,231	17,259	17,286	17,314	17,342	17,369
55	17,194	17,221	17,249	17,277	17,304	17,332	17,359	17,387	17,414
60	17,239	17,267	17,294	17,322	17,349	17,377	17,404	17,432	17,459
65	17,284	17,312	17,339	17,367	17,394	17,422	17,450	17,477	17,505
70	17,329	17,357	17,384	17,412	17,440	17,467	17,495	17,522	17,550
75	17,375	17,402	17,430	17,457	17,485	17,512	17,540	17,567	17,595
80	17,420	17,447	17,475	17,502	17,530	17,557	17,585	17,613	17,640
85	17,465	17,492	17,520	17,548	17,575	17,603	17,630	17,658	17,685
90	17,510	17,538	17,565	17,593	17,620	17,648	17,675	17,703	17,730
95	17,555	17,583	17,610	17,638	17,665	17,693	17,721	17,748	17,776
100	17,600	17,628	17,655	17,683	17,711	17,738	17,766	17,793	17,821

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 721,331	$ 722,615	$ 723,899	$ 725,184	$ 726,468	$ 727,752	$ 729,036	$ 730,321	$ 731,605
55	$ 723,277	$ 724,561	$ 725,846	$ 727,130	$ 728,414	$ 729,699	$ 730,983	$ 732,267	$ 733,552
60	$ 725,223	$ 726,508	$ 727,792	$ 729,076	$ 730,361	$ 731,645	$ 732,929	$ 734,214	$ 735,498
65	$ 727,170	$ 728,454	$ 729,738	$ 731,023	$ 732,307	$ 733,591	$ 734,876	$ 736,160	$ 737,444
70	$ 729,116	$ 730,401	$ 731,685	$ 732,969	$ 734,254	$ 735,538	$ 736,822	$ 738,107	$ 739,391
75	$ 731,063	$ 732,347	$ 733,631	$ 734,916	$ 736,200	$ 737,484	$ 738,769	$ 740,053	$ 741,337
80	$ 733,009	$ 734,293	$ 735,578	$ 736,862	$ 738,146	$ 739,431	$ 740,715	$ 741,999	$ 743,284
85	$ 734,956	$ 736,240	$ 737,524	$ 738,809	$ 740,093	$ 741,377	$ 742,662	$ 743,946	$ 745,230
90	$ 736,902	$ 738,186	$ 739,471	$ 740,755	$ 742,039	$ 743,324	$ 744,608	$ 745,892	$ 747,177
95	$ 738,848	$ 740,133	$ 741,417	$ 742,701	$ 743,986	$ 745,270	$ 746,554	$ 747,839	$ 749,123
100	$ 740,795	$ 742,079	$ 743,364	$ 744,648	$ 745,932	$ 747,217	$ 748,501	$ 749,785	$ 751,070

Table 6.3.6 Case 4 - Lj = 650 ft., N = 2 lanes

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	34,025	34,097	34,169	34,241	34,313	34,385	34,457	34,529	34,601
55	34,109	34,181	34,253	34,325	34,397	34,469	34,541	34,613	34,685
60	34,192	34,264	34,336	34,408	34,480	34,552	34,624	34,696	34,768
65	34,275	34,347	34,419	34,491	34,563	34,635	34,707	34,779	34,851
70	34,358	34,430	34,502	34,574	34,646	34,718	34,790	34,862	34,934
75	34,441	34,513	34,585	34,657	34,729	34,801	34,873	34,945	35,017
80	34,525	34,597	34,669	34,741	34,813	34,885	34,957	35,029	35,101
85	34,608	34,680	34,752	34,824	34,896	34,968	35,040	35,112	35,184
90	34,691	34,763	34,835	34,907	34,979	35,051	35,123	35,195	35,267
95	34,774	34,846	34,918	34,990	35,062	35,134	35,206	35,278	35,350
100	34,857	34,929	35,001	35,073	35,145	35,217	35,289	35,361	35,433

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	32,779	32,806	32,834	32,861	32,889	32,916	32,944	32,972	32,999
55	32,824	32,851	32,879	32,907	32,934	32,962	32,989	33,017	33,044
60	32,869	32,897	32,924	32,952	32,979	33,007	33,034	33,062	33,089
65	32,914	32,942	32,969	32,997	33,024	33,052	33,080	33,107	33,135
70	32,959	32,987	33,014	33,042	33,070	33,097	33,125	33,152	33,180
75	33,005	33,032	33,060	33,087	33,115	33,142	33,170	33,197	33,225
80	33,050	33,077	33,105	33,132	33,160	33,187	33,215	33,243	33,270
85	33,095	33,122	33,150	33,178	33,205	33,233	33,260	33,288	33,315
90	33,140	33,168	33,195	33,223	33,250	33,278	33,305	33,333	33,360
95	33,185	33,213	33,240	33,268	33,295	33,323	33,351	33,378	33,406
100	33,230	33,258	33,285	33,313	33,341	33,368	33,396	33,423	33,451

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 1,362,719	$ 1,364,003	$ 1,365,287	$ 1,366,572	$ 1,367,856	$ 1,369,140	$ 1,370,425	$ 1,371,709	$ 1,372,993
55	$ 1,364,665	$ 1,365,950	$ 1,367,234	$ 1,368,518	$ 1,369,803	$ 1,371,087	$ 1,372,371	$ 1,373,656	$ 1,374,940
60	$ 1,366,612	$ 1,367,896	$ 1,369,180	$ 1,370,465	$ 1,371,749	$ 1,373,033	$ 1,374,318	$ 1,375,602	$ 1,376,886
65	$ 1,368,558	$ 1,369,842	$ 1,371,127	$ 1,372,411	$ 1,373,695	$ 1,374,980	$ 1,376,264	$ 1,377,548	$ 1,378,833
70	$ 1,370,505	$ 1,371,789	$ 1,373,073	$ 1,374,358	$ 1,375,642	$ 1,376,926	$ 1,378,211	$ 1,379,495	$ 1,380,779
75	$ 1,372,451	$ 1,373,735	$ 1,375,020	$ 1,376,304	$ 1,377,588	$ 1,378,873	$ 1,380,157	$ 1,381,441	$ 1,382,726
80	$ 1,374,397	$ 1,375,682	$ 1,376,966	$ 1,378,250	$ 1,379,535	$ 1,380,819	$ 1,382,103	$ 1,383,388	$ 1,384,672
85	$ 1,376,344	$ 1,377,628	$ 1,378,913	$ 1,380,197	$ 1,381,481	$ 1,382,766	$ 1,384,050	$ 1,385,334	$ 1,386,618
90	$ 1,378,290	$ 1,379,575	$ 1,380,859	$ 1,382,143	$ 1,383,428	$ 1,384,712	$ 1,385,996	$ 1,387,281	$ 1,388,565
95	$ 1,380,237	$ 1,381,521	$ 1,382,805	$ 1,384,090	$ 1,385,374	$ 1,386,658	$ 1,387,943	$ 1,389,227	$ 1,390,511
100	$ 1,382,183	$ 1,383,468	$ 1,384,752	$ 1,386,036	$ 1,387,320	$ 1,388,605	$ 1,389,889	$ 1,391,173	$ 1,392,458

Table 6.4 provides total costs for the alternative based upon the above numbers. A spreadsheet, set up for this purpose, allows what-if scenarios, and changes in assumptions and unit costs. Cost items that may be potentially significant but are not included here (this monograph is meant to be illustrative only) include:

- Grading and compacting of pavement subgrade and
- Landscaping and finish work

Table 6.4.1 Case 5 - Lj = 300 ft., N = 1 lane

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	50	75	100	125	150	175	200	225	250
50	5,361	5,433	5,505	5,577	5,649	5,721	5,793	5,865	5,937
55	5,399	5,471	5,543	5,615	5,687	5,759	5,831	5,903	5,975
60	5,437	5,509	5,581	5,653	5,725	5,797	5,869	5,941	6,013
65	5,475	5,547	5,619	5,691	5,763	5,835	5,907	5,979	6,051
70	5,513	5,585	5,657	5,729	5,801	5,873	5,945	6,017	6,089
75	5,551	5,623	5,695	5,767	5,839	5,911	5,983	6,055	6,127
80	5,590	5,662	5,734	5,806	5,878	5,950	6,022	6,094	6,166
85	5,628	5,700	5,772	5,844	5,916	5,988	6,060	6,132	6,204
90	5,666	5,738	5,810	5,882	5,954	6,026	6,098	6,170	6,242
95	5,704	5,776	5,848	5,920	5,992	6,064	6,136	6,208	6,280
100	5,742	5,814	5,886	5,958	6,030	6,102	6,174	6,246	6,318

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	50	75	100	125	150	175	200	225	250
50	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
55	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
60	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
65	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
70	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
75	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
80	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
85	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
90	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
95	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335
100	4,115	4,142	4,170	4,197	4,225	4,252	4,280	4,308	4,335

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 179,607	$ 180,892	$ 182,176	$ 183,460	$ 184,745	$ 186,029	$ 187,313	$ 188,598	$ 189,882
55	$ 179,702	$ 180,987	$ 182,271	$ 183,555	$ 184,840	$ 186,124	$ 187,408	$ 188,693	$ 189,977
60	$ 179,798	$ 181,082	$ 182,366	$ 183,651	$ 184,935	$ 186,219	$ 187,504	$ 188,788	$ 190,072
65	$ 179,893	$ 181,177	$ 182,461	$ 183,746	$ 185,030	$ 186,314	$ 187,599	$ 188,883	$ 190,167
70	$ 179,988	$ 181,272	$ 182,556	$ 183,841	$ 185,125	$ 186,409	$ 187,694	$ 188,978	$ 190,262
75	$ 180,083	$ 181,367	$ 182,652	$ 183,936	$ 185,220	$ 186,505	$ 187,789	$ 189,073	$ 190,358
80	$ 180,178	$ 181,462	$ 182,747	$ 184,031	$ 185,315	$ 186,600	$ 187,884	$ 189,168	$ 190,453
85	$ 180,273	$ 181,558	$ 182,842	$ 184,126	$ 185,411	$ 186,695	$ 187,979	$ 189,264	$ 190,548
90	$ 180,368	$ 181,653	$ 182,937	$ 184,221	$ 185,506	$ 186,790	$ 188,074	$ 189,359	$ 190,643
95	$ 180,464	$ 181,748	$ 183,032	$ 184,316	$ 185,601	$ 186,885	$ 188,169	$ 189,454	$ 190,738
100	$ 180,559	$ 181,843	$ 183,127	$ 184,412	$ 185,696	$ 186,980	$ 188,265	$ 189,549	$ 190,833

Table 6.4.2 Case 5 - Lj = 300 ft., N = 2 lanes

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	8,976	9,048	9,120	9,192	9,264	9,336	9,408	9,480	9,552
55	9,014	9,086	9,158	9,230	9,302	9,374	9,446	9,518	9,590
60	9,052	9,124	9,196	9,268	9,340	9,412	9,484	9,556	9,628
65	9,090	9,162	9,234	9,306	9,378	9,450	9,522	9,594	9,666
70	9,128	9,200	9,272	9,344	9,416	9,488	9,560	9,632	9,704
75	9,166	9,238	9,310	9,382	9,454	9,526	9,598	9,670	9,742
80	9,205	9,277	9,349	9,421	9,493	9,565	9,637	9,709	9,781
85	9,243	9,315	9,387	9,459	9,531	9,603	9,675	9,747	9,819
90	9,281	9,353	9,425	9,497	9,569	9,641	9,713	9,785	9,857
95	9,319	9,391	9,463	9,535	9,607	9,679	9,751	9,823	9,895
100	9,357	9,429	9,501	9,573	9,645	9,717	9,789	9,861	9,933

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
55	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
60	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
65	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
70	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
75	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
80	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
85	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
90	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
95	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950
100	7,730	7,757	7,785	7,812	7,840	7,867	7,895	7,923	7,950

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 327,780	$ 329,064	$ 330,349	$ 331,633	$ 332,917	$ 334,202	$ 335,486	$ 336,770	$ 338,055
55	$ 327,875	$ 329,160	$ 330,444	$ 331,728	$ 333,012	$ 334,297	$ 335,581	$ 336,865	$ 338,150
60	$ 327,970	$ 329,255	$ 330,539	$ 331,823	$ 333,108	$ 334,392	$ 335,676	$ 336,961	$ 338,245
65	$ 328,065	$ 329,350	$ 330,634	$ 331,918	$ 333,203	$ 334,487	$ 335,771	$ 337,056	$ 338,340
70	$ 328,161	$ 329,445	$ 330,729	$ 332,014	$ 333,298	$ 334,582	$ 335,867	$ 337,151	$ 338,435
75	$ 328,256	$ 329,540	$ 330,824	$ 332,109	$ 333,393	$ 334,677	$ 335,962	$ 337,246	$ 338,530
80	$ 328,351	$ 329,635	$ 330,919	$ 332,204	$ 333,488	$ 334,772	$ 336,057	$ 337,341	$ 338,625
85	$ 328,446	$ 329,730	$ 331,015	$ 332,299	$ 333,583	$ 334,868	$ 336,152	$ 337,436	$ 338,721
90	$ 328,541	$ 329,825	$ 331,110	$ 332,394	$ 333,678	$ 334,963	$ 336,247	$ 337,531	$ 338,816
95	$ 328,636	$ 329,921	$ 331,205	$ 332,489	$ 333,774	$ 335,058	$ 336,342	$ 337,627	$ 338,911
100	$ 328,731	$ 330,016	$ 331,300	$ 332,584	$ 333,869	$ 335,153	$ 336,437	$ 337,722	$ 339,006

Table 6.4.3 Case 5 - Lj = 350 ft., N = 1 lane

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	5,961	6,033	6,105	6,177	6,249	6,321	6,393	6,465	6,537
55	5,999	6,071	6,143	6,215	6,287	6,359	6,431	6,503	6,575
60	6,037	6,109	6,181	6,253	6,325	6,397	6,469	6,541	6,613
65	6,075	6,147	6,219	6,291	6,363	6,435	6,507	6,579	6,651
70	6,113	6,185	6,257	6,329	6,401	6,473	6,545	6,617	6,689
75	6,151	6,223	6,295	6,367	6,439	6,511	6,583	6,655	6,727
80	6,190	6,262	6,334	6,406	6,478	6,550	6,622	6,694	6,766
85	6,228	6,300	6,372	6,444	6,516	6,588	6,660	6,732	6,804
90	6,266	6,338	6,410	6,482	6,554	6,626	6,698	6,770	6,842
95	6,304	6,376	6,448	6,520	6,592	6,664	6,736	6,808	6,880
100	6,342	6,414	6,486	6,558	6,630	6,702	6,774	6,846	6,918

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
55	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
60	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
65	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
70	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
75	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
80	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
85	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
90	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
95	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935
100	4,715	4,742	4,770	4,797	4,825	4,852	4,880	4,908	4,935

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 204,200	$ 205,485	$ 206,769	$ 208,053	$ 209,338	$ 210,622	$ 211,906	$ 213,191	$ 214,475
55	$ 204,295	$ 205,580	$ 206,864	$ 208,148	$ 209,433	$ 210,717	$ 212,001	$ 213,286	$ 214,570
60	$ 204,391	$ 205,675	$ 206,959	$ 208,244	$ 209,528	$ 210,812	$ 212,097	$ 213,381	$ 214,665
65	$ 204,486	$ 205,770	$ 207,054	$ 208,339	$ 209,623	$ 210,907	$ 212,192	$ 213,476	$ 214,760
70	$ 204,581	$ 205,865	$ 207,149	$ 208,434	$ 209,718	$ 211,002	$ 212,287	$ 213,571	$ 214,855
75	$ 204,676	$ 205,960	$ 207,245	$ 208,529	$ 209,813	$ 211,098	$ 212,382	$ 213,666	$ 214,951
80	$ 204,771	$ 206,055	$ 207,340	$ 208,624	$ 209,908	$ 211,193	$ 212,477	$ 213,761	$ 215,046
85	$ 204,866	$ 206,151	$ 207,435	$ 208,719	$ 210,004	$ 211,288	$ 212,572	$ 213,856	$ 215,141
90	$ 204,961	$ 206,246	$ 207,530	$ 208,814	$ 210,099	$ 211,383	$ 212,667	$ 213,952	$ 215,236
95	$ 205,056	$ 206,341	$ 207,625	$ 208,909	$ 210,194	$ 211,478	$ 212,762	$ 214,047	$ 215,331
100	$ 205,152	$ 206,436	$ 207,720	$ 209,005	$ 210,289	$ 211,573	$ 212,858	$ 214,142	$ 215,426

Table 6.4.4 Case 5 - Lj = 350 ft., N = 2 lanes

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	10,176	10,248	10,320	10,392	10,464	10,536	10,608	10,680	10,752
55	10,214	10,286	10,358	10,430	10,502	10,574	10,646	10,718	10,790
60	10,252	10,324	10,396	10,468	10,540	10,612	10,684	10,756	10,828
65	10,290	10,362	10,434	10,506	10,578	10,650	10,722	10,794	10,866
70	10,328	10,400	10,472	10,544	10,616	10,688	10,760	10,832	10,904
75	10,366	10,438	10,510	10,582	10,654	10,726	10,798	10,870	10,942
80	10,405	10,477	10,549	10,621	10,693	10,765	10,837	10,909	10,981
85	10,443	10,515	10,587	10,659	10,731	10,803	10,875	10,947	11,019
90	10,481	10,553	10,625	10,697	10,769	10,841	10,913	10,985	11,057
95	10,519	10,591	10,663	10,735	10,807	10,879	10,951	11,023	11,095
100	10,557	10,629	10,701	10,773	10,845	10,917	10,989	11,061	11,133

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
55	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
60	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
65	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
70	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
75	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
80	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
85	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
90	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
95	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150
100	8,930	8,957	8,985	9,012	9,040	9,067	9,095	9,123	9,150

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 376,966	$ 378,250	$ 379,535	$ 380,819	$ 382,103	$ 383,388	$ 384,672	$ 385,956	$ 387,241
55	$ 377,061	$ 378,345	$ 379,630	$ 380,914	$ 382,198	$ 383,483	$ 384,767	$ 386,051	$ 387,336
60	$ 377,156	$ 378,441	$ 379,725	$ 381,009	$ 382,294	$ 383,578	$ 384,862	$ 386,147	$ 387,431
65	$ 377,251	$ 378,536	$ 379,820	$ 381,104	$ 382,389	$ 383,673	$ 384,957	$ 386,242	$ 387,526
70	$ 377,347	$ 378,631	$ 379,915	$ 381,200	$ 382,484	$ 383,768	$ 385,052	$ 386,337	$ 387,621
75	$ 377,442	$ 378,726	$ 380,010	$ 381,295	$ 382,579	$ 383,863	$ 385,148	$ 386,432	$ 387,716
80	$ 377,537	$ 378,821	$ 380,105	$ 381,390	$ 382,674	$ 383,958	$ 385,243	$ 386,527	$ 387,811
85	$ 377,632	$ 378,916	$ 380,201	$ 381,485	$ 382,769	$ 384,054	$ 385,338	$ 386,622	$ 387,907
90	$ 377,727	$ 379,011	$ 380,296	$ 381,580	$ 382,864	$ 384,149	$ 385,433	$ 386,717	$ 388,002
95	$ 377,822	$ 379,107	$ 380,391	$ 381,675	$ 382,960	$ 384,244	$ 385,528	$ 386,812	$ 388,097
100	$ 377,917	$ 379,202	$ 380,486	$ 381,770	$ 383,055	$ 384,339	$ 385,623	$ 386,908	$ 388,192

Table 6.4.5 Case 5 - Lj = 400 ft., N = 1 lane

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	6,561	6,633	6,705	6,777	6,849	6,921	6,993	7,065	7,137
55	6,599	6,671	6,743	6,815	6,887	6,959	7,031	7,103	7,175
60	6,637	6,709	6,781	6,853	6,925	6,997	7,069	7,141	7,213
65	6,675	6,747	6,819	6,891	6,963	7,035	7,107	7,179	7,251
70	6,713	6,785	6,857	6,929	7,001	7,073	7,145	7,217	7,289
75	6,751	6,823	6,895	6,967	7,039	7,111	7,183	7,255	7,327
80	6,790	6,862	6,934	7,006	7,078	7,150	7,222	7,294	7,366
85	6,828	6,900	6,972	7,044	7,116	7,188	7,260	7,332	7,404
90	6,866	6,938	7,010	7,082	7,154	7,226	7,298	7,370	7,442
95	6,904	6,976	7,048	7,120	7,192	7,264	7,336	7,408	7,480
100	6,942	7,014	7,086	7,158	7,230	7,302	7,374	7,446	7,518

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
55	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
60	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
65	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
70	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
75	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
80	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
85	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
90	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
95	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535
100	5,315	5,342	5,370	5,397	5,425	5,452	5,480	5,508	5,535

c) Total Costs for Alternative

Width (ft)	Length (ft) 50	75	100	125	150	175	200	225	250
50	$ 228,793	$ 230,078	$ 231,362	$ 232,646	$ 233,931	$ 235,215	$ 236,499	$ 237,784	$ 239,068
55	$ 228,888	$ 230,173	$ 231,457	$ 232,741	$ 234,026	$ 235,310	$ 236,594	$ 237,879	$ 239,163
60	$ 228,984	$ 230,268	$ 231,552	$ 232,837	$ 234,121	$ 235,405	$ 236,689	$ 237,974	$ 239,258
65	$ 229,079	$ 230,363	$ 231,647	$ 232,932	$ 234,216	$ 235,500	$ 236,785	$ 238,069	$ 239,353
70	$ 229,174	$ 230,458	$ 231,742	$ 233,027	$ 234,311	$ 235,595	$ 236,880	$ 238,164	$ 239,448
75	$ 229,269	$ 230,553	$ 231,838	$ 233,122	$ 234,406	$ 235,691	$ 236,975	$ 238,259	$ 239,544
80	$ 229,364	$ 230,648	$ 231,933	$ 233,217	$ 234,501	$ 235,786	$ 237,070	$ 238,354	$ 239,639
85	$ 229,459	$ 230,744	$ 232,028	$ 233,312	$ 234,597	$ 235,881	$ 237,165	$ 238,449	$ 239,734
90	$ 229,554	$ 230,839	$ 232,123	$ 233,407	$ 234,692	$ 235,976	$ 237,260	$ 238,545	$ 239,829
95	$ 229,649	$ 230,934	$ 232,218	$ 233,502	$ 234,787	$ 236,071	$ 237,355	$ 238,640	$ 239,924
100	$ 229,745	$ 231,029	$ 232,313	$ 233,598	$ 234,882	$ 236,166	$ 237,451	$ 238,735	$ 240,019

Table 6.4.6 Case 5 - Lj = 400 ft., N = 2 lanes

a) Total Area to be Excavated in Square Yards (SY)

	Length (ft)								
Width (ft)	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	11,376	11,448	11,520	11,592	11,664	11,736	11,808	11,880	11,952
55	11,414	11,486	11,558	11,630	11,702	11,774	11,846	11,918	11,990
60	11,452	11,524	11,596	11,668	11,740	11,812	11,884	11,956	12,028
65	11,490	11,562	11,634	11,706	11,778	11,850	11,922	11,994	12,066
70	11,528	11,600	11,672	11,744	11,816	11,888	11,960	12,032	12,104
75	11,566	11,638	11,710	11,782	11,854	11,926	11,998	12,070	12,142
80	11,605	11,677	11,749	11,821	11,893	11,965	12,037	12,109	12,181
85	11,643	11,715	11,787	11,859	11,931	12,003	12,075	12,147	12,219
90	11,681	11,753	11,825	11,897	11,969	12,041	12,113	12,185	12,257
95	11,719	11,791	11,863	11,935	12,007	12,079	12,151	12,223	12,295
100	11,757	11,829	11,901	11,973	12,045	12,117	12,189	12,261	12,333

b) Areas to be Paved in Square Yards (SY)

	Length (ft)								
Width	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
50	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
55	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
60	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
65	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
70	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
75	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
80	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
85	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
90	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
95	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350
100	10,130	10,157	10,185	10,212	10,240	10,267	10,295	10,323	10,350

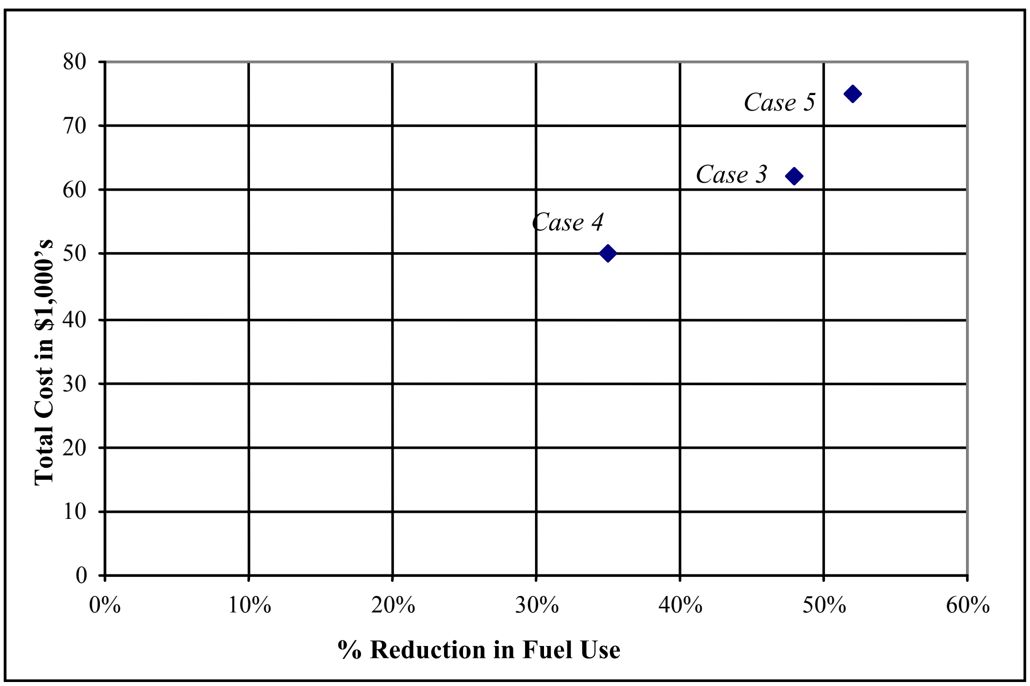
c) Total Costs for Alternative

Width (ft)	Length (ft)								
	50	75	100	125	150	175	200	225	250
50	$ 426,152	$ 427,436	$ 428,721	$ 430,005	$ 431,289	$ 432,574	$ 433,858	$ 435,142	$ 436,427
55	$ 426,247	$ 427,531	$ 428,816	$ 430,100	$ 431,384	$ 432,669	$ 433,953	$ 435,237	$ 436,522
60	$ 426,342	$ 427,627	$ 428,911	$ 430,195	$ 431,480	$ 432,764	$ 434,048	$ 435,333	$ 436,617
65	$ 426,437	$ 427,722	$ 429,006	$ 430,290	$ 431,575	$ 432,859	$ 434,143	$ 435,428	$ 436,712
70	$ 426,533	$ 427,817	$ 429,101	$ 430,385	$ 431,670	$ 432,954	$ 434,238	$ 435,523	$ 436,807
75	$ 426,628	$ 427,912	$ 429,196	$ 430,481	$ 431,765	$ 433,049	$ 434,334	$ 435,618	$ 436,902
80	$ 426,723	$ 428,007	$ 429,291	$ 430,576	$ 431,860	$ 433,144	$ 434,429	$ 435,713	$ 436,997
85	$ 426,818	$ 428,102	$ 429,387	$ 430,671	$ 431,955	$ 433,240	$ 434,524	$ 435,808	$ 437,093
90	$ 426,913	$ 428,197	$ 429,482	$ 430,766	$ 432,050	$ 433,335	$ 434,619	$ 435,903	$ 437,188
95	$ 427,008	$ 428,293	$ 429,577	$ 430,861	$ 432,145	$ 433,430	$ 434,714	$ 435,998	$ 437,283
100	$ 427,103	$ 428,388	$ 429,672	$ 430,956	$ 432,241	$ 433,525	$ 434,809	$ 436,094	$ 437,378

EVALUATION OF ALTERNATIVES

As indicated previously there exist several approaches to evaluating which are the best alternatives. For example, one might examine the cost effectiveness of each alternative design with respect to each of the operational outputs. Figure 6.1 illustrates the concept. Case 4's cost is significantly lower than the other two alternative costs yet its percent reduction in delay is only minimally lower (part a) and its increase in fuel consumption is actually lower as well (part b). This is known as the "cost effectiveness" approach to evaluating alternatives. One of its main advantages is that it eliminates the heavy reliance on numbers and scores that other approaches use in an attempt to combine different measures.

(a)



(b)

Figure 6.1 Cost Effectiveness Example

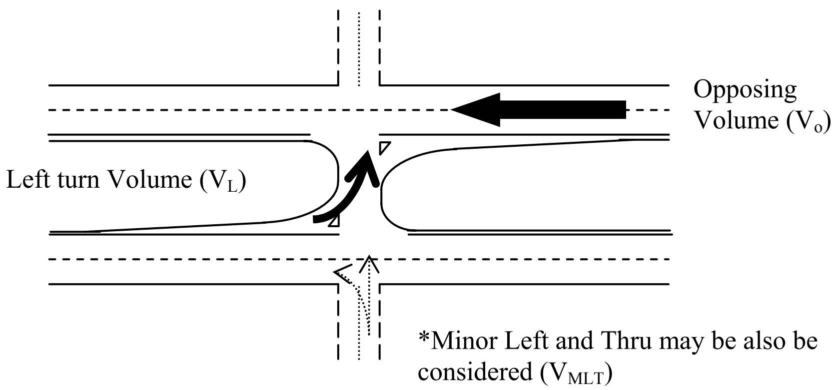
VII. DEVELOPMENT OF THE GENERAL GUIDELINES

Previous chapters described the traffic operational problems associated with rural median crossovers, alternative treatments, performance measures, the potential for simulation and the Highway Capacity Manual for analyzing specific sites, and cost estimates for improvements. This chapter describes how the CORSIM simulation model was used, along with the previous material, to develop the generalized guidelines for evaluating sites.

MODEL DEVELOPMENT

Simulation tools do not readily yield answers to what should be fairly simple questions. They are data intensive, and require expertise and computing resources to use them. A simpler tool would add value to the rural median crossover design process. Such a graphical tool was developed as part of this project and uses the concept depicted in Figure 7-1. The figure address the typical problem of a crossover having a left turn flow (V_L) off of the expressway with insufficient capacity of gaps in the approaching expressway traffic (V_o). A queue then forms that can eventually spill back onto the expressway through lanes. If the major highway left turn volume using the crossover and its opposing volume were low enough (i.e., below the curve) then no change would be needed. However, if the major highway left turn volume and its opposing volume were high enough (i.e., above the curve), then it would be likely that an improvement was needed.

Note that Figure 7-1 only addresses the left turn flow (V_L) off of the expressway and the approaching expressway traffic (V_o). There may be situations where side road traffic wishes to completely cross the expressway or cross expressway traffic coming from the left in order to reach the median for a left turn onto the expressway. This minor left and through combination of movements is shown as V_{MLT} in Figure 7-1. If the median was congested, this minor through and left turn demand might instead make a right turn onto the expressway, followed by a U-turn at a downstream median opening. However, if these vehicles are likely to use the subject median, one might simply add them to the expressway left turn flow (V_L).



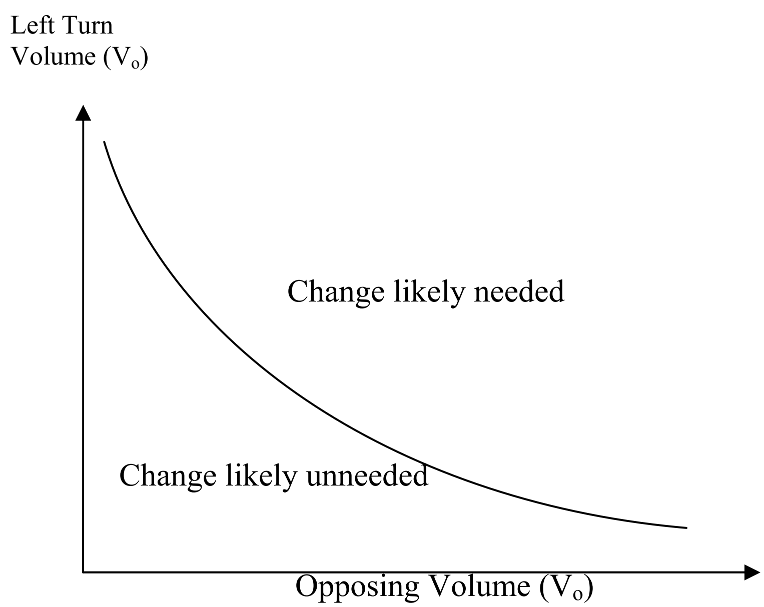
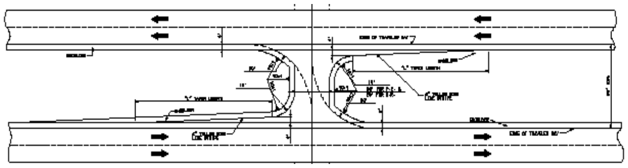
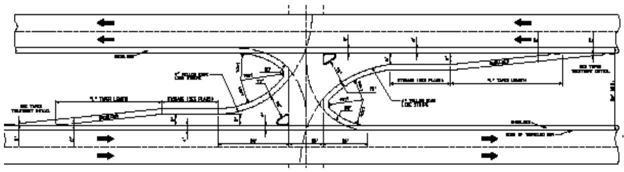


Figure 7-1: Concept of the Assessment Tool

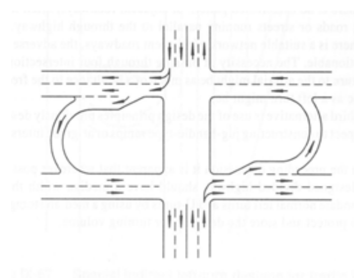
As indicated previously, rural expressway facilities can generate hazardous crossing situations and confusing vehicle operations at rural median crossovers. As volumes increase through a crossover area, multiple vehicles can be positioned in the median so they actually block each other and impede visibility to oncoming vehicles. A tool similar to the one depicted in Figure 7-1 was developed for each of five different crossovers. The five alternative designs are depicted in Figure 7-2.



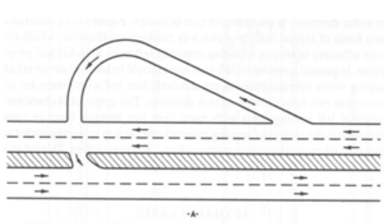
a) Type I Crossover



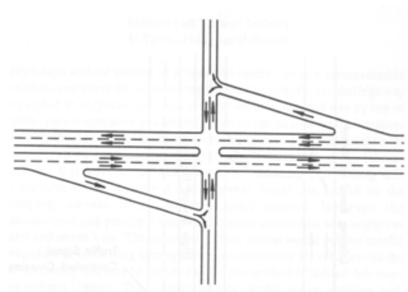
b) Type II Crossover



c) Type III Crossover



d) Type IV Crossover



e) Type V Crossover

Figure 7-2: Rural Crossover Alternatives

The schematic shown in Figure 7-3 exemplifies how the crossovers are represented within the CORSIM software. Links are one directional segments and nodes are usually the intersections of two or more links. In this case, links from 1 to 3 and from 4 to 2 represent the arterial, or major road, segments and links 5-7 and 6-8 represent the undivided minor road. Link 5-6 represents the median roadway. Several assumptions made for inputs to CORSIM are summarized in Table 7-1. To generate the graphs shown in Figure 7-4, runs were made at each opposing volume level, varying left turn flows, until the critical queue length for the particular crossover type was reached – critical queues for each crossover type are provided in Table 7-2. For example, for an opposing volume of 200 vph on a type II crossover, CORSIM runs were made for each 10 mph increment of left turn volume and maximum queues were recorded. When the maximum critical queue value was reached, that left turn volume level was recorded along with the 200 vph opposing volume for the Type II crossover curve. Critical values are based upon the 200 foot minimum design for turn lanes and 60 foot design for median widths practiced by Missouri – thus resulting in an maximum eight vehicle queue in the former case and three vehicle queue in the latter.

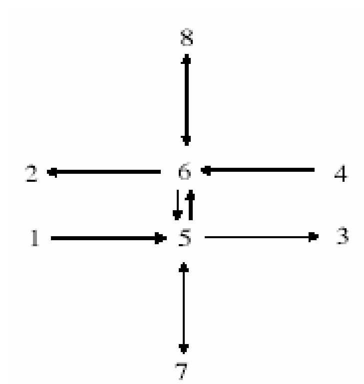


Figure 7-3: Network Representation in CORSIM

Table 7-1: Assumptions

Volume distributions			
Description	*% Left*	*% Through*	*% Right*
Main Road Approaching leg	25%	70%	5%
Main Road Advancing Leg	5%	90%	5%
Minor Road	0%	75%	25%
Median	10%	90%	0%

Geometry		
Description	*Value*	*Median Type*
Median grade	0%	
Lane width	12 ft.	
Free flow speed of major road	65 mph	
Free flow speed of minor road	45 mph	
Percentage of trucks	7%	
Length of storage lane	200 ft.	Types II and III
Length of extra lane	200 ft.	Types IV and V
Distance on Minor Road from extra lane to Main Road	200 ft.	Type V
Operational parameters taken from CORSIM defaults		

Table 7-2: Critical Values in Generating Maximum Queue Curves

Location	*Vehicles in Queue*	*Median Type*
Left turn lanes	8	Types II and III
Extra lanes	8	Types IV and V
Minor Road from extra lane to Main Road	8	Type V
Median	3	All types

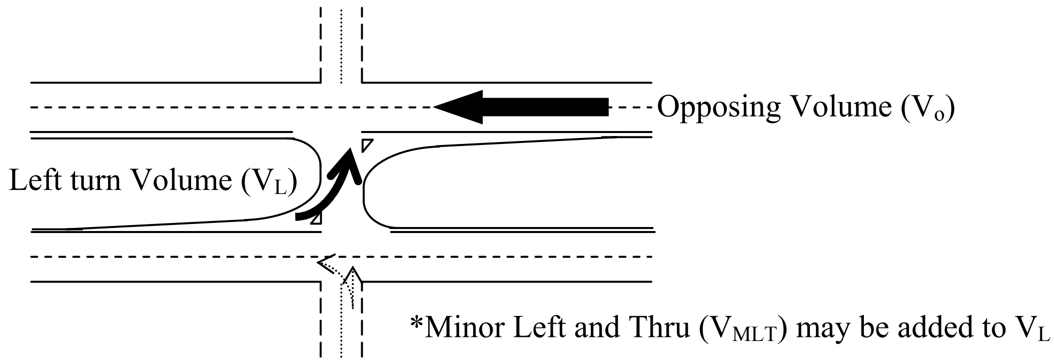
Note that the simulation tool requires assumptions about acceptable queue size (storage length). If the number of vehicles which can be stored is significantly different from that indicated, then the results will be less reliable.

DISCUSSION OF RESULTS

As indicated previously, Figure 7-4 depicts the overall queue length results for all five crossover types considered. For opposing volumes up to approximately 450 vph, it appears that the Type II crossover is superior to all but Type III. Thereafter, Types V and III are superior. Indeed, Type III seems to be the best performing of all from a queue perspective – which is the variable of concern for this study. When considering an upgrade from an existing Type II crossover, the Type III is without question superior to the other alternative designs considered – both from an operational as well as economic perspective. Table 7-3 shows estimated construction costs for upgrading from a Type II median crossover to Types III, IV and V.

Referring to Figure 7-4, at many locations the major highway through volume, V_o, that conflicts with the opposing major highway left turn, V_L, will be the principal conflict of interest. However, there may be locations where the side road through and left turn volumes, V_{MLT}, also contribute to potential queuing in the median. If median queuing causes extensive delays or would cause side road traffic to queue in the highway through lanes, one would expect the potential V_{MLT} traffic to turn right onto the highway (and later make a U-turn) rather than use the median. If the analysts suspects that this will not be the case, then the analyst may add the V_{MLT} traffic to V_L.

Figure 7-4 should be viewed as a general guide relating to queue length at crossovers with traffic characteristics typical of many crossovers in Missouri. It does not necessarily indicate the best crossover type for any specific crossover. There are many other factors (including crash history, land availability, budget resources, local traffic patterns, etc) that may factor into decision making.



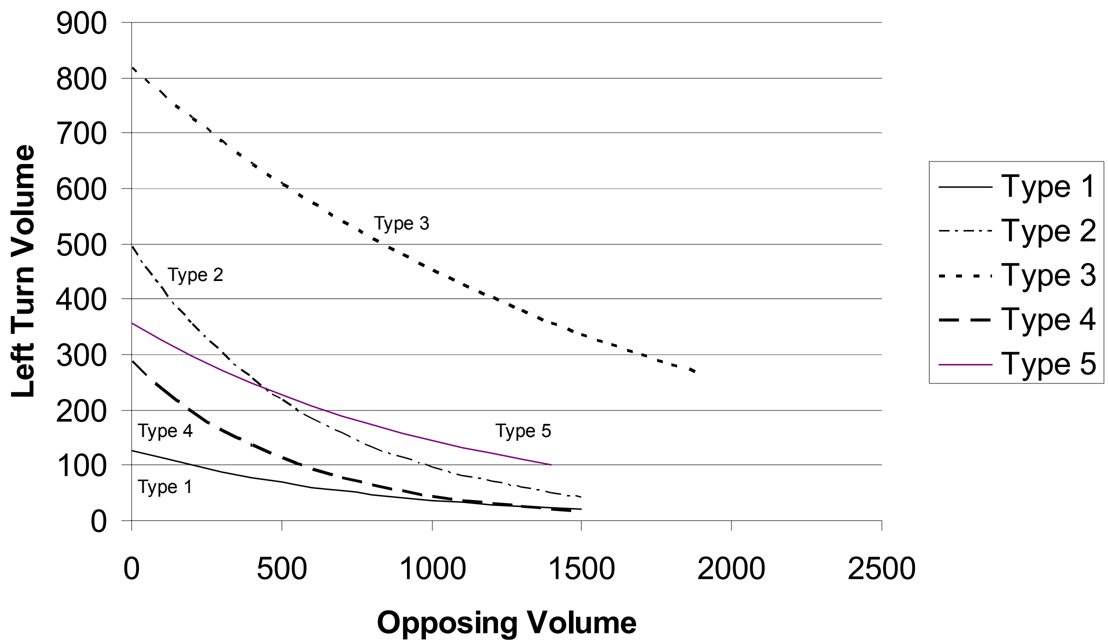


Figure 7-4. Decision Tool for Median Crossovers

Table 7-3. Estimated Construction Costs

Crossover Type	*Upgrade Cost Range*
II	\$20,000 to \$35,000
III	\$80,000 to \$120,000
IV	\$375,000 to \$406,000
V	\$300,000 to \$350,000

Type III crossovers do not require installation of additional roadways for "jug handles" which potentially need additional right of way and substantial earthwork as do both Types IV and V and are therefore less expensive to construct. Key operational features of the Type III are 1) the separation of crossing traffic from turning traffic provided by Type III thus reducing conflict complexity, and 2) the additional conflicts caused by Types IV and V due to the rerouting of left turn vehicles such that they must cross their own through traffic. For example, northbound left turn vehicles in the Type IV and V designs are forced to cross northbound through traffic.

Although the Type III provides substantial operational superiority over Types IV and V and at potentially lower costs, there may be situations in which considerations other than encroachment would govern a crossover's operation in which case the other crossover types could be deemed superior alternatives. For example, since Type III requires all left turning traffic to make a U-turn, median width must be adequate to accommodate large vehicle turning radii. If it is not, and large vehicle volumes are significant, thus requiring vehicles to encroach on the outer lane, then traffic operations modeling may not capture reductions in performance due to this condition.

Application of the tool shown in Figure 7-4 consists of determining the high volume combination of left turn/opposing flows on the arterial and plotting them. If the volumes plot below the curve of a particular type of crossover then it is adequate from an operational standpoint – that is, queues should not exceed the critical values described above. Points above the curve indicate that alternative treatments should be considered – that is, queues are expected to exceed the critical values.

APPLICATION TO FIELD SITES

Data were collected from five crossover sites that were identified by MODOT as potentially problematic. The following properties are common (approximately) to all five sites:

- Median grade: 0%
- Lane width= 12 ft
- Free flow speed of major road = 65 mph
- Free flow speed of minor road= 45 mph
- Percentage of trucks = 7%

The sites, which are all unsignalized, Type II rural crossovers, are:

1. US 61 and Tropicana is in Moscow Mills, Missouri. US 61 is the major road, runs north-south and has two lanes in each direction. Tropicana runs eastbound and is a two lane minor road under stop control. The median lanes are under yield control. There is no westbound leg at this intersection. This intersection is a high accident location and suffers from a too-narrow median and poor sight distances.

2. US 60 and Highway C/K is in Seymour, Missouri. US 60 is the major road, runs eastwest and has two lanes in each direction. Highway C runs north-south and is a two lane minor road under stop control. The median lanes are under yield control. Due to increases in right angle accidents after its upgrade from Type I to Type II, it was determined that for this geometry, the left turn lane creates sight distance restrictions.

3. US 61 and South Lincoln Dr is in Troy, Missouri. US 61 is the major road, runs north-south and has two lanes in each direction. South Lincoln Drive runs eastbound and is a two lane minor road under stop control. The median lanes are under yield control. There is no left turn lane provided in the south bound direction. At peak times, this intersection does not have adequate storage in its left turn bays on the major road. Consequently, vehicles tend to encroach on the through lanes on US 61. It also is a high accident location.

4. **US 63 and Route H** is in Boone County. US 63 is the major road, runs north-south and has two lanes in each direction. Route H serves the Columbia Regional Airport. The median lanes are under stop control. There is a 150 ft. left turn deceleration lane provided in the nouthbound approach and a 500 ft. left turn deceleration lane provided in the southbound approach. There is right turn channelization on the eastbound approach of Route H and a right turn deceleration lane on the northbound approach on Highway 63. .

5. **US 50 and Cityview Drive** is in Cole County. US 50 is the major road, runs east-west and has two lanes in each direction. Cityview Drive has one lane in each direction. The median lanes are under stop control and the median width is only 40 feet (less than the desired 60 foot minimum). There is a 260 ft. left turn deceleration lane provided on the eastbound approach and a 160 ft. left turn deceleration lane provided in the westbound approach. There is a 180 ft. right turn lane on the westbound approach. The southbound road is flared to store a right turning vehicle.

Data on intersection geometrics, lane use, traffic volumes, traffic composition, and control type were collected at each site. Peak hour volumes were collected using video cameras on tripods.

As discussed earlier graphs were generated from the simulation results for all five crossover types and are shown in Figure 7-4.

Plotting these values on Figure 7-4 results in Figure 7-5. Volumes at sites 1 and 3 seem to warrant improvement to a Type III crossover. Site 2 has volumes low enough that even a Type I would accommodate them adequately. These findings are consistent with MODOT’s plans for improvement of these locations. Both sites 1 and 3 have been targeted as locations in need of improvement. Site 1 will be part of a larger project in which three RMC’s within only a few hundred feet of each other along US 61 will be combined into one interchange. For site 3, there are no immediate plans for improvements due to fiscal constraints. The upgrade to Type III for site 3 would especially address the core issue of encroaching vehicles in the through lanes. This site, and other similar ones across the State of Missouri, were the driving forces behind MODOT’s sponsorship of the project being described in this paper. Site 2 has problems other than volume related ones. Its problems relate to sight distance issues which this tool would not capture.

Site 5 has a left turn volume that indicates operational problems during peak periods. The largest queue observed at this site was six vehicles; large enough for vehicles to be queued in the deceleration lane but not large enough to encroach on the driving lanes. When this type of queue was present, side road through traffic waited until space was available in the median. Occasionally side-by-side queuing for same direction traffic was noted in the median. This would have precluded opposite direction traffic from entering its allocated median space if such traffic had been present.

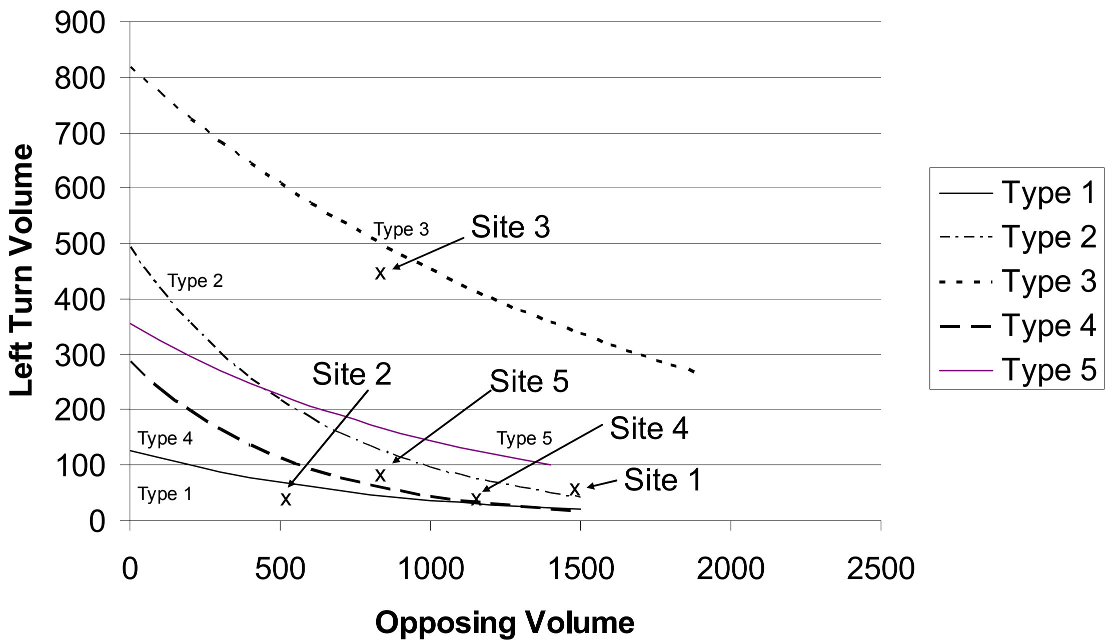


Figure 7-5. Application of Decision Tool to Five Sites

SUMMARY

The simulation tool CORSIM was used in this project to generate a simple graphical tool that may be used to assess alternative rural median crossover designs. The application of the tool was demonstrated as well. The tool relates through and left turn volumes with crossover type and allows a simple assessment of when each type is appropriate. The recommendations that derive from this tool for these five sites are consistent with what is known about the sites' problems.

Type III crossovers were found to be better as an upgrade from Type II than the other crossover design options considered. Volume levels that the Type III crossover can accommodate without exceeding queues that would result in encroachment are significantly higher than any of the other designs. Its costs are significantly lower than the other alternatives as well.

LIMITATIONS

Though minor road volume, median length, composition of traffic and grade of the intersection could vary significantly from those assumed for this work. It was assumed that these variables may reasonably be estimated using commonly found values. However, if it happens that the tool developed as part of this work becomes widely used, further research should be done to include the assumed variables.

IMPLEMENTATION PLAN

The procedure described in this report is based upon known characteristics of traffic flow and the results of simulation modeling. Simulation modeling can be used as a rational method to predict traffic operations. However, simulation does not replace the need to observe traffic operational response to new design concepts. For that reason, MoDOT may wish to collect traffic operational field data (e.g., speed, delay, travel time, queue length, etc.) to verify and calibrate the modeling approach when one or more field applications of the alternative design concepts described in this report are implemented in Missouri.

REFERENCES

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   www.modot.state.mo.us/design/stdplan/english_images/20350l.pdf

3. *Highway Capacity Manual,* Special Report 209 – Third Edition, Transportation Research Board, National Research Council, Washington, D.C., 1998.

4. Harwood, D. and W. Glauz, *NCHRP Synthesis of Highway Practice 281: Operational Impacts of Median Width on Larger Vehicles,* Transportation Research Board, National Research Council, Washington, D.C., 2000.

5. Harwood, D., M. Pietrucha, M. Wooldridge, R. Brydia, and K. Fitzpatrick, *NCHRP Report 375: Median Intersection Design,* Transportation Research Board, National Research Council, Washington, D.C., 1995.

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11. Elefteriadou, L., J.D. Leonard II, G. List, H. Lieu, M. Thomas, R. Giguere, G. Johnson, R. Brewish. "Beyond the Highway Capacity Manual: Framework for Selecting Simulation Models in Traffic Operational Analysis," *Transportation Research Record 1678*, Transportation Research Record, 1999.

APPENDIX 1: ANNOTATED BIBLIOGRAPHY

The most basic references for highway design and operation references are already familiar to most readers of this report. These include AASHTO's *A Policy on Geometric Design of Highways and Streets* (1994), the *Manual on Uniform Traffic Control Devices* (1988), and the *Highway Capacity Manual* (1998). This report has also made extensive use of the *Highway Capacity Software* (Release 3, 1999) and NETSIM, a simulation program within CORSIM in the Traffic Software Integrated System , or TSIS, Version 4.32 (1999). A summary of some of the other relevant literature related to the rural median crossover is presented below in the following sections:

- Summaries of Design Guidance
- Problem Area Identification
- Improvement Measurement
- Operational Analysis

SUMMARIES OF DESIGN GUIDANCE

NCHRP Report 279 – *Intersection Channelization Design Guide*, by Timothy R. Neuman. Transportation Research Board, National Research Council, Washington D.C. (1985).

> The report provides principles and criteria for the applicability of channelization. Many examples are presented in detail.

NCHRP Report 375 - *Median Intersection Design,* by Douglas W. Harwood, Martin T. Pietrucha, Mark D. Woodldridge, Robert E. Brydia, and Kay Fitzpatrick. Transportation Research Board, National Research Council, Washington D.C. (1995).

> This report focused on the selection of median widths for at-grade intersections on divided highways. It also presents some geometric and traffic control measures, including various median widths, left-turn lanes, offset left-turn lanes, indirect left-turn lanes, U-turn treatments, median acceleration lanes, and traffic control on the median roadway, etc.

NCHRP Synthesis 225 – Left-Turn Treatments at Intersections, by James L. Pline. Transportation Research Board, National Research Council, Washington D.C. (1996).

> This report presents basic considerations for left turn treatments and summarizes design, signing, pavement marking, and signal considerations. Performance measures are presented as well as a discussion of special applications.

NCHRP Synthesis 281 – *Operational Impacts of Median Width on Larger Vehicles,* by Douglas W. Harwood and William D. Glauz. Transportation Research Board, National Research Council, Washington D.C. (2000).

> Current median practices of the states are summarized. Operational and safety problems are then described. Alternative improvement techniques are then presented.

PROBLEM AREA IDENTIFICATION

John C. Falcocchio, Robert M.Michel, Herbert S. Levinson, and Solomon Assefa, *Priority Ranking of Problem Intersections in Brooklyn, N.Y.,* ITE Journal, Vol. 64, No. 5, May 1994.

> The paper developed a problem ranking approach to judge a list of capital projects for improving traffic in North Brooklyn, N.Y. The process used delay and accident measures to determine the severity of problems at study locations. A severity score, to rank problems, was based on the severity index and an intersection importance factor. These two components, in turn, were measured by traffic volume and stop delay or number of accidents.

N.M. Katamine, *Various Volume Definitions with Conflicts at Unsignalized Intersections*, Journal of Transportation Engineering, Vol. 126, No. 1, Jan. /Feb. 2000.

> Through a traffic conflicts technique, this paper presents research carried out at 15 four-leg intersections in the capital of Jordan. By defining 13 types of volume, 11 types of conflicts, and 4 levels of severe grades, based upon field data collection and computers analysis, the author concluded:
>
> - The effects of the approach volume on the correlation between volume and conflicts, in general, is made obvious when considering severity grade G4 (defined by the paper)
> - Three basic volumes governing the correlation between volume and relevant conflicts were indicated by the corresponding definition of the paper.
> - The use of some other volumes, defined by the paper as SP volume, XP volume, V-type volume, and CV volume, may provide misleading correlation with conflicts at intersections.

IMPROVEMENT MEASUREMENT

Ahmed Essam Radwan, Kumares C. Sinha, and Harold L. Michael, *Guidelines for Traffic Control at Isolated Intersections on High-Speed Rural Highways,* Transportation Research Record 737, Transportation Research Board, National Academy of Science, Washington D.C. (1979).

> Using field studies and traffic simulation, the paper presented warrants for selecting alternative traffic control at isolated intersections on high-speed rural highways. Two-way stop signs, pre-timed signals, semi-actuated signals, and fully actuated signals were evaluated over a range of traffic volume on major and minor approaches. The warrants were based on the criterion of minimum total annual cost, which include annual accident cost, delay cost, fuel cost, construction and maintenance cost of equipment, non-fuel operation cost, etc.

Daniel B. Fambro, John M. Mason, Jr., and Nancy Straub Cline, *Intersection Channelization Guidelines for Longer and Wider Trucks*, Transportation Research Record 1195, Transportation Research Board, National Research Council, Washington D.C. (1988).

> Using a computer model and defining 2 singles (WB-50), 2 doubles (WB-70), and one triple (WB-100) as design vehicles, the paper generalized results into five topic areas: minimum turning radii, turning templates, cross-street width occupied, turning roadway width and channelization guidelines for longer and wider trucks. These guidelines include the minimum required curb radii to eliminate encroachment into either opposing or adjacent traffic lanes on the cross-street and the minimum required width of turning roadway.

James A. Bonneson, Patrick T. McCoy, and Jess E. Truby, Jr., *Safety Improvements at Intersections on Rural Expressways: A Survey of State Departments of Transportation,* Transportation Research Record 1385, Transportation Research Board, National Research Council, Washington D.C. (1993).

> The state of the practice of measures that state highway departments used to improve traffic safety at intersections on rural expressways is described by the survey. According to the results of the survey, potential measurements include access control, traffic control measures, and geometric design measures. Most states indicated that an access opening is provided for each abutting parcel that cannot be served by other means, while median openings are provided only at intersections of the expressway and other public roads. As to traffic control measures, the responding states indicated that traffic signals were the most commonly applied measures. Other traffic control measures mentioned included specialized or enhanced signing and marking applications. Geometric design measures included alternative median widths, alternative left-turn bay, other left-turn treatments, interchanges, and some other geometric designs, such as adding a right-turn bay, lengthening the left-turn bay, adding a median acceleration lane, and adding a right-turn acceleration lane.

Joseph E. Hummer, Charles V. Zegeer, and Fred R. Hanscom, *Effects of Turns by Larger Trucks at Urban Intersections*. Transportation Research Record 1195, Transportation Research Board, National Research Council, Washington D.C. (1988).

> The results showed that small curb radii, narrow lane widths, and narrow total street widths were among the geometric features associated with increased operational problems. Trailer length was found to be a most critical element to smooth operations than trailer width for the truck tested.

OPERATIONAL ANALYSIS

Kay Fitzpatrick, *Gaps Accepted at Stop-Controlled Intersections*, Transportation Research Record 1303, Transportation Research Board, National Research Council, Washington D.C. (1991).

Data were used to determine intersection sight distance, capacity, queue length, and delay at unsignalized intersections. These data have also been used to determine the need for traffic signal, the capacity of a left-turn lane, warrants for left-turn signal phasing and storage lanes. In areas that experience significant truck traffic, gaps accepted by truck drivers should be considered. Six intersections were selected to collect field data. The Greenshield, Raff, and logit methods were selected to evaluate the gap data. The following conclusions were drawn for gap-acceptance by passenger car and by truck:

- Passenger car driver's 50 percent probability of accepting a gap was generalized as 6.5 sec. for both left and right turns and as 8.25 sec. for the 85 percent probability of accepting a gap at a moderate to high-volume intersection. A 10.5 sec. gap represents the 85 percent probability of accepting a gap at an intersection where the accepted gaps were influenced by low volume and the intersection geometry.

- Truck drivers' 50 percent probability of accepting a gap was generalized as 8.5 sec. In general, at a high-volume location, 85 percent of the truck drivers accepted a 10.0 sec. gap; at a low-volume location, 15.0 sec. was the accepted gap value.

- Some of the critical gap values determined at several of the intersections were influenced by geometric of traffic characteristics.

Michael Kyte, Chris Clemow, Naseer Mahfood, B. Kent Lall, and C. Jotin Khisty, *Capacity and Delay Characteristics of Two-way Stop-controlled Intersections*, Transportation Research Record 1320, Transportation Research Board, National Research Council, Washington D.C. (1991).

Data were collected from a wide range of two-way stop-controlled intersections. Collected data included sight distance, upstream control and platoon characteristics, flow rate, delay, major-street gap, accepted and rejected gap data. It was concluded that:

- Average queue time increases as the subject approach flow rate increases.

- Average service time increases as the flow rate on the conflicting approaches increases.

- Minor-street capacity decreases as the major-street flow rate increases.

- Accepted gap are not constant, but very as a result of several factors, including queue time (inverse relationship), service time (slight inverse relationship), number of rejected gaps (inverse relationship), major street flow rate (inverse relationship), and directional movement of the subject vehicle.

- Service time and total delay increase as major-street flow rate increases

- The time in queue is not correlated to the major-street flow rate

  A preliminary set of models to estimate capacity and delay was developed, including models to calculate capacity, total delay, queue time, and service time of minor-street.

Shane M. Velan and Michael Van Aerde, *Gap Acceptance and Approach Capacity at Unsignalized Intersections,* ITE Journal, Vol. 66, No.3, March 1996.

> Using a microscopic gap acceptance model, under the defined base scenario of an opposed left turn from an unsignalized approach, several results were examined, including opposed approach capacity, size of critical gap, rate of temporal decay of the critical gap, and size of follow-up time. The paper concluded that:
>
> - The opposing flow rate is determined primarily by the number of opposing lanes, their saturation flow rates, and the size of the critical gap and its rate of decay.
>
> - The opposed approach capacity is controlled by the saturation flow rate of the opposed approach.

Wayne K. Kittelson and Mark. A. Vandehey, *Delay Effects on Driver Gap Acceptance Characteristics at Two-way Stop-controlled Intersections,* Transportation Research Record 1320, Transportation Research Board, National Research Council, Washington D.C. (1991).

> This paper examined the 1985 Highway Capacity Manual definition of critical gap for two-way stop-controlled intersections. A revision of the definition of critical gap considering both gap acceptances and gap rejections was presented first. The authors expressed it as "the median probability of accepting a gap of a given size" instead of "the median gap size that is accepted by drivers in a given situation" defined by HCM (1985). Some consequent conclusions were drawn:
>
> - Critical gap is affected by the delay time. Drivers accept shorter gaps as front-of-queue delay increases.
>
> - Any delay-based LOS criterion for TWSC intersections should incorporate lower delay thresholds than are used for signalized intersections, at least in the LOS D, E and F regions.
>
> - The type of major-street conflict (same direction versus opposite direction) that is experienced also affects critical gap for minor-street left-turning vehicles. The directional distribution of major-street traffic can have a substantial effect on the capacity of this movement.

APPENDIX 2: SUMMARY OF STATE AND LOCAL MEDIAN DESIGN PRACTICES, OPERATIONS AND SAFETY

Appendices A-F of National Cooperative Research Program Report 375: *Median Intersection Design* do not appear in the printed version of the report. These six appendices are available through a loan from the NCHRP. They are entitled:

A. Summary of Questionnaire Responses from State and Local Agencies
B. Field Observational Studies at Divided Highway Intersections
C. Evaluation of Accident Histories at Field Observational Sites
D. Evaluation of Statewide Accident Data for Divided Highway Intersections
E. Effect of Median Width on Traffic Operations at Signalized Intersections
F. Sight Distance Implications of Off-Setting Left-Turn Lanes at Divided Highway Intersections

Five of these six, Appendices A-E, are briefly summarized below. The purpose of this summary is to provide the reader with some of the relevant information in those appendices. The information here may also be useful so that one can determine whether to borrow those appendices from NCHRP.

NCHRP 375 APPENDIX A - SUMMARY OF QUESTIONNAIRE RESPONSES FROM STATE AND LOCAL AGENCIES

STATE HIGHWAY AGENCIES

43 responses of 50

Minimum Median Widths - Rural 3-64 ft. (41% greater than 30 ft.)
- Urban 1-30 ft. (57% 10ft. or less)-37 states

Desirable Median Widths - Rural 18-84 ft. (63% greater than 50 ft.)
- Urban 9-64 ft. (35% greater than 30 ft.) – 33 states

Maximum Median Widths - Rural 25- 300 ft. (36% greater than 100 ft.)- 22 states
- Urban 16- 101 ft. (71% 50 ft. or less)- 20 states

31 of 38 states consider the effect of median width on intersection operations when choosing the median width.

One state uses median widths of 150 ft. at intersections to create a dual intersection operation. 50% of the reporting agencies indicated that storage considerations affect the width of the median.

Left-turning vehicles and safe separation are also considered in median width design.

Special Provisions

Bicycles- 9 states
Pedestrians- 18 states
Left-turn Lanes-30 states
Indirect LT- 4 states
U-turns- 17 states
Other vehicle types- 6 states

10 state highway agencies intentionally design narrow medians to prevent storage of left-turning and crossroad vehicles in the median. 19 states have encountered operational or safety difficulties with these medians.

Medians were narrowed to increase capacity and operational efficiency, and to reduce the required right-of-way.

Vehicle overhang, inadequate U-turn space, and through-lane encroachment. Many states stated that the narrow medians were only a problem where left-turn lanes did not exist. Additional problems were lack of refuge areas and inability for expansion.

Signalized intersections at narrow medians cause problems with signal placement, pavement markings, left-turn treatments, and signal timing issues.

6 state agencies indicated that their policies account for the difference between signalized and unsignalized intersections.

77% of the responding states indicated that they are satisfied with their current design policies. Many indicated that the median policies were too broad and needed to be more specific, in every aspect of the design. 8 states reported that changes are being considered to their median design policy.

LOCAL HIGHWAY AGENCIES

19 responses of 51

7 use design policies in AASHTO Green Book
5 have created their own policy
5 use the state policy
9 have no formal design policy
(some overlap of answers)

Minimum widths- 1.5 to 50 ft.
Desirable widths- 8 to 60 ft.
Maximum widths-12 to 110 ft.

11 agencies make some estimation of queuing requirement for left turns in designing median widths.

88% of the local agencies have guidelines regarding left-turn lanes
42% consider bicyclists
63% consider pedestrians
63% consider U-turns
36% consider driveway median openings
52% consider larger vehicle types

2 agencies intentionally design narrow medians, these and 4 others have encountered operational and safety problems at medians that are too narrow.

5 local agencies reported operational and safety problems with wide medians.

The problems with wide medians involved left-turning vehicles blocking each other's sight lines and driver confusion when entering the median area to turn.

Nearly no local agencies differ their policies between signalized and unsignalized intersections.

94% of the local agencies were content with their current guidelines for median width. 3 agencies were considering to their median policies.

NCHRP 375 APPENDIX B - FIELD OBSERVATIONAL STUDIES AT DIVIDED HIGHWAY INTERSECTIONS

40 study sites

-20 rural four-leg intersections
-8 suburban four-leg unsignalized intersections
-6 suburban four-leg signalized intersections
-6 special feature intersections
    2 with tapered offset LTL
    1 with parallel offset LTL
    2 with median acceleration lanes
    2 three-leg intersections

Field studies states were California, Iowa, Illinois, Kansas, Maryland, Missouri, New Jersey, Pennsylvania, Texas, and West Virginia.

Major road was a divided highway and the minor road was an undivided highway or street in all cases.

Characteristics of Intersections

Rural Unsignalized Intersections

Uninterrupted flow on major road and STOP control on minor road approaches.

8 intersections had amber warning signals on the major and red signals on the minor road.

Major roads were four-lane divided highways with speed limit of 55 mph and minor road were two-lane undivided highways.

Median roadway control methods:
- 7 with STOP control
- 7 with YIELD control
- 6 with no control
- Rural special feature sites had no median roadway control

Median widths varied from 30 to 144 ft, and all were depressed, unpaved medians.

Turn Lanes:
Major road LT lanes: 16
Major road RT lanes: 11
Minor road LT lanes: 2
Minor road RT lanes: 2

Suburban Unsignalized Intersections

All the suburban sites had major road uninterrupted flow and STOP control on the minor road approaches. Geometric configurations were the same as for the rural unsignalized intersections.

The major road speed limits were 50 and 55 mph.

Median widths roadway control:
- 4 intersections with YIELD control
- 4 intersections with no control

Median was of both the depressed and raised variety.

Turn Lanes:
Major road LT lanes: 7
Major road RT lanes: 5
No minor road LT or RT

Suburban Signalized Intersections

There were 2 or 3 through lanes per major approach, and 1 or 2 through lanes per crossroad approach.

Major road speed limits ranged from 45 to 55 mph.

Sites included raised and depressed medians.

Median widths ranged from 16 to 207 ft.

4 sites were signalized as a single intersection, with the other two sites designed as a double intersection with medians of over 200 ft.

Turn Lanes:
Major road LT lanes: 4
Major road RT lanes: 3
Minor road LT lanes: 1
Minor road RT lanes: 4

Special Feature Intersections

3 rural unsignalized
3 suburban signalized

Specific special features are stated in the opening of this summary section.

STUDY RESULTS

Turning Behavior

Rural Unsignalized Intersections
Median widths less than 50 ft.- left turn movements tend to occur in front of one another.
Median widths greater than 50 ft- left turn movements occur behind one another (nearly all).

Suburban Unsignalized Intersections
Median widths less than 50 ft.—nearly all LTs turned in front of one another.
Median widths greater than 50 ft.- LT turned in front also (LT channelization exists)

Undesirable Driving Behavior on Median Roadway

Side-by-side queuing on the median roadway by vehicles traveling the same direction
Stopping at an angle on the median roadway
Encroachment on the through lanes of the major roadway.

General Driving Movements and Undesired Behavior Frequency

Major road left/ Major road left same approach- 25.5% of undesired maneuvers
Crossroad left/ Crossroad left same approach -10.2%
Major road left/ Major road left opposite approach- 8.7%
Crossroad left/ Major road left from right approach- 8.1%
Crossroad through/ Crossroad left same approach-5.0%
Crossroad left/ Cross through from same approach- 4.5%
Major road left/ Crossroad left from left approach-4.3%
Crossroad through/ Major road left from right approach- 4.1%

64.3% of undesired maneuvers involved vehicles traveling in the same direction
35.7% involved vehicles traveling in the opposite direction

Most common source of undesirable behavior appears to be competition for space between vehicles traveling in the same direction through the median.

Median Width and Median Opening Length Effects

Rural Unsignalized Intersections:

Undesirable movements tend to decrease as median width increases- correlation is weak, though, and is barely significant at 90% confidence. Predominant undesirable movements is angle stopping.

Rates of undesired movements increase as the median opening length increases. The relationship is highly significant at 99.9% confidence. Therefore, median opening length should not be unnecessarily large.

There was a statistically significant inverse correlation between the slenderness ratio (ratio of median width to median opening) and the number of undesired movements. This information was not found to be helpful due to the correlations already established between the median width and the median opening individually.

Suburban Unsignalized Intersections

Undesirable movements tend to increase as median width increases, and the number of undesirable movements decrease as median opening increases, however it must be noted that the sample size is small. Angle stopping was the predominant undesired movement.

Traffic Control Devices

11.6 to 42.7% of drivers in the median roadway were noncompliant with the STOP sign control, where 31 to 39% of drivers made rolling stops. No traffic conflicts resulted from these results.

Traffic control type was not found to diminish the effects of median width and median opening on driver behavior.

Signalization Effects

Intersections that operated as a single unsignalized intersection had few undesirable movements, however, one of the state agencies had difficulty in loop placement and signal system design.

The two wide-median intersection sites that acted as two signalized intersections had troubles with both angle stopping and major road encroachment, mainly on the median roadway.

Tapered and Parallel Offset Left-Turn Lanes

Undesirable movements at these sites involved backing in the through lanes to get to a missed turn lane and crossing of the gore area to enter a turn lane after entrance was missed, however, the frequency of these occurrences was low, and undesirable movements at these intersection in general were rare.

Median Acceleration Lanes

The median acceleration lanes studied appeared to improve operations by reducing the need for cars to stop in the median roadway. The rates of undesirable movements were low at each of these study sites.

NCHRP 375 APPENDIX C - EVALUATION OF ACCIDENT HISTORIES AT FIELD OBSERVATIONAL SITES

For the rural unsignalized intersections, no significant correlation was found between the median width and accident rates. The other intersection types had sample sizes to provide a meaningful result.

The suburban unsignalized intersection with the highest accident rates had a 26 ft. median, and it is suspected that the narrow median might be a contributing factor to the high accident rates.

Rear-end collisions were the most common at the suburban signalized intersections, however, the accident pattern is not related to the median area design.

The effects of trucks were not found to be very significant in either number of accidents or by encroaching onto the major roadway.

The samples were insufficient to provide evidence of a superior left-turn lane design.

The sample of wrong-way accidents was too small to determine the effects of median width on wrong-way accidents.

NCHRP 375 APPENDIX D - EVALUATION OF STATEWIDE ACCIDENT DATA FOR DIVIDED HIGHWAY INTERSECTIONS

California database used for the analysis.

Poison and log-normal regression analyses were used to analyze the accident data from the database on about 6800 intersections on divided highways.

At rural four-leg unsignalized intersections, it was determined that accident frequency decreases as median width increases, with the result found to be statistically significant.

No statistically significant relationship was found to exist between accident frequency and median width at three-leg unsignalized intersections.

At urban/suburban four-leg signalized intersections, accident frequency was found to increase over median widths for 14 to 80 ft., with the result being statistically significant.

At three-leg urban/suburban intersections, accident frequency was found to increase with increasing median width, with the result being statistically significant.

NCHRP 375 APPENDIX E - EFFECT OF MEDIAN WIDTH ON TRAFFIC

OPERATIONS AT SIGNALIZED INTERSECTIONS

There are least two possibilities for signalization of an intersection at a divided roadway, wheher a single intersection signalization design or a diamond intersection signalization design. The former appears to be more appropriate for narrow medians, while the latter appears to be more feasible for wide medians.

At single intersection signalizations, delay increases as median width increases.

The breakdown points occur at the following widths to determine whether to use single or diamond signal design:

- High Volumes: 98 to 148 ft.
- Moderate Volumes: 200 to 300 ft.
- General Case: 100 ft or less for single signal
150 ft. or more for diamond

However, the scenarios presented in the section are not likely to match design situations, due to forecasting inaccuracies, and so the designer is cautioned to use their judgment.

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