EXECUTIVE SUMMARY

An Evaluation of the MICHIGAN URBAN DIAMOND INTERCHANGE with respect to the SINGLE POINT URBAN INTERCHANGE

by

Paul B. W. Dorothy, Ph.D.

and

Thomas L. Maleck, Ph.D., P.E.

February 1998

COLLEGE OF ENGINEERING
MICHIGAN STATE UNIVERSITY
EAST LANSING, MICHIGAN 48824
The Michigan Department of Transportation (MDOT) is considering the much needed rehabilitation and upgrading of many interchanges found in urban environments. Thus, MDOT and Michigan State University (MSU) undertook a joint effort to evaluate the appropriateness of an urban interchange geometric configuration, the Single Point Urban Interchange (SPUI), as an alternative design to those presently used by MDOT. In particular, the Michigan Urban Diamond Interchange (MUDI) and the traditional diamond were investigated. A field review was conducted to collect information about the geometric design, signal operation, pedestrian control and pavement markings of SPUIs, as none currently exist in Michigan. The field review showed that the design and operation of SPUIs vary greatly from state to state. Thus, the SPUI and MUDI designs were computer modeled to facilitate a comparison of their respective operational characteristics. A traditional diamond was also modeled to generate a frame of reference. The results showed that the SPUI operation is adversely affected with the addition of frontage roads. MUDI operation, in most situations, is superior to that of either a SPUI and diamond interchange configuration. Also, there was less migration of delay to downstream intersections with a MUDI configuration than with either a SPUI or diamond. Finally, MUDI operation, in most situations, is insensitive to the proximity of the closest downstream node, while the SPUI operation is sensitive.
NOTICE

This document is disseminated under the sponsorship of the Michigan Department of Transportation and the United States Department of Transportation in the interest of information exchange. The sponsors assume no liability for its contents or use thereof.

The contents of this report reflect the views of the authors who are solely responsible for the facts and accuracy of the material presented. The contents do not necessarily reflect the official views of the sponsors.

The State of Michigan and the United States Government do not endorse products or manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the objectives of this document.

This report does not constitute a standard, specification or regulation.
# TABLE OF CONTENTS

**LIST OF FIGURES** ........................................................................................................ ii

**1.0 INTRODUCTION** ........................................................................................................ 1

1.1 Introduction .................................................................................................................. 1
1.2 Statement of the Problem ............................................................................................... 1

**2.0 OPERATION AND DESIGN OF URBAN INTERCHANGES** ......................... 4

2.1 The Urban Diamond Interchange ............................................................................... 4
2.2 The Michigan Urban Diamond Interchange (MUDI) .................................................. 5
2.3 The Single Point Urban Interchange (SPUI) ............................................................... 7

**3.0 STATE OF THE PRACTICE** .............................................................................. 8

**4.0 FIELD REVIEW OF THE SPUI** ................................................................. 9

**5.0 METHODOLOGY** .................................................................................................. 11

5.1 Network Configuration ............................................................................................... 12
5.2 Signal Operation ......................................................................................................... 15
5.3 Variables Modeled ....................................................................................................... 19
5.4 Measures of Effectiveness (MOEs) ..................................................................... 21

**6.0 SIMULATION RESULTS** .................................................................................. 22

6.1 Interchange Performance without Frontage Roads ............................................... 23
6.2 Migration of Delay without Frontage Roads .............................................................. 25
6.3 Interchange Performance with Frontage Roads ....................................................... 26
6.4 Migration of Delay with Frontage Roads ................................................................. 29
6.5 Sensitivity to Proximity of Closest Downstream Node ......................................... 29

**7.0 CONCLUSIONS** ................................................................................................. 34

**LIST OF REFERENCES** ............................................................................................. 38
LIST OF FIGURES

Figure 1.1: Typical Single Point Urban Interchange (SPUI) Configuration without Frontage Roads ................................................................. 2

Figure 1.2: Typical Single Point Urban Interchange (SPUI) Configuration with Frontage Roads ................................................................. 2

Figure 1.3: Typical Michigan Urban Diamond Interchange (MUDI) Configuration with Frontage Roads ......................................................... 3

Figure 1.4: Typical Diamond Interchange Configuration with Frontage Roads ...... 3

Figure 5.1: Link/Node Diagram for Diamond Configuration .................................... 13

Figure 5.2: Link/Node Diagram for MUDI Configuration ........................................ 13

Figure 5.3: Link/Node Diagram for SPUI Configuration .......................................... 14

Figure 5.4: Phasing Diagram for MUDI Configuration ........................................... 17

Figure 5.5: Phasing Diagram for SPUI Configuration without Frontage Roads ...... 17

Figure 5.6: Phasing Diagram for SPUI Configuration with Frontage Roads .......... 18

Figure 5.7: Phasing Diagram for Diamond Configuration ...................................... 18

Figure 6.1: Interchange Area Total Time for 70% Left Turns, without Frontage Roads, 1.6 kilometer (1 mile), 5-lane Arterial ........................................ 24

Figure 6.2: Interchange Area Total Time for 30% Left Turns, without Frontage Roads, 1.6 kilometer (1 mile), 5-lane Arterial ........................................ 24

Figure 6.3: Downstream Area Total Time for 50% Left Turns, without Frontage Roads, 1.6 kilometer (1 mile), 5-lane Arterial ........................................ 27

Figure 6.4: Interchange Area Total Time for 70% Left Turns, with Frontage Roads, 1.6 kilometer (1 mile), 5-lane Arterial ........................................ 27

Figure 6.5: Downstream Area Total Time for 50% Left Turns, with Frontage Roads, 1.6 kilometer (1 mile), 5-lane Arterial ........................................ 30

Figure 6.6: Interchange Area Total Time for 70% Left Turns, without Frontage Roads, 5-lane Arterial, Varying Spacing Scenarios ........................... 30
1.0 INTRODUCTION

1.1 Introduction

As Michigan marks its 100th year of auto manufacturing, it should also be noted that freeways in the Detroit area have been in service since 1942. Many of the early interchanges preceded the Interstate system and, thus, Interstate design standards. The Michigan Department of Transportation (MDOT) is considering the much needed rehabilitation and upgrading of many of these interchanges located in the urban environments. MDOT and Michigan State University (MSU) undertook a joint effort to evaluate the appropriateness of an urban interchange geometric configuration, the Single Point Urban Interchange (SPUI) (Figures 1.1 and 1.2), as an alternative design to those presently used by MDOT. In particular, the Michigan Urban Diamond Interchange (MUDI) (Figure 1.3) and the traditional diamond (Figure 1.4) were investigated.

1.2 Statement of the Problem

There are no SPUIs in Michigan and most of the known SPUIs are located in southern states. Although this interchange design has been around for over 25 years, it has only recently become more prominent due to claims of its efficient operation. However, the benefits of the SPUI have been the subject of some debate. As the popularity of these interchanges increases in other areas of the country, they have been suggested as a logical alternative to the MUDI. Thus; the Michigan Department of Transportation (MDOT) commissioned Michigan State University to study the operational characteristics of the SPUI for application in Michigan. In addition, since both the traditional diamond and MUDI are widely used in urban areas of Michigan, the operational characteristics of these interchange configurations were also of interest.

Executive Summary
Figure 1.1: Typical Single Point Urban Interchange (SPUI) Configuration without Frontage Roads (Not to Scale)

Figure 1.2: Typical Single Point Urban Interchange (SPUI) Configuration with Frontage Roads (Not to Scale)

Executive Summary - 2
Figure 1.3: Typical Michigan Urban Diamond Interchange (MUDI) Configuration with Frontage Roads (Not to Scale)

Figure 1.4: Typical Diamond Interchange Configuration with Frontage Roads (Not to Scale)

Executive Summary
Since no SPUIs exist in Michigan, operational experience with this interchange configuration was lacking. MDOT raised several concerns regarding the operation of urban interchanges in Michigan. These concerns affecting urban interchange design included: ability to progress the arterial cross-road, compatibility with frontage roads, sensitivity to the level (volume) of left-turning traffic, migration of delay to downstream intersections, need to provide special case signing and pavement markings for positive guidance of drivers, ability to accommodate pedestrians and operational efficiency at volume levels nearing capacity. As a result, a field review was conducted to collect information about the geometric design, signal operation, pedestrian control, and pavement markings of SPUIs.

While some evaluation of the SPUI design has been done in the past, the literature review determined that nothing has been published with regard to the ability to progress the arterial cross-road, compatibility with frontage roads, sensitivity to left-turning traffic, migration of delay, or traffic levels nearing capacity. Additionally, while the operational characteristics of a boulevard intersection have been studied and the results published, the MUDI design, which is unique to Michigan, has never been formally studied and there is no literature on the subject. Thus, the SPUI and MUDI designs were computer modeled to facilitate a comparison of their respective operational characteristics. Furthermore, a traditional diamond interchange was modeled to generate a frame of reference for the results.

2.0 OPERATION AND DESIGN OF URBAN INTERCHANGES

2.1 The Urban Diamond Interchange

The configuration shown in Figure 1.4 is an example of an urban diamond interchange with a city street, freeway and parallel frontage roads. The at-grade
intersections of the frontage roads with the crossroad usually have stop-and-go traffic signals. If the freeway is below grade and the crossroad is at grade, then traffic exiting the freeway is going uphill and traffic entering the freeway is going downhill which is beneficial for both movements. This design of the diamond interchange allows traffic entering and exiting the freeway to do so at relatively high speeds. Moreover, if the freeway is depressed, the at-grade intersections have no sight restrictions typically created by freeway structures or differences in grades. Unfortunately, this configuration has relatively low capacity because all of the turning movements occur at the intersections and left-turning vehicles have to yield to oncoming traffic. Thus, there are several areas where traffic spillback may exceed the storage space.

2.2 The Michigan Urban Diamond Interchange (MUDI)

The Michigan Department of Transportation (MDOT), borrowing from its indirect left-turn strategy implemented for most at-grade urban boulevards, modified the traditional urban diamond in an effort to increase the capacity. This modified diamond interchange configuration will be referred to as the Michigan Urban Diamond Interchange (MUDI) (Figure 1.3). This configuration evolved during the design and construction of freeways in the early and mid 1960s.

The MUDI is an urban diamond with left-turning vehicles being routed through separate left-turn structures known as directional cross-overs. Thus, left-turning movements are prohibited at the intersection. As an example, a driver traveling from bottom to top along the arterial wanting to access the left entrance ramp to the freeway would make a direct left-turning maneuver at a standard diamond interchange. For the MUDI, the driver would turn right at the first frontage road, travel to the directional cross over, make a U-turn through the
cross over, travel from right to left to the arterial, cross the arterial and access the entrance ramp, thus completing the desired left turn. Similarly, a driver desiring to access a business adjacent to the service road in the opposite direction would use the cross-overs to change direction and gain access. Evident in these maneuvers is the associated increased travel distance.

The distance that the directional cross over structure is placed from the crossroad is a function of the cycle length of the traffic signals and the speed of the movement. Properly designed, if the left-turning maneuver described above began from the start of green, it should receive a green indication at both the cross over and the arterial. Thus, it does not have to stop and the total travel time for this indirect left turn would equal approximately one-half of the cycle length.

In urban areas, access to property abutting the freeway is often of such importance as to require parallel frontage roads. In addition, Intelligent Transportation System (ITS) strategies, such as ramp metering, function better with continuous frontage roads. However, the intersections of the frontage roads with the cross-road usually require the use of traffic signals. These closely spaced traffic signals may have a significant negative impact upon the operation and capacity of the cross-road.

The addition of U-turn lanes to the cross over structures, as shown in Figure 1.3, is cost-effective when there is a major development or other large attractor of traffic located in the top left or bottom right quadrants of the interchange. For example, freeway traffic traveling from left to right destined for a development in the top left quadrant would exit normally at the ramp to the arterial but immediately use the U-turn structure to access the top frontage road and, thus, the abutting property. This traffic never enters the intersection with

Executive Summary 6
the arterial and, consequently, this strategy can significantly increase the capacity of the intersection.

2.3 The Single Point Urban Interchange (SPUI)

An example of a SPUI without frontage roads is shown in Figure 1.1. The primary feature of the SPUI is that all through and left-turn maneuvers converge at one signalized intersection area as opposed to two separate, closely spaced signals as with the traditional diamond. In addition, opposing left-turn movements operate to the left of each other, contrary to the right-hand rule. This allows for a relatively simple phasing sequence to be used to control conflicting movements. This phasing sequence typically consists of three phases accommodating: both cross-road through movements, both off-ramp left-turn movements, and both crossroad left-turn entrance movements. The right-turn movements are usually allowed to free-flow. However, if frontage roads are present (Figure 1.2), there is a need to add a fourth phase, resulting in a reduction in capacity of the other phases. In addition, because of the physical size of many of the SPUIs, a relatively long clearance interval is required between the phases.

A limitation in the SPUI design is that the close physical relationship of the bridge abutments, roadway cross-sections, and offset left-turn paths may constrain the ability to easily upgrade the design in the future. In addition, these limitations make it difficult to utilize this design in an area where the crossroad and freeway intersect at a skew. Furthermore, the horizontal alignment of the left-turn paths can affect the amount of right-of-way needed.
3.0 STATE OF THE PRACTICE

A literature review, e-mail survey and telephone survey were conducted. They identified several aspects of SPUI design that would need to be addressed in the field review and the simulation modeling. These aspects can best be presented by grouping them into several topic areas: geometric design, signal operation, pedestrian control, pavement markings, and simulation modeling.

Several inconsistencies in the geometric design of SPUIs were discovered. The studies by Bonneson and Messer (3) and Leisch, et. al. (13) raised the concern that the operation of a SPUI may be adversely affected by the addition of continuous frontage roads due to the need for a fourth signal phase. However, the responses from the e-mail survey listed the adaptability to frontage roads as one of the major advantages of the SPUI design.

The study by Messer and Bonneson (14) stated that dual left-turns were typically used on both approach legs of the off-ramps and arterial cross-street. However, Leisch (12) contends that the efficiencies gained by fully utilizing the 3-phase signal are lost if more than one left-turning volume requires dual turning lanes.

The signal operation of SPUIs varied by location. Messer and Bonneson (14) studied the operation of 36 SPUIs and observed the dominant traffic signal control to be isolated traffic actuated operation. This was reinforced by the results of the telephone survey in which most of the states reported that they rely solely on traffic actuated signalization along the arterial. However, most arterials in Michigan are operated in a progressed-coordinated system. Only one state from the e-mail survey and two states from the telephone survey stated that their agencies progressed the traffic on the arterial.
The reported ability to accommodate pedestrians varied. Bonneson and Messer (3) reported that the typical SPUI signal phasing does not provide for a protected pedestrian phase to occur across the cross-road. However, the district engineer for Duluth reported that pedestrians did not have a problem.

The reported need for pavement markings also varied. As part of the e-mail survey, one state reported that they used conventional pavement markings, another state reported that pavement markings may be a problem, and a third state reported that there is a need for extensive pavement markings. Merritt (15) stated that the SPUI design needs to rely heavily on guide signing, pavement markings, and lane use signing for the necessary positive guidance of drivers.

The studies by Fowler (10) and Leisch, et. al. (13) used computer modeling to compare the operation of a SPUI and a TUDI. However, both studies used TRANSYT-7F which is a macroscopic model and is best suited to modeling large networks, not individual intersections. In addition, the study by Fowler (10) only modeled 24 scenarios and the study by Leisch, et. al. (13) only modeled ten scenarios.

4.0 FIELD REVIEW OF THE SPUI

While the MUDI configuration can be compared to a boulevard intersection, the SPUI configuration has no direct comparison. Based on information gathered through the e-mail and telephone surveys, sites were selected in several states for inclusion in the field review. These sites were located in Indiana, Illinois, Minnesota, Florida, Missouri and Arizona.

During a typical field review, the engineers and technicians responsible for the operation of the SPUI interchange being studied were interviewed. These interviews
included a visit to the site where the operation of the SPUI was discussed. If possible, plan view drawings, signing plans, aerial photographs, signal timings, traffic volumes, in-house studies, and, economic data pertaining to the SPUI in question were collected. In the field, extensive photographs and video of the interchange were taken.

Based on the field review conducted between January 1996 and May 1996, subjective observations can be made about the design and operation of a SPUI. These observations are based upon the consensus of the team which conducted the field review and can best be presented by grouping them into the topic areas: geometric design, signal operation, pedestrian control, and pavement markings.

The most significant geometric design difference of the SPUIs reviewed is between a SPUI with the cross-road going over the freeway and a SPUI with the freeway going over the cross-road. The SPUI with the cross-road going over the freeway was found to look and operate more like a conventional signalized intersection. Another design difference was related to the physical size of the interchange. SPUIs without dedicated U-turn lanes appeared to accommodate U-turns as well as those with dedicated U-turn lanes. The smaller designs were observed to function better than the larger designs. In addition, the Right-of-Way requirements are less with the smaller designs. In some cases, the structures were noisy resulting in complaints from nearby residents. Because of the large size of these structures required when the freeway goes over, the roadway under the structure is dark. These undesirable structure characteristics are not present when the cross-road goes over the freeway.

Furthermore, in the case where the freeway goes over the cross-road, sight distance is a concern. Several engineers expressed strong opinions that the use of continuous frontage
roads with a SPUI negates the advantages of the design. Finally, the geometry of the typical on-ramps may result in a sideswipe crash problem.

The signal operation strategy employed by each state differed significantly. Cycle lengths varied from 80 seconds to 180 seconds, with longer cycle lengths usually having fully actuated signal phases for all movements. The interchanges reviewed were operating below capacity and, at this level, progression of the cross-road was not a problem. If the interchange area was very large, the clearance times became quite long and there was significant driver confusion. Finally, the best placement of traffic signal heads occurred in designs where the cross-road went over the freeway, allowing the signal heads to be located on a single overhead tubular beam.

The ability to accommodate pedestrians varied greatly between designs. Typically, it was not difficult for pedestrians to move parallel to the cross-road and cross the ramp movements. However, due to the characteristics of the SPUI, there is always traffic moving through the intersection. This makes it difficult for pedestrians to cross the cross-road.

The need for pavement marking in large SPUIs is paramount. However, these pavement markings can overlap and cause driver confusion. This resultant driver confusion is most pronounced when the cross-road is skewed.

5.0 METHODOLOGY

Sufficient traffic volumes were not present at any of the locations visited during the field review to allow for a field determination of operation at capacity. Thus, to compare the relative operational characteristics of the interchange configurations in question, computer modeling of each geometric configuration was used. The computer model selected for this
analysis was TRAF-NETSIM (a component model of CORSIM), which is a stochastic, microscopic model.

5.1 Network Configuration

To compare the operation of a diamond interchange (Figure 5.1), a MUDI (Figure 5.2), and a SPUI (Figure 5.3), several decisions were made about the network geometry. First, it was decided to model the arterial crossroad as both a five-lane and seven-lane pavement. The cross-section of the five-lane facility consists of four through lanes (two in each direction) and a continuous center left-turn lane (CCLTL), while the seven-lane facility consists of six through lanes (three in each direction) and a CCLTL.

Next, the size of the network had to be determined. Since a major concern with regard to interchange operation is the interchange’s effect on the downstream nodes of the arterial, it was decided to model both the interchange area and one arterial downstream node on either side of the interchange. These downstream nodes were modeled as the intersection of the arterial with a five-lane arterial with a CCLTL. Since an arterial is said to have “perfect geometry” if the intersections are 0.8 kilometers (one-half mile) or 1.6 kilometers (one mile) apart, these downstream intersections were initially placed at 1.6 kilometers from the interchange. The perfect geometric spacing of these intersections allows for optimal signal progression, thus minimizing delay. The impact of minor crossroads and driveways was not modeled.

Once the spacing of these downstream intersections had been determined, their geometry had to be defined. For each approach to the downstream intersections, a 168 meter (550 foot) left and right turning bay was provided. In the interchange area, a 168 meter (550 foot) left and right turning bay was provided.
Figure 5.1: Link/Node Diagram for Diamond Configuration
(Not to Scale)

Figure 5.2: Link/Node Diagram for MUDI Configuration
(Not to Scale)
Figure 5.3: Link/Node Diagram for SPUI Configuration
(Not to Scale)
foot) right turn bay was provided on the arterial approach for both the MUDI and diamond interchange. Additionally, a 168 meter (550 foot) right turn bay was provided on the frontage road for traffic wishing to make a right turn from the frontage road to the arterial for both configurations. In the SPUI interchange area, the length of the right turn bays was shortened to 69 meters (225 feet), as the right turn was operating in a free-flow condition.

5.2 Signal Operation

For the purposes of the computer model, a free flow speed of 72 kph (45 mph), or 20 meters per second (66 feet per second), was assumed for the arterial, minor crossroads and frontage roads. Based on this free flow speed and an intersection separation of 1.6 kilometers (one mile), the optimal cycle lengths were determined to be a multiple of 40 seconds. Longer cycle lengths will accommodate more vehicles per hour due to the lower frequency of starting delays and clearance intervals. Thus, an 80 second cycle was selected for the downstream nodes for all cases. An 80 second cycle was also selected for the operation of the MUDI. However, since the modeled arterial was to be operated in a progressed-coordinated system, a 160 second cycle (double cycle) was selected for the interchange signals in both the SPUI and the diamond interchange due to the need for long phase changes and clearance intervals. Further, given the freeflow speed of 72 kph (45 mph), the minimum phase change interval (yellow and overlapping red) for each phase was determined to be 5 seconds. This phase change interval ensures that approaching vehicles can either stop or clear the intersection without conflicts.

The modeled arterial was to be operated in a progressed-coordinated system, so a definite time relationship exists between the start of green intervals at adjacent intersection signals. Thus, signal offsets had to be determined. Since both downstream intersections were
placed with perfect geometric spacing from the interchange, the free flow speed was assumed to be 72 kph (45 mph), and a cycle length of either 80 or 160 seconds was used, an offset of 0 seconds was selected to best provide for progression of traffic along the arterial. When the spacing of the closest downstream intersection was changed to 0.8 kilometers (one-half mile), this offset was changed to one half a cycle or 40 seconds. Furthermore, when the spacing of the closest downstream intersection was changed to 1.2 kilometers (three-fourths mile), this offset was changed to 20 seconds for the closest node and 60 seconds for the node placed at 2.0 kilometers (one and one-quarter mile).

The signal phasing diagram for the intersection of the minor five-lane CCLTL and the arterial was the same for both downstream nodes. It was assumed that the volume ratio between the arterial and the minor crossroads would be 70/30. Thus, the green split between the arterial and crossroad would also be 70/30.

The phasing diagram for the MUDI signals was determined (Figure 5.4) using a green split of 60/40. In addition, an offset had to be determined for the crossover signals of the MUDI design. At the free flow speed of 72 kph (45 mph), or 20 mps (66 fps), a vehicle requires 8.3 seconds to traverse the 168 meters (550 feet) from the intersection to the crossover. The desired offset for the crossover signal is one which reduces the delay to arterial traffic wishing to make an indirect left turn while not adversely affecting the progression of the arterial. If a vehicle left the stop bar of the crossroad intersection at the free-flow speed and there were no cars at the crossover signal, this offset would be 8.3 seconds. However, there is typically a queue of vehicles, mostly comprised of exiting freeway traffic wishing to make an indirect left turn onto the arterial, waiting at the crossover signal. For the best progression of the arterial traffic, this queue must begin to

Executive Summary
Figure 5.4: Phasing Diagram for MUDI Configuration

Figure 5.5: Phasing Diagram for SPUI Configuration without Frontage Roads
Figure 5.6: Phasing Diagram for SPUI Configuration with Frontage Roads

Figure 5.7: Phasing Diagram for Diamond Configuration
dissipate before indirect left turning traffic from the arterial reaches the crossover signal. This will result in an offset that is less than the 8.3 seconds. The study done by Dorothy, et. al. (8) determined the best crossover signal offset to be four seconds.

A signal phasing diagram was developed for the SPUI for the case where no frontage roads were present (Figure 5.5) and for the case where frontage roads were present (Figure 5.6). A concern with signalizing the SPUI is the need for a long phase change interval to allow traffic to clear the intersection. Thus, the minimum phase change interval of 5 seconds was increased to 9 seconds for all SPUI movements except for the frontage road movements.

Finally, the signal phasing diagram for the diamond (Figure 5.7) was determined. A concern with signalizing the diamond interchange is the need for a clearance interval to allow time for traffic which has turned left from the ramp and is stored on the structure to begin clearing before releasing arterial traffic. Thus, a 12 second clearance interval was provided. This clearance interval advances the green time for traffic stored in the median of the diamond, allowing it to clear the median area before giving the remaining arterial traffic a green indication.

5.3 Variables Modeled

There were four major variables of interest addressed in this study: traffic volumes, turning percentages, frontage roads and distance to the closest downstream node.

The networks were loaded by considering the percent saturation of the entry links of the arterial. For the entry links of the arterial, it was assumed that each entry lane had a capacity of 1800 vehicles per hour of green. With this in mind, a simple incremental volume structure was identified for study based on arterial entry link saturation values of
0.3, 0.5, 0.7, 0.9, and 1.0. The minor downstream crossroad entry links were assumed to have a per lane hourly volume ratio of 30/70 when compared to the arterial entry links. Furthermore, the network was modeled with an in-balance in traffic flow for both the frontage roads and exit ramps. It was assumed that there was a 70/30 imbalance in flow between traffic approaching from the left and traffic approaching from the right (Figures 6.1, 6.3, and 6.5). The maximum frontage road volume was assumed to be 600 vehicles per hour.

The second variable addressed was turning percentages. First, turns from the minor crossroad to the arterial were fixed at 20 percent toward the interchange and 10 percent away from the interchange. Turns from the arterial to the minor crossroad were fixed at 10 percent left and 10 percent right. Second, for arterial traffic approaching the interchange, it was assumed that 25 percent wanted to turn left to access the on-ramp, 25 percent wanted to turn right to access the other on-ramp, and 50 percent wanted to continue on the arterial. Third, turning traffic exiting the freeway was varied to test the sensitivity of the designs to the volume of left turning traffic. Thus, values of 30, 50, and 70 percent left turns from the exit ramps were modeled. Finally, it was assumed that the volume of traffic entering on a particular frontage road would also exit on that frontage road.

The third variable addressed was the existence of frontage roads. In Michigan, depressed freeway segments typically are built with frontage roads to access the adjacent properties. Thus, the operation of a particular interchange configuration with and without frontage roads was of interest.

The final variable addressed was the distance to the closest downstream node. Early in the project, a concern was raised about the effect that an interchange would have on a closely
spaced intersection. In addition, it was desired to determine how an interchange configuration would function in an arterial that did not have perfect geometry. Thus, the distance to the closest downstream node was varied. To keep the size of the network constant, as a downstream node was moved closer to the interchange area, its counterpart on the other side of the interchange was moved and equal distance away from the interchange. The first value modeled was a spacing of 1.6 kilometers (one mile) to either side of the interchange area allowing for perfect progression on the arterial. The second value modeled was a spacing of 0.8 kilometers (one-half mile) on one side and 2.4 kilometers (one and one-half mile) on the other side. This spacing still allows for perfect progression of the arterial. However, the proximity of one of the downstream nodes to the interchange may be a factor. Finally, a spacing of 1.2 kilometers (three-fourths mile) to one side and 2.0 kilometers (one and one-quarter mile) to the other side of the interchange was modeled. This configuration does not allow for perfect progression along the arterial, but does keep a larger separation between the closest intersection and the interchange.

5.4 Measures of Effectiveness (MOEs)

A TRAF-NETSIM simulation run produces an output that summarizes the traffic movements and various measures of effectiveness (MOEs) for both the network as a whole and for individual links. The MOEs that were selected for this study were: interchange area total time and downstream area total time. In TRAF-NETSIM, the MOE “total time” is made up of move time and delay time.

An effort was made to delineate an interchange area and a downstream area in the computer model. The physical size of these areas was the same for all models. However, inside the area, the size of the interchange may vary. The nodes numbered 7 and 8 were coded...
as dummy nodes (i.e. no change in the traffic stream occurs at them) to allow MOEs to be gathered for both the interchange area (the area bounded on the top by node 7 and on the bottom by node 8) and the downstream area (the area above node 7 plus the area below node 8).

A criticism of the indirect left-turn strategy used by the MUDI configuration is that while conflicts from left turning vehicles have been removed from the intersection, these drivers are penalized by being forced to travel a greater distance to use the cross over. Thus, delay should not be used as a MOE, as it would be unclear if the delay savings at an intersection were being offset by the extra travel time imposed on left-turning traffic. Therefore, total time, which represents the amount of time all vehicles spent in the network as a combination of travel time and delay time, was selected as a MOE.

6.0 SIMULATION RESULTS

Based on the variables selected for study, an hour of operation for 300 individual models was simulated. Each model used the same random number seed. Since TRAF-NETSIM brings the simulated network to equilibrium before starting to collect statistics and the network will be simulated for one hour of operation, the results should be repeatable and independent of the random number seed. The network was simulated for a saturation up to 100 percent to aid in determining when simulation results become invalid due to delay occurring outside the environment of the analysis. However, TRAF-NETSIM may produce unreliable results when run at levels of saturation approaching 100 percent. Thus, the results of the 100 percent saturation runs will not be discussed.
The values of start-up lost time and headway were not calibrated or validated based on field data. Since Michigan does not have a SPUI, it was not possible to determine what values would be applicable for Michigan drivers utilizing a SPUI. However, the default values imbedded in the model for start-up lost time (2.0 seconds) and headway (1.8 seconds), which are based upon national averages, were used for each interchange type.

6.1 Interchange Performance without Frontage Roads

Figure 6.1 illustrates the performance of the interchange configurations without the presence of frontage roads and with a five-lane arterial cross-section. The situation modeled in this scenario is for the extreme case of 70 percent of the vehicles exiting the freeway and desiring to turn left onto the arterial. At 30 percent saturation, all three interchange configurations performed approximately the same. However, at 50 percent saturation, the total time for the MUDI and SPUI configurations was only 60 percent of that for the traditional diamond. Additionally, at 70 percent saturation, the total time for the MUDI configuration was 25 percent less than the SPUI and 36 percent less than the traditional diamond. Finally, at 90 percent saturation, the total time for the MUDI configuration was 16 percent less than the SPUI and 20 percent less than the traditional diamond.

When the percent left turns is reduced to 50 percent the operational advantage of the MUDI is reduced, but continues to follow the same pattern as the 70 percent left-turn case outlined above.

As the percentage of left turns is decreased to 30 percent (Figure 6.2), the operational characteristics of both the MUDI and the SPUI configuration change at higher levels of saturation. At 70 percent saturation, the total time for the MUDI was 28 percent less than both
Figure 6.1: Interchange Area Total Time For 70% Left Turns, w/out Frontage Roads, 1.6 kilometers (1 mile), 5-lane Arterial

Figure 6.2: Interchange Area Total Time For 30% Left Turns, w/out Frontage Roads, 1.6 kilometers (1 mile), 5-lane Arterial
the SPUI and traditional diamond, which perform approximately the same. Finally, at 90 percent saturation, the total time for the MUDI was 23 percent less than the SPUI and 10 percent less than the traditional diamond. Thus, at 90 percent saturation, the traditional diamond is operationally superior to the SPUI, as measured by this single MOE.

Much of the same pattern is shown when the arterial cross-section is changed from a five-lane cross-section to a seven-lane cross-section. The major differences are that at 30 percent saturation, the total time for both the MUDI and SPUI was 35 to 40 percent less than the traditional diamond for all turning percentages. In addition, the MUDI with a seven-lane arterial begins to operationally outperform the SPUI at 50 percent saturation as opposed to at 70 percent saturation with a five-lane arterial.

Based on the MOE “interchange area total time”, in all cases, the MUDI configuration either equals or exceeds the operational performance of the SPUI and traditional diamond configuration. These operational advantages are most pronounced when the percentage of left-turning traffic is high and the level of saturation is high. The operational advantages of the SPUI are greatly reduced as the percentage of left-turning traffic is reduced, with the traditional diamond outperforming the SPUI at high levels of saturation and low levels of left-turning traffic.

6.2 Migration of Delay without Frontage Roads

In this research effort, there is concern that greatly enhanced urban interchange configurations may demonstrate an improved operation at the freeway, but may merely move the delay to the first signalized intersection upstream or downstream. Thus, their advantages
(if any) may be exaggerated. Therefore, this analysis also evaluated the operation of the downstream nodes.

As illustrated in Figure 6.3, which is a specific case with 50 percent left turns, five-lane arterial cross-section and no frontage roads, there was no evidence that either the MUDI or SPUI configuration resulted in moving delay to the downstream nodes. However, the total time for the downstream area when fed by traffic from the traditional diamond interchange is greater for all but the 30 percent saturation level, suggesting a migration of delay. In addition, when the specific case with 50 percent left turns, seven-lane arterial cross-section and no frontage roads is examined, this trend continues for the traditional diamond. At 70 percent saturation, the modeling of the SPUI also shows this effect.

6.3 Interchange Performance with Frontage Roads

Many, if not most, of the MUDIs in Michigan are located where frontage roads are provided. Usually these frontage roads parallel the urban freeway for a considerable distance and provide access to abutting property. The need for local access in a major urban area was a primary consideration in the evolution of the MUDI design since frontage roads would need to be provided.

Figure 6.4 illustrates the performance of the interchange configurations with the presence of frontage roads, a left-turning percentage of 70 percent and a five-lane cross-road. At 30 percent saturation, all three interchange configurations performed approximately the same, which is consistent with the results from simulations without frontage roads. However, at 50 percent saturation, the total time for the MUDI configuration was 21 percent less than the SPUI and 59 percent less than the traditional diamond. This represents a divergence from

*Executive Summary* 26
Figure 6.3: Downstream Area Total Time For 50% Left Turns, w/out Frontage Roads, 1.6 kilometers (1 mile), 5-lane Arterial

![Graph showing downstream area total time for 50% left turns without frontage roads.]

Figure 6.4: Interchange Area Total Time For 70% Left Turns, with Frontage Roads, 1.6 kilometers (1 mile), 5-lane Arterial

![Graph showing interchange area total time for 70% left turns with frontage roads.]

Executive Summary 27
the results of simulations without frontage roads, in which the MUD! and SPUI performed the same at 50 percent saturation. At 70 percent saturation, the total time for the MUDI configuration was 18 percent less than the SPUI and 29 percent less than the traditional diamond. Finally, at 90 percent saturation, the total time for the MUDI configuration was 13 percent less than the SPUI and 33 percent less than the traditional diamond.

The results when the percentage of left-turning traffic has been reduced to 50 and 30 percent are consistent with the scenario involving 70 percent left-turns outlined above.

Much the same pattern is shown when the arterial cross-section is changed from a five-lane to a seven-lane cross-section. As with the scenarios having no frontage roads, one major difference was that at 30 percent saturation, the total time for both the MUDI and SPUI was 35 to 40 percent less than that of a traditional diamond for all turning percentages. Additionally, for all left turning percentages, at 90 percent saturation, the traditional diamond operationally outperforms the SPUI. Moreover, for left-turning percentages of 50 and 30 percent, the SPUI performed similar to the traditional diamond at saturation levels of 50 and 70 percent. However, in the scenario where the left-turning percentage was set at 70 percent, the results of the MUDI simulations are not valid past the 70 percent saturation mark. This is due to a spillback of traffic on one of the model’s entry links, which resulted in delay occurring outside the environment of the analysis.

As with the scenarios involving the performance of the interchange configurations without frontage roads, based on the MOE “interchange area total time,” the MUDI configuration with frontage roads either equaled or outperformed both the SPUI and the traditional diamond, except where the MUDI could not be evaluated.
6.4 Migration of Delay with Frontage Roads

When the operation of the downstream nodes was examined for evidence of the migration of delay, a trend was evident. For example, in the scenario representing 50 percent left-turning traffic, frontage roads and a five-lane arterial cross-section (Figure 6.5), there is evidence of a migration effect from both the SPUI and traditional diamond interchange configurations. This trend is also exhibited when the arterial cross-section is widened to seven-lanes. Thus, for all cases involving frontage roads, the MUDI was operationally superior in having less migration of delay to the downstream intersections.

6.5 Sensitivity to Proximity of Closest Downstream Node

The effect that the proximity of the closest downstream node has on either the MUDI or SPUI interchange operation was also studied. Three spacing scenarios were considered:

- 1.6 kilometers (one mile) which allows for perfect progression along the arterial while maintaining adequate separation between the intersection and interchange area;

- 1.2 kilometers (three-quarter mile) which does not allow perfect progression along the arterial, but still maintains adequate separation between the intersection and interchange area;

- 0.8 kilometers (one-half mile) which allows for perfect progression along the arterial, but the proximity of the intersection to the interchange area may affect operation.

All the scenarios involving sensitivity testing of the proximity of the downstream node were modeled without the presence of frontage roads.
Figure 6.5: Downstream Area Total Time For 50% Left Turns, with Frontage Roads, 1.6 kilometers (1 mile), 5-lane Arterial

Figure 6.6: Interchange Area Total Time for 70% Left Turns, w/out Frontage Roads, 5-lane Arterial, Varying Spacing Scenarios
When modeled with a five-lane arterial cross-section, 70 percent left-turns and 30 to 50 percent saturation, the MUDI configuration (Figure 6.6) performed approximately the same for all three spacing scenarios. In addition, the MUDI configurations with the closest downstream node placed at 1.6 kilometers (one-mile) and 1.2 kilometers (three-quarter mile) from the interchange continued to perform approximately the same for all levels of saturation. However, at 70 percent saturation and greater, the MUDI configuration with the closest downstream node placed at 0.8 kilometers (one-half mile) from the interchange exhibited greater interchange area total time than the other two MUDI spacing scenarios. At 70 percent saturation, the MUDI 0.8 kilometer spacing scenario had approximately 40 percent more total time than the other MUDI spacing scenarios, while at 90 percent saturation, the total time was 35 percent more.

When the percent left-turns was reduced to 50 percent, the simulation results for the MUDI configuration were similar to that of the 70 percent left-turning scenario described above. However, when the percent left-turns was reduced to 30 percent, the MUDI configuration performed approximately the same for all three spacing scenarios and all levels of saturation. In addition, when the arterial cross-section was changed to seven lanes, the MUDI configuration performed approximately the same for all three spacing scenarios and all levels of saturation.

Thus, the only conditions where the MUDI configuration was affected by the spacing of the closest downstream node were the scenarios using 70 percent left turning traffic, an arterial cross-section of five lanes, saturation levels of 70 percent or greater and a proximity of 0.8 kilometers (one-half mile). However, the models were coded with an imbalance in traffic flow of 70/30 between traffic approaching from the left and traffic approaching from the right.
(Figure 5.2). Since, this increase in total time only appeared with a left-turning percentage of 70 percent, an arterial cross-section of five lanes and when the model was operating at near capacity, the most likely cause of this increase is a spillback from the limited storage available between the downstream intersection and the interchange.

When modeled with a five-lane arterial cross-section, 70 percent left turns and 30 percent saturation, the SPUI configuration (Figure 6.6) performed approximately the same for all three spacing scenarios. However, at 50 percent saturation, the interchange area total time for the SPUI configurations with 1.2 kilometer (three-quarter mile) and 0.8 kilometer (one-half mile) separation was approximately 35 percent greater when compared to the 1.6 kilometer (one mile) spacing scenario. At saturation levels of 70 percent or greater, the SPUI configuration with 1.6 kilometer (one mile) separation performed approximately the same as the SPUI configuration with a 1.2 kilometer (three-quarter mile) separation. However, at 70 and 90 percent saturation, the total time for the SPUI configuration with 0.8 kilometer (one-half mile) separation was approximately 15 percent and 20 percent greater, respectively, when compared to the other SPUI spacing scenarios. These results are also reflected in the performance of the SPUI configuration with a seven-lane arterial cross-section.

When the percent left-turns was reduced to 50 percent, the simulation results were similar to that of the 70 percent left-turn scenario for saturation levels of 30, 50, and 90 percent. However, at 70 percent saturation, the SPUI configuration performed approximately the same for all spacing scenarios. When the percent left-turns was reduced to 30 percent, the simulation results were also similar to the 70 percent left-turn scenario for all saturation levels. At both 50 and 30 percent left-turning traffic, the scenarios modeled with a seven-lane arterial cross-section reflected similar results.

Executive Summary 32
Unlike the MUDI configuration, the total time for the SPUI configuration was adversely affected for all percent left-turning scenarios when the spacing to the closest downstream node was reduced to 0.8 kilometers (one-half mile). In addition, at 50 percent saturation, the scenarios modeling a separation of 1.2 kilometers (three-quarter mile) resulted in greater total time than the comparable models with a separation of 1.6 kilometers (one mile).

In all cases, the performance of the MUDI configuration with a separation of 1.6 kilometers (one mile) or 1.2 kilometers (three-quarter mile) either equals or exceeds the operational performance of the SPUI. In addition, for levels of saturation of 50 percent or less, the MUDI configuration with a separation of 0.8 kilometers (one-half mile) also either equals or exceeds the operational performance of the SPUI. Furthermore, at higher saturation levels, the operational performance of the SPUI configuration was adversely affected by a separation of 0.8 kilometers (one-half mile). Thus, in most cases, the MUDI configuration appears to be insensitive to the proximity of the closest downstream node, while the SPUI configuration is sensitive to the proximity of the downstream node.

For both arterial cross-sections and all three spacing scenarios of the downstream node, the MUDI configuration showed no evidence of migration of delay. In addition, the SPUI configuration with a five-lane cross-section and 1.6 kilometer (one mile) spacing also showed no evidence of migration of delay to the downstream nodes. However, for levels of saturation of 50 percent or greater, all other SPUI configuration scenarios resulted in higher total times, suggesting a migration of delay.
7.0 CONCLUSIONS

Since no Single Point Urban Interchanges exist in Michigan, it was necessary to determine the state of the practice for SPUI design from other states. This was accomplished by conducting a literature review, AASHTO e-mail survey, telephone survey and field review. The results of this "state of the practice" review showed that the design and operation of SPUIs vary greatly from state to state.

The most significant difference in the geometric designs of SPUIs was between a SPUI with the cross-road going over the freeway and a SPUI with the freeway going over the cross-road. The SPUIs with the cross-road going over the freeway were found to look and operate more like a conventional signalized intersection. Because of this less driver confusion was observed. In addition, routing the freeway over the cross-road exposes the freeway and major traffic volume to preferential icing in cold weather climates. Another geometric design difference was related to the physical size of the interchange. SPUIs without dedicated U-turn lanes appeared to accommodate U-turns, for all but the largest of trucks, as well as those with dedicated U-turn lanes. The resulting increase in size to accommodate U-turn lanes may be counterproductive due to an increase in clearance times.

The signal operation strategy employed by each state differed significantly. Cycle lengths varied from 80 seconds to 180 seconds, with longer cycle lengths usually having fully actuated signal phases for all movements. The placement of traffic signal heads in designs where the cross-road went over the freeway resulted in the signal heads being located on a single overhead tubular beam.
The ability to accommodate pedestrians varied between designs. Typically, it was not difficult for pedestrians to move parallel to the cross-road and cross the ramp movements. However, it was difficult for pedestrians to cross the cross-road.

The need for pavement markings in large SPUIs is paramount. These pavement markings can overlap and cause driver confusion. This resulting driver confusion is more pronounced when the cross-road is skewed.

The SPUI and MUDI designs were computer modeled using TRAF-NETSIM to facilitate a comparison of their respective operational characteristics. Furthermore, a traditional diamond interchange was modeled to generate a frame of reference for the results. An hour of operation for 300 individual modeling scenarios was simulated. The results of the simulation modeling are based on this finite number of scenarios defined by the four main variables addressed by this study: traffic volumes, turning percentages, frontage roads and distance to the closest downstream intersection.

Not all modeling scenarios that were simulated returned results that were valid. In a limited number of scenarios, a spillback of traffic on one of the model’s entry links resulted in delay occurring outside the environment of the analysis.

The measures of effectiveness (MOEs) selected for this study were interchange area total time and downstream area total time, where “total time” is made up of both move time and delay time.

Based on the MOE interchange area total time, MUDI operation, in most situations, is superior to that of a SPUI and traditional diamond interchange configurations. This is true of scenarios modeled both with and without the presence of frontage roads. These operational advantages are most pronounced when the percentage
of left-turning traffic is high and the level of saturation is high. In addition, the
operational advantages of the SPUI are greatly reduced as the percentage of left-turning
traffic is reduced, with the traditional diamond outperforming the SPUI at high levels of
saturation and low levels of left-turning traffic.

The study addressed the concern that greatly enhanced urban interchange
configurations may demonstrate an improved operation at the freeway interchange area,
but may merely move delay to the first signalized intersection upstream or downstream.
Thus, the advantages (if any) of the interchange improvement may be exaggerated. Based
on the MOE downstream area total time, there was less migration of delay to downstream
intersections with a MUDI configuration than with either a SPUI or traditional diamond
configuration. For all scenarios without the presence of frontage roads, the traditional
diamond interchange configuration resulted in moving delay to the downstream nodes.
While there was no evidence that the SPUI configuration resulted in moving delay to the
downstream nodes when modeled with a five-lane arterial cross-road, when modeled with
a seven-lane cross-road, the SPUI configuration shows this effect at high levels of
saturation. Both the SPUI and the traditional diamond show this effect when modeled
with the presence of frontage roads.

The affect that the proximity of the closest downstream node has on either the
MUDI or SPUI interchange operation was also studied for scenarios without the presence
of frontage roads. Based on the MOEs interchange area total time and downstream area
total time, MUDI operation, in most situations, is insensitive to the proximity of the
closest downstream node, while the SPUI operation is sensitive to the proximity of the
closest downstream node. For both arterial cross-sections (five-lane and seven-lane) and
all three spacing scenarios of the downstream node, the MUDI configuration showed no evidence of migration of delay. In addition, the SPUI configuration with a five-lane cross-section and 1.6 kilometer (one mile) spacing also showed no evidence of migration of delay to the downstream nodes. However, for higher levels of saturation, all other SPUI configuration scenarios resulted in higher total times, suggesting a migration of delay.

Based on the simulation modeling performed as part of this study, MUDI operation, in most situations, is superior to that of a SPUI or traditional diamond interchange.
LIST OF REFERENCES


*Executive Summary* 38
