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INTERCHANGE DESIGN AND SOFTWARE ANALYSIS

Final Report

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16. Abstract
The Phoenix metropolitan area has been witnessing a substantial growth in population and urban travel. Over the next two decades, close to 230 miles of additional freeways will be added to the network. With this growth in facility design and construction, different designs of urban interchanges need to be considered.

The goal of this research effort is to assess available computer software in terms of their ability to simulate urban interchanges, and recommend a computer program which is capable of conducting both design and analysis applications for different urban interchanges. In the design mode, the program would search for the optimum design that would minimize the construction costs and road user costs. The analysis mode would enable the analyst to assess the system performance for a given existing site.

To reach this goal, the following tasks are identified:

1. Review all available literature related to this subject.
2. Acquire and assess all available computer software that directly or indirectly deal with interchange design and/or analysis.
3. Develop a detailed work plan for any recommended software modification or development, and establish the anticipated project duration and estimated budgets.
4. Prepare a report summarizing findings of this study.

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INTRODUCTION

Interchanges are formed when two facilities intersect at different levels and turning movements are accommodated by using ramps or loop ramps. There are several basic interchange forms and their application at a particular site is determined by the number of intersection legs, traffic volume using the interchange, topography, design controls, proper signing, and designer's initiative.

The three basic types of interchanges are the diamond interchanges, the cloverleafs, and the directional interchanges. Variations of the basic designs are introduced to handle variations in traffic volume, topography, and traffic controls.

Interchanges located in urban areas are designed to serve higher traffic volume than interchanges designed for rural facilities. The availability of right-of-way is certainly a major constraint imposed on the interchange designer, and may result in three or four level structures.

The Phoenix metropolitan area has been witnessing a substantial growth in population and urban travel. Over the next two decades, close to 230 miles of additional freeways will be added to the network. With this growth in facility design and construction, different designs of urban interchanges need to be considered.

Other metropolitan areas are heavily involved in projects to rehabilitate and reconstruct major sections of the urban interstate system. Whether a new freeway is being added to the network or rehabilitation is being conducted on existing facilities, it is essential to develop a set of warrants for different types of urban interchanges at any given site. Such warrants would include factors such as traffic demand, land availability and cost, traffic control strategies, frontage road spacings, interchange capacity, construction costs, and road user costs.

A systematic approach is essential to test a large number of design alternatives, and select the most effective design. To be able to evaluate large numbers of design alternatives, one needs to select computer software that can simulate the operation of urban interchanges. Two criteria are deemed essential in this selection process "ability" and "credibility". Ability to simulate a given interchange operation, and credibility of the produced output to reasonably represent the real world.

Research Goal and Tasks

The goal of this research effort is to assess available computer software in terms of their ability to simulate urban interchanges, and recommend a computer program which is capable of conducting both design and analysis applications for different urban interchanges. In the design mode, the program would search for the optimum design that would minimize the construction costs and road user costs. The analysis mode would enable the analyst to assess the system performance for a given existing site.

To reach this goal, the following tasks are identified:

1. Review all available literature related to this subject.
2. Acquire and assess all available computer software that directly or indirectly deal with interchange design and/or analysis. The assessment should include: run the software using a selected site in the Phoenix area, evaluate the reasonableness of the produced results, and identify the strengths and weaknesses of the software.
3. Develop a detailed work plan for any recommended software modification or development, and establish the anticipated project duration and estimated budgets.
4. Prepare a report summarizing findings of this study.

Background Information

Interchange Designs

The three basic designs of urban interchanges are the diamond interchanges, the cloverleafs, and the directional interchanges. As far as urban diamond interchanges, there are six forms for that interchange, and they are:

1. Conventional Diamond Interchange (CDI)
2. Compressed Diamond
3. Split Diamond

4. Single Point Diamond Interchange (SPDI)
5. Three-Level Diamond
6. Three-Level Stacked Diamond

This report addressed eight interchange types, the six types of diamonds listed above, partial cloverleaf and full cloverleaf interchanges.

The conventional diamond [Figure 1] is the most used interchange on urban freeways. It is used where a major or a minor arterial intersects with a freeway, and it is most suitable in suburban and urban locations with traffic volumes that are low to moderate, and where right-of-way is restrictive. The conventional diamond is characterized by dual intersections, three-phase signal control with overlap movements, and tight turning radii.

The compressed diamond [Figure 2] is a special design of the conventional diamond in which the distance between the dual intersections is shorter than that of the conventional diamond. This design results in either a shorter left turn storage on the bridge deck or sharper turning radii. Both conventional and compressed diamonds are controlled by traffic signals operating under three-phase scheme with overlap movements.

The split diamond interchange [Figure 3] is most suitable at locations where two close parallel arterials, either one-way or two-way arterials, intersect with a freeway and where frontage roads can be utilized. The capacity of a split diamond is normally high especially when used with a pair of one-way streets. The signal phasing schemes of this type of interchange is no different than the conventional diamond.

The Single Point Diamond Interchange (SPDI), known in some literature as the urban interchange or Single Point Urban Interchange, is essentially an interchange which combines two separate diamond ramp intersections into one large at-grade intersection that accommodates all turning movements and through traffic. Although the SPDI was introduced over two decades ago, little information has been published about it's efficiency and capacity. Recently, it became more attractive because of its compact design which requires less right-of-way. This special design of a

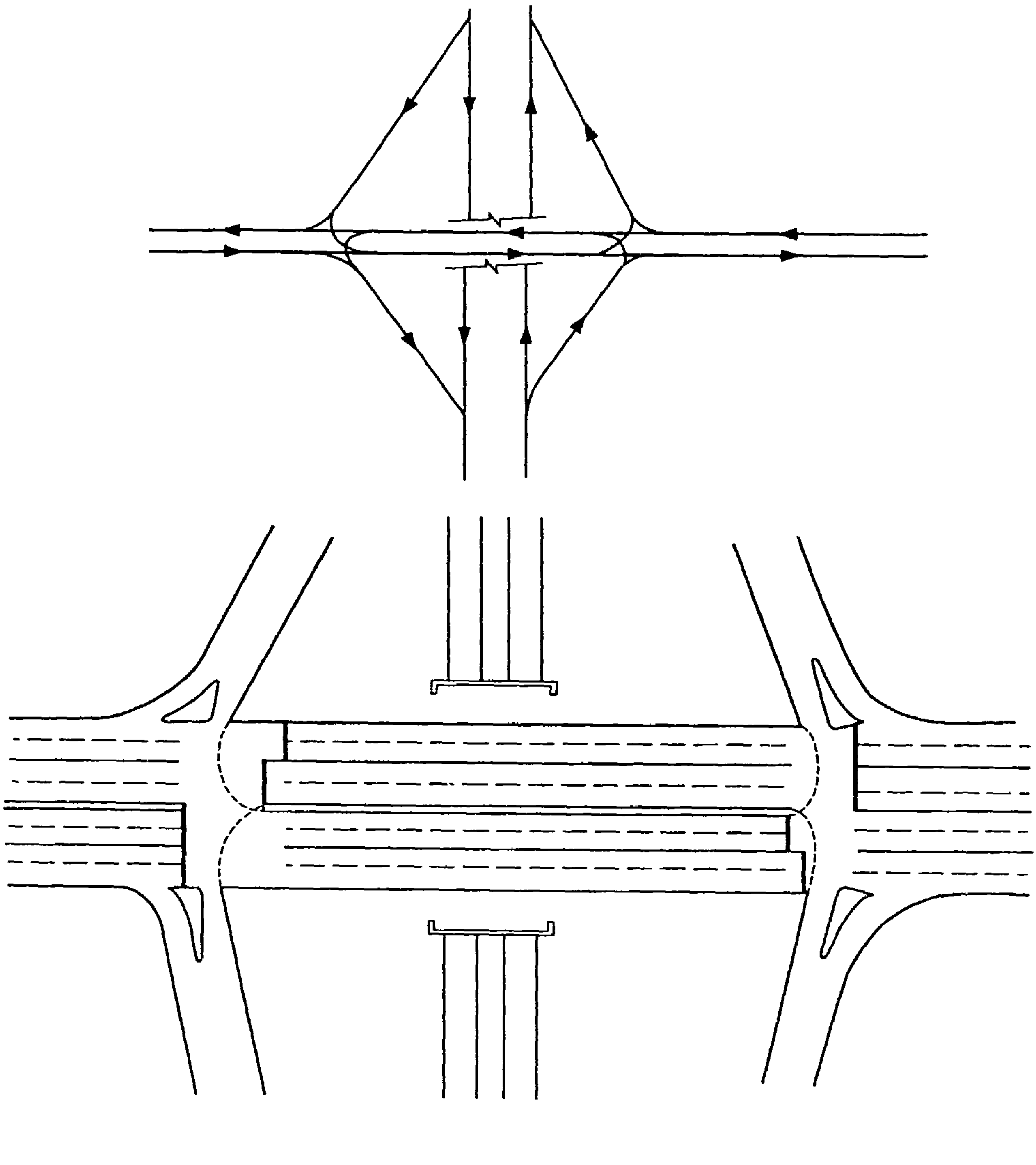


Figure 1. The Conventional Diamond Interchange

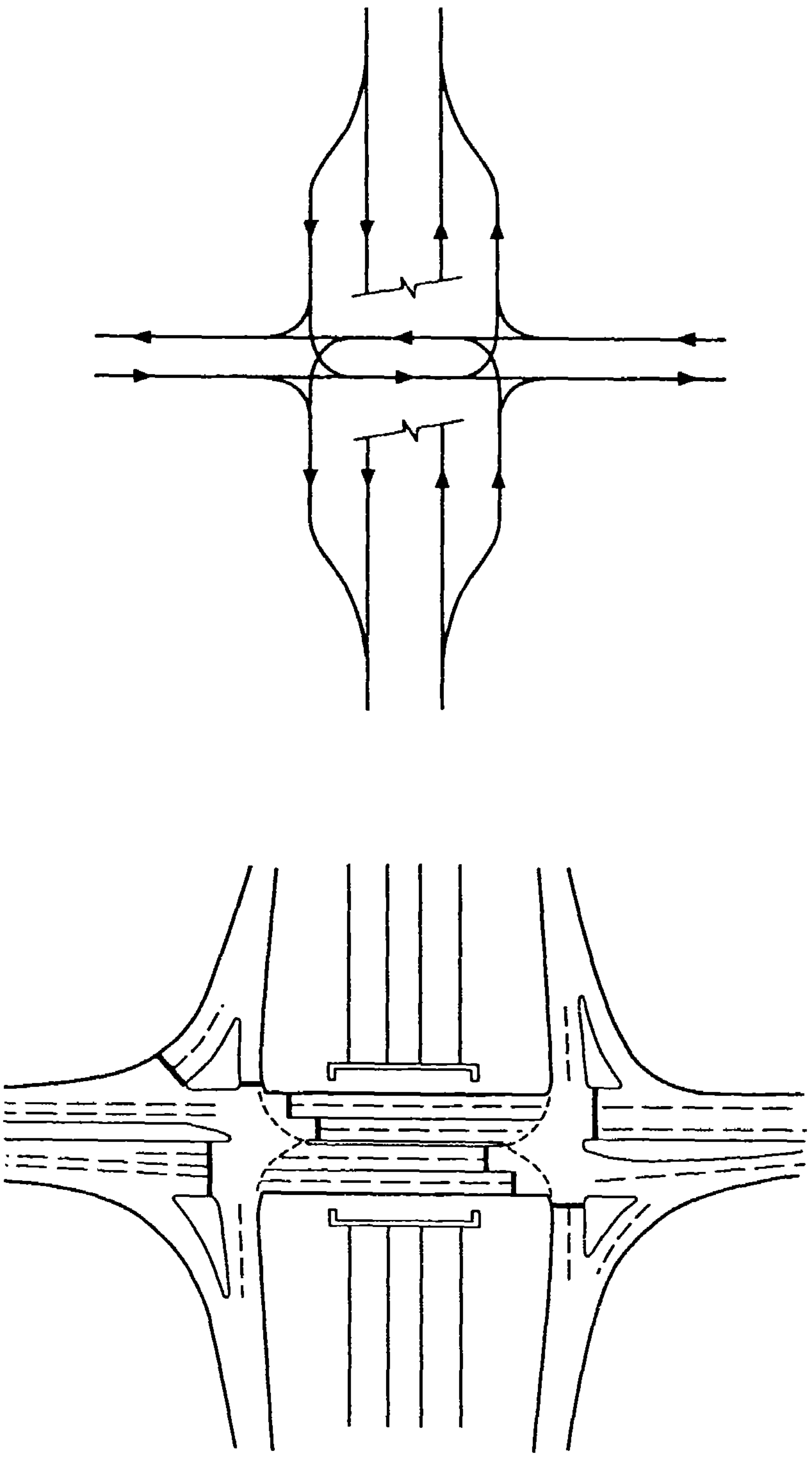


Figure 2. The Compressed Diamond Interchange

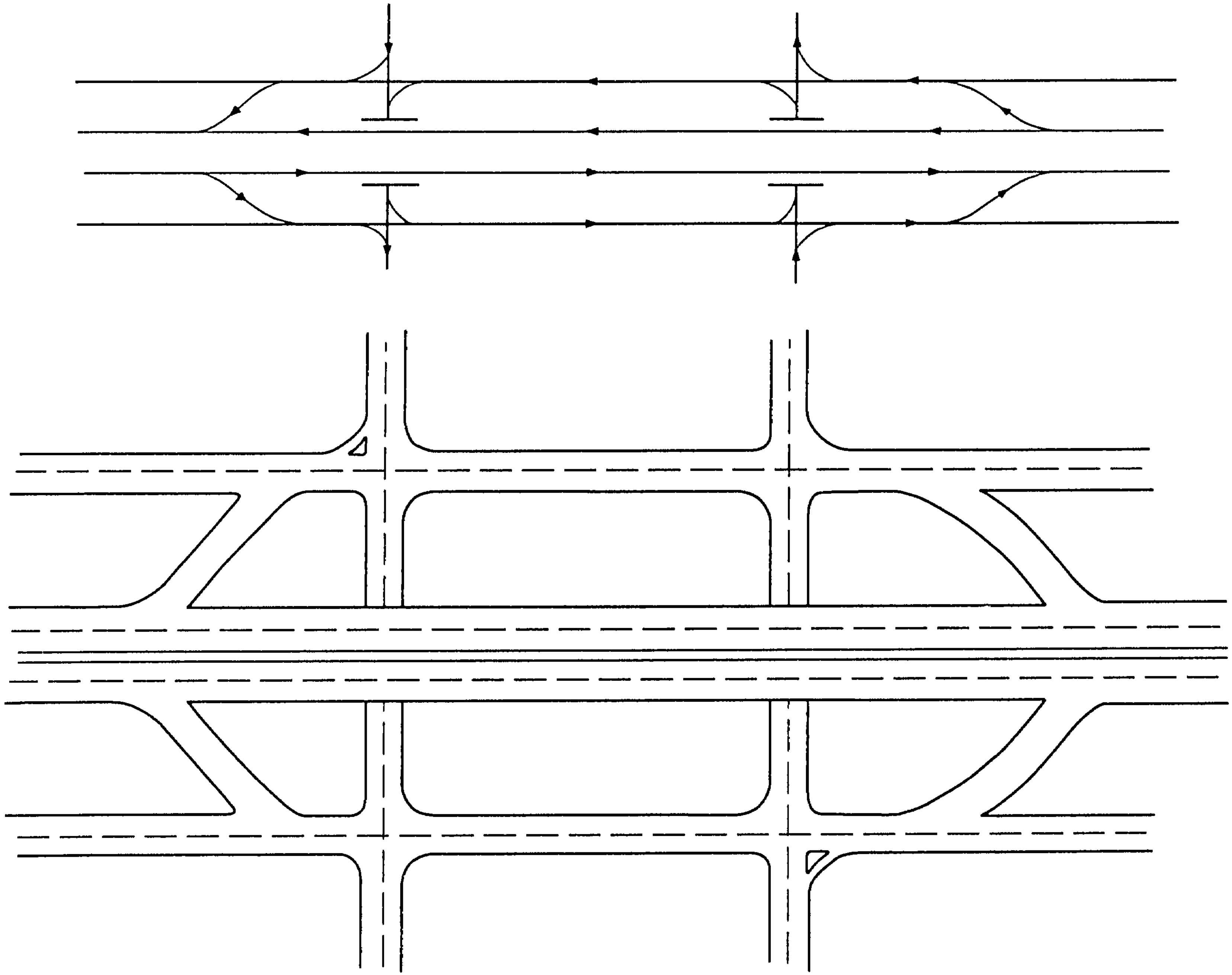


Figure 3. The Split Diamond Interchange

diamond interchange [Figure 4], operates as a single three-phase intersection as opposed to the dual intersection created by the conventional diamond. The through movement from the off-ramp traffic can be prohibited which results in less delay to off-ramp traffic. This design is not suited to integration with frontage roads.

Using the SPDI at a freeway that interchanges with a high volume cross street may result in a large structure. Such structure becomes expensive especially if the cross street is carried over the freeway. The reason being that the high volume on the cross street would require more through and left turning lanes than the traditional two through lanes in each direction. In addition, to provide the large left turning radius through the intersection, the stop lines on the cross street have to be set sufficiently apart resulting in an exceptionally wide intersection.

The three level diamond is most suitable for interchanging two freeways with limited right-of-way. The turning movements are handled at an intermediate level between the two freeways, and it is treated as an at-grade intersection. As depicted in Figure 5, the at-grade intersection is composed of four, one-way approaches, and the left-turning maneuver is unopposed. The use of two-phase signal control at the four approaches has the potential of handling more traffic than other forms of diamonds. Furthermore this design is better suited to handle frontage roads.

The three-level stacked diamond is a three-level arrangement, for the two freeway facilities and an at-grade intersection to handle the interchanging movements, as shown in Figure 6 (1). It's right-of-way requirements are slightly less than those of the conventional three-level diamond, and its capacity is somewhat higher because the at-grade intersection operates as a single two-phase control.

Partial cloverleaf interchanges are composed of two 90° turning ramps and two 270° turning loop ramps as shown in Figure 7. They are used at a freeway interchanging with a relatively low volume cross street. The partial cloverleaf is essentially treated as two isolated at grade intersections either unsignalized or signalized. Each intersection is designed as a T intersection with potential three-phase signal control.

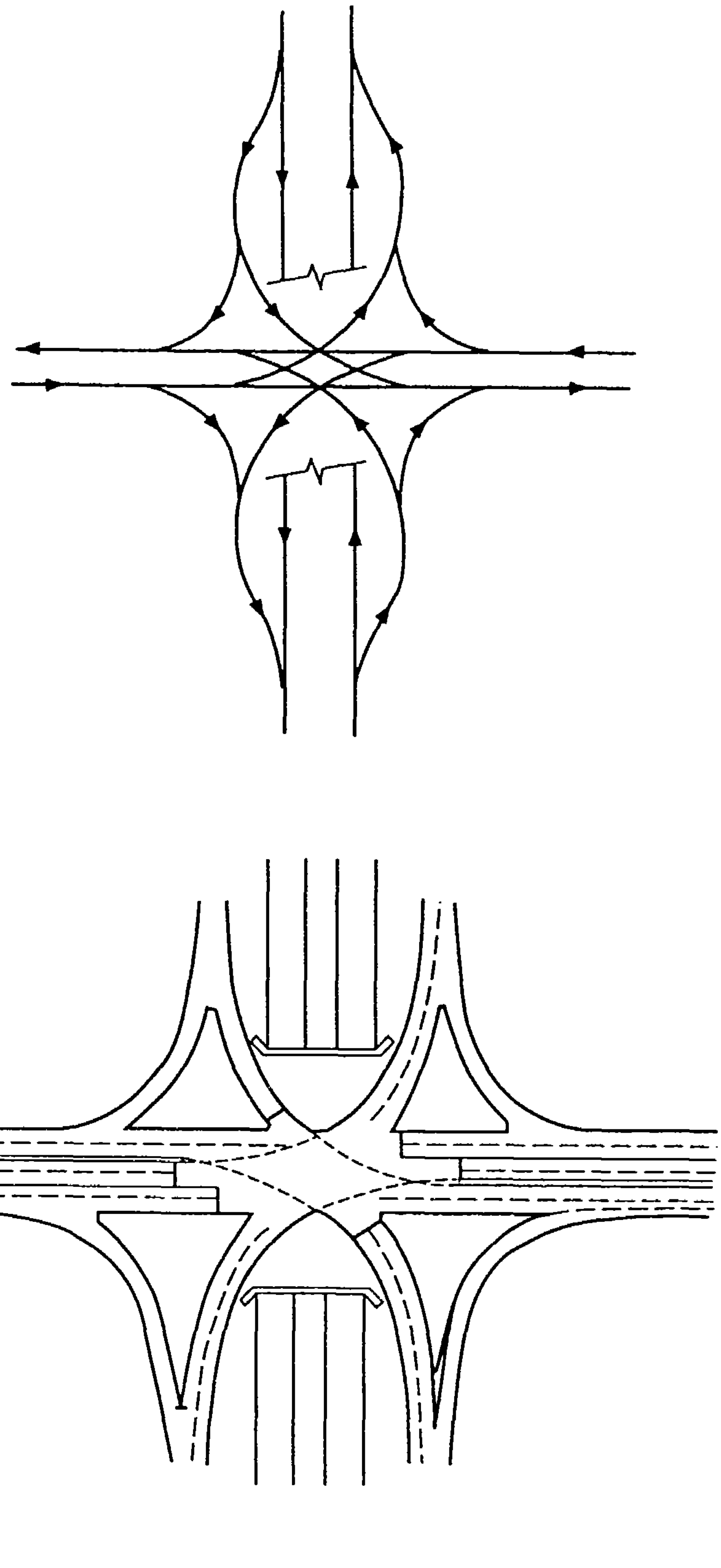


Figure 4. The Single Point Diamond Interchange

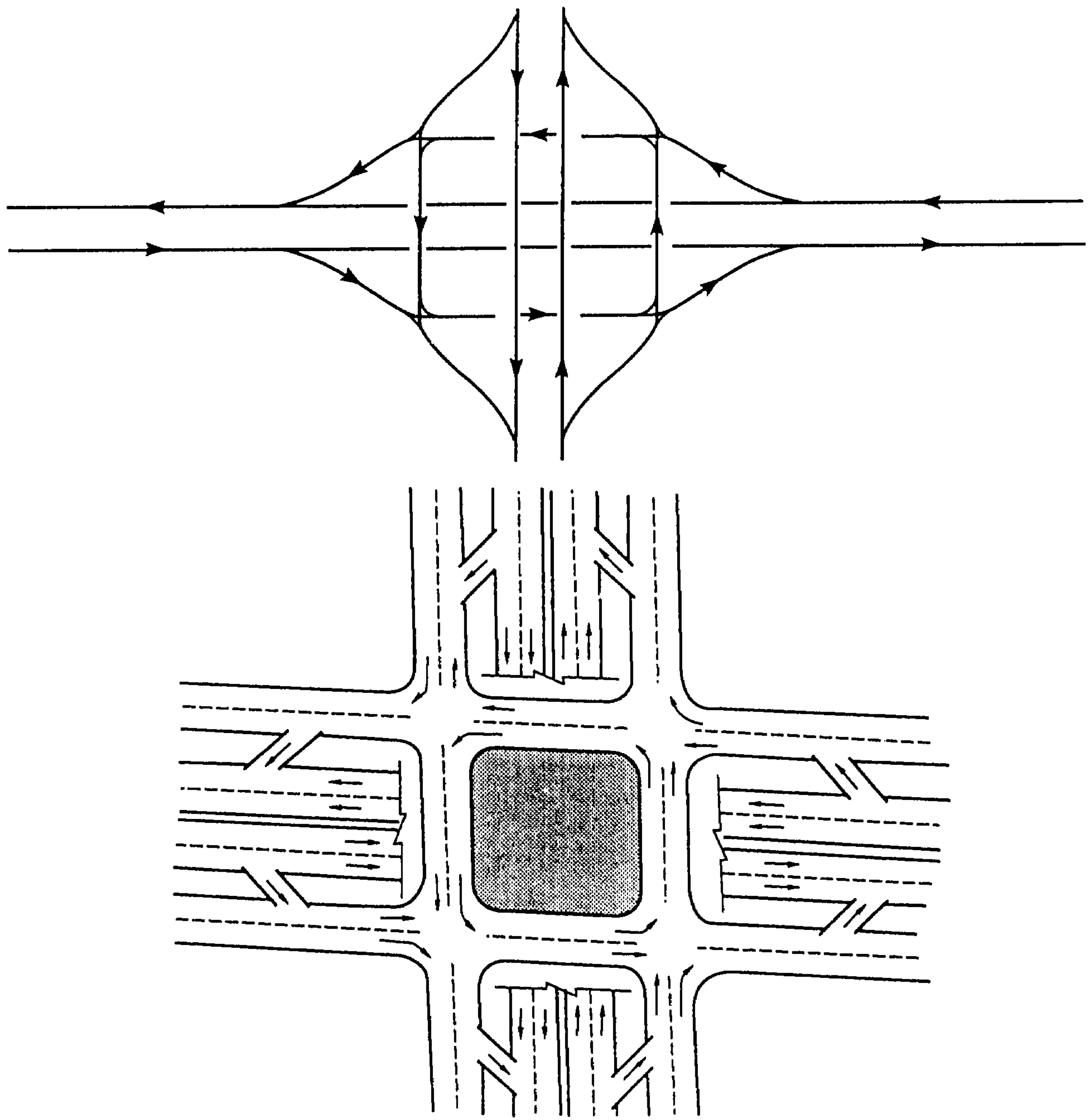
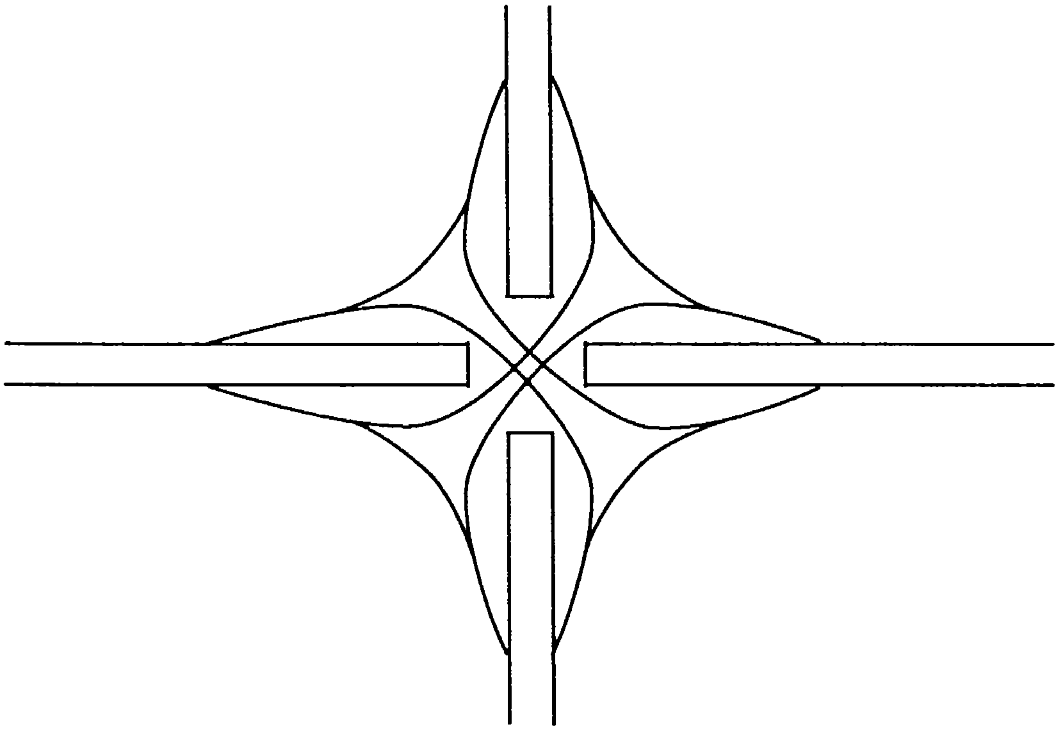
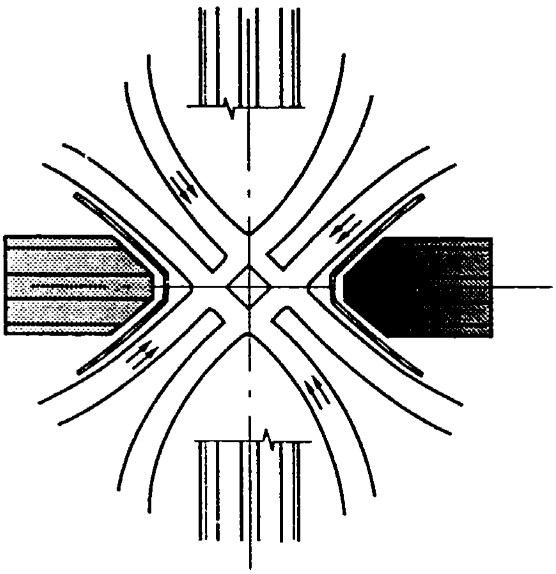


Figure 5. The Three Level Diamond





At-Grade Intersection

Figure 6. The Three Level Stacked Diamond.

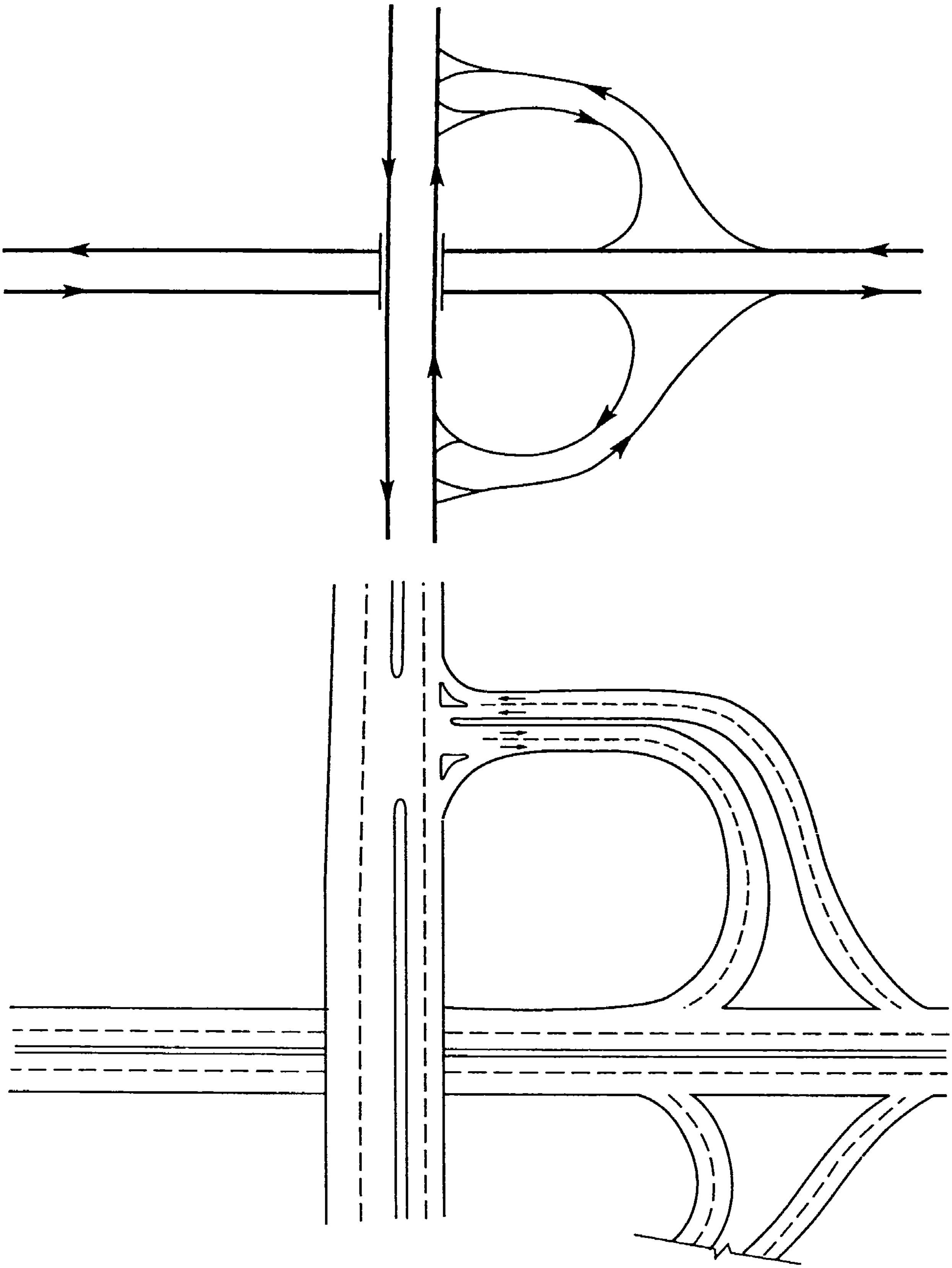


Figure 7. The Partial Cloverleaf Interchange

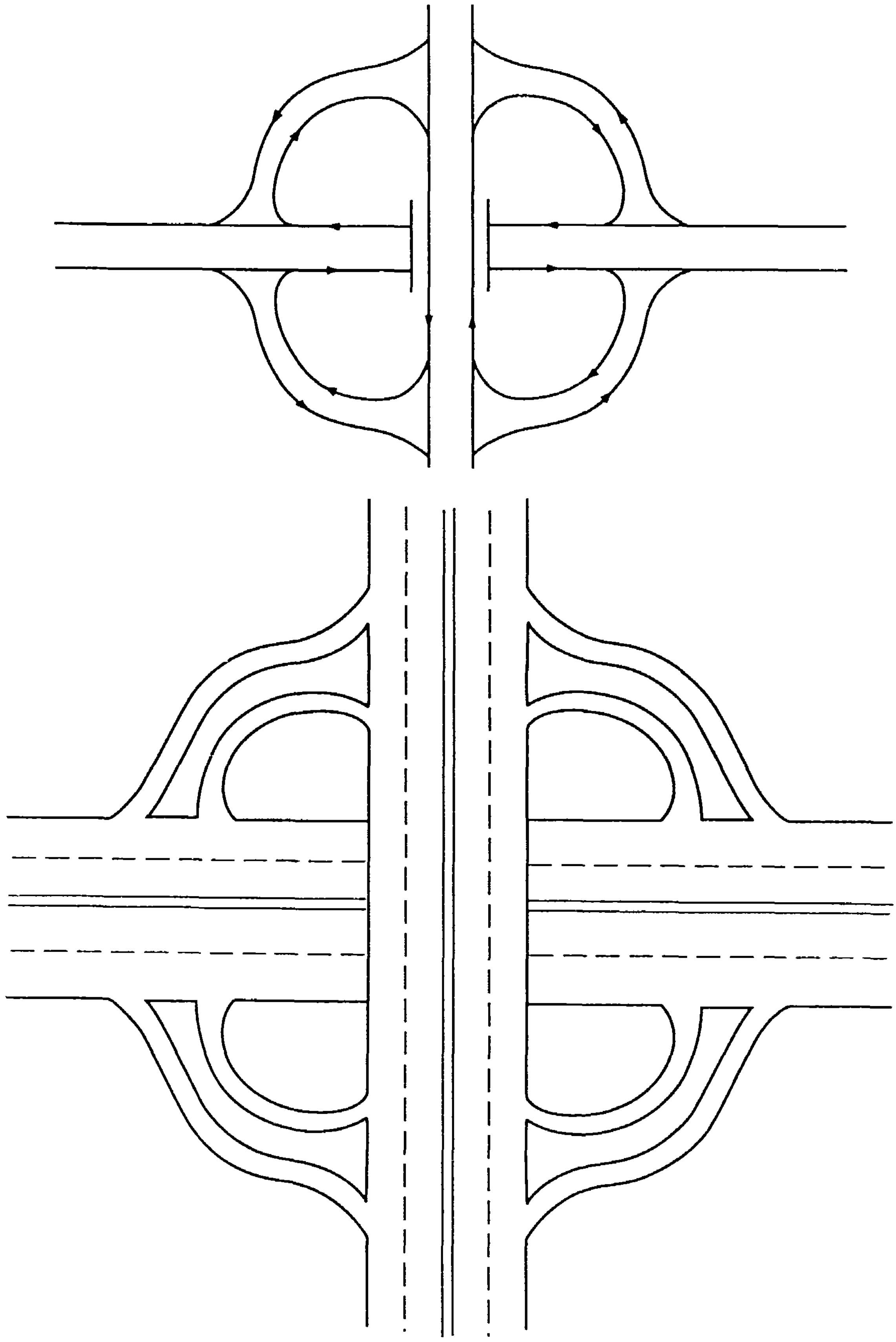


Figure 8. The Full Cloverleaf Interchange

The full cloverleaf interchange [Figure 8] is widely used in rural areas where interchanging volumes between the two freeways are low to moderate and more importantly no restrictions on right-of-way availability. This interchange has limited applications in urban areas because of its limited capacity and the problems associated with weaving maneuvers. For high turning volumes, three-level diamonds or directional interchanges are more suitable. Both full cloverleaf and directional interchanges are non-signalized intersections.

Literature Search

The first model for the capacity analysis of the CDI was developed by Pinnell and Capelle (2,3). Capacity considerations were based solely on the operation of the four phase signal plan with overlap pattern because this phasing pattern provided the best operation under peak flow conditions.

The second generation of models for the CDI was developed by Messer, et. al. (4,5,6) at the Texas Transportation Institute. Messer's work has resulted in the development of PASSER III computer model which is used to analyze various CDI phasing patterns in terms of capacity and delay.

Witkowski (7) developed a methodology to evaluate the possible economic benefits of a grade separated interchange versus an at-grade interchange. The grade separated interchange which Witkowski used was the SPDI. He estimated total delay per vehicle for the two configurations and used it in the economic analysis.

Brymer and Urbanik (8) attempted to develop a methodology to determine when grade separations are appropriate. This methodology includes an economic analysis based on a benefit/cost study for ranking three-level diamond interchange. Delay estimates were derived using the TRANSYT-7F model. Leisch, et. al. (9) conducted a comparative assessment of the SPDI and compressed diamond. The conclusions reached in this study were based on computer simulation runs using the TRANSYT-7F model. The following statement was quoted:

> "The analyses presented make it evident that applications are limited for the Single-point diamond. Generally speaking, the compressed diamond is less costly, has similar right-of-way requirements, and is more efficient."

It is evident from this literature search that most research and field experience have been limited to the CDI. It is imperative that more work be done to evaluate the new interchange configurations like the SPDI, the compressed diamond, and the three-level diamond. Furthermore, an assessment of available traffic simulation models is important to decide whether these programs can simulate the different diamond configurations or modifications to these models are needed to achieve such a goal.

TRAFFIC SIGNAL SYSTEM ANALYSIS COMPUTER SOFTWARE

Traffic signal system analysis computer software can be generally classified into two major categories: macroscopic models and microscopic models. Macroscopic computer models are those software that utilize mathematical expressions to analyze traffic flow over urban streets and determine the system measures of effectiveness (delay, queue, fuel consumption, etc.). Two types of activities can be carried out using these models namely optimization and simulation. The optimization option permits the user of the software to search for the best signal timing plan which results in the lowest vehicular deiay. Simulation is applied to predetermined signal settings to assess the system performance.

Examples of macroscopic computer models are SOAP, TRANSYT-7F, PASSER II-87, SIGOP, and MAXBAND. The SOAP model is used for isolated intersections only, while the remaining models are tailored for arterials and grid networks. Although the last four computer models are suitable for multi-intersection operation, they can be used to simulate a single or dual intersection setting. All five models are deterministic.

PASSER III-88 is another macroscopic computer model that was developed exclusively to evaluate conventional diamond interchanges. It can be applied to an isolated interchange and a frontage road progressive system.

Microscopic computer models are those computer programs that simulate individual vehicle movements through the street system and update their status for every small time increment. Such models can be used to investigate a wide mix of traffic control and traffic management strategies, including pretimed or actuated signal control, and sign control, special-use or general-use of traffic lanes; and standard or channelized geometrics. Microscopic simulation models are designed to consider different statistical distributions for driver types, vehicle types, gap acceptance, vehicular speeds and other factors. The ability to simulate vehicle movements in each lane and select different design and control alternatives make them more attractive than macroscopic models. However, microscopic models require more input data than macroscopic models.

There are three microscopic simulation programs available on the market: NETSIM, TEXAS, and EVIPAS. While both NETSIM and TEXAS are simulation models only, EVIPAS can be used for both simulation and optimization. Both EVIPAS and TEXAS are solely designed for isolated intersections, and NETSIM can be used for both isolated and grid networks.

For the purpose of this study, five computer models were selected, and they are: PASSER II-87, PASSER III-88, TEXAS, TRAF-NETSIM, and TRANSYT-7F. SOAP, SIGOP, MAXBAND, and EVIPAS computer models were excluded from the analysis for the following reasons:

1. The SOAP model is suitable for determining the best signal parameters for an isolated intersection. Simulating a CDI operation requires two adjacent signals which can not be handled by this model.
2. Both SIGOP and MAXBAND determine the optimum signal setting for an arterial or a grid network. Since TRANSYT-7F can perform the same function and is widely accepted by the user community, it was decided to choose this model over SIGOP and MAXBAND.
3. The EVIPAS model was excluded because it is only available for mainframe computers and it requires long execution time.

The next section of the report documents the attempts to simulate different types of highway interchanges using the five chosen computer programs. Two general categories are identified: interchanges that are widely used in urban areas like the CDI and the SPDI and where field data is available for them, and interchanges that no data was available for them and hypothetical computer runs were conducted like the three-level diamond. For each interchange type of the first category, the five computer models were coded and advantages and drawbacks of the computer programs were recognized. As for the second category, the five programs were assessed in an abstract form to decide whether they are able to simulate the uncommon types of interchanges like the compressed diamond, three-level diamond, and cloverleafs.

CATEGORY I: COMMON INTERCHANGE TYPES

Simulation of the SPDI

In order to evaluate the five selected computer programs, a SPDI was selected in Tempe, Arizona (10). It is the first of its type ever constructed in the state of Arizona. A recent count at this site indicated that the P.M. peak hour volume is 5011 vehicles per hour and the 24 hour volume is 65,264 vehicles.

The condition diagram of the interchange is shown in Figure 9. As the diagram shows, the eastbound approach, University Drive, has four lanes consisting of a through-right, a through, and two left-turn lanes. The westbound approach has five lanes consisting of a right turn, two through, and two left-turn lanes. A raised median separates eastbound and westbound traffic on both approaches. The dual left-turn paths on both approaches are based on a 279 foot turning radius with pavement markings provided through the intersection. Right-turn channelization is also provided on both approaches.

Both the northbound and southbound off-ramps have four lanes consisting of two right-turn and two left-turn lanes. The dual left-turn paths on both approaches are based on a 270 foot turning radius. The separation between on-ramp and off-ramp approaches is approximately 215 feet. Channelization of the off-ramp terminals prohibit both northbound and southbound movements across the interchange.

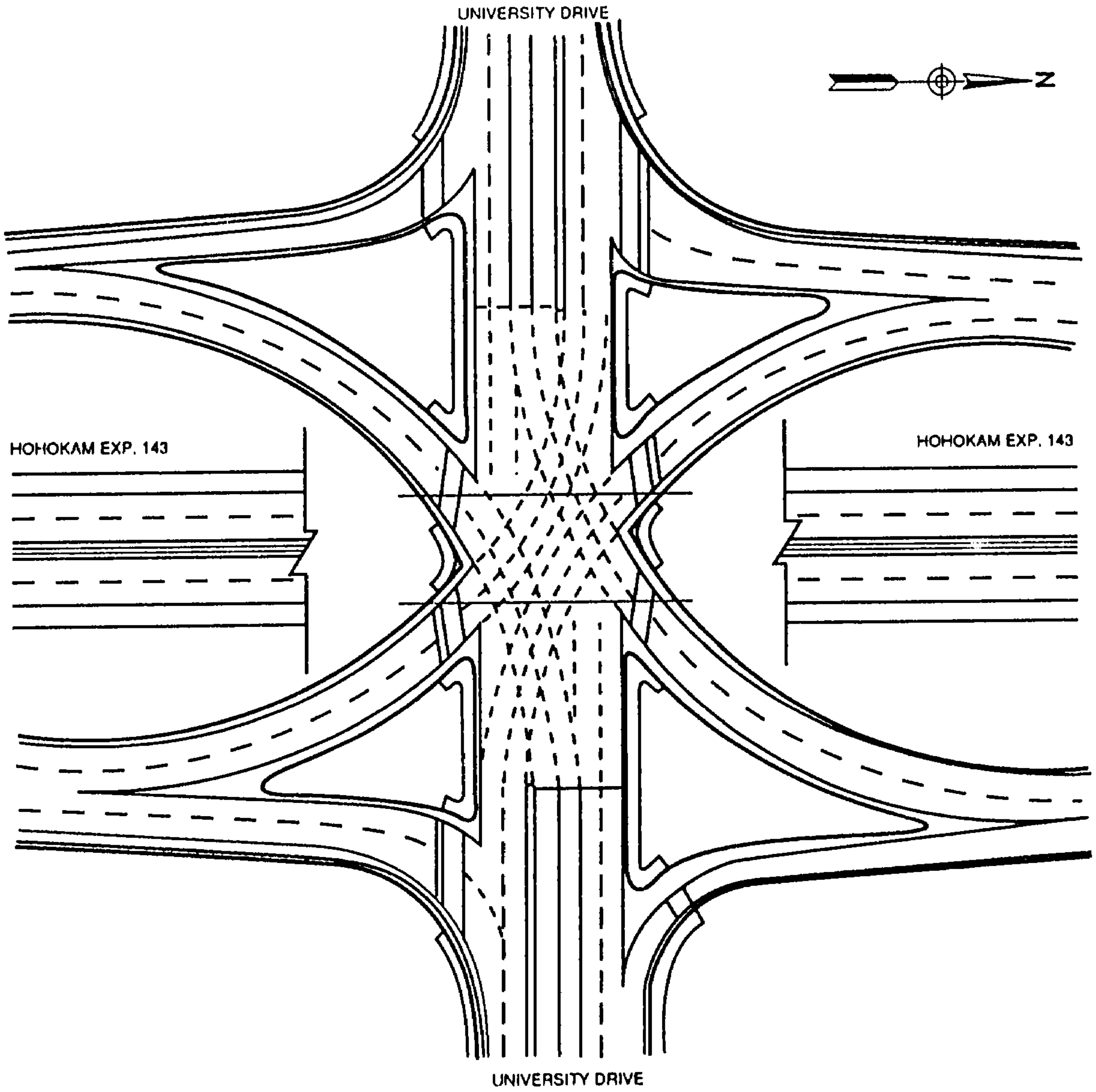
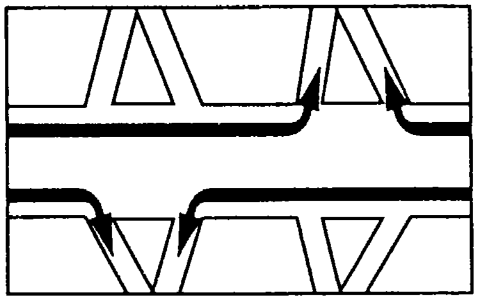
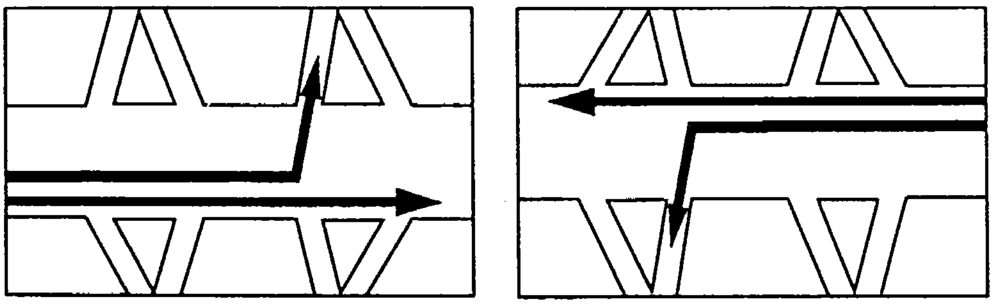


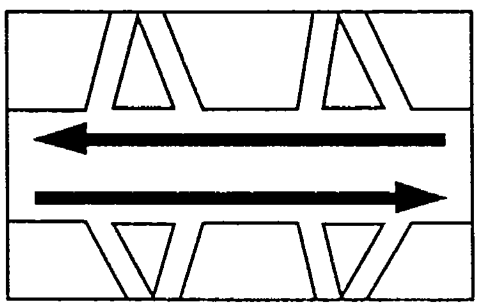
FIGURE 9 : SPDI CONDITION DIAGRAM



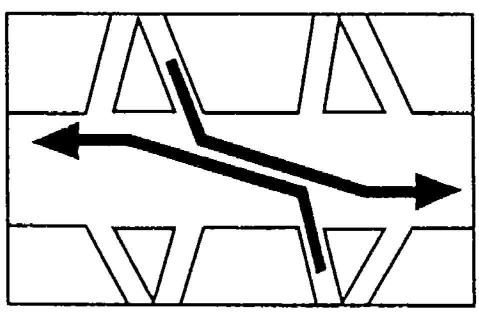
FIRST PHASE



OVERLAP PHASES



SECOND PHASE



THIRD PHASE

Figure 10: PHASING DIAGRAM FOR THE SPDI

TABLE 1 - SIGNAL PHASING TIMES
(Source: Reference Number 10)

	EB-LT	WB	NB-LT	WB-LT	EB	SB-LT
Minimum Green	8	10	5	8	10	5
Maximum Green	30	35	30	30	35	30
Yellow	3.0	4.3	3.0	3.0	4.3	3.0
Red clearance	2.0	6.2	7.8	2.0	6.2	7.8
Vehicle Extension	0.5	1.2**	0.5	0.5	0.2	0.5
Average Phase @ P.M. Peak	16	35*	16	17.5*	34.5	17

* Includes Overlap Phase

**Higher than normal to handle truck traffic

The traffic signal phasing is a three-phase operation. The signal phase times are shown in Table 1 and the phase movements are shown in Figure 10. An overlap phase is initiated when either the eastbound or the westbound left-turn movement dissipates before the other. Induction loops are located on all approach lanes for the actuation and extension of each phase.

Traffic data related to vehicular volumes and delay were collected during the evening peak and are summarized in Table 2. It was reported that all queues cleared the intersection during the respective green phase for each movement, except the eastbound through movement (10).

The stopped-time delay measurements were based on 15 second observations and were conducted for all four left-turn movements. Stopped-time delay is defined as the time during which the traffic is actually standing still (11). The travel time delay measurements were made by timing vehicles when they crossed a point located at a certain distance up-stream the stop-bar to when they crossed the stop-bar. This travel distance was set at 800 feet up-stream the stop-bar of the left-turn movements for the northbound and southbound, and 1000 feet up-stream the stop-bar of the through movement for the eastbound and westbound (11).

TABLE 2 TRAFFIC DATA SUMMARY
(SOURCE: REFERENCE NUMBER 10)

	EASTBOUND			WESTBOUND			NORTHBOUND		SOUTHBOUND	
	LEFT	*THROUGH*	*RIGHT*	*LEFT*	*THROUGH*	*RIGHT*	*LEFT*	*RIGHT*	*LEFT*	*RIGHT*
Intersection Data										
Number of Lanes	2	2	0	2	2	1	2	2	2	2
Peak Hour Volume	463	1227	308	635	592	583	72	331	568	232
Delay (Seconds)										
Stopped Time Delay	30.7	-	-	32.8	-	-	29.6	-	31.6	-
Travel Time Delay										
at 1000 ft	-	84	-	53.4	44.7	18.5	-	-	-	-
at 800 ft	-	-	-	-	-	-	45.0	-	54.2	-

PASSER II-87 SOFTWARE:

PASSER II-87 is the most recent release of the Progression Analysis and Signal System Evaluation Routine developed by Texas Transportation Institute for the Texas State Department of Highways and Public Transportation (12). The basic purpose of the model is to assist the traffic engineer in determining optimal traffic signal timings for progression along an arterial considering various multiphase sequences. It is a macroscopic, deterministic optimization model. The delay estimate in this model is based on a modified Webster's delay formula to take into account the differences in arrival rates between green and red intervals.

To simulate the SPDI in PASSER II-87, it was assumed that the interchange is composed of two close intersections with zero signal offset. It was also assumed that the saturation flow rate is 1800 vehicle per hour of green per lane regardless of the movement type (left turn or through movement). The results of the simulation runs are documented in a later section of the report.

Some of the advantages of using the PASSER II model is the simplicity of data input and the ability to simulate different types of signal phasing schemes.

However, the use of PASSER II-87 has several disadvantages. The main disadvantage is the inability of the user to input the appropriate clearance interval of each phase. One possibility to overcome this shortcoming is to add the clearance interval to the green phase. Regardless of the user input, the model assumes a fixed phase lost time of 4.0 seconds and the user has no way of changing this value. Another disadvantage of using PASSER II-87 is that the model has no special treatment for right turn traffic, and no allowance for separate right turning lanes.

PASSER III-88 SOFTWARE:

The PASSER III-88 is the recent release of the Progression Analysis and Signal System Evaluation Routine, model III for diamond interchanges (13). The model was developed to determine the optimal phase patterns, splits and internal offsets at signalized isolated interchanges. In addition, the model is capable of optimizing system cycle length and progression offsets for one-way frontage roads.

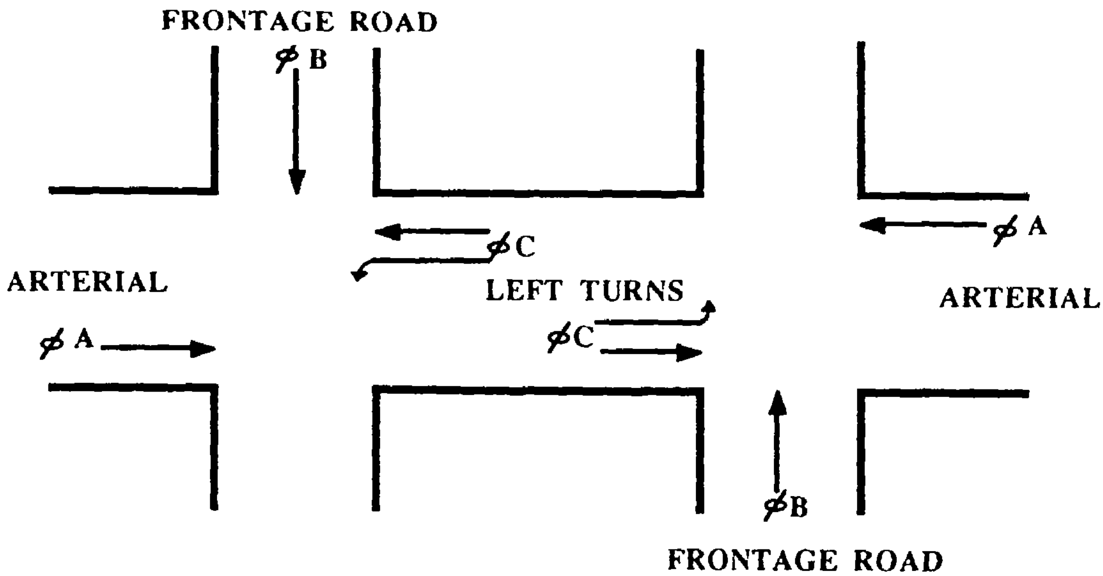
The isolated interchange logic simulates the operation of the interchange into two sides, a right side and a left side. Five basic signal phases are allowable and they are shown in Figure 11. There are two possibilities for off-ramp left turners either lead or lag to the on-ramp movement. Several phasing combinations can be generated and the model tests these alternatives to find the optimum pattern and offsets. Webster's delay equation is used for the optimization process.

Because PASSER III-88 is designed exclusively for the "conventional" diamond, it was observed that several assumptions had to be made to simulate the SPDI operation. No apparent advantages were identified using this software. Similar to PASSER II-87, it was noticed that the clearance interval was overlooked in the analysis process. However, PASSER III-88 provides for separate right turning movement analysis as well as simulation of separate turning lanes. One severe limitation is that PASSER III-88 is a fixed-sequence program which limits its application to only the five predetermined sequences.

TRANSYT-7F SOFTWARE:

The TRANSYT-7F model is the Americanized version of the TRAffic Network Study Tool model developed by the Transport and Road Research Laboratory of the United Kingdom (14). It is a macroscopic deterministic, time scan optimization model for optimizing the signalization on arterials and grid networks.

Intersections are represented by nodes in TRANSYT and links represent streets connecting those intersections. Each link can represent a traffic movement at any given node. The SPDI is represented in TRANSYT by coding two nodes with zero offset. The delay model used in TRANSYT is a modified version of the Webster formula. The hill-climbing procedure used in TRANSYT is not applicable for the case of diamond interchanges because there is no offset between the two signals. The model is used only for simulation.



PHASING CODE	LEFT SIDE PHASE SEQUENCE			LEFT TURN SEQUENCE	RIGHT SIDE PHASE SEQUENCE		
1	A	B	C	LEAD-LEAD	A	B	C
2	A	C	B	LAG-LEAD	A	B	C
3	A	B	C	LEAD-LAG	A	C	B
4	A	C	B	LAG-LAG	A	C	B
1A	A	B	C	TTI-LEAD	A	B	C

FIGURE 11: PHASING CODE DESCRIPTION USED BY PASSER III-88

The advantage of using TRANSYT is the ability to simulate each movement separately and include the clearance interval for each phase. Furthermore, the model can simulate other geometric features such as the location of the stop-bar, and location of transit stops. The results of the simulation runs for the SPDI are documented in a later section of the report.

TRAF-NETSIM SOFTWARE:

TRAF is a system of traffic simulation models designed to represent traffic flow on any existing highway facility. NETSIM, which is an abbreviation for NETwork SIMulation model, composed of the prefix NET for surface street network and the suffix term SIM for microscopic simulation. Individual vehicles are simulated through the system along the links, according to specified controls at nodes (intersections), stochastically determined turning movements, and deterministic car following. No set paths are modeled as turning movements are purely random.

NETSIM has a multiplicity of features and user options. Virtually any feasible geometric configuration, traffic control system, traffic management strategy and demand configuration can be modeled. The type of network may vary from a single intersection, up to a complex grid network.

The most recent release of TRAF-NETSIM has the capability to produce static and dynamic representation of traffic movements (15). The static option produces static graphs reporting on links and network wide measures of effectiveness such as stopped delay, and queue length. The dynamic logic produces animation of individual vehicle movements on selected links. Animation is produced for one node only and it is limited to a distance of 500 feet on either side of that node.

To simulate a SPDI operation in NETSIM, the interchange is split into two intersections 215 feet apart. Pretimed signal operation was implemented with a three phase plan. Although NETSIM can simulate actuated signal operation, it was decided to simulate the SPDI operation as pretimed for two reasons. The first reason is that the actuated logic requires extensive data collection which is not available for this site and the second reason was that although all other macroscopic software (PASSER, TRANSYT, etc.) have the ability to evaluate actuated signal schemes they do not simulate the actuated operation in the true sense. More specifically, macroscopic models do not change the green duration of a signal phase from one cycle to the other the way microscopic models do. The average phase durations documented in Table 1 were used as NETSIM input. Because of the stochastic nature of NETSIM, 10 runs were implemented with different starting random number seeds and the average stopped delay was calculated. The results of the NETSIM runs are documented in a later section of the report.

The advantages of using NETSIM to simulate the SPDI operation are:

1. Different intersection geometries can be tested.
2. The graphic presentation of this system makes it easy to check the network geometrical configuration and the effectiveness of the control strategy.
3. NETSIM does not have a delay model like other macroscopic models, so the user does not have to be concerned about the validity of these formulae. The user can utilize the different statistical distributions embedded in NETSIM to make the measure of effectiveness produced by the model match those observed in the field.

The drawbacks of using NETSIM are:

1. The model can not simulate vehicle paths in the intersection. It makes the vehicle disappear from one link right at the stop-bar and then recreates it on a downstream link. The advantage of the large turning radii provided by the SPDI is then underestimated.
2. Like any other microscopic model, the interchange is represented by two close intersections and statistics are collected for the whole network.
3. Vehicles are generated according to a uniform distribution and the user has no way of changing the arrival pattern like the TEXAS model.

TEXAS SOFTWARE:

The Traffic EXperimental and Analytical Simulation model is a microscopic simulation program developed to analyze alternative designs of isolated intersections (16). The model will simulate any intersection configuration controlled by stop signs or yield signs or traffic signals. Like NETSIM, the TEXAS model can simulate all traffic signal schemes such as two-phase or up to six-phase pretimed controller; eight-phase, dual ring, semiactuated or full actuated controller; and permissive and/or exclusive left turn control schemes.

The TEXAS model can be used effectively to simulate the SPDI operation. The interchange is coded as an isolated intersection with an extra wide median between the on and the off ramps. The user can input different arrival distributions for each approach of the interchange. These options make the TEXAS program more attractive than the NETSIM model. Furthermore, the ability to display traffic movements on the computer screen (animation option) adds more credibility to the model.

The TEXAS model has some limitations and they are:

1. The interference to traffic caused by pedestrian moving simultaneously with vehicular traffic can not be simulated.
2. The model does not simulate the effect of approach grade. This can be compensated for somewhat by using different headway distributions.
3. There is no provision for coordination or the effect of adjacent signals. This factor becomes a critical consideration when the urban interchange is part of a major arterial with a predetermined progression plan.

Results of the SPDI Simulations:

Stopped delays, as produced by the programs and documented in Table 3, were adopted for the comparative assessment of the five computer programs. These observations were made for left turn movements only on all four approaches. Both NETSIM and TEXAS determine stop time delay comparable to the procedure used in the field and that is to record the queue length every 15 seconds. However, the two PASSER programs and the TRANSYT program utilize a modified Webster delay equation. The original Webster delay equation is essentially based on total vehicular delay which includes stopped time delay and delay incurred by vehicles during the deceleration and acceleration cycles. Therefore, delay figures produced by these programs are expected to be relatively higher than the observed values.

TABLE 3 SIMULATION DELAY RESULTS OF THE SPDI

		East-Bound Left Turn	*West-Bound Left Turn*	*North-Bound Left Turn*	*South-Bound Left Turn*	*Weighted Average of All Four Movements*
PM Peak Hour Traffic Volume		463	635	72	568	
Macro. Models	PASSER II-87 (sec/veh)	38.3	56.20	27.10	32.80	42.57
	PASSER III-88 (sec/veh)	23.17	39.68	29.37	32.76	32.59
	TRANSYT-7F (sec/veh)	39.8	76.50	32.80	46.80	55.21
Micro. Models	NETSIM (sec/veh)	2.82	5.54	36.62	84.12	31.78
	TEXAS (sec/veh)	36.83	100.40	32.73	36.44	59.75
	Observed Data (sec/veh)	30.70	32.80	29.60	31.60	31.71

Table 3 contains the field results and the simulated results. Using the PM Peak hour field observations as a bench mark for comparisons, it can be observed that the results of PASSER III-88 are the closest to the field results for the three macroscopic models under evaluation. As for the microscopic models, it appears from the first glance that the NETSIM model produces comparable results to the field data based on the weighted average delay figures. Closer examination of the results revealed that the TEXAS model seems to be more suitable for simulating the SPDI because it produced delay figures close to the field data figures for three out of the four movements. It is important to point out that the stopped delay data collected at this site was collected for one hour of a given day. More sites and more observations for each site should be collected to provide a more credible assessment.

Initial findings of this research indicate that the TEXAS model has a good potential to be used as an evaluation tool of the SPDI performance. While this research was being conducted the Transportation Research Center at the University of Texas, the developer of the TEXAS model, modified the current version of the model to simulate urban interchange operation. No public release has been made yet of that version and the Texas Highway and Public Transportation Department is currently evaluating the program.

SIMULATION OF THE CONVENTIONAL DIAMOND INTERCHANGE

The CDI is the interchange most commonly found in urban areas where the arterial street is carried over or under the freeway facility, and accessibility to and from the freeway is provided by using four ramps. The interchange may be treated as two isolated signalized intersections 250 to 350 feet apart. The storage area on the bridge deck is a critical element in determining the interchange capacity. The signal phasing scheme of this type of interchange may specifically affect its performance.

TABLE 4 TRAFFIC DATA SUMMARY FOR THE CONVENTIONAL DIAMOND INTERCHANGE
(SOURCE: REFERENCE NUMBER 10)

	S.R. 87 (ARTRIAL)						*S.R. 360 OFF-RAMPS*			
	SOUTH-BOUND			NORTH-BOUND			WEST-BOUND		EAST-BOUND	
	LEFT	*THROUGH*	*RIGHT*	*LEFT*	*THROUGH*	*RIGHT*	*LEFT*	*RIGHT*	*LEFT*	*RIGHT*
Number of Lanes	1	2	1	1	3	1	1.5	1.5	2	1
Volume of P.M. Peak Hour	271	1316	712	302	1307	303	335	281	517	345
Average Phase Length (Seconds)	16.8	30	-	18.5	30	-	25		25	
Yellow	4.5	4.5	-	4.5	4.5	-	4.0		4.0	
Red Clearance	2.0	2.0	-	2.0	2.0	-	2.0		2.0	

Cycle Length = 92.50 Seconds
Lost Time = 19.0 Seconds

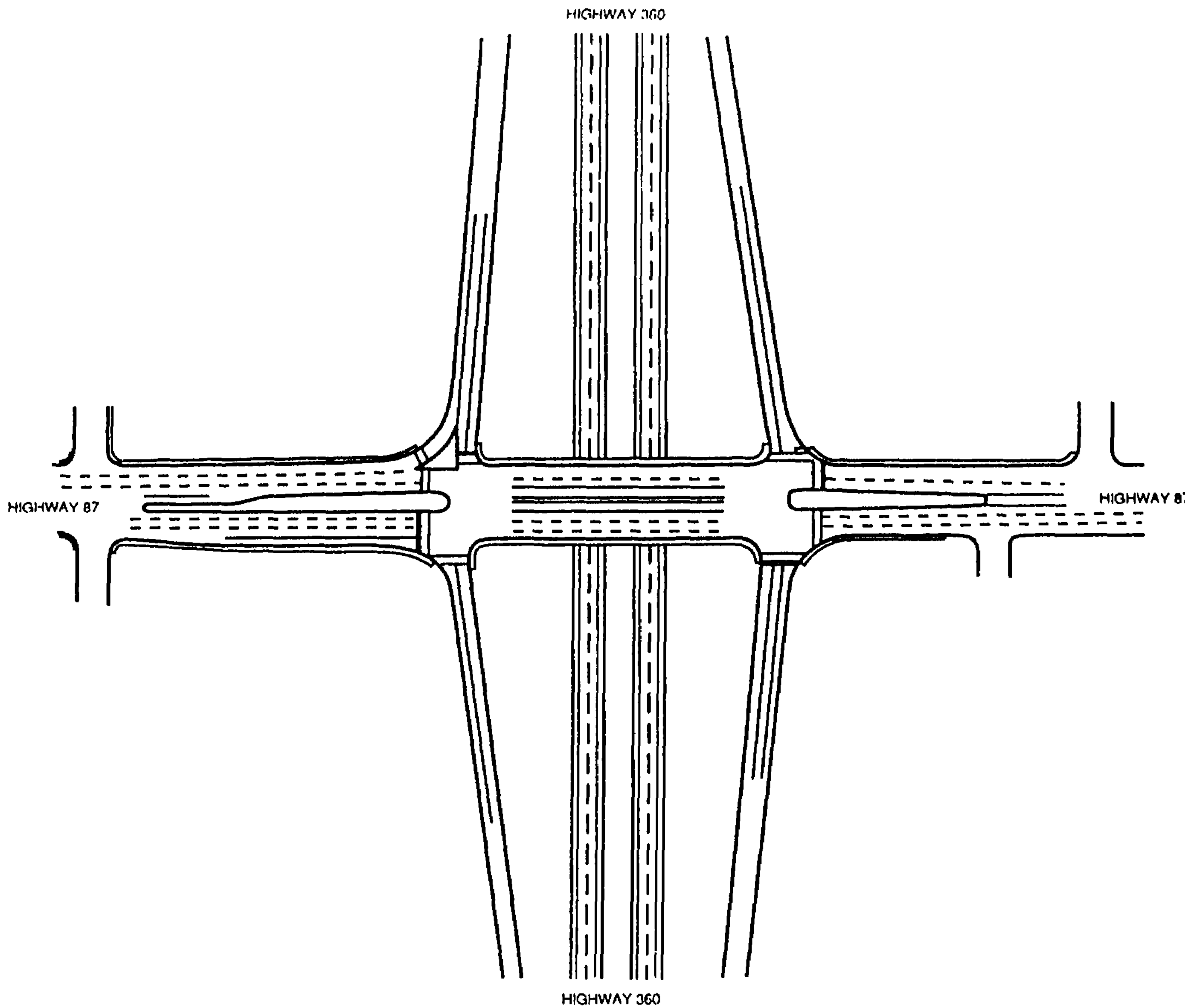


FIGURE 12 "CONVENTIONAL" DIAMOND CONDITION DIAGRAM

To test the ability of PASSER II-87, PASSER III-88, TRANSYT-7F, TRAF-NETSIM and TEXAS models to simulate the CDI operation, an interchange in Mesa, Arizona was adopted for this purpose (10). Figure 12 displays a layout of the conventional diamond and Table 4 documents traffic data summary of this interchange.

The five phasing schemes adopted by the PASSER III-88 model, as shown earlier in Figure 11, were used in testing computer software. No delay data was available for the conventional diamond in Mesa, however the delay statistics produced by the computer models were used to conduct a comparative assessment of these models. The purpose of the comparative assessment was to test whether the computer models produce comparable results.

The coding of the conventional diamond could not be accomplished for the TEXAS model because the phasing code for this model is limited to a single intersection. Therefore, the assessment was limited to the other four programs. Table 5 displays the delay results in seconds per vehicle as calculated by the four programs. All three macroscopic models produced comparable results with respect to the five phase orders under consideration. The only exception was observed for the TTI-Lead phase as applied to the PASSER III program. The difference between the TTI scheme and the lead-lead scheme is that the TTI phase order considers a 12 second offset between the left side of the interchange and the right side. PASSER III logic did not permit the TTI evaluation for a 95 second cycle length, and the cycle length had to be increased to 120 seconds. This change in the cycle length was probably the reason for producing a higher delay figure than the other four phases.

The results of the NETSIM model varied more than those of other models for different phase orders. This finding was as expected for two reasons, the first is that NETSIM is a microscopic model and traffic events are processed in smaller time increments allowing more accurate calculation of the impact of signal phasing schemes on vehicular delay. The second reason is attributed to the stochastic nature of the model which would be included in the analysis of the effects of random events.

TABLE 5 DELAY RESULTS OF THE CONVENTIONAL DIAMOND
(SECONDS/VEHICLE)

PHASE ORDER	PASSER II-87	PASSER III-88	TRANSYT-7F	NETSIM
Lead-Lead	45.10	39.06	181.97	26.80
Lag-Lead	43.90	38.66	185.79	66.20
Lead-Lag	44.10	37.96	181.04	58.60
Lag-Lag	42.90	37.11	184.87	26.00
TTI-Lead	44.70	62.57*	181.49	42.80

*Simulated for a cycle length of 120 seconds

The second issue that is worthy of a discussion is the absolute values of the delay figures produced by the models. *Both PASSER models produced comparable delay values, but the TRANSYT and the NETSIM models did not.* Due to the lack of field data availability at conventional diamond interchanges, no conclusions can be reached as to which model is more accurate in simulating the conventional diamond then the other.

CATEGORY II UNIQUE INTERCHANGE CONFIGURATIONS

This section addresses the other six interchange configurations that did not have field data available and they are: the compressed diamond, the split diamond, the three-level diamond, the stacked diamond, the partial cloverleaf, and the full cloverleaf.

The compressed diamond configuration is almost identical to the CDI as far as signal phasing plans. It is treated as two signalized intersections that are separated by a distance that can be as short as 150 feet. The only difference between the two configurations is that the compressed diamond has a shorter left turn storage on the bridge deck which could result in a spill back of left turning traffic to the upstream intersection resulting in an interchange lock. However, if the TTI phasing is used, the interior storage does not become a problem. All four models, PASSER II-87, PASSER III-88, TRANSYT, and TRAF-NETSIM, were found to be capable of simulating the compressed diamond.

The split diamond, as depicted in Figure 3, can be viewed as two conventional diamond interchanges split in the center line of the arterial street. The two frontage roads are parallel to the freeway, and they carry one-way traffic. For the purpose of coding this type of interchange into the five computer programs, one can treat it as two conventional diamond interchanges with some movements not provided. Therefore, all four programs that were tested for the CDI are also capable of simulating the split diamond, and they are: PASSER II-87, PASSER III-88, TRAF-NETSIM, and TRANSYT-7F.

The three-level is composed of four at-grade intersections. For each intersection, all four approaches are one-way streets that operate as a traffic interchange zone between the two freeway facilities. All four intersections are controlled by two-phase signals. Because both TRAF-

NETSIM and TRANSYT-7F are designed to simulate an isolated intersection or group of intersections forming a street grid, they can both be coded to simulate the three-level diamond interchange. The other three programs can not be used to simulate this diamond configuration because PASSER II-87 simulates arterial streets only, PASSER III-88 designed for a CDI, and TEXAS is only suitable for an isolated intersection.

The stacked diamond interchange can be simplified into an isolated at-grade intersection with four-one way approaches as was shown in Figure 6. Four programs, PASSER II-87, TEXAS, TRAF-NETSIM, and TRANSYT-7F, can simulate the at-grade intersection of the stacked diamond successfully. PASSER III-88 is the only program that can not accomplish this task because it is designed specifically for the conventional diamond.

Partial cloverleaf interchanges essentially operate as two T intersections independently set from each other. If these two intersections are close then signal phasing can be arranged to provide coordination of traffic movements. Only three programs, PASSER II-87, TRAF-NETSIM, and TRANSYT-7F, can simulate this interchange. The TEXAS model is able to simulate each T intersection separately, however, it can not simulate the two as a system. PASSER III-88 can not simulate the partial cloverleaf because it can not handle two-way traffic flow at either sides of the interchange.

As for the full cloverleaf interchange, none of the five programs can simulate this type of interchange. The reason being that all five programs deal with signalized intersections. Table 6 contains a summary of the five computer programs considered in this study and whether they can simulate different interchange types.

TABLE 6 ABILITY OF THE FIVE COMPUTER PROGRAMS TO SIMULATE DIFFERENT INTERCHANGES

	PASSER II-87	*PASSER III-88*	*TEXAS*	*TRAF-NETSIM*	*TRANSYT-7F*
Conventional Diamond	Yes	Yes	No*	Yes	Yes
Compound Diamond	Yes	Yes	No*	Yes	Yes
Split Diamond	Yes	Yes	No*	Yes	Yes
Single-Point Diamond	Yes	Yes	Yes	Yes	Yes
Three-Level Diamond	No	No	No	Yes	Yes
Stacked Diamond	Yes	No	Yes	Yes	Yes
Partial Cloverleaf	Yes	No	No	Yes	Yes
Full Cloverleaf	No	No	No	No	No

*The Diamond Interchange version of TEXAS was not considered.

CONCLUSIONS:

The goal of this study was to assess all available computer software in terms of their ability to simulate different interchange configurations. Five computer programs and eight types of interchanges were evaluated. The following conclusions were drawn from the study:

1. All five computer programs can simulate the SPDI operation.
2. Each program has some unique features that makes it more attractive to use over the others.
3. It appears from the limited data available and computer runs made, that the PASSER III-88 and the TEXAS model results of the SPDI were the closest to the field data.
4. The conventional diamond, compressed diamond, and split diamond interchanges can be simulated by four of the five computer programs under investigation. The current version of the TEXAS model can not handle this kind of interchange, however, the next release of the TEXAS model will permit the user to simulate the diamond interchange.
5. Both TRAF-NETSIM and TRANSYT-7F are able to simulate the three-level diamond, the stacked diamond, and the partial cloverleaf interchange.
6. None of the five computer programs is able to simulate the full cloverleaf interchange.
7. Although all five models are able to produce system measure of effectiveness such as delay and queue length, they can not determine the construction and operation costs of different highway interchanges.

It is evident from these conclusions that most of the available software lack the ability to simulate all types of interchanges and determine the different cost items needed to assess the various interchange designs. The next section of the report recommends further research work to address this issue.

Recommendations for Future Research

To assess different urban interchange designs, one needs to determine certain cost items. Capital cost estimates depends on numerous variables including ramps design, bridge span and design, and traffic control devices. Maintenance cost and road user costs are periodical items that depend primarily on traffic and environmental factors. All of the available computer programs are able to estimate road user costs under varying traffic conditions. However, these models neither produce construction and maintenance costs, nor they convert the delay figures to road user costs. A study is needed to produce a computer model that is able to draw on existing computer programs and utilize new computer code to determine the total cost of any interchange configuration.

WORK PLAN

Problem Statement

The different designs of highway interchanges in urban areas have created confusion and uncertainty for highway engineers. What may work at a particular location may be totally unsuitable at other locations. The decision of suitability is based primarily on economic analysis. Therefore, highway engineers need an evaluation tool that would assist them in determining cost items for different types of highway interchanges. Available computer models are only able to estimate part of the road user cost. Furthermore, not all the model can simulate all urban interchange types.

Study Objectives

The proposed study has the following objectives:

1. Identify the parameters needed to simulate the different interchange types and collect this information from the field.
2. Develop a computer program that simulate the full cloverleaf interchange operation.
3. Develop an economic analysis computer program to estimate different cost components for different interchange designs.

4. Develop a computer Decision Support System (DSS) that the highway user can use interactively on a micro computer to conduct what if type analysis on different interchange designs.

To attain these objectives, the following tasks were outlined.

TASK 1 - INTERCHANGE OPERATION PARAMETERS

To simulate the different interchange designs using the five computer models assessed in this report, the user must input a set of parameters related to geometric design features, signal timing parameters, and driver characteristics. The geometric design features include a number of lanes, lane width, location of stop bars, spacing between ramp terminals, left turn pockets, and other relevant factors. The signal timing parameters are basically signal phases, cycle length and splits, and offsets between adjacent signals. All these parameters are site specific and varies from one site to the other.

The driver characteristic parameters are the saturation flow rate, the lost time per phase, and the clearance period needed by the driver to safely clear the interchange. These parameters significantly affect the delay statistics generated by the computer models. Values have been recommended for different types of diamond interchanges, however, these values may not apply to all interchanges.

The purpose of this task is to survey the literature concerning these parameters and collect field data to supplement the recommended values. For example, a five second clearance interval could be sufficient for a conventional diamond, but it is certainly short for a single point diamond interchange. The outcome of this task is a set of recommended parameters provided to the Decision Support System user. More information on the DSS is provided in a later task.

TASK 2 - SIMULATION OF FULL CLOVERLEAF

In this task, a computer model will be developed to simulate the full cloverleaf interchange operation. The operation of this type of interchange does not involve traffic signals, instead, it consists of eight terminals located on the two freeways. Four of those are entrance ramps and four are exit ramps. At the entrance ramps, vehicles have to accelerate to the freeway speed then merge with traffic. At the exit ramp, vehicles have to reduce their speed and exit the freeway. Vehicles on the ramps travel at a fairly constant speed. Delays may occur at both types of ramps due to speed change and possible queue build up at the entrance ramps.

The proposed computer model should be microscopic to handle the merging phenomenon. Measure of effectiveness such as stopped delay, queue delay, total delay, queue length are needed.

TASK 3 - ECONOMIC ANALYSIS MODEL

A computer program will be developed for the sole purpose of determining the three cost components: construction, maintenance, and road user costs. The road user cost is estimated from the measure of effectiveness produced by the computer simulation models. The construction and maintenance costs are determined from the geometrics of the interchange and other relevant factors. The organization of the simulation and cost estimation process is conducted at the top level using the DSS, as will be described in the next section.

TASK 4 - DECISION SUPPORT SYSTEM

A DSS is an interactive computer program that permits the user to input the interchange parameters and review the results of the economic analysis on the screen. Not only DSS is used for a single case but it can also be applied to several design options and the user may then review the results interactively to compare results and pick the best alternative. The DSS acts as a shell that contains one or more computer program and coordinates the interaction among the different models. Figure 13 displays a conceptual diagram for a proposed DSS.

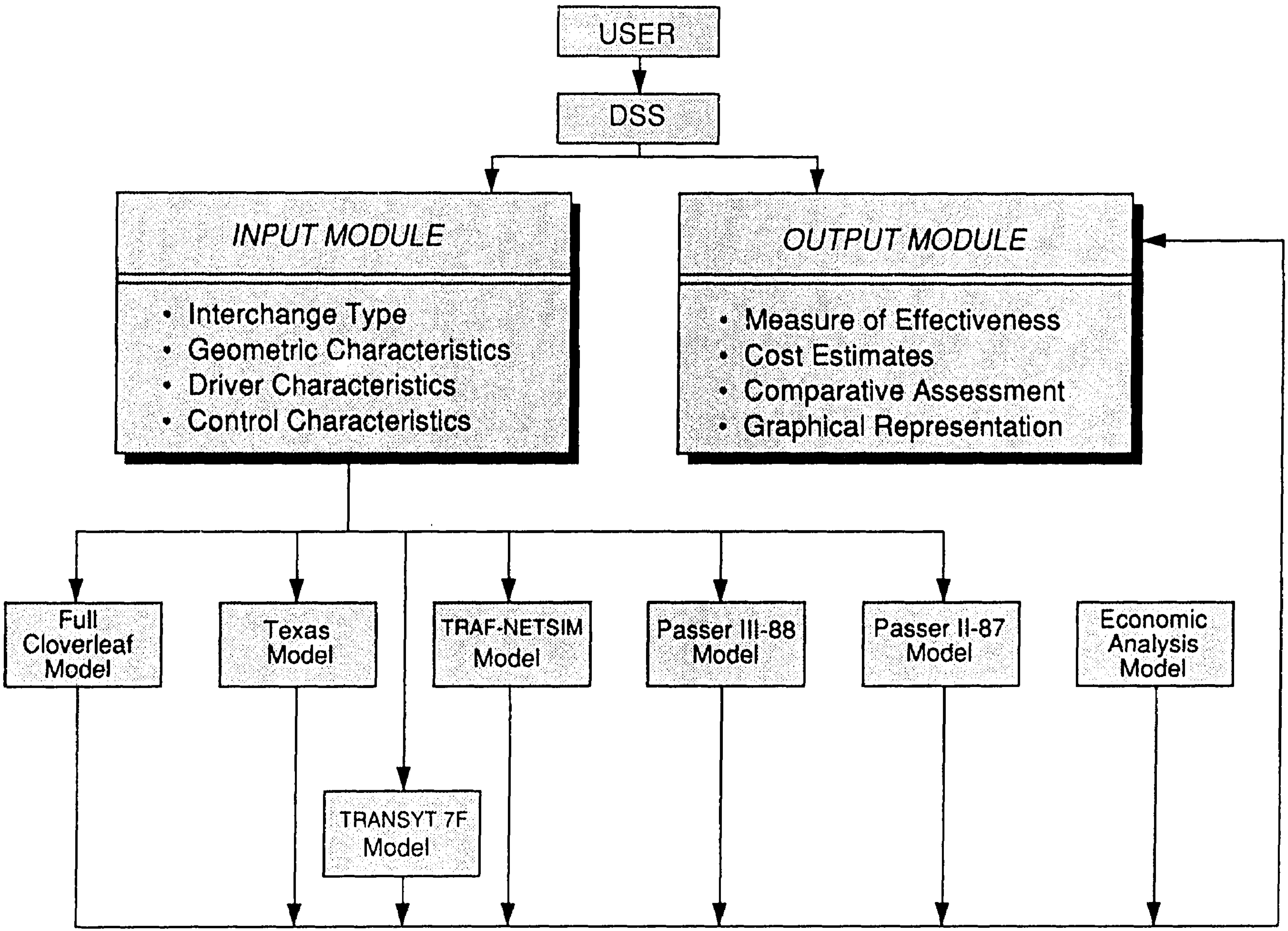


Figure 13. Decision Support System Flow Chart

TASK 5 - PREPARE FINAL REPORT

Prepare a final report which documents all assumptions, data collected, economic analyses, and computer programs developed during the course of the research. A user manual is provided to document the DSS and step-by-step user manual.

Anticipated Project Duration: ***12 Months***

Estimated Budget: ***$75,000***

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