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16. Abstract

Current trends in the design of diamond interchanges include several new configurations which are well suited to certain topographical and traffic demand constraints. Of these new types, it appears that the single-point urban interchange (SPUI) has generated the most interest.

This interim report summarizes the research conducted during the first year of a three-year study. Specifically, the first year's research activity has focused on a field survey and evaluation of six SPUIs located in five states. The data collected during this field study were used to assess both the design and the operation of SPUIs. In this regard, selected design, operational, safety, structural, and economic issues have been presented and discussed in this report. Subsequent project reports will focus on an examination of SPUI capacity and delay based on analytic traffic models and field data.

As a result of the survey and evaluation process, it appears that the SPUI is a viable alternative to other diamond interchange configurations in certain situations. It is adaptable to locations where right-of-way is limited and appears to operate efficiently under traditional NEMA 8-phase control. On the other hand, it does not appear to be well-suited to continuous frontage road situations because of capacity restrictions that result from an additional signal phase.

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A NATIONAL SURVEY OF SINGLE-POINT URBAN INTERCHANGES

by

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Research Report 1148-1
Research Study Number 2-18-88-1148
Guidelines for Operational Control of Diamond Interchanges

Sponsored by the

Texas State Department of Highways and Public Transportation

In cooperation with the

U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas

March 1989

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

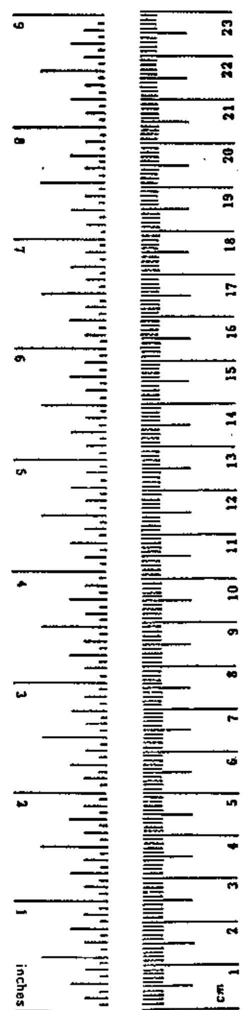
VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
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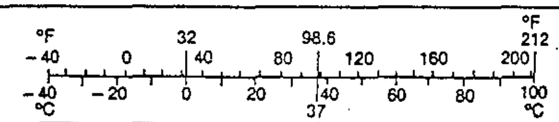

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

Current trends in the design of diamond interchanges include several new configurations which are well suited to certain topographical and traffic demand constraints. Of these new types, it appears that the single-point urban interchange (SPUI) has generated the most interest.

This interim report summarizes the research conducted during the first year of a three-year study. Specifically, the first year's research activity has focused on a field survey and evaluation of six SPUIs located in five states. The data collected during this field study were used to assess both the design and the operation of SPUIs. In this regard, selected design, operational, safety, structural, and economic issues have been presented and discussed in this report. Subsequent project reports will focus on an examination of SPUI capacity and delay based on analytic traffic models and field data.

As a result of the survey and evaluation process, it appears that the SPUI is a viable alternative to other diamond interchange configurations in certain situations. It is adaptable to locations where right-of-way is limited and appears to operate efficiently under traditional NEMA 8-phase control. On the other hand, it does not appear to be well-suited to continuous frontage road situations because of capacity restrictions that result from an additional signal phase. In general, the capacity of the interchange appears to have geometric limitations.

KEY WORDS: Single-point diamond interchange, Single-point urban interchange, Urban interchange, Diamond interchange.

PROJECT SUMMARY

Current trends in the design of diamond interchanges reflect improvements in signal control and geometry that have substantially increased both the capacity and safety of the at-grade ramp/crossroad intersections. In addition, new types of diamond interchanges have been designed that have features which are better suited to certain topographical and traffic demand constraints. Of these new types, it would appear that only the single-point urban interchange (SPUI) is capable of accommodating continuous frontage roads without the use of additional grade separation structures.

Controversy surrounds the design and operational efficiency of the new SPUI. Specifically, there is some uncertainty regarding the maximum volume that can be served by the signalized ramp/crossroad intersection. There is also some uncertainty about the SPUI's operational performance under a variety of traffic conditions. To date there has been very little published and the amount of operational experience with these new interchanges is limited.

This report summarizes the research conducted during the first year of a three-year study. Specifically, the first year's research activity has focused on a field survey and evaluation of six SPUIs located in five states. The data collected during this field study were used to assess the design and operation of SPUIs. In this regard, selected design, operational, safety, structural, and economic issues have been presented in this report. Subsequent project reports will focus on an examination of SPUI capacity and delay based on analytic traffic models and field data.

As a result of the survey and evaluation process, it appears that the SPUI is a viable alternative to other diamond interchange configurations in certain situations. It is adaptable to locations where right-of-way is limited and appears to operate efficiently under traditional NEMA 8-phase control. On the other hand, it does not appear to be well-suited to continuous frontage road situations because of capacity restrictions that result from an additional signal phase. In general, the capacity of the interchange appears to have geometric limitations. The relative efficiency of the SPUI with respect to the conventional diamond interchange has yet to be fully resolved.

IMPLEMENTATION

This report contains the findings of a field survey and evaluation of six operational SPUIs. These findings are expected to inform Texas State Department of Highways and Public Transportation engineers about the current state-of-the-art in SPUI design and operation, since there are presently none in Texas. In addition, these findings suggest that SPUIs may have application in the State of Texas, subject to certain limitations. The full extent of these limitations has not been fully resolved nor have recommendations been formulated for this report. However, these recommendations will be forthcoming in the final report in the form of design guidelines and control strategies for the SPUI and other diamond interchange configurations.

The potential benefits to be derived from the implementation of the final report will be an improved understanding of critical design and operational issues related to the SPUIs and other types of diamond interchanges. The intent is to provide a working document that can be used in the formulation of appropriate design and traffic control guidelines, policies, and standards as they pertain to specific diamond interchange elements.

At this point, additional research is underway in several areas of the project. In particular, several other diamond interchange configurations are in the process of being studied or evaluated. Additional analysis of the data collected at the six SPUIs is also being conducted. Computer models for SPUI operation are being formulated, tested, and evaluated. A project report addressing the capacity and operational analysis of SPUIs will be prepared during the Summer of 1989. Upon completion of these project tasks, a final report will be prepared that documents the proposed design guidelines and control strategies for five different diamond interchange configurations including the SPUI.

ACKNOWLEDGMENTS

The research reported herein was performed as a part of a study entitled "Guidelines for Operational Control of Diamond Interchanges." This study was conducted by the Texas Transportation Institute for the Texas State Department of Highways and Public Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Dr. Carroll J. Messer of the Texas Transportation Institute served as research supervisor, and Mr. Herman E. Haenel of the Texas State Department of Highways and Public Transportation served as technical coordinator.

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  Mr. Keith A. Crawford, Director, Traffic Engineering Department

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  Mr. T. Wallace Hawkes, Executive Vice President

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* New Mexico Highway Department
  Mr. Charles Trujillo, Design Engineer

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Mr. Robert Mannell, Assistant State Location Engineer

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DISCLAIMER

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1. INTRODUCTION

1.1 PROBLEM STATEMENT

As operational experience has shown, the intersection of two high-volume facilities leads to a corresponding high demand for traffic interchange between these facilities. To accommodate this demand, highway interchanges of various configurations have been designed to act as a conduit for routing traffic safely and efficiently between the two intersecting roadways.

One of the simplest and most efficient interchange configurations is the diamond interchange--so named because of the shape formed by its diagonal on/off-ramps between intersecting roadways. The advantages of the diamond interchange are its nominal right-of-way requirements, simplicity of design, uniform and consistent pattern of right-hand ramp-freeway connections, and convenient adaptability to the Texas frontage road system.

Diamond interchanges are best suited to the intersection of freeways, expressways, and major arterials with minor arterials and collector streets. This preference is related to the diamond interchange's inability to adequately serve high-volume through and left-turn movements. This deficiency results from the need to serve conflicting traffic movements at the two, at-grade ramp/crossroad intersections. The nature of the conflict often necessitates the installation of traffic signals to effect a temporal movement separation. In any case, conflicting movements create a capacity limitation; regardless of whether or not signals are installed. As a result, diamond interchanges are usually not ideally suited to situations where demands are high for both the crossroad and exit ramps.

Current trends in the design of diamond interchanges reflect improvements in signal control and geometry that have substantially increased both the capacity and safety of the at-grade ramp/crossroad intersections. In addition, new types of diamond interchanges have been designed that have features which are better suited to certain topographical and traffic demand constraints. To date these recent innovations in diamond interchange design and traffic control have been implemented on a location-by-location basis; generally without the benefit of the knowledge or the experiences of other highway engineering agencies.

This research project was undertaken in recognition of the need for a better understanding of the relationship between the design and operation of all types of diamond interchanges (including recent innovations). In particular, five types of diamond interchanges will be addressed during the course of this project. Upon its completion, a set of guidelines, strategies, and computer models will be provided that will assist the engineer in selecting a control strategy that is compatible with a specific interchange design. These guidelines will also include a methodology for assessing the quality of traffic flow provided by the proposed design.

1.2 BACKGROUND

The diamond interchange is the most widely used type of interchange at intersections of major streets where right-of-way is limited, turning volumes are low to moderate, and continuous frontages roads exist. The three most common types of diamond interchanges are the conventional diamond, the split diamond and the three-level diamond. Figure 1-1 illustrates these three basic interchange types.

Within the past two decades, advances in the geometric design and traffic control of diamond interchanges have increased capacity and safety at some existing interchanges. These advances have come about primarily as a result of experiences gained by engineers through practical application and fundamental research. In addition to enhancements in the design and control of common diamond interchanges, three new types of urban diamond interchanges have evolved in recent years: the single-point urban interchange, the three-point diamond interchange, and the three-level stacked diamond interchange. Figure 1-2 presents schematics of these three types of interchanges. Of these three new types, it would appear that only the single-point urban interchange is capable of accommodating continuous one-way frontage roads without the use of additional grade separation structures.

Controversy surrounds the operational efficiency of the new diamond interchange types with respect to the more common types. This controversy has been primarily directed towards the single-point urban interchange and specifically questions the maximum volume that can be served by the signalized ramp/crossroad intersection. One author claims that the single-point urban interchange has superior capacity to the conventional diamond interchange (1). In contrast, another author (2) suggests that the additional capacity provided by the single-point urban interchange is "...lost if more than one of the four left-turn movements requires double left-turn lanes and the cross street (demand) necessitates more than two through lanes in each direction." This same author also contends that high-volume single-point urban interchanges often create unduly expansive structures by virtue of their need for a large area of open, uncontrolled pavement (possibly as large as 120 by 300 feet) to serve turning vehicles.

The introduction of the single-point urban interchange, like any new design or prototype, has been the focus of a considerable amount of controversy. This controversy has resulted from the many uncertainties about its operational performance under a variety of traffic conditions. To date there has been very little published and the amount of operational experience with these new interchanges is limited. In fact, none have been built in Texas. Of the few articles that are available in this area (3,4), none have discussed the effects of frontage road traffic on interchange operations.

Based on the preceding discussion, there appears to be an immediate need to develop a set of design controls and operational strategies for the single-point urban interchange for application in Texas. In this regard, this research will be initially directed toward an evaluation of current design and operational elements of the single-point urban interchange. Ultimately, a set of design guidelines and control strategies will be developed to assist the engineer in formulating an appropriate interchange design and implementing an efficient control strategy.

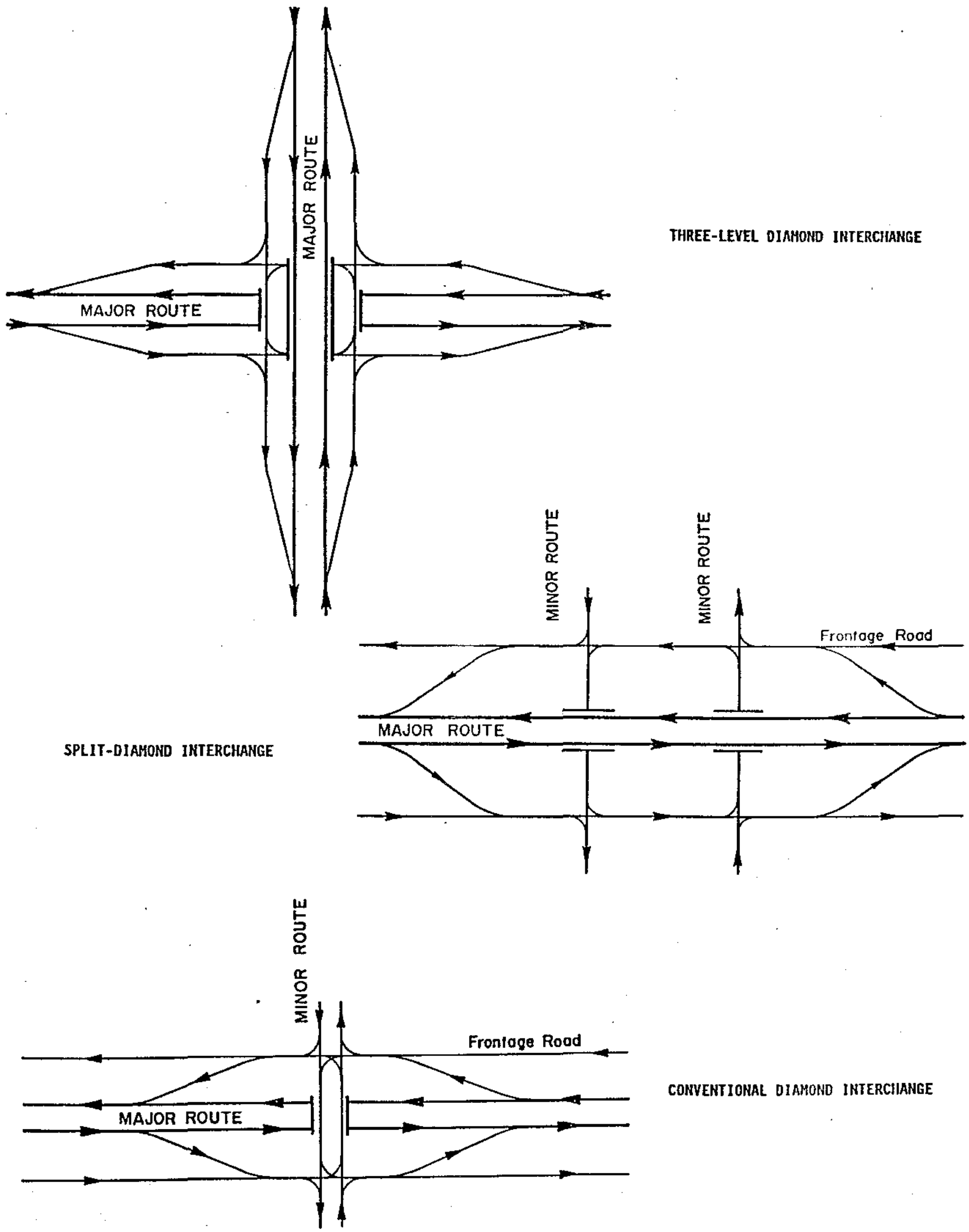


Figure 1-1. Typical Diamond Interchange Configurations.

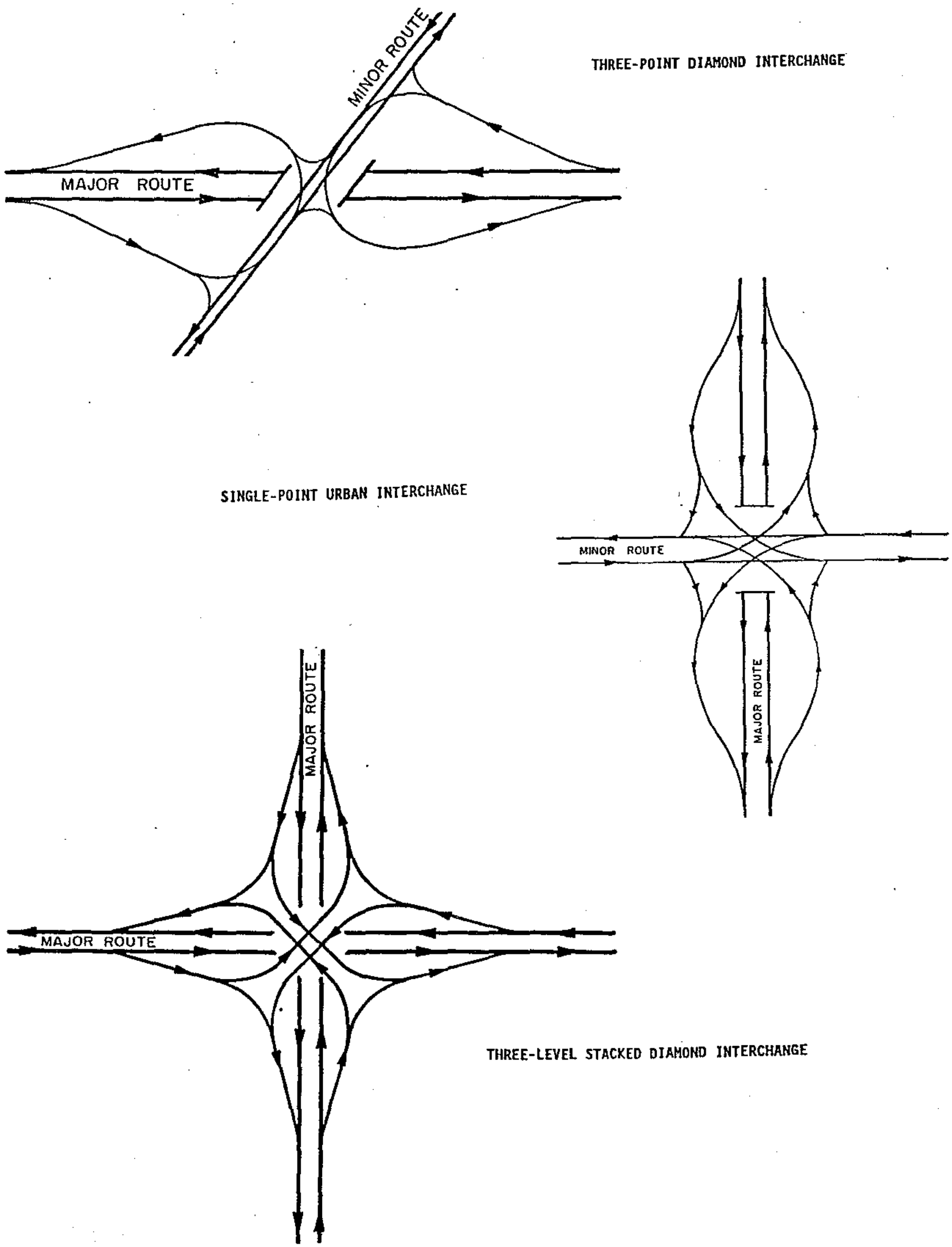


Figure 1-2. New Diamond Interchange Configurations.

1.3 RESEARCH OBJECTIVES

As stated in Section 1.1, the goal of the three-year study is to develop procedures for identifying and evaluating an appropriate design and efficient control strategy for five diamond interchange configurations. These five configurations include:

1. Conventional Diamond
2. Single-Point Urban Diamond
3. Split Diamond
4. Three-Point Diamond
5. Three-Point Stacked Diamond

This research report has been prepared to summarize the research conducted during the first year of the three-year study. Specifically, the first year's research activity focused on a survey and evaluation of the single-point urban interchange configuration. An interim project report presented to the Texas State Department of Highways and Public Transportation contains the specific details of the first year's research efforts and a complete description of the interchanges surveyed (5). The remaining sections of this research report summarize the survey results and present the findings from an evaluation of these single-point urban interchanges.

2. SINGLE-POINT URBAN INTERCHANGE SURVEY

2.1 THE SINGLE-POINT URBAN INTERCHANGE

Within the past two decades, a "new" diamond interchange configuration has emerged that is claimed to offer improved traffic-carrying ability, safer operation, and reduced right-of-way needs. This "new" interchange, shown in Figure 2-1, has been called by many names including the urban interchange, single-point diamond, compressed diamond, urban grade-separated diamond, single-signal interchange, and the single-point urban interchange (or SPUI, as it will be referred to in the remainder of this report).

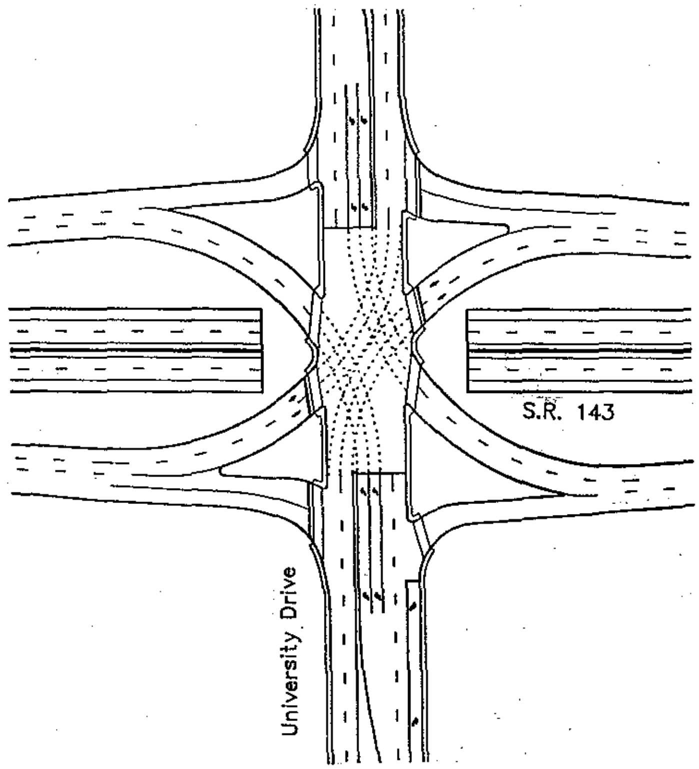
The SPUI configuration provides engineers another design alternative in situations where traffic conditions warrant the grade-separation of two intersecting routes. Although professional opinion varies in regard to the SPUI's capabilities, many would agree that the SPUI is functionally similar to a high-type, at-grade intersection. The major difference being the grade-separation of the major road through movements. The SPUI has also been compared with the conventional diamond. In this instance, the most notable difference is the method used to control and guide left-turn traffic through the interchange.

Like the conventional diamond interchange, the SPUI design is adaptable to situations where the major road passes over (elevated design) or under (depressed design) the crossroad. The more common, elevated-design SPUI is shown in Figure 2-1 while the depressed-design SPUI is shown in Figure 2-2.

The most novel feature of the SPUI is its approach to serving the off-ramp left-turn movement. In contrast to the approach used at conventional diamond interchanges, off-ramp left-turn paths at a SPUI are inverted such that they do not conflict with one another. The benefits of this approach are twofold: 1) a relatively simple phasing sequence can be used to regulate the interchange's conflicting movements, and 2) dual-lane left-turn paths can be easily accommodated as a result of larger turn radii.

With regard to signal phasing, the SPUI design can be operated with a standard NEMA 8-phase, dual-ring controller. This capability simplifies the interchange's signal phasing and its interconnection with adjacent crossroad intersections. The typical phase sequence consists of three basic phases (plus overlaps): 1) both crossroad left-turn movements; 2) both crossroad through movements; and 3) both off-ramp left-turn movements. The major road through movements are grade-separated and, thus, are not interrupted by the traffic signal. If a frontage road through movement is provided, a fourth phase would be required; however, this would result in a reduction in the capacity of the other phases.

The SPUI has been the subject of considerable controversy with respect to its design and operational effectiveness. There are many uncertainties about the interchange's traffic signal phasing, signing, and delineation requirements; sight distance availability; operational efficiency; pedestrian accommodations; safety; and cost-effectiveness. Each of these areas of uncertainty will be more thoroughly addressed in later sections of this report.



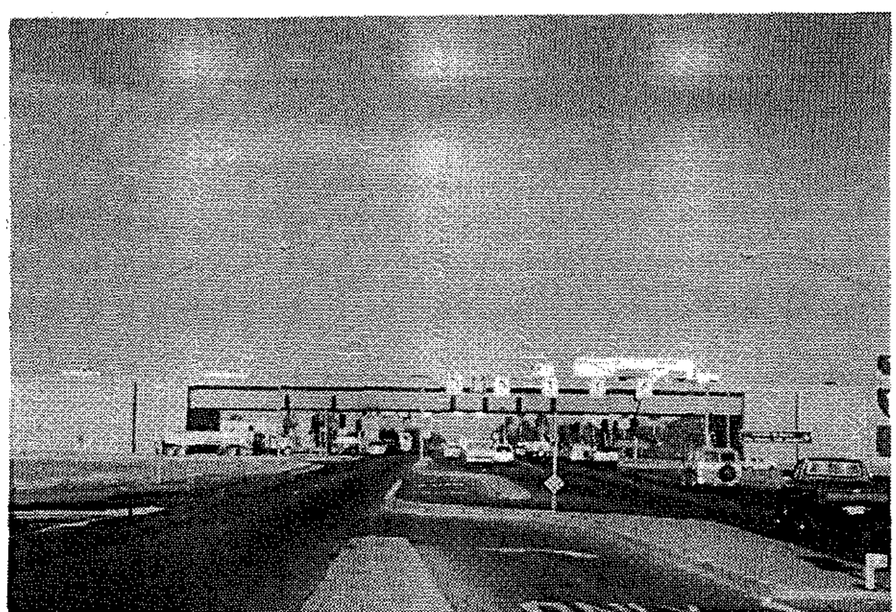


Figure 2-1. Elevated Single-Point Urban Interchange located in Phoenix, Arizona.

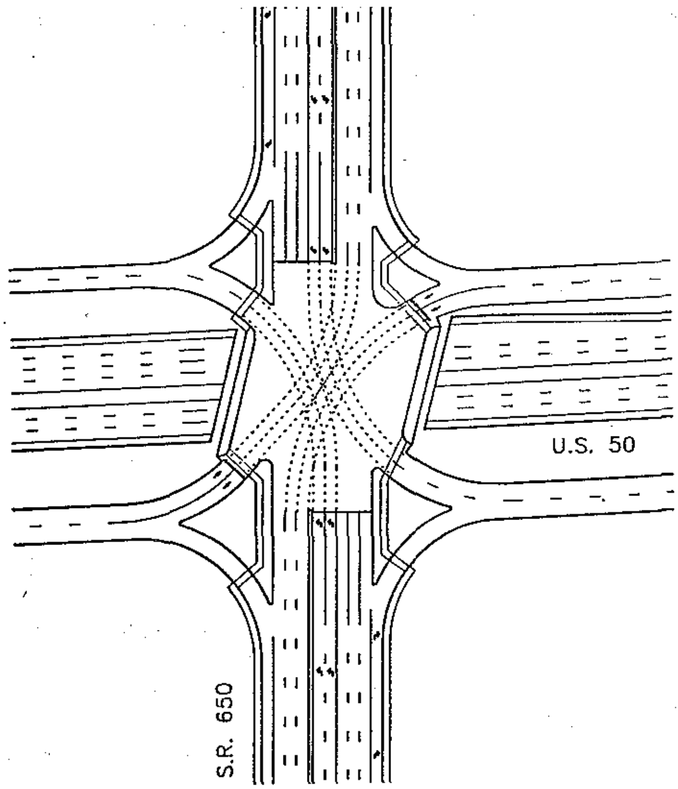


Figure 2-2. Depressed Single-Point Urban Interchange located in Fairfax, Virginia.

2.2 IDENTIFICATION OF SINGLE-POINT URBAN INTERCHANGES

An initial task for this research was the identification of representative examples of SPUIs. In this regard, several Texas State Department of Highways and Public Transportation district offices were contacted. Based on these contacts, it was learned that Texas had no operational SPUIs. Thus, the survey task was expanded wherein over 20 agencies throughout the United States were contacted. These initial contacts were made by telephone and followed with a letter survey and request for additional information.

Response to the national survey was very satisfactory with all agencies contacted returning a survey form. In most instances, the responding agency also sent accompanying information such as geometric plan sheets and signal timings. Table 2-1 lists the 17 SPUIs located as part of this initial task.

Table 2-1. Single-Point Urban Interchange Locations.[1]

No.	Location	Status
1.	US 50 & SR 650, Fairfax, Virginia	Operational
2.	US 19 & SR 60, Clearwater, Florida	Operational
3.	US 19 & SR 694, Pinellas Park, Florida	Operational
4.	SR 143 & University Drive, Phoenix, Arizona	Operational
5.	2100 South & 3200 West, West Valley City, Utah	Operational
6.	Paseo Del Norte & Coors Blvd., Albuquerque, New Mexico	Operational
7.	US 85 & Evans Avenue, Denver, Colorado	Operational
8.	Keystone & I-80, Reno, Nevada	In design
9.	SR 421 & SR 60, Frankfort, Kentucky	Operational
10.	Seventh Avenue & I-74, Moline, Illinois	Operational
11.	Squaw Peak Parkway & Thomas Road, Phoenix, Arizona	Construction
12.	Papago Frwy. & 7th Avenue, Phoenix, Arizona	Construction
13.	Papago Frwy. & 7th Street, Phoenix, Arizona	Construction
14.	I-85 & SR 16, Charlotte, North Carolina	Construction
15.	Tudor Freeway, Alaska	Construction
16.	US 50 & Fairlakes Road, Fairfax, Virginia	Operational
17.	US 75 & SR 370, Bellevue, Nebraska	In design

Notes: 1 - Current status as of April, 1988.

Based on the information gathered from the questionnaire, several candidate sites were selected for further study. The suitability of a particular interchange was partly determined by how closely it fit predefined selection criteria and partly by the uniqueness of the interchange design. As a minimum, an interchange had to satisfy four criteria to be considered for the field survey. In order of preference, an interchange should:

1. Be signalized, having either pretimed or actuated control;
2. Be in an urban setting;
3. Exhibit relatively higher ranges of volumes; and
4. Have nominal geometrics and operating conditions.

As a result of the survey and selection process, six sites were selected for field study. These sites are listed in Table 2-2.

Table 2-2. Single-Point Urban Interchanges - Locations Studied.

				Total Lanes			
				Ramp		Cross Road	
No.	Location	Type	Comments	Left	Right	Left	Thru
1.	US 50 & SR 650 Fairfax, Virginia	A	Y	4	2	4	6
2.	US 19 & SR 60 Clearwater, Florida	B	Y,L	4	2	2	6
3.	US 19 & SR 694 Pinellas Park, Florida	B	Y	3	2	2	6
4.	SR 143 & University Drive Phoenix, Arizona	B	S	4	4	4	4
5.	3200 West & 2100 South West Valley City, Utah	B	Y,L	3	2	2	4
6.	Paseo Del Norte & Coors Blvd. Albuquerque, New Mexico	B	Y	4	3	4	6

Key To Comments: A - Intersection above structure - a freeway underpass.
B - Intersection beneath structure - a freeway overpass.
L - Lights in pavement to guide left-turn movement.
S - Ramp right-turn movement signalized.
Y - Ramp right-turn movement yield or merge controlled.

2.3 DATA COLLECTION REQUIREMENTS

Due to the general complexity of interchange operations, several data collection techniques were necessary to record all pertinent and essential characteristics. These techniques included: 1) 35-mm slide and print film inventory, 2) audio-video film inventory, 3) field inventory of physical features and dimensions, and 4) inventory of geometric and signal timing plan information. Information recorded included:

1. Signal head placement and lens arrangement.
2. Pavement markings.
3. Structure and embankment design.
4. Channelization techniques.
5. Lane configuration and usage.
6. Sight distance perspectives.
7. Signing system (e.g., type, message, location).
8. Downstream conditions (e.g., intersections, medians).
9. Vertical profile of roadway and topographic relief.
10. Unusual/unexpected conditions.

In addition to the operational characteristics and design features recorded during the field survey, information was also requested from the appropriate agencies. In general, this information included the following:

1. Horizontal design details at 20':1" or 50':1" scale.
2. Signal phasing.
3. Controller type (i.e., pretimed or actuated).
4. Phase timings; fixed and/or variable interval settings.
5. Controller characteristics (e.g., model, configuration).
6. Interconnection/coordination strategy.
7. Pavement marking design.
8. Vertical profile for crossroad and ramp center lines.
9. Detector design and placement.
10. Accident history, frequency, and rate.
11. Traffic volumes (e.g., daily, hourly, turning movement).

2.4 OVERVIEW OF SURVEY SITES

The following subsections briefly describe the individual SPUIs surveyed. Particular features of each site will be more fully described and discussed in Section 3. A scale drawing of each interchange is included in the Appendix.

2.4.1 US 50 & SR 650 - Fairfax, Virginia

The SPUI at US 50 (Arlington Boulevard) and SR 650 (Gallows Road) is located in the Washington D.C. suburb of Fairfax, Virginia, near Interstate 495 (Capitol Beltway) (see Figure A-1). Prior to the construction of the SPUI, traffic was served by an at-grade signalized intersection. As a result of increased traffic demands and high local right-of-way costs, a SPUI design was proposed in about 1979; the present design was completed in 1983.

US 50 is a six-lane, expressway that extends from Fairfax on the west to the City of Arlington on the east. US 50 passes underneath the interchange with SR 650. SR 650 is also a six-lane major arterial that serves more locally oriented traffic demands to the north and south of US 50. At its intersection with the on/off-ramps from US 50, SR 650 widens to provide additional, exclusive lanes for the left- and right-turning movements.

2.4.2 US 19 & SR 60 - Clearwater, Florida

The SPUI at US 19 and SR 60 (Gulf-To-Bay Boulevard) is located on the eastern side of Clearwater; near the west shore of Tampa Bay (see Figure A-2). This interchange was one of the earliest constructed using the SPUI design; it was opened to traffic in the early 1970's. This interchange replaced an existing, high-volume, at-grade intersection.

The major route through the interchange, US 19, is oriented in a north-south direction while the minor route, SR 60, extends in the east and west directions. Within the study area, SR 60 functions as a major arterial with access points at most intersecting streets (about 1/4 mile intervals).

US 19 is a four-lane freeway that serves the major activity centers within the urban area and the surrounding inter-regional area. Its function is unique in that it is the only major highway providing north-south access on the west side of Tampa Bay.

One of the unique features of this interchange is the use of unidirectional, wide-beam, 65-watt lights in the pavement. These lights are strategically located to delineate the edge of the left-turn movement travel paths. The lights are interconnected with the traffic signal controller such that they are illuminated only when the respective left-turn phase is activated and only during the evening hours. In addition, they are turned on sequentially at the beginning of the phase to draw the driver's attention to the intended travel path.

2.4.3 US 19 & SR 694 - Pinellas Park, Florida

The SPUI at US 19 (SR 55) and SR 694 (Gandy Boulevard) is located in Pinellas Park--a suburban community on the northwest side of St. Petersburg, Florida (see Figure A-3). This interchange was one of the earliest constructed using the SPUI design; its design was completed in 1971.

The major route through the interchange, SR 694, is oriented in an east-west direction and serves as a main route between the Tampa and St. Petersburg area. The minor route, US 19, is oriented in a northwest to southeast direction and serves traffic having both local and regional destinations. Within the study area, US 19 functions as a major arterial with access points only at intersections with collector streets or other arterials. SR 694 is a four-lane facility that has a high-speed freeway character to the east of the interchange but transitions into a major arterial on the west.

2.4.4 SR 143 & University Drive - Phoenix, Arizona

The SPUI at SR 143 (Hohokam Expressway) and University Drive is located on the southeast edge of Phoenix; just to the west of Tempe (see Figure A-4). In fact, University Drive is the main east-west arterial through Tempe. This interchange was designed in 1983 and opened to traffic in 1985. It replaced an existing at-grade intersection.

The major route through the interchange, SR 143, is oriented in a north-south direction and serves as a main traffic carrier between north and south Phoenix. The minor route, University Drive, is oriented in an east-west direction and serves traffic with both local and regional destinations. Within the study area, University Drive functions as a major arterial providing direct access from Phoenix to the Tempe area.

SR 143 is a four-lane freeway that serves the major activity centers of the Phoenix area. It is one of the few roads that crosses the Salt River and the first such crossing to the east of the Sky Harbor International Airport.

2.4.5 3200 West & 2100 South - West Valley City, Utah

The SPUI at 3200 West and 2100 South (SR 201) is located just to the south and west of Salt Lake City (see Figure A-5). In fact, West Valley City is one of Salt Lake City's suburban communities. There is a relatively high percentage of trucks at this interchange, most of which have double and triple trailers. This interchange's design was completed in 1979.

The major route through the interchange, 2100 South, is oriented in an east-west direction and serves as a main route between the cities of Magna and Salt Lake City. It also serves as a connection between I-215 and I-80. 2100 South is a four-lane freeway.

The minor route, 3200 West, is oriented in a north-south direction and serves traffic with both local and regional destinations. Within the study area, 3200 West functions as a four-lane minor arterial providing access to nearby land uses and to more distant connections to the south. To the north, 3200 West terminates within a business park. Outside of the interchange area, 3200 West has a two-lane cross-section.

2.4.6 Paseo Del Norte & Coors Boulevard - Albuquerque, New Mexico

The SPUI at Paseo Del Norte and Coors Boulevard (SR 448) is located on the northwest side of Albuquerque (see Figure A-6). In fact, it is actually located just inside the south boundary of the town of Alameda. The design of this interchange was completed in late 1985. It replaced an existing at-grade intersection.

The major route through the interchange, Paseo Del Norte, is oriented in an east-west direction and serves as a main route between Albuquerque and its northwest suburbs. Paseo Del Norte is also one of the few routes that crosses over the Rio Grande River. This river runs north to south, parallel to Coors Boulevard and partially divides Albuquerque into east and west sections.

Coors Boulevard is the only major, north-south route on the west side of the Rio Grande River. Within the study area, Coors Boulevard functions as a major arterial providing limited access to the intersecting street system.

2.5 SUMMARY OF SURVEY OBSERVATIONS

In general, the design and operation of the six SPUIs surveyed varied considerably. Although some of this variation relates to differences in local practice, there is still some variability in many of the basic interchange elements that may be the result of limited experience with the SPUI. The most important of these elements are listed in Table 2-3 and described in the following subsections.

2.5.1 Geometric Elements

This section addresses the geometric elements at the six SPUIs studied. In general, these SPUIs are fairly representative of the SPUI type of design--four- or six-lane crossroads with single or dual left-turn lanes.

1. None of the SPUIs studied had a continuous, one-way frontage road system combined with the on/off-ramps. In fact, an initial letter survey did not reveal any currently in operation. Two-way frontage road systems were found at sites #4 (Phoenix) and #5 (West Valley City); however, they are not coincident with the on/off-ramps. Rather, the frontage road alignment is parallel and offset from the freeway on/off-ramps. This

Table 2-3. Summary of Single-Point Urban Interchange Elements.

Element	Interchange Site[1]: 1	2	3	4	5	6
1. Minor Street Cross Section						
Number of lanes:	10	7	7	7	5	10
Median width (feet):	4	6	4	4	4	24
Total width (feet):	126	94	88	80	80	133
2. Turn Radii (feet)[2]						
Cross road left-turn:	275	200	255	260	270	200
Cross road right-turn:	125	125	80	65	70	222
Off-ramp left-turn:	200	200	220	260	267	530
Off-ramp right-turn:	112	125	80	90	70	192
3. Stop Line Separation (feet):	251	195	220	250	250	230
4. Ramp-To-Ramp Width (feet)						
At cross road:	165	85	80	88	123	168
Maximum within R.O.W.:	290	195	240	330	340	360
5. Bridge Dimensions (feet)						
Length (along major road):	200	210	360*	210	300*	200
Width (along cross road):	120	80	76	85	115	80
6. Clearance Interval (seconds)						
Actual All-Red:	28.0	3.5	3.0	16.0	6.0	na
Calculated All-Red[3]:	18.5	11.8	11.5	20.2	15.5	15.5
7. Number of Signal Heads:	14	14	14	26	12	18
8. Critical Lane Capacity (vehicles/hour):	1120	1475	1460	1230	1385	1400
9. Current ADT On Cross Road:	28,000	52,000	40,000	40,000	45,000	na
10. Accident Rate[4]:	na	2.70	na	0.88	1.35	na

Notes: 1 - Site numbers relate to the following sites:
1 - US 50 & SR 650, Fairfax, Virginia
2 - US 19 & SR 60, Clearwater, Florida
3 - US 19 & SR 694, Pinellas Park, Florida
4 - SR 143 & University Drive, Phoenix, Arizona
5 - 3200 West & 2100 South, West Valley City, Utah
6 - Paseo Del Norte & Coors Boulevard, Albuquerque, New Mexico

2 - Turn radius reported represents the average of both radii.
3 - Interval calculated using ITE methodology.
4 - Accident rate calculated as number of accidents per million entering vehicles.
* - Denotes a three-span bridge; all others are single-span.
na - Data not available.

offset is nominal along the basic freeway section but increases at the crossroad to minimize adverse vehicular interaction between the on/off-ramp and frontage road intersections.

2. Turn movements from the major road are always separated on the off-ramps into left- and right-turning movements as they approach the SPUI, each movement having its own lane or lanes. The more recently constructed SPUIs typically have more generous off-ramp designs than did the older SPUIs. In this regard, these newer designs have wider ramp cross sections, longer exclusive lane development, and larger turn path radii.

3. All of the SPUIs surveyed have advance left-turn lanes on the crossroad approaches to the interchange.

4. All of the SPUIs surveyed have one or more dual-lane left-turn movements on the off-ramp approaches. In fact, four of the six sites have dual-lanes for both off-ramp left-turn movements.

5. Typically the radius of the crossroad left-turn path is equal to (or slightly less than) that of the off-ramp left-turn path. In particular, the radius of the crossroad left-turn path was found to be in the range of 175 to 275 feet. Similarly, the radius of the off-ramp left-turn path was found to be in the range of 200 to 267 feet at five of the six SPUIs. The sixth SPUI (Albuquerque) has a particularly large off-ramp left-turn radius of 530 feet.

6. Distances between stop lines measured along the crossroad varied from 195 to 250 feet. This is at least 100 feet greater than that found at a conventional, signalized at-grade intersection.

2.5.2 Traffic Operations Elements

This section addresses operational elements at the six SPUIs studied. In general, all SPUIs were operating satisfactorily during the times studied.

1. All SPUIs use NEMA 8-phase dual-ring control with leading crossroad left-turns. The left-turn phase always operates in a protected-only mode.

2. At some SPUIs, the off-ramp right-turn maneuver was observed to have frequent queueing, which suggested near-capacity operation. In spite of this restriction, the off-ramp right-turn movement is generally not signalized. One exception to this is at the Phoenix site (#4). At this location, the right-turn movement is signalized by providing a green arrow coincident with the crossroad left-turn phase. Detectors on the right-turn approach were installed but eventually disabled to prevent right-turn traffic from extending the crossroad left-turn phase.

3. A wide variation in signal change intervals was found among the six SPUIs studied. This variation was most notable in the duration of the all-red (red clearance) intervals.

4. The total of all, all-red clearance intervals at the SPUIs studied ranged from 3.0 to 28.0 seconds (total for all three phases). To isolate

differences in local practice, all-red intervals were calculated for each SPUI using the methodology described in the ITE's Engineering Handbook (6). These calculated intervals are shown in Table 2-3.

2.5.3 Safety-Related Elements

This section addresses the operation of the SPUI with respect to accident history and driver behavior. Based on the findings from the field study, the following observations have been noted.

1. Accident rates obtained for three of the SPUIs are quite varied and do not suggest any trend. In fact, the average rate of all these SPUIs is not significantly different from that of a typical signalized intersection (i.e., 1.2 accidents per million entering vehicles) (7).

2. A review of the accident diagrams at two SPUIs indicates that accidents occur on the off-ramps at twice the rate that they occur on the crossroad. In particular, rear-end collisions among turning vehicles on the off-ramps is the single most common type of accident.

3. Occasionally, a crossroad driver (wanting to access the major route) was observed to enter the SPUI in the left-hand through lane and then incorrectly make a left-turn from this through lane once past the small center island. It was noted that this erroneous maneuver is very similar to the typical left-turn maneuver at a conventional diamond interchange.

2.5.4 Other Elements

This section summarizes any observations and findings that were not previously discussed. In general, these findings relate to the pedestrian crossing and lighting facilities at the SPUIs studied.

1. Most SPUIs had sidewalks and painted crosswalks for pedestrians crossing the on/off-ramps parallel to the crossroad. Because the SPUI's operation is different from other signalized intersections, there is a potential for pedestrian confusion as to when it is safe to cross each ramp junction. However, observation of pedestrian behavior at SPUIs suggests that this is not as significant a problem as initially perceived. Those pedestrians observed appeared to make the correct choice by walking coincident with the crossroad through phase.

2. In all cases, there were no crosswalks provided for pedestrians to use in crossing the crossroad. Moreover, typical SPUI signal phasing does not provide for a protected pedestrian phase to occur across the crossroad.

3. Only two SPUIs have lights in the pavement to guide left-turning traffic: Clearwater, Florida and West Valley City, Utah. Of these two SPUIs, only the one in Clearwater has pavement lights in current use.

4. Most SPUIs use some type of high mast or complete interchange lighting scheme to illuminate the entire interchange area, particularly the critical on- and off-ramp areas.

3. SINGLE-POINT URBAN INTERCHANGE EVALUATION

3.1 ELEMENTS OF THE EVALUATION PROCESS

One of the objectives of this research project was to assess the design and operation of SPUIs. Ultimately, the findings from this assessment would be used in the development of guidelines for selecting efficient diamond interchange designs and traffic control strategies.

The research conducted to date has focused on the SPUI, particularly on those elements of the SPUI that are new and unique to highway and traffic engineers. In this regard, the following sections discuss the pertinent findings from a field survey and assessment of the SPUI. This discussion provides an evaluation of the design and functional performance of SPUIs in terms of the physical elements that comprise it. Site-specific data from the field survey will be used to add a sense of perspective to the discussion.

3.2 GEOMETRIC DESIGN EVALUATION

As shown in Figure 3-1, the basic cross section of the crossroad at a SPUI is very similar to that of a high-volume, at-grade intersection. In contrast, the major roadway cross sections are different by virtue of the grade separation and left-turn treatment inherent to the SPUI design. More specifically, the left-turn maneuvers from the major roadway at an at-grade intersection are made from inside the through traffic lanes. On the other hand, the same left-turn maneuvers at a SPUI are made from outside the through lanes, passing under (or over) the major roadway.

The design of the SPUI also shares some similarities with that of the conventional diamond interchange. These similarities stem from: 1) the need to grade-separate the major through movement; and 2) the need for one-way, diamond-type ramps in each quadrant. In contrast, their main differences are found in the geometry and operation of the ramp-crossroad intersections. One of these differences is the left-turn treatment--the SPUI inverts its left-turn movements such that the paths of opposing left-turn vehicles do not conflict with one another (similar to the left-turn movement at an at-grade intersection). This situation results in only one signalized conflict area. In contrast, conventional diamond interchanges have both ramp junctions signalized; thereby, creating two closely spaced signalized intersections.

The fundamental differences between the SPUI and conventional intersection or interchange design have raised several performance issues and concerns. These issues are primarily in the areas of driver expectancy and design consistency. The following discussion will comment on possible reasons for this concern by discussing each of the unique design elements of the SPUI.

3.2.1 Cross Section

In general, crossroad cross sections at SPUIs were found to have from four to six through lanes, always one or two left-turn lanes, zero to two right-turn lanes, a median, and possibly outside shoulders. Lane widths were

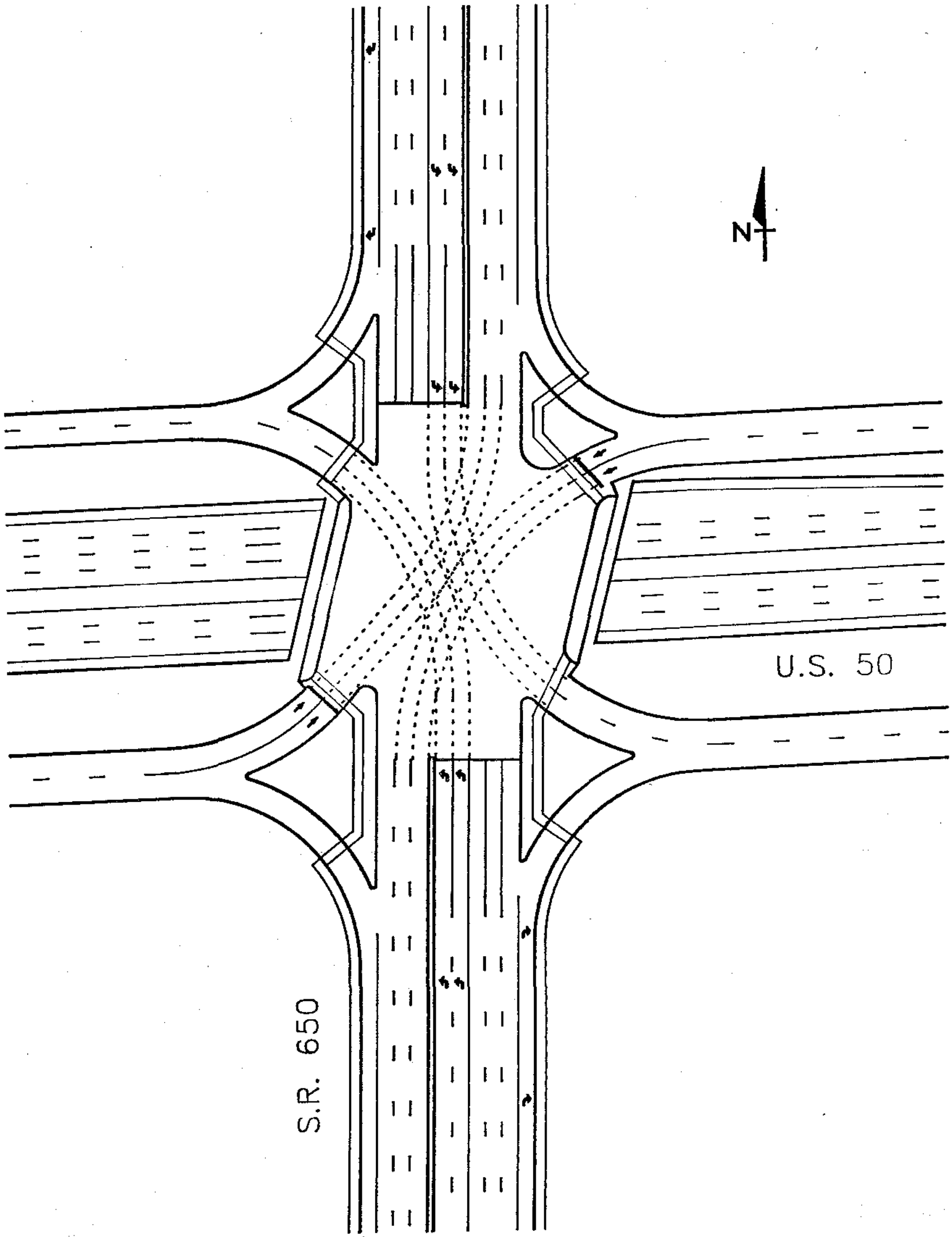


Figure 3-1. Typical Single-Point Urban Interchange.

usually 12 feet, median widths varied from 4 to 24 feet, and individual shoulder widths were found to be as wide as 10 feet. The total width, from back-of-curb to back-of-curb varied from 80 to 130 feet. Figure 3-1 illustrates the geometric features of depressed-design SPUI in Fairfax, Virginia. In many respects, it typifies the design components of the SPUI.

The basic crossroad cross section for the SPUI is composed of the same fundamental components as at a high-type at-grade intersection (e.g., advance left-turn bays, multiple through lanes, a median, etc.). In fact, efficient SPUI operation is dependent on single- or dual-lane left-turn bays constructed on the crossroad in advance of the interchange. In contrast, the SPUI and the conventional diamond interchange are likely to differ in the need for and location of storage bays for left-turn traffic. Advance left-turn bays are not always needed at conventional diamond interchanges.

The need for advance bays at conventional diamond interchanges is dependent on the type of signal phasing used and the amount of separation between ramp junctions. In particular, those conventional diamond interchanges that use the "4-phase with overlap" phase sequence or those that have sufficient distance within the interchange for bay development do not need advance left-turn bays. Moreover, the "4-phase with overlap" sequence is well suited to interchanges with limited ramp separation (i.e., "tight" designs) but may not operate efficiently if freeway ramp U-turn volumes are present unless separate U-turn lanes are provided. In summary, the SPUI always needs advance left-turn bays; a conventional diamond interchange using "4-phase with overlap" does not need advance left-turn bays; and a conventional diamond interchange with other than "4-phase with overlap" phasing may need advance turn lanes if internal ramp separation does not provide sufficient length for left-turn bay development.

Similar to an at-grade intersection, the SPUI has the ability to offset opposing left-turn bays on the crossroad. By offsetting opposing turn lanes, the SPUI has the potential to require less right-of-way if the conventional diamond interchange design requires advance left-turn bays. On the other hand, if the conventional diamond interchange design specifies the "4-phase with overlap" phase sequence and if U-turn traffic is nonexistent, then the need for left-turn lanes is eliminated and the conventional diamond interchange has the potential to require less right-of-way along the crossroad.

Because of their different cross-sectional needs, any comparison of crossroad cross sections among SPUIs and conventional diamond interchanges must be sensitive to the type of signal phasing (and related left-turn treatment) used at the conventional diamond interchange. A comparison between the SPUI and the conventional diamond interchange using a coordinated 3-phase sequence may lead to the conclusion that the SPUI requires less right-of-way. On the other hand, this may not be the case when comparing a SPUI with a conventional diamond interchange that uses "4-phase with overlap" phasing.

In general, the SPUI right-of-way requirements along the major roadway are quite similar to that of the conventional diamond. A survey of several SPUIs found the minimum distance between ramps to be 195 feet. This distance is measured from back-of-curb to back-of-curb parallel to the crossroad. This minimum width is directly related to the width of the major roadway and the on/off-ramps. The width of 195 feet was found at a SPUI having a four-lane major roadway with a nominal width of 80 feet and two ramps measuring 26 feet each. This particular interchange was observed to have operational problems that are believed to be related to its narrow width. The back-of-curb to back-of-curb widths of the six SPUIs studied are shown in Figure 3-2.

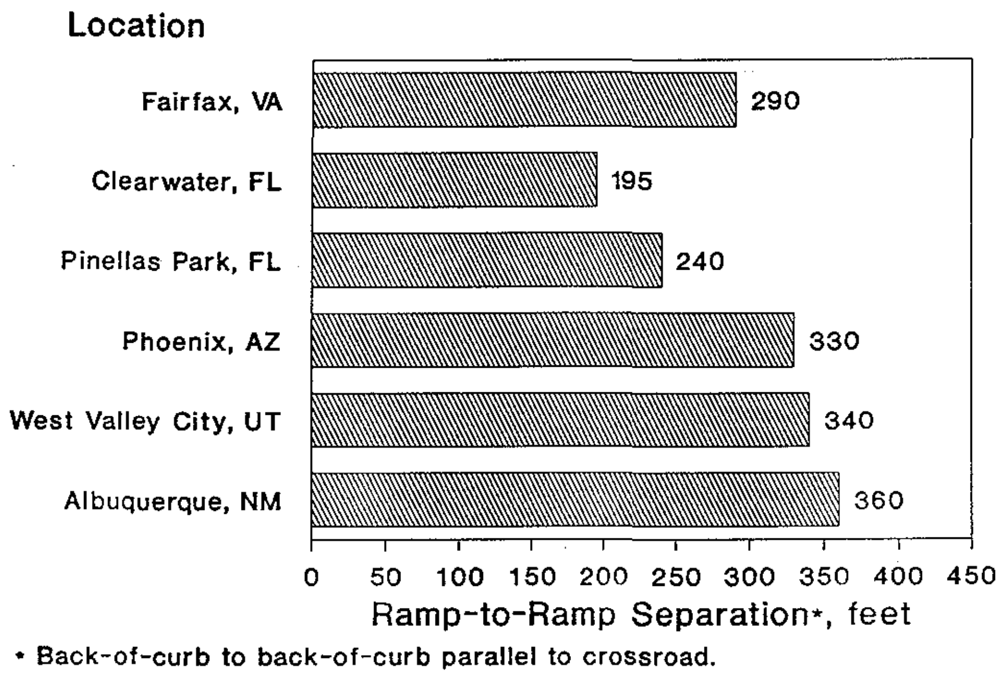


Figure 3-2. Horizontal Ramp-To-Ramp Separation.

It has been suggested that the SPUI has the advantage of being adaptable to relatively narrow rights-of-way. In fact, it has been suggested that a "tight" SPUI design requires "considerably less" width along the major roadway than would a conventional diamond interchange (1,8). In this regard, it has been implied that a conventional diamond interchange would require at least 250 feet between ramp curbs (8). Comparable SPUI widths are shown in Figure 3-2. This comparison suggests that a SPUI can be constructed within a narrower major road right-of-way than could a conventional diamond interchange. On the other hand, the SPUI design would require a longer span bridge and may experience operational problems on the narrow ramps.

Several SPUIs have been constructed that are much wider than the minimum possible width. Apparently, the SPUI's "advertised" potential for right-of-way savings is not the dominant reason for its selection over other design alternatives. At this point, it is probably fair to say that the SPUI and some variations of the conventional diamond interchange generally have similar right-of-way requirements.

3.2.2 Left-turn Requirements

The left-turn maneuver at a SPUI is one of the more unique elements of its design. In general, both the crossroad and off-ramp left-turn movements have travel paths with large radii, typically in the range of 200 to 300 feet. In contrast, the left-turn radii at conventional diamond interchanges range from 50 to 75 feet.

With respect to a conventional diamond interchange, the SPUI's large left-turn radii appear to have the advantage of better operation, particularly if large trucks form a significant portion of the traffic stream. Another apparent advantage of the SPUI's left-turn treatment stems from the fact that its opposing left-turn tracking paths are offset and thereby permit the simultaneous operation of opposing left-turn movements. This is similar to the left-turn operation at high-type at-grade intersections. This type of design provides a smoother turning maneuver and is probably more efficient than the double conflicting left-turn maneuvers inherent to conventional diamond interchanges.

Examination of off-ramp geometrics suggests that the radius of the left-turn movement is dictated by the right-of-way requirements, bridge span lengths, and width of the major roadway. In general, larger radii consume more right-of-way and/or increase the bridge length. On the other hand, these left-turn radii are also somewhat dependent on the width of the major roadway --a wider roadway will necessitate longer radii. In design, the size of the left-turn radii are primarily dictated by the right-of-way and bridge structure costs.

3.2.3 Right-turn Requirements

The operational analysis of most intersections is generally based on the assumption that the effect of right-turning traffic on overall operations is negligible and can be ignored. However, this assumption may not be valid at SPUIs. In fact, SPUI off-ramp right-turn movements appear to have a major impact on traffic operations (as do the on-ramp right-turn movements but to a lesser extent).

SPUI design with respect to right-turn geometrics has been found to vary in the number of lanes available and the type of operation (i.e., shared or exclusive lane use and stop, yield, or merge control). Experience with SPUI off-ramps suggests that left- and right-turn interactions may adversely affect ramp operation and safety. In general, the coexistence of left- and right-turn traffic in the same ramp throat area can restrict overall traffic flow unless these movements are provided exclusive lanes; this is true for any type of diamond interchange. However, the provision of exclusive lanes appears to be particularly important at SPUIs because the signalized operation of the left-turn movement is not compatible with the yield operation of the right-turn movement. More specifically, when the off-ramp left-turn phase is on, the off-ramp right-turning vehicles are restricted from entry to the crossroad by the opposing off-ramp left-turn vehicles (which move during the same phase). As a result, when left-turn vehicles can enter the interchange the right-turn vehicles are heavily opposed and when the right-turn vehicles can enter with little conflict the left-turn vehicles are stopped by the signal.

Current design practice varies widely in the treatment of off-ramp right-turn geometry. In particular, some SPUI designs have exclusive right-turn entrance lanes onto the crossroad, while other designs merge right-turn traffic into the outside through lane. Similarly, right-turning radii ranging from 70 to 200 feet were found during the field survey. Much of the variability in radii can be explained by differences in design volume and local practice; however, it may also be an indication of the need for better understanding of the right-turn maneuver's design requirements at a SPUI.

3.2.4 Channelization

It appears that the intrinsic features of SPUI design require a large area of relatively uncontrolled pavement in the center of the interchange area into which traffic flows from almost every direction. Consistent with the design of most large intersections, the SPUI design commonly includes some form of channelization to minimize this uncontrolled area. In addition to regulating traffic flow, this channelization is used to separate conflicting traffic streams and to provide areas of pedestrian refuge.

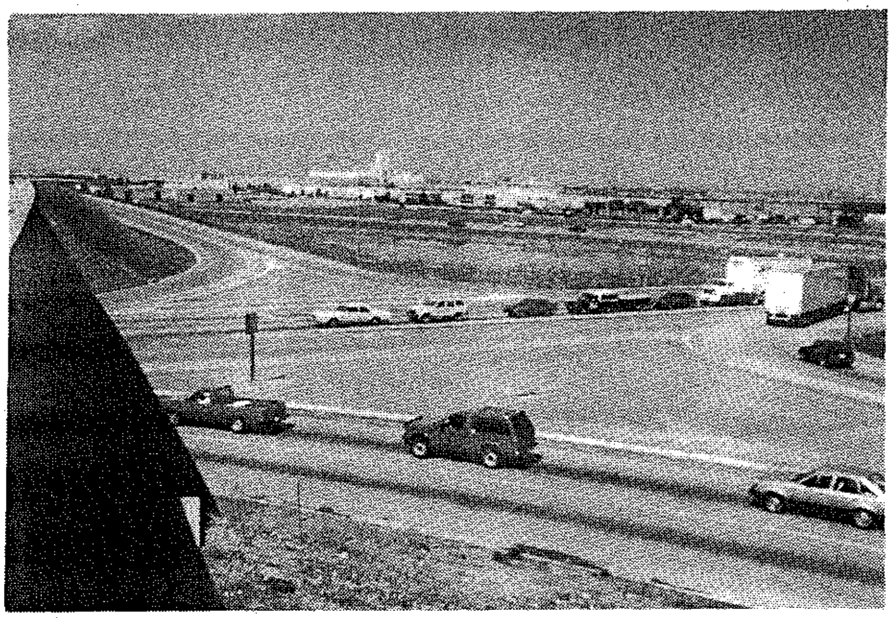
Typically, SPUI's have four large islands--one at each ramp/crossroad intersection. Based on the field survey data, the surface area of these islands was found to vary from 2400 to 33,000 square feet. To illustrate this variability in island design (and ramp geometrics in general), Figure 3-3 is provided on the following page.

Other channelized areas at SPUI's often include a small island at the center of the intersection area and raised medians along the crossroad. At least one SPUI was found to have several other channelized islands within the intersection area (in addition to the center island) to further separate the left-turn movements.

3.2.5 Sight Distance

The design of many roadway elements is based on providing minimum (or desirable) stopping sight distance for the driver. However, sight distance within an interchange must be sufficient for the driver to perceive and react to potentially hazardous conditions or multiple information sources. The increased amount and complexity of information presented to a driver approaching an interchange requires even more time for the detection, reaction, and maneuver components of the driving task. The total distance needed by the driver to complete the decision-response process is often called "decision sight distance." In general, decision sight distance exceeds desirable stopping sight distance by about 300 feet.

Based on sight-distance considerations, the horizontal and vertical alignments at an SPUI should be designed to provide more than the minimum stopping sight distance. In fact, AASHTO policy specifically identifies the interchange as a critical area wherein the design should be based on decision sight distance (9). Although this recommendation is primarily directed towards sight distance along the major roadway, it also applies to the on/off-ramps and crossroad.



a) 3200 West & 2100 South, West Valley City, Utah.

b) US 19 & SR 694, Pinellas Park, Florida.

Figure 3-3. Off-ramp Geometry at Two Single-Point Urban Interchanges.

The design of the SPUI has several elements that affect driver sight distance. These elements include the basic horizontal and vertical alignments, skew angle, bridge support treatment, and the location and placement of traffic signal heads. Each of these elements affects the sight distance provided to drivers on the crossroad and the off-ramps; however, their effect on drivers on the off-ramps may be more severe.

Traffic signal visibility by off-ramp drivers can be restricted in many instances by the retaining wall structure associated with an elevated major roadway. To various degrees, the signal head is often located on the approaching driver's left, along the leading edge of the bridge structure. However, this location is usually not ideal in terms of visibility because it is not along the driver's immediate travel path. In addition, the suitability of this location may be further compromised by designs that have skewed alignments and/or minimal separation between the ramp and grade separation structure. Figure 3-4 contrasts the visibility of the off-ramp left-turn signal heads at two different SPUIs.

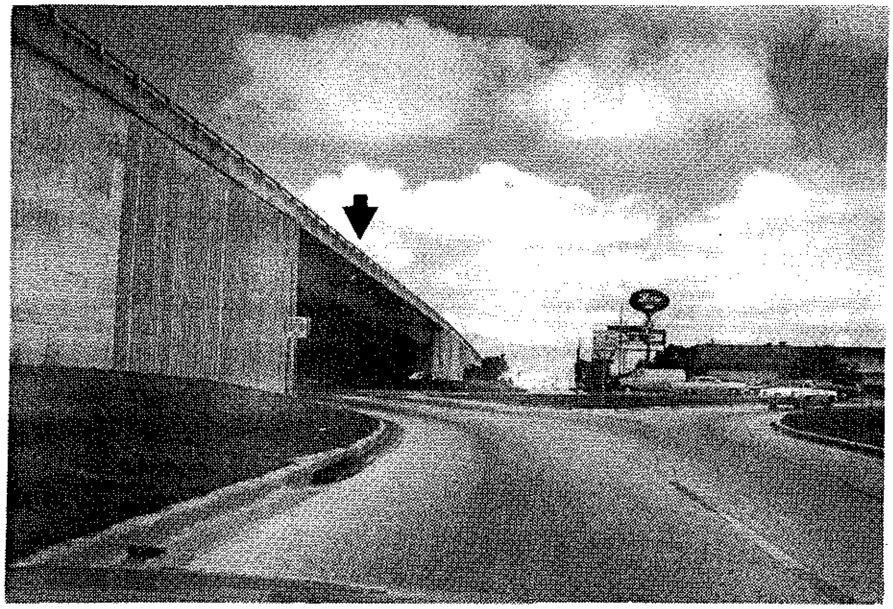
Another element of the SPUI design that affects sight distance is the bridge support structure. In general, SPUIs have been constructed using both single-span and three-span structures. In addition to number of spans, these designs differ in the type of end treatment - the three-span structure uses an open-end, sloped-earth abutment, whereas the single-span uses a closed-end, vertical retaining wall/abutment combination. Observation of both abutment designs suggests that the open-end span offers better sight distance through the interchange area than does the closed-end abutment. The open-end span may also reduce the driver's perception of restrictiveness (or "tunnel" effect) caused by the shorter, single-span with vertical abutments.

3.2.6 Stop Line Separation

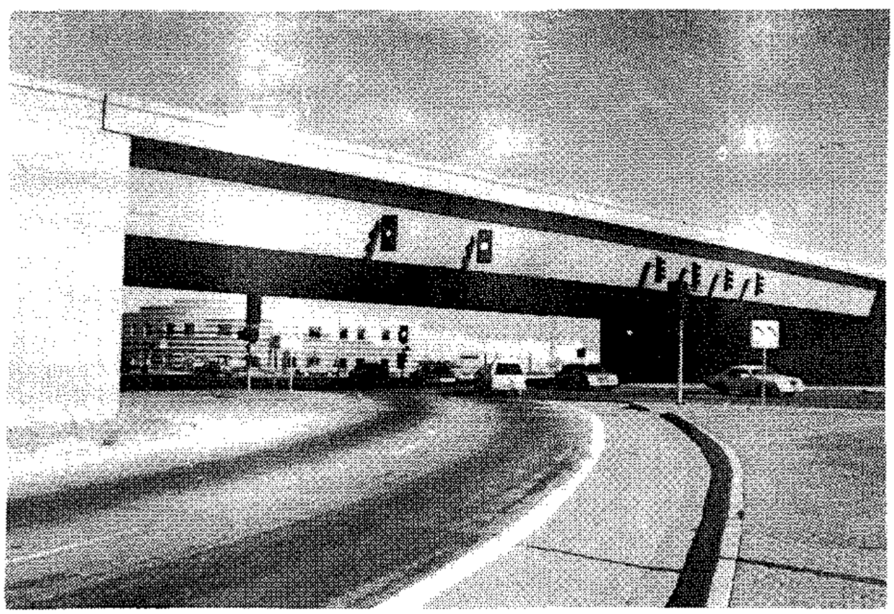
For this discussion, stop line separation is defined as the distance between opposing through traffic stop lines as measured along the crossroad. Although the impact of longer stop line separation is not, as yet, well understood, it is likely that the safety and quality of operation will deteriorate as this distance increases.

The most important criterion for locating stop lines at any intersection is that they be placed such that vehicles stopped behind them are not in the path of conflicting traffic. However, from the standpoint of efficient traffic operations, stop lines should be placed as close as possible to the intersection conflict area to minimize the time motorists need to cross (or clear) the intersection. This preference reflects the fact that signal capacity is increased when clearance time is reduced. Thus, there would appear to be an optimum stop line separation that is wide enough to avoid vehicular conflict but not so wide as to degrade safety or efficiency.

The field survey found stop line separations in the range of 195 to 250 feet. The variation of this distance among the six SPUIs is shown in Figure 3-5. Factors that appear to influence stop line location include left-turn radii, bridge width, and skew angle between the intersecting roadways. In general, stop line separation tends to increase with increasing bridge width, angle of skew, left-turn radii, and frontage road treatment.



a) US 19 & SR 60, Clearwater, Florida.



b) SR 143 & University Drive, Phoenix, Arizona.

Figure 3-4. Signal Head Visibility at Two Single-Point Urban Interchanges.

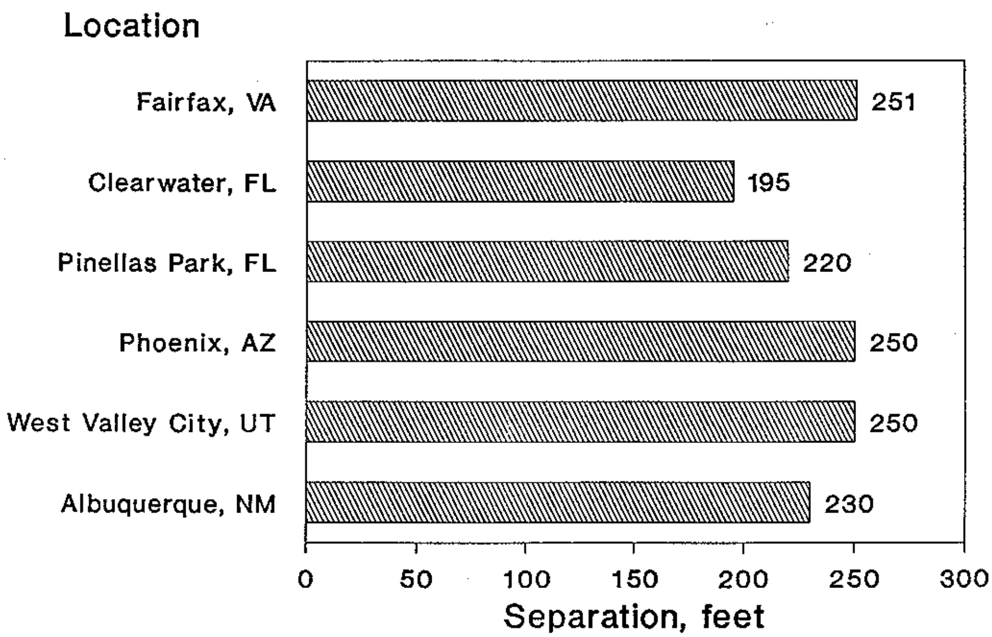


Figure 3-5. Stop Line Separation Along Crossroad.

Bridge width can affect stop line separation because the signal heads mounted on each side must be at least 40 feet from the crossroad stop line. This minimum separation is needed to satisfy the Manual on Uniform Traffic Control Devices' (MUTCD) signal visibility requirements. Similarly, skew can affect stop line separation because it increases the effective width of the bridge along the crossroad. In recognition of the adverse effects of skew on traffic operations, one engineering firm with experience in SPUI design suggests that skew angle be kept at 30 degrees or flatter, if possible (10).

The field survey of operational SPUIs indicated a wide variety of skew angles. In particular, the angle of skew was found to vary from -12 degrees to +15 degrees. The sign of the skew angle is defined as the rotation of the crossroad relative to the major roadway--a clockwise rotation of the crossroad from normal being positive.

A preliminary, analytic investigation of the effects of skew indicates that a negative skew increases stop line separation, although it may also marginally improve the visibility of the off-ramp, left-turn signal heads. This effect can be seen in Figure 3-6, which shows a SPUI location having a negative 12-degree skew. In this instance, the counterclockwise rotation of the crossroad tends to "push" the stop lines further back along the crossroad. The need to move the stop lines back stems from the "minimum 40-foot stop line setback" criterion recommended by the MUTCD.

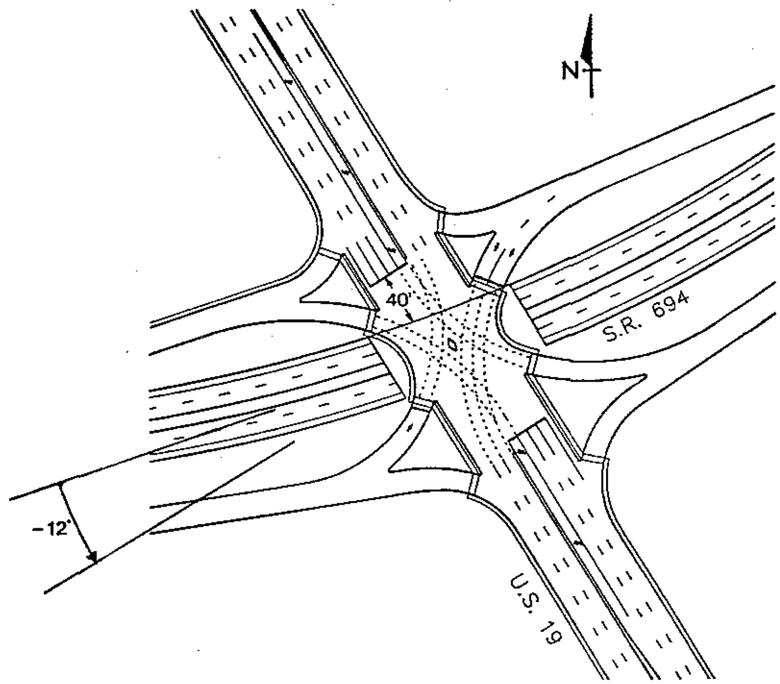


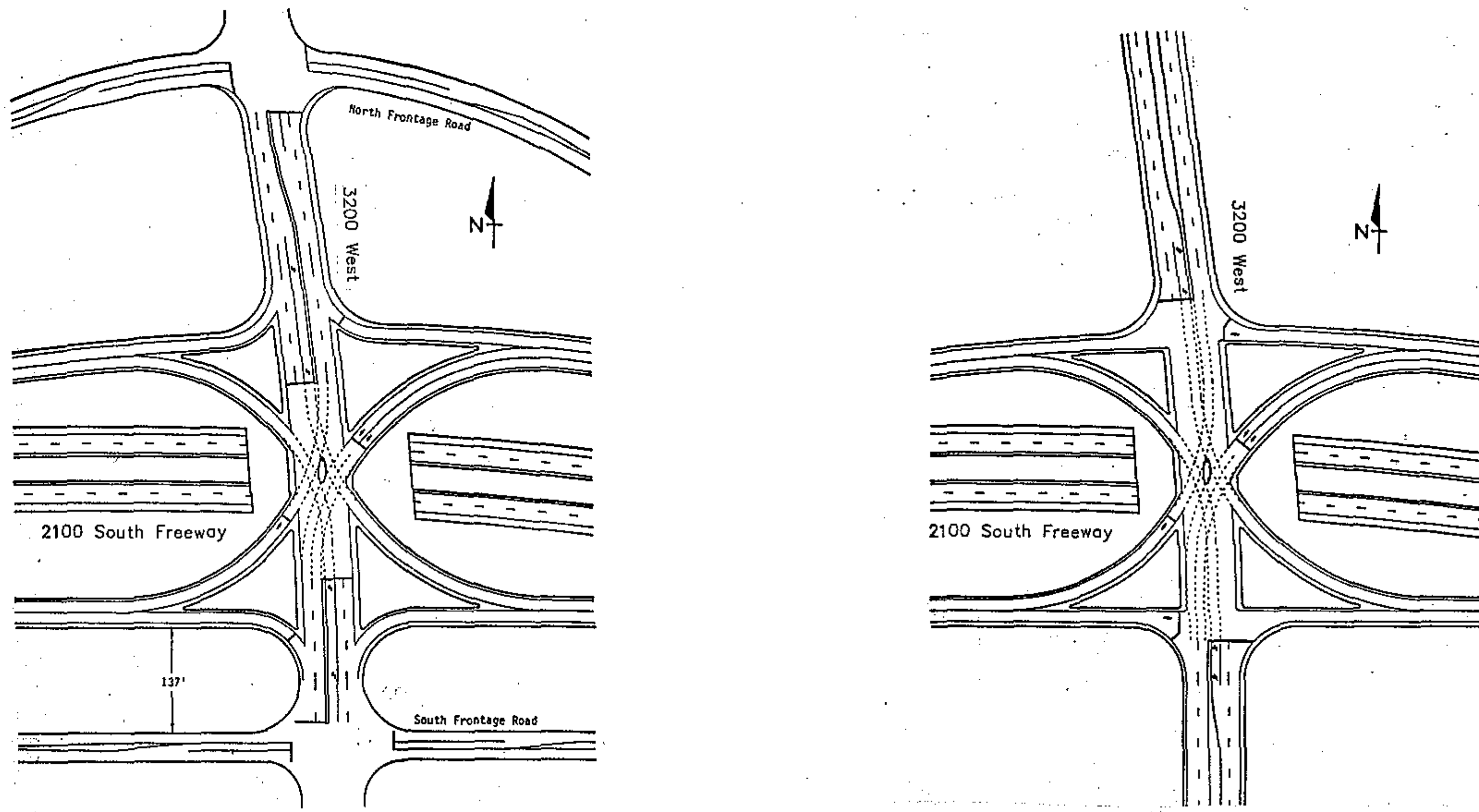
Figure 3-6. Effect of Skew Angle on Stop Line Separation.

3.2.7 Frontage Roads

Frontage roads along major urban roadways serve as important access routes to adjacent businesses. Frontage roads also collect and distribute traffic between the major roadway and the local street system. Desirable operational features of frontage roads in urban areas are that they be one-way and continuous. Despite the many advantages of frontage roads, the connection of the continuous frontage road with the interchange ramps at the crossroad junction can add significant operational complexity to the interchange.

In general, two continuous frontage road treatments are applied at SPUIs: 1) the frontage roads are laterally offset (or separated) along the crossroad, as shown in Figure 3-7a; or 2) the frontage roads and ramps are merged into one junction with the crossroad, as shown in Figure 3-7b. In the second treatment, the frontage roads can only serve one-way traffic. Although it is possible to have a continuous frontage road system with the SPUI design, the few SPUIs that have frontage roads merged with the ramps have been designed such that the frontage roads terminate at the crossroad.

The offset two-way frontage road system depicted in Figure 3-7a was studied during several peak and nonpeak hours of the day. Although the frontage road signals are coordinated with the SPUI signal, traffic operations were found to be very complex and congested during most of the peak rush hours.



a) Offset Frontage Road.

b) Combined Off-Ramp and Frontage Road.

Figure 3-7. Frontage Road Treatments at Two Single-Point Urban Interchanges.

To date, it is estimated that half of all SPUIs have offset or discontinuous frontage roads (i.e., those that terminate at the crossroad). Although the capability for extending the frontage road system through the SPUI exists, there is some concern about the adverse effect that the additional frontage road signal phase may have on interchange operation. In addition to the additional signal phase, there is concern that frontage roads will increase stop line separation which may also indirectly reduce the interchange's capacity by increasing signal clearance interval requirements.

3.3 STRUCTURAL DESIGN EVALUATION

The structural features of the SPUI present several unique design challenges. In general, the SPUI configuration can be applied to both elevated and depressed major roadways. The seemingly simple structural designs of either grade separation type, although physically quite different, are both equally complex. Complexities are introduced for many reasons including long bridge span requirements, high retaining walls, and constraints resulting from the ramp/structure interaction. These complexities necessitate a very thorough structural design and construction analysis. This process does, however, have the potential to be simplified by increased design standardization as further experience with the SPUI design is acquired.

3.3.1 Elevated and Depressed Designs

The SPUI design can accommodate either a depressed or an elevated major roadway. Currently, both elevated and depressed designs have been built and are operational (see Figures 2-1 and 2-2). Both design types have application, depending on economic, topographic, groundwater, utility, and environmental constraints for a given site. Compromise solutions that have partially depressed or partially elevated designs are possible, but are believed to be nonexistent at this time. It is estimated that there are about 10 elevated SPUIs for every depressed SPUI in the United States. In fact, several depressed SPUIs were observed to be under construction in Phoenix, Arizona, at the time of the field survey.

Of the two designs, the depressed SPUI appears to have the greater design complexity. Apparently, the complication stems primarily from the integration of ramp terminals with the expansive bridge deck. In addition, the timing and sequencing of construction are critical to balance the interactive stresses that result from the ramp and bridge deck interface. An excellent discussion of the complexities encountered during the design and construction of a depressed SPUI in Phoenix, Arizona, can be found in a recent issue of Civil Engineering (11).

3.3.2 Bridge Span Length

The design of the bridge structure is one of the most complicated and expensive components of the SPUI. These attributes are the result of the large clear span distances necessitated by the SPUI design. Additional complications may also be introduced when the "depressed" SPUI design is used (as discussed previously).

In general, the depressed and elevated SPUI designs require center clear span lengths of about 120 and 200 feet, respectively. The latter distance seems to be slightly less (about 10 percent) if a three-span structure is used. Figure 3-8 illustrates the bridge span lengths of the six SPUI's studied. A comparison of those SPUIs with single-span bridges indicates that the span lengths are fairly constant at 200 feet. This figure may be compared to span lengths in the range of 100 to 150 feet found at conventional diamond interchanges.

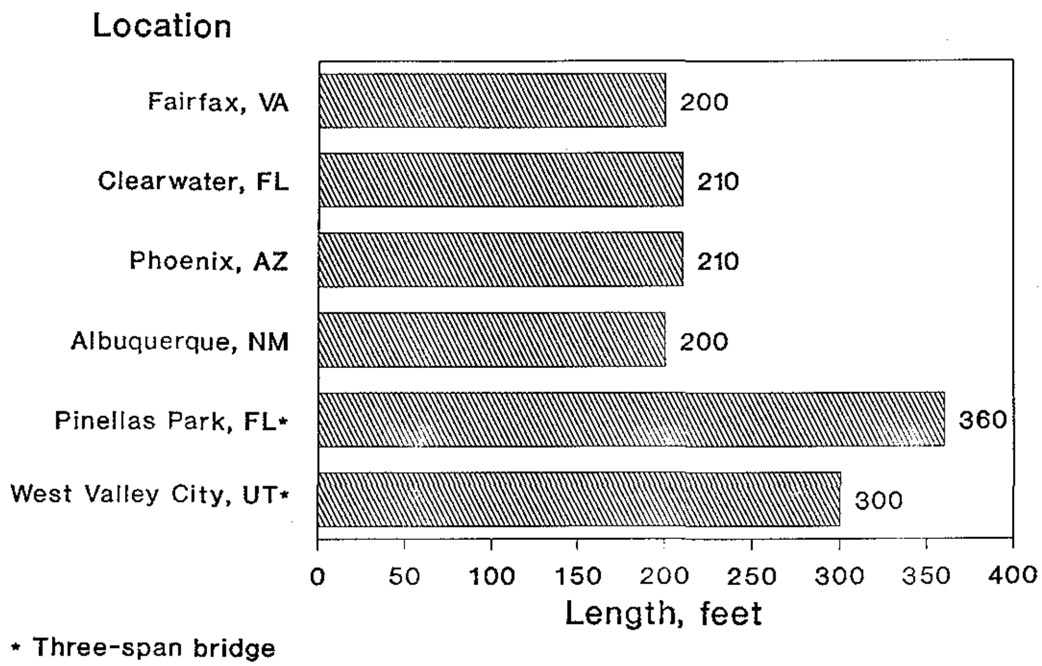


Figure 3-8. Bridge Span Length.

It should be noted that a SPUI under construction in Salt Lake City, Utah, has a single-span bridge length of 270 feet and a width of 160 feet. This bridge is being designed to carry an eight-lane cross section over a four-lane industrial park access road. Its massive size is due partly to the width of the crossroad and partly to the narrow right-of-way available along the freeway alignment. Because right-of-way is limited, the off-ramp, left-turn radii must be placed almost entirely under the bridge deck. As a result, the bridge span was lengthened to accommodate the "tight" (limited ramp-to-ramp separation) design.

The longer bridge span lengths common to the SPUI necessarily influence the structure's depth and the lateral spacing of its girders. In general, the longer-span structures require deeper girders, closer spacing between girders, or both. The depth of structure at the SPUI's surveyed was fairly constant at about 8 feet. In comparison, the structural depth at a conventional diamond interchange is usually in the range of 3 to 5 feet.

The girders for long-span bridges may be constructed of steel or prestressed concrete. Although steel has been the more commonly used material, concrete has been used at a few SPUIs. The girder section most commonly used is the box shape; however, I-beams have also been used when made of steel. Concrete construction uses the box-section girder exclusively with either pre- or post-tensioning.

3.4 FUNCTIONAL PERFORMANCE EVALUATION

Some of the more controversial issues regarding SPUIs are related to their operational safety and efficiency. Conceptually, these issues would appear obvious and definable when considering the overall operation of the interchange but, in fact, several traffic elements interact within the interchange area that tend to obscure the SPUI's true operational nature.

In general, the functional performance of any signalized junction can be assessed in terms of the following measures: volume-to-capacity ratio, delay, percent stopping, quality of flow, and accident history. These measures are primarily directed towards assessing vehicular performance; however, similar measures could be applied to both pedestrian and bicycle traffic.

Traffic demands at the SPUIs surveyed are consistent with those found at other conventional diamond interchanges and high-type signalized intersections. Figure 3-9 illustrates the range of daily crossroad traffic volumes found during the field survey.

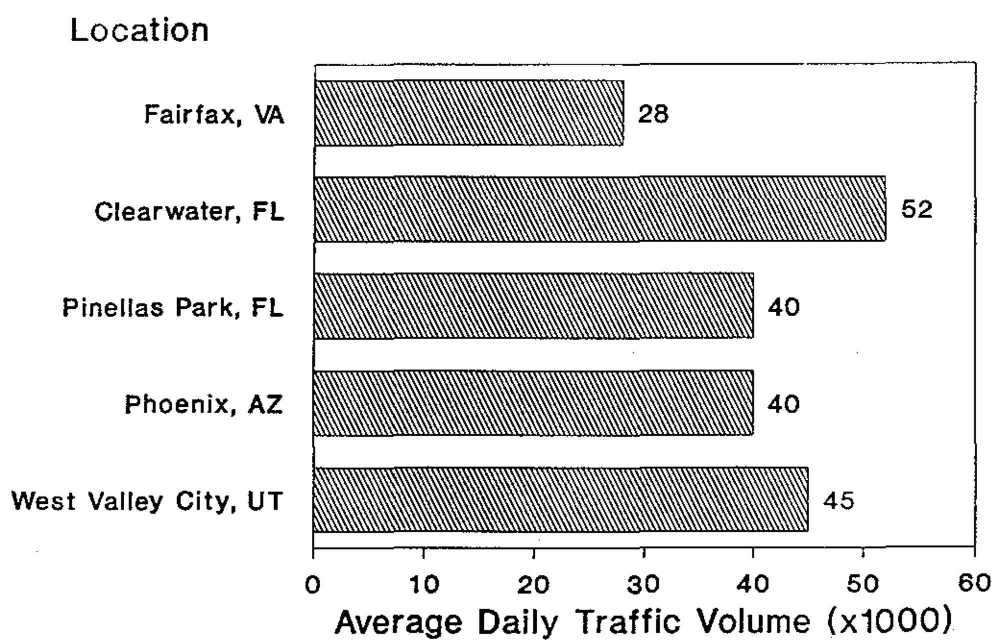


Figure 3-9. Daily Traffic Volume on Cross Road.

The operation of a SPUI is more complex than might be initially perceived. This complexity stems from the many unique elements of the SPUI including the:

1. Unique operation of the on- and off-ramps at their intersection with the crossroad.
2. Large area of uncontrolled pavement within the interchange and the potentially long time interval between conflicting phases needed to clear this area.
3. Pedestrian crossings and their signal phasing.
4. Geometric elements that are inconsistent with driver expectation.
5. Operational differences between the left-turn maneuvers at conventional and single-point diamond interchanges.

Each of these issues will be briefly discussed in the following sections.

3.4.1 Traffic Capacity

Typically, the type and number of traffic lanes in the basic interchange cross section is a function of the approach capacity needed to serve traffic demands. Therefore, any comparison of cross-sectional needs between interchange types is dependent on the amount of approach capacity that each interchange configuration provides.

The principal advantage of using an interchange design over an at-grade intersection is the elimination of major route traffic from the intersection. Of course, this is accomplished by grade separating the major roadway from the at-grade conflict area. Once the major road traffic demand is removed, the intersection is reduced to that of the crossroad with the remaining major road turn movements. The result is a modest increase in capacity for the remaining at-grade movements and a significant increase in capacity for the grade-separated movement.

The comparison of potential capacity between the SPUI and conventional diamond interchange is not as obvious as with the upgrade from an at-grade intersection to an interchange. Previous studies have suggested that a SPUI can offer an increase in capacity depending on geometrics and traffic distribution; however, these estimates have ranged from 0 to 100 percent (2,8,10). This variability is primarily a result of the various assumptions made by each analyst and serves to further illustrate the present uncertainty about the SPUI's operational nature.

Based on experience with the SPUI's operation, it appears that the total capacity of the interchange is largely influenced by the number of traffic lanes, the number of signal phases, the degree of balance in traffic demands, the amount of traffic interaction on the off-ramps, and the amount of time lost clearing the intersection area after each conflicting signal phase. Obviously, a fair comparison of the capacity between the SPUI and the conventional diamond interchange must consider each of these conditions individually and in combination.

To illustrate current philosophical differences in SPUI operation, current signal timing strategies observed during the field study have been compiled. This compilation indicates that full-actuated five-phase control is fairly standard at SPUIs. However, observed timings of the yellow change interval and the all-red clearance interval vary widely from site to site; as shown by Figure 3-10. Undoubtedly, differences in signal timing philosophy and methodology exist among the local agencies responsible for the various SPUIs.

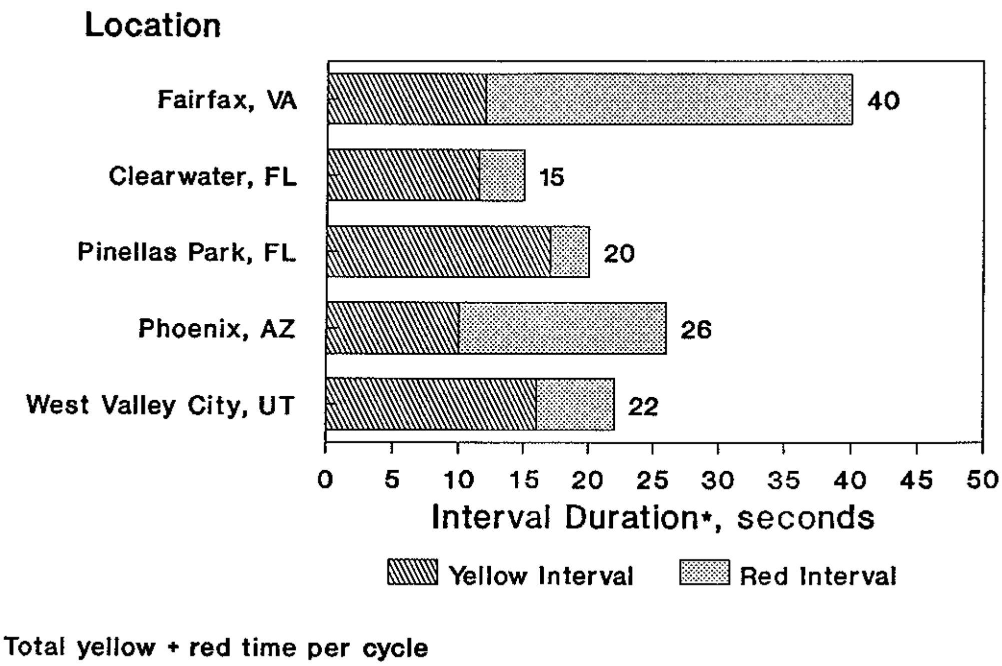


Figure 3-10. Total Change Interval for Three Phases.

3.4.2 Ramp Operations

The operational efficiency and safety of the SPUI is believed to be particularly sensitive to ramp terminal performance. This is thought to be true for both the on- and off-ramps; however, the off-ramps appear to be more critical to overall operation. The on-ramps generally operate satisfactorily, since the only area of potential conflict is where the left- and right-turning flows merge. However, operational problems have been found to arise in the on-ramp merge area under high-volume conditions. At least one agency has resolved this situation by assigning right-of-way to left-turning traffic via a YIELD sign.

Off-ramp movements at two SPUIs were found to have significant interaction because of the different traffic control methods used for left- and right-turning traffic (i.e., left-turn signal vs. right-turn yield or merge). The problem is most serious when the two movements share a common ramp lane (or lanes) such as would be found during high-volume periods and/or when fully separated lanes are not provided. The combination of mixed control modes and directional preferences creates an adverse interaction between the two flows. Ideally, the two flows would have exclusive left- and right- turning lanes of sufficient length along the off-ramp to store the maximum number of left-turn vehicles that would arrive each signal cycle (see Section 3.2.3).

The merge capacity of the off-ramp right-turn movement into the crossroad is also a potential problem. Unlike most signalized intersections, right-turn movements at SPUIs do not have a concurrent through phase to provide entrance opportunity. As a result, right-turn traffic usually must merge into acceptable gaps in the cross traffic. This right-turn operation is complicated by the SPUI's signal phase sequence which projects traffic in dense platoons past the right-turn merge point during two of the three basic signal phases. The only time right-turn traffic on the off-ramp can efficiently merge is during the crossroad left-turn phase; however, this phase may not always be long enough to satisfy the right-turn demand.

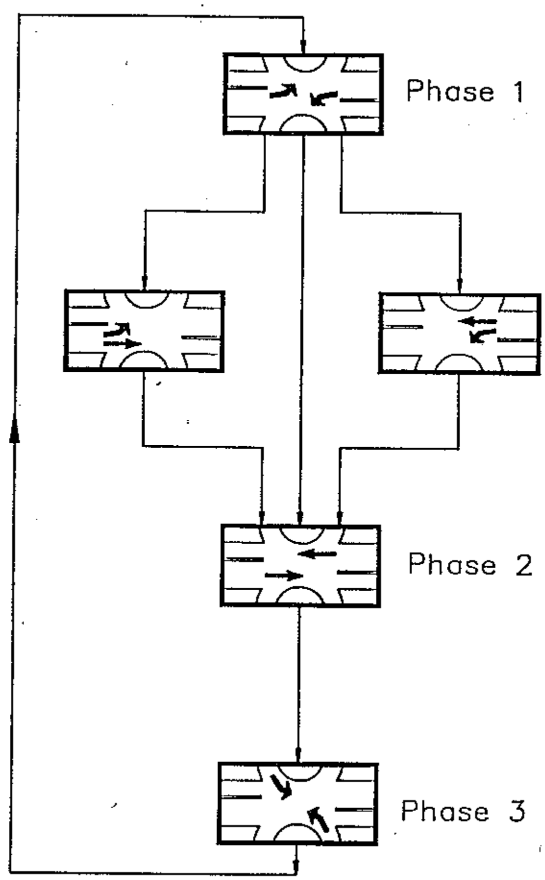
On a broader scale, the off-ramp right-turn merge may also be complicated by being relatively near downstream signals (as would be found with offset, signalized frontage roads). Problems that are created by this situation include high-speed-differential weaving maneuvers and the potential for rear-end accidents. In addition, it appears that drivers may be reluctant to use right-turn merging lanes, provided on the crossroad, when downstream signals are present. When this occurs, the drivers resort to a yield-type operation and merge from the off-ramp directly into the nearest through traffic lane. Obviously, this action creates considerable delay and congestion for ramp traffic during periods of high demand.

Remedies to the SPUI's off-ramp right-turn merge problem have included right-turn signalization and detectorization. To date, these remedies have had only mixed success because of their tendency to adversely affect the interchange's overall operation.

3.4.3 Traffic Control

There are many elements to the traffic control scheme used at SPUIs. These include the type of controller, signal phasing, coordination, signal head placement, advance lane-use signing, and pavement markings. Each of these will be discussed briefly in the following paragraphs.

Most of the SPUIs studied used NEMA 8-phase controllers. This type of control offers a uniformity, simplicity, and interconnection capability that is highly desirable and difficult to match with conventional diamond interchange control. This NEMA controller serves traffic using either three or four basic phases (i.e., 5 or 8 NEMA phases) depending on whether or not continuous one-way frontage roads are present. The basic 3-phase sequence, shown in Figure 3-11, is used at all SPUIs except those with continuous frontage roads. When continuous one-way frontage roads are present, a fourth phase is added following Phase 3.



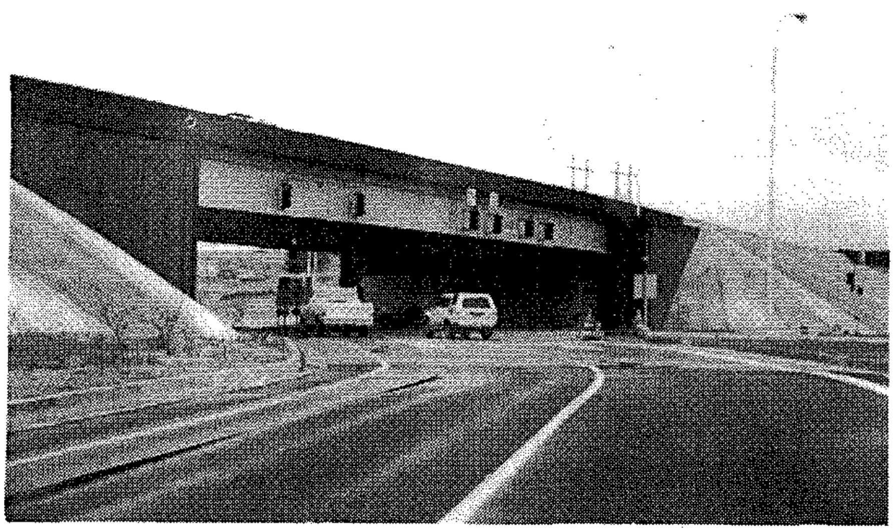
Standard NEMA 8-Phase Control.

Figure 3-11. Typical Phase Sequence at Single-Point Urban Interchanges.

Signal head placement is dependent on the type of grade separation. The depressed SPUI design commonly uses a box-shaped span-wire configuration to support the signal heads, as shown in Figure 3-12a. In contrast, signal heads used with elevated bridge designs are almost always mounted on both the side of the bridge and suspended from beneath the bridge deck, as shown in Figure 3-12b. For either design, additional signal heads and supports are needed if the right-turn movements are signalized.

Some concern has been raised about the location and visibility of the off-ramp left-turn signal heads for the elevated SPUI design. Currently, the only advance signal heads used are those mounted along the side of the bridge structure (see Figure 3-4). This location may be only marginally visible to oncoming motorists, depending on their angle of approach to the structure. It

a) US 50 & SR 650, Fairfax, Virginia.



b) Paseo Del Norte & Coors Boulevard,
Albuquerque, New Mexico.

Figure 3-12. Signal Head Placement at Two Single-Point Urban Interchanges.

is possible that the left-turn signal heads would be more effective if they were extended further away from the side of the bridge.

Guidance through the SPUI intersection area is aided by the use of skip stripes along the left-turning paths. Unfortunately, these markings are often obliterated after only a few months of operation. Even when the stripes are maintained properly, their effectiveness is limited during periods of inclement weather (e.g., snow and/or ice).

In recognition of the SPUI's inherent need for positive guidance through the conflict area, several designs have included embedded, directional pavement lights. These lights are more commonly used to delineate airport runways; however, they have had some application to roadway delineation. In particular, they have been installed at SPUIs along one or both sides of the left-turn path and are sequentially activated by the left-turn signal.

At present, application of these pavement lights has been only marginally successful, although they do appear to be effective in guiding vehicles through the interchange at night. It would appear that the poor maintenance history (including frequent repair, cleaning, and high replacement cost) experienced at the few SPUIs where pavement lights have been installed will have to be improved before the lights will become more acceptable. To date, user experience suggests that pavement lights are probably not cost-effective.

Several existing, elevated SPUI designs use advance lane-use signing in recognition of the SPUI's unconventional operation (with respect to conventional diamond interchanges). Conceptually, this approach is reasonable and consistent with the driver's need for supplemental information in areas of unusual geometry or competing information sources. The typical approach to advance signing at complex intersections is to support lane use signs over each lane on the approach. Desirably the sign support structure would be located at or just beyond the point where the left-turn lane is fully developed (see Figure 2-1). Another, slightly less effective but more economical approach would be to locate the lane use signs along the side of the bridge structure (as shown in Figure 3-12b).

3.4.4 Safety

The unusual, or at least unfamiliar, geometry and operation of the SPUI raises several concerns about the safety provided for both pedestrians and motorists traveling through the interchange. In particular, the fundamental provision of a pedestrian crossing phase is not easily added to the basic 3-phase sequence without significant compromise in capacity (during periods of pedestrian use). This problem stems primarily from the lack of a through traffic phase across the crossroad which would provide a concurrent pedestrian crossing opportunity. Pedestrian and bicycle traffic crossing the ramps, parallel to the crossroad, are also disadvantaged in those instances where the right-turn ramp movements are unsignalized.

Of course, pedestrian issues may not be of great concern when the SPUI is located in areas where there is no pedestrian activity. However, in most urban areas some pedestrian activity is inevitable and must be considered. Potential treatments include adding exclusive pedestrian signal heads and phases or, as a minimum, providing a place of refuge on the crossroad median to facilitate pedestrians crossing during consecutive left-turn phases. Another possibility would be to incorporate a pedestrian/bicycle overpass into the grade separation structure.

Accident data for a limited number of SPUIs have been collected and examined to determine the existence and extent of any safety problems. The annual accident rates found during this investigation, shown in Figure 3-13, indicate a high degree of variability which is characteristic of the random nature of accidents.

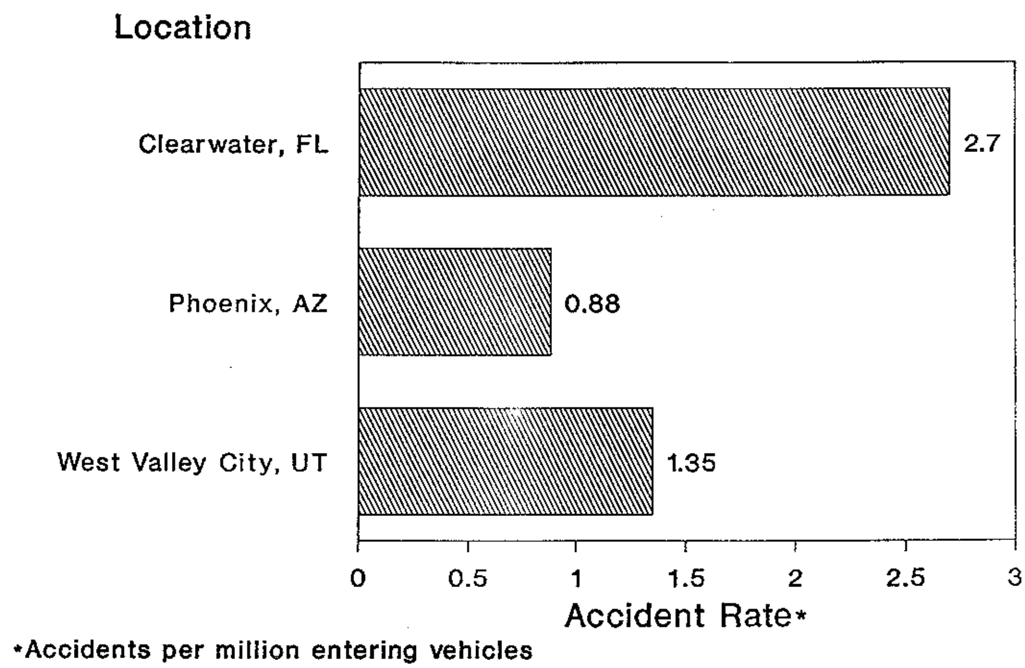


Figure 3-13. Accident Rates.

A review of the collision diagrams for each SPUI provided limited insight into recurring accident patterns. However, there did appear to be a relatively large number of rear-end accidents on the off-ramps at the Clearwater, Florida, site. It is possible that this problem is due to a deficiency in SPUI ramp geometry; however, additional study will be necessary to be more conclusive. For example, it is not clear from the collision diagrams whether right-turning vehicles rear-ended other right-turning vehicles or whether some left-turning vehicles also rear-ended right-turning vehicles.

To supplement the sparse accident history at these relatively new SPUIs, traffic conflict studies may be necessary to determine driver behavior at SPUIs. Based on the field study, several unusual maneuvers have been observed that suggest that only a small percentage of drivers may be confused by the SPUI's design and operation.

3.5 COST-EFFECTIVENESS EVALUATION

One recent benefit-cost analysis compared the SPUI to an at-grade intersection (3). This analysis considered driver operating costs, accident reduction, and vehicle emissions for three traffic demand levels. This analysis was based on a life-cycle of 20 years and allowed for nominal traffic growth over this period. Based on this analysis, it was concluded that the SPUI would yield benefit/cost ratios of 2.5 to 3.5, depending on traffic demand. Moreover, the author concluded that SPUIs were economically viable at daily entering traffic levels as low as 40,000 vehicles, provided that the traffic growth rate was over 3.5 percent per year.

3.5.1 Basic Cost Components

There are many components of the SPUI that are unique and, as a result, have higher than normal costs associated with them. These components include the various design, construction, and maintenance elements of the initial interchange cost as well as the costs incurred during the interchange's daily operation. The initial cost components that are relatively higher with the SPUI design include the bridge structure, the retaining wall, and possibly the right-of-way.

In addition to the initial cost components, the SPUIs unique features impact the magnitude of the secondary, or daily, cost components. These components must also be considered for their incremental contribution to the operating cost of the interchange. These components may include: restrictions in visibility and access to adjacent property, increases (or decreases) in accident frequency and severity, road user costs (including delay, stops, and fuel consumption), and environmental impact costs.

3.5.2 Right-of-Way Costs

Unquestionably, the SPUI requires more right-of-way than would an at-grade intersection. This additional area is the result of the greater cross-sectional width needed along the major roadway. The additional components of this width include the grade separation transition zone and the basic width of both ramp cross sections. Brown and Walters have estimated that an SPUI would require "three times as much right-of-way" as an at-grade intersection, assuming both designs have the same number of approach lanes (8).

A comparison of the SPUI's right-of-way needs with that of the conventional diamond are not quite as conclusive as the previous comparison. The more commonly held belief is that the SPUI requires less right-of-way than does the conventional diamond interchange of similar capacity and with similar design criteria (1,8,10,11). This reduction in right-of-way would result from the overlapping or inverting of the left-turn movements within the SPUI. This permits the off-ramps to be located much nearer to the grade separation structure than they would be at a conventional diamond interchange.

Another instance where SPUI right-of-way needs may be comparatively less than at conventional diamond is along the crossroad. In particular, the SPUI design allows the crossroad left-turn bays to be offset (i.e., oppose one another). In contrast, a conventional diamond interchange that has advance left-turn lanes cannot offset these lanes. As a result, the SPUI will have a narrower right-of-way need, given the same number of lanes in the cross section. Based on this type of comparison, it has been suggested that the SPUI requires only about 75 percent of the right-of-way needed by the conventional diamond interchange built for similar geometric and demand conditions (8). It should also be noted that this conclusion may not be true if the conventional diamond interchange uses "4-phase with overlap" signal phasing. This type of phasing could preclude the need for advance left-turn bays on the crossroad.

3.5.3 Cost Estimates

Several estimates of SPUI design and construction costs have recently been published (3,8). More important than the actual numbers stated is the wide variation in the assumptions and components included in the cost estimates. In general, the cost of any traffic facility is highly dependent on the cost of right-of-way, construction materials, and labor for each specific area. Recognizing these sources of variability, one author has estimated the cost of SPUI design and construction (excluding right-of-way) at $5.5 million for a "standard" design with an elevated major roadway (8). This figure of $5.5 million is also quoted by another source as the construction cost for an SPUI with an elevated major roadway (3).

To illustrate the potential for cost variability, another author has stated that design and construction costs are in the range of $2.6 to $3.6 million for an SPUI with a depressed major roadway. This is in itself significantly lower than the $5.5 million previously estimated. It is even more significant when reflecting on the previous author's contention that the depressed design would have higher costs than the elevated design (i.e., higher than $5.5 million).

The initial cost of an elevated SPUI is likely to be higher than that of a conventional diamond interchange. The magnitude of this difference is a result of the longer bridge span, increased height of fill, and overall complexity of the SPUI design. A depressed SPUI design would probably add to the cost of design and construction because of the additional expanse and complexity of the bridge structure.

The additional cost of the SPUI compared to the conventional diamond interchange may be offset by the SPUI's reduced right-of-way needs. In recognition of these assumptions, it is estimated that the cost of the SPUI is in the range of $1 - $2 million (not including the right-of-way costs) over that of the conventional diamond.

4. INTERPRETATION OF SURVEY FINDINGS

Most elements of the SPUI have been discussed in general terms in the preceding sections. Those elements that were unusual, significant in effect, or frequently found at more than one SPUI during the field survey were considered important and deserving of further comment. The following sections will describe these elements and provide some interpretation of their impact.

4.1 GEOMETRIC ELEMENTS

1. Because none of the SPUIs had continuous frontage roads combined with the on/off-ramps, it was not possible to observe the impact of frontage roads on SPUI operation. However, if frontage roads were to exist, it is expected that they would increase stop line separation. In fact, stop line separation would probably equal the ramp-to-ramp width within the right-of-way. Frontage road traffic would also require an additional signal phase which would reduce the capacity of the other movements.

2. Large left-turn radii for a SPUI appear to have the advantages of:

   * Higher saturation flow rates and lower travel times.
   * Less off-tracking and/or adjacent lane encroachment.
   * Better perception-sight distance for drivers along the intended path.
   * Better visibility of bridge-mounted signal heads on off-ramps.
   * Increasing the separation between off-ramp left- and right-turn movements at their junction with the crossroad.

3. Large left-turn radii for a SPUI appear to have the disadvantages of:

   * Requiring more right-of-way (as much as other diamond interchanges).
   * Requiring greater separation of stop lines.
   * Requiring drivers to travel longer distances through the central interchange area with reduced positive guidance.
   * Creating larger islands and thus greater island areas to maintain.

4. When large left-turn radii (over 250′) are used on the off-ramps, medians wider than 4 feet can often be used to minimize stop line separation on the crossroad.

5. Factors that might necessitate larger left-turn radii include: a wider bridge structure, wider crossroad medians, and the skew angle between major and minor roadway alignments.

6. Factors that might increase stop line separation include: a wider bridge structure; a narrower median; a wider crossroad width; dual crossroad left-turn lanes; continuous frontage roads; and skew between roadway alignments.

7. Typically, the radius of the crossroad left-turn path is equal to (or slightly less than) that of the off-ramp left-turn path. However, a sharp skew in roadway alignments can disrupt this equivalence.

4.2 TRAFFIC OPERATIONS ELEMENTS

1. The limited field study suggests that there is some inconsistency in the timing of signal change intervals at SPUIs. This variation is most notable in the duration of the all-red, or red clearance, intervals. The use of an adequately-timed all-red interval at the end of each signal phase would seem particularly appropriate for SPUIs because of their large clearance distances.

2. Most SPUIs use NEMA 8-phase dual-ring control with leading crossroad left-turns. This type of control strategy offers a uniformity, simplicity, and interconnection capability that may not be available with conventional diamond interchange control.

3. The crossroad left-turn movement operates in the protected-only mode. It is assumed that permissive phasing is not used because of high crossroad speeds, three or more lanes on the opposing approach, long turn paths, and need for supplemental left-turn signals beyond the bridge structure.

4. At some SPUIs, the off-ramp right-turn maneuver may experience frequent queueing which would imply near-capacity operation. However, it is possible that this operation is a result of low entrance capacity as opposed to high right-turn demand. The entrance capacity for a "YIELD" controlled ramp movement is inversely related to the flow rate on the crossroad, which is typically quite high. In spite of this restriction, the off-ramp right-turn movement is generally not signalized.

5. If the off-ramp right-turn movement is signalized, the duration of the all-red interval of the preceding phase should be increased to include the additional time conflicting movements would need to clear the right-turning path. Of course, this would also increase the phase lost time which would result in a reduction in total SPUI capacity. Detectorizing the off-ramp right-turn movement has been tried with unsuccessful results at one SPUI in Phoenix.

6. In general, the calculated all-red interval for a SPUI is about three times longer than that found at typical signalized intersections. The use of appropriately-calculated, as opposed to no, all-red clearance intervals should result in a total capacity reduction of about 15 percent; however, the intersection should operate more safely. Because of their inherent need for long clearance intervals, SPUIs are often designed with additional through or left-turn lanes (beyond the number of lanes needed at a typical signalized intersection with similar traffic volumes) to compensate for the capacity reduction.

7. Based on a capacity analysis of selected configurations, the signalized conflict area at a SPUI should be able to serve the following maximum entering daily traffic volumes. Assumptions include a K factor of 0.085 and a directional split of 55:45 percent.

Lane Configuration:	Crossroad Through	Crossroad Left	Off-ramp Left	Maximum Intersection ADT
	4	1	1	42,000
	4	1	2	49,000
	4	2	1	49,000
	4	2	2	53,000
	6	1	1	60,000
	6	1	2	62,000
	6	2	1	63,000
	6	2	2	63,000

This table illustrates the effect that SPUI geometry has on capacity (via increased clearance intervals). In general, total capacity increases as lanes are added; however, the net increase becomes smaller as the number of lanes is increased.

8. When downstream signalized intersections along the crossroads are relatively close (i.e., less than 800 feet), they may:

   * Have queues extending back to the diamond interchange.
   * Reduce the efficiency of traffic flow by creating weaving sections.
   * Reduce the capacity of the off-ramp right-turn movements.
   * Require the signalization of the off-ramp right-turn movements.

4.3 SAFETY-RELATED ELEMENTS

1. From the limited amount of accident data that has been examined, it is not possible to conclude that the SPUI configuration has a relatively higher rate of accidents than other signalized intersections or interchanges.

2. A review of the accident diagrams at two SPUIs indicates that most accidents occur on the off-ramps. In particular, rear-end collisions among turning vehicles on the off-ramps is the single most common type of accident. One method of improving off-ramp safety might be to increase the separation between the off-ramp left- and right-turn movements at the crossroad junction. Of course, this would also increase the right-of-way needs for the SPUI.

3. In addition to the turn movement interaction described in #2 above, signal visibility may also be a factor in the high accident rates found on the off-ramps. At all SPUIs with elevated major roadways, the off-ramp signal heads are mounted on the edge of the bridge structure, to the left of the driver's line of vision. As a result, signal visibility is reduced to minimum levels. This problem could be avoided by supplemental signals or, as a minimum, offset by advance warning signs.

4. In general, the geometric design of the SPUI is "new" to many drivers. Advance lane use signing, pavement marking lights, nominal stop line separation, and additional channelization are techniques that should be considered to improve driver guidance through the interchange area.

4.4 OTHER ELEMENTS

1. Most SPUIs had sidewalks and painted crosswalks for pedestrians crossing the on/off-ramps parallel to the crossroad. Because the SPUI's operation is different from other signalized intersections, there is a potential for pedestrian confusion as to when it is safe to cross each ramp junction. However, observation of pedestrian behavior at SPUIs suggests that this is not as significant a problem as initially perceived. Those pedestrians observed appeared to make the correct choice by walking coincident with the crossroad through phase.

2. In general, crosswalks have not been provided for pedestrians to use in crossing the crossroad. Moreover, typical SPUI signal phasing does not provide for a protected pedestrian phase (or movement) to occur across the crossroad. This deficiency would be a serious problem if pedestrian crossings were needed parallel to the major route, particularly if the route was conducive to pedestrian activity (e.g.,along an arterial).

3. Only two SPUIs have lights in the pavement to guide left-turning traffic: Clearwater, Florida, and West Valley City, Utah. Of these two, only the one in Clearwater has lights in current use. In general, the lights are relatively expensive, costly to maintain, and do not appear to be very reliable in highway environments. Moreover, they may not be necessary if the SPUI is effectively illuminated with some type of roadway lighting and if raised pavement markers are installed along the left-turn paths.

4. Most SPUIs use some type of high mast or complete interchange lighting to illuminate the interchange area, particularly the critical on- and off-ramp areas. Although the effectiveness of this lighting has not been fully investigated, experience with the SPUI's operation and influence on driver behavior indicates that its lighting needs equal or exceed that of a conventional diamond interchange.

In summary, the SPUI is a very unique type of diamond interchange. Under certain situations, it appears to be a viable alternative to other diamond interchange configurations. However, its nontypical geometric design features and unusual operation may make some engineers reluctant to accept it as a design alternative. This apprehension is understandable given the cost and long-term impact of this type of design decision. Unfortunately, the issue of when and under what circumstances a SPUI should be selected is yet to be fully resolved by the profession. However, a significant step in this direction has been taken by this research in terms of a better understanding of the SPUI's unique design and operational features.

REFERENCES

1. Hawkes, T. W. and Falini, M.D. "The Urban Interchange," Public Works, February, 1987, pp. 45-46.

2. Leisch, J. P. "Innovations of Diamond Interchanges in the Urban Environment," ITE Journal, Washington, D.C., November, 1985, pp. 24-26.

3. Witkowski, J.M. "Benefit Analysis for Urban Grade Separated Interchanges," Journal of Transportation Engineering, Vol. 114, No. 1 January, 1988, pp. 93-109.

4. Wilshire, R., et. al., Traffic Control Systems Handbook, Report No. FHWA-IP-85-12, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., April, 1985, pp. 3.56-57.

5. Messer, C.J., and J. A. Bonneson. "1988 Annual Report on Guidelines for Operational Control of Diamond Interchanges." Report No. TTI-2-18-88-1148. Texas Transportation Institute, College Station, Texas, December, 1988.

6. Homburger, W.S., ed. Transportation and Traffic Engineering Handbook. 2nd ed. Institute of Transportation Engineers, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1982, p. 756.

7. Federal Highway Administration and Texas Transportation Institute. Synthesis of Safety Research Related to Traffic Control and Roadway Elements. Vol. 1. FHWA-TS-82-232, Federal Highway Administration, Washington, D.C., 1982, chapter 5, p.13.

8. Brown, S. and G. Walters. "The Single-Signal Interchange." ITE 1988 Compendium of Technical Papers. Institute of Transportation Engineers, Washington, D.C., 1988.

9. A Policy on Geometric Design of Highways and Streets. American Association of State Highway and Transportation Officials, Washington, D.C., 1984, p. 145.

10. The Urban Interchange. Greiner Engineering Sciences, Inc., not dated.

11. Chandra, V. and G. Szecsei. "Elegant Interchanges for Tight Urban Spaces." Civil Engineering. Vol 58, No. 9, American Society of Civil Engineers, New York, N.Y., September, 1988.

APPENDIX

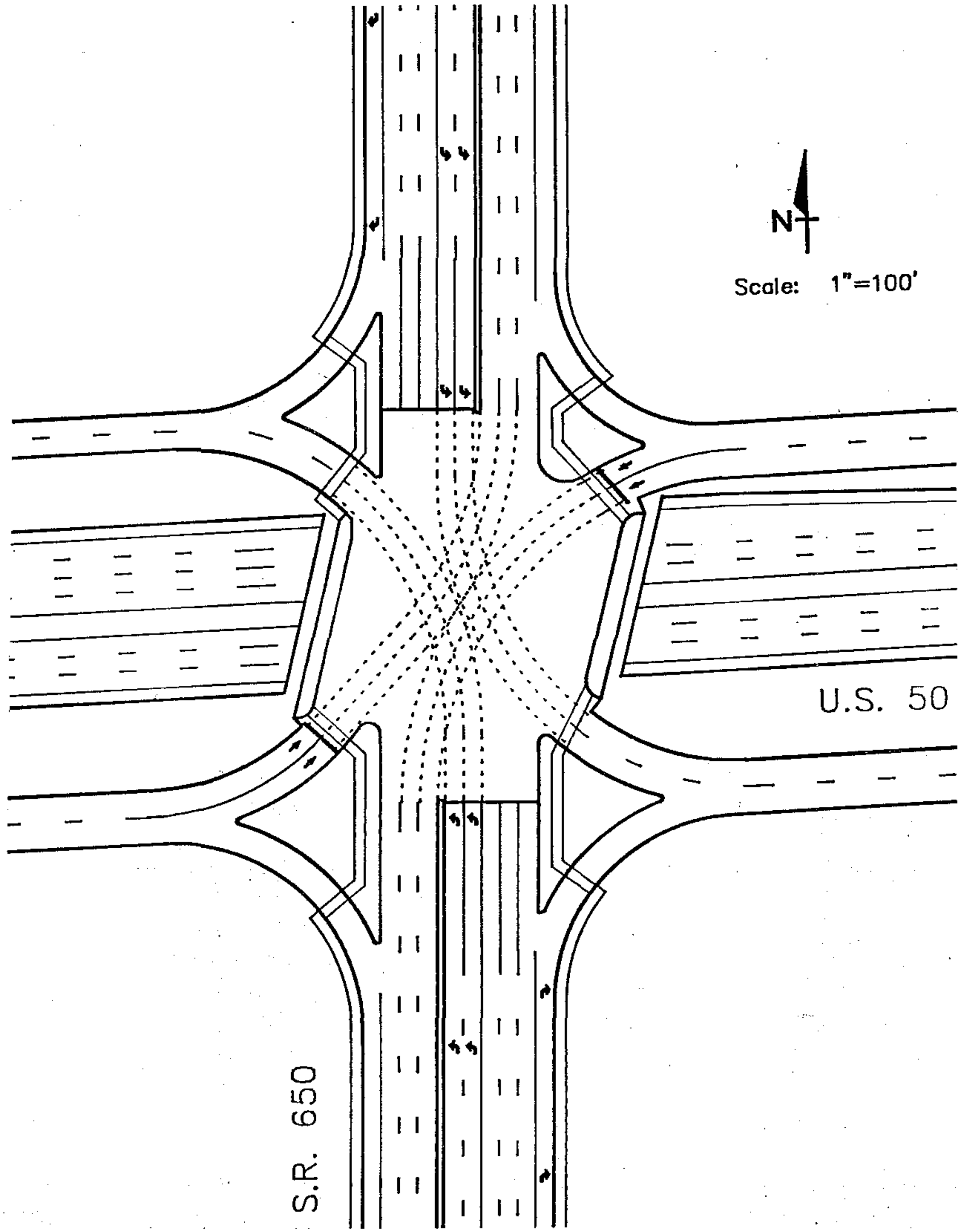


Figure A-1. US 50 & SR 650, Fairfax, Virginia.

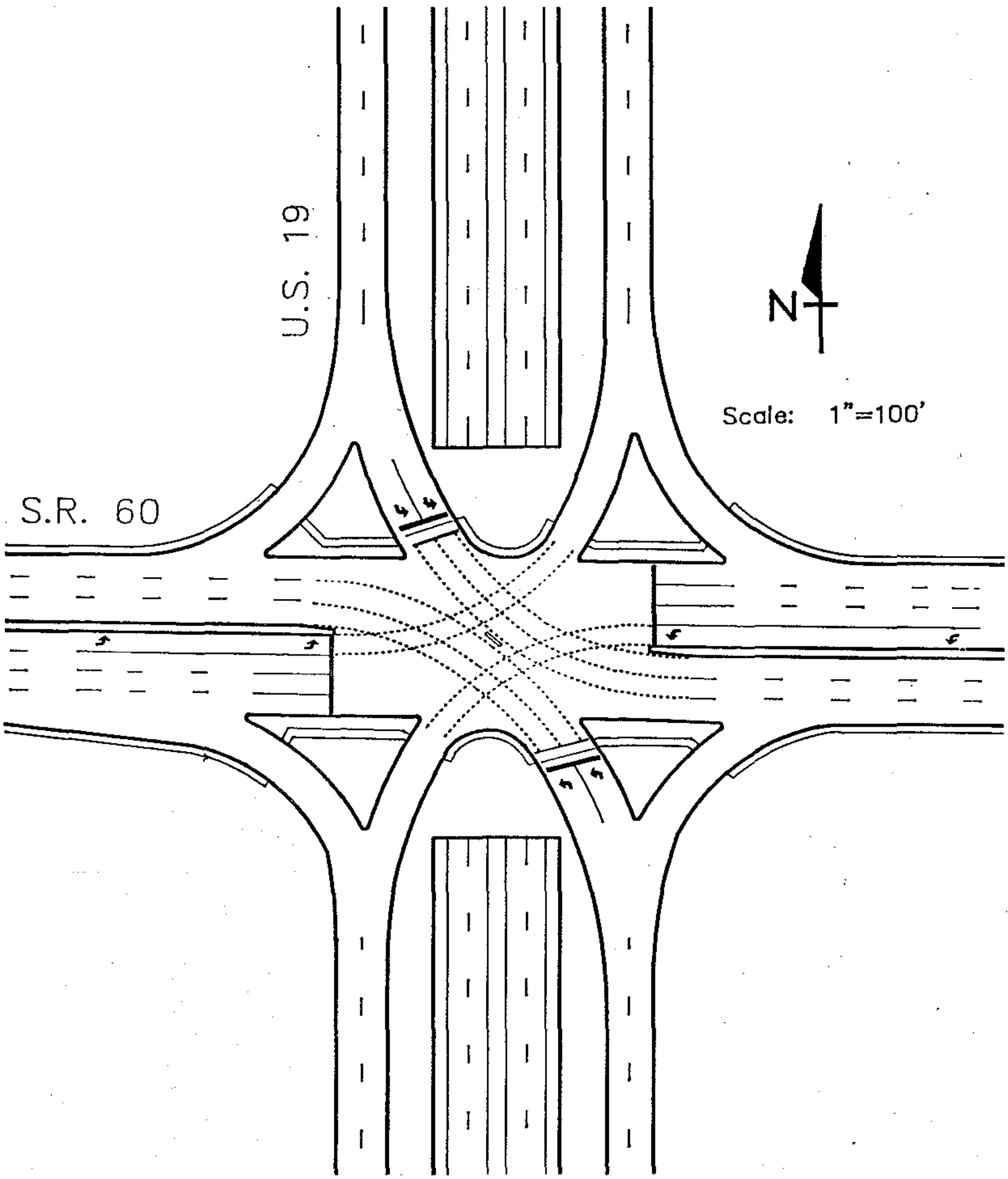


Figure A-2. US 19 & SR 60, Clearwater, Florida.

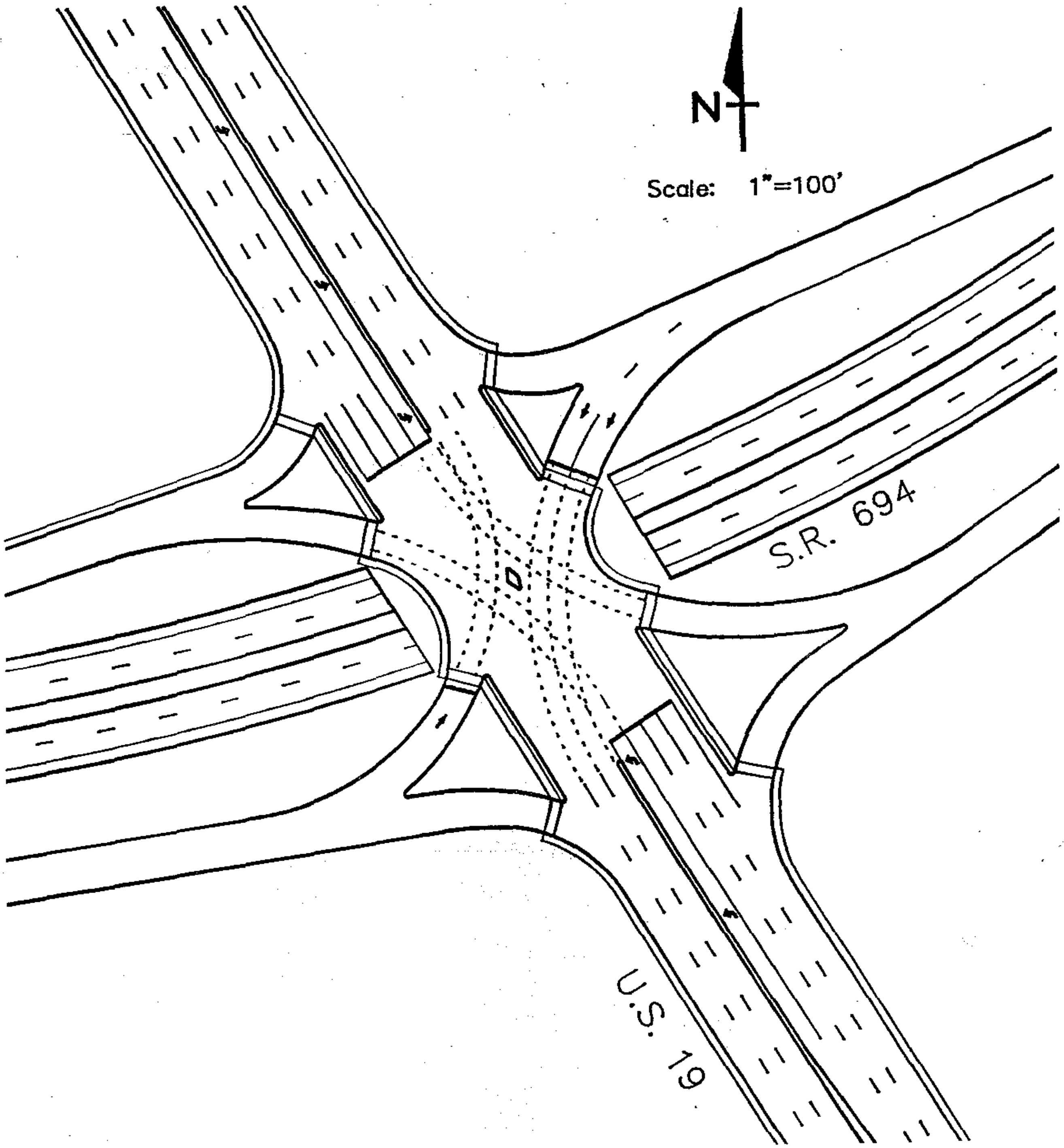


Figure A-3. US 19 & SR 694, Pinellas Park, Florida.

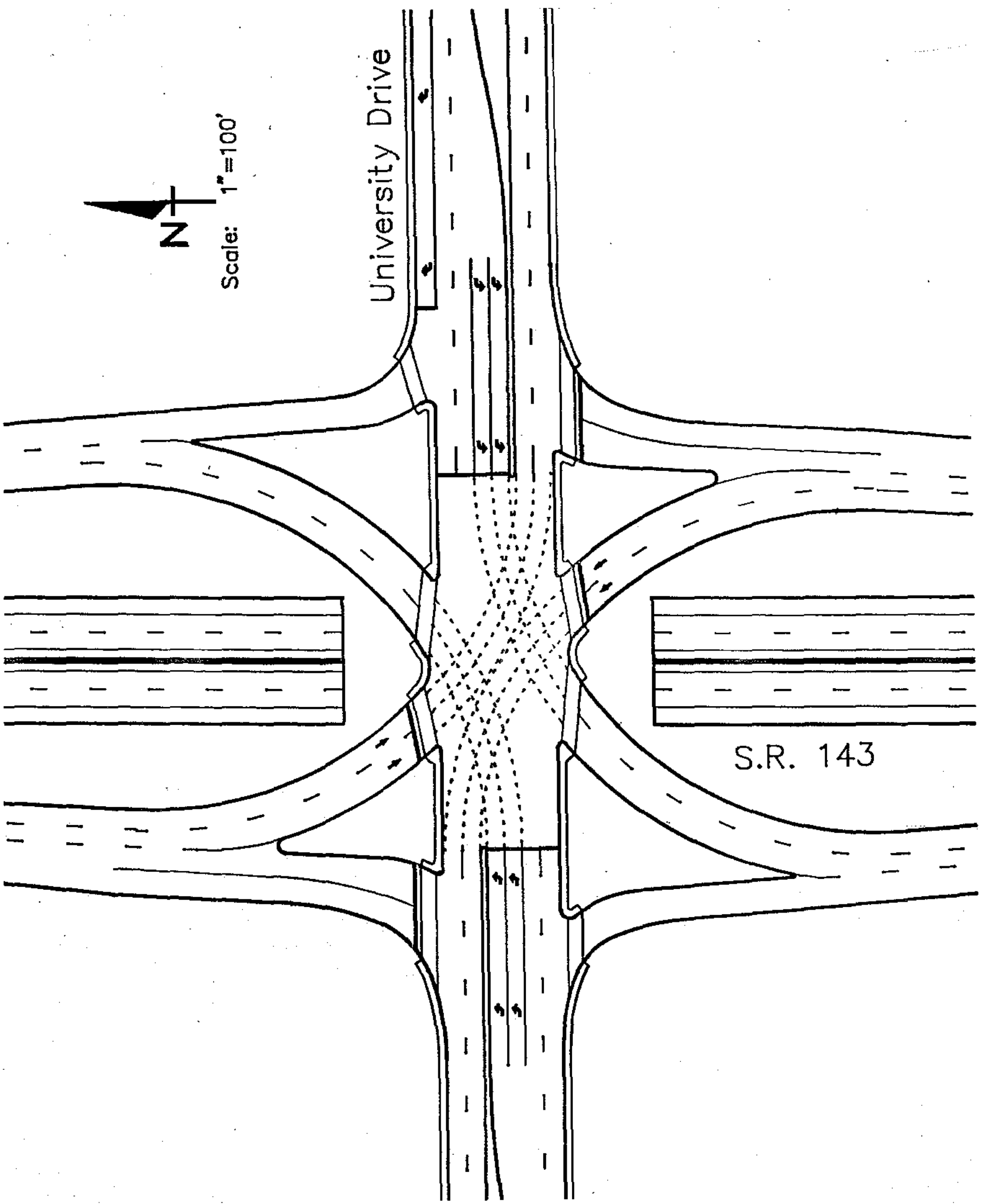


Figure A-4. SR 143 & University Drive, Phoenix, Arizona.

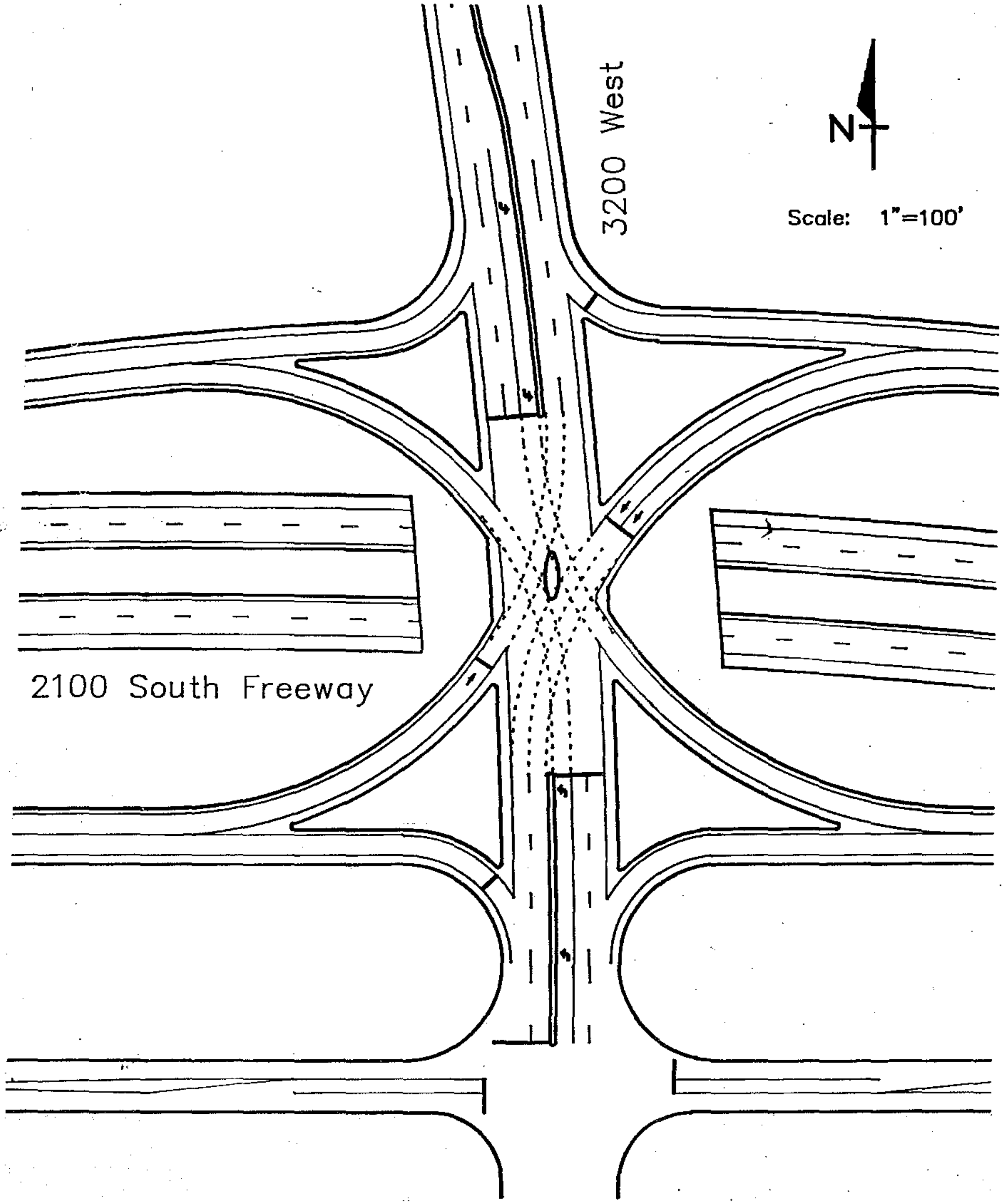


Figure A-5. 3200 West & 2100 South, West Valley City, Utah.

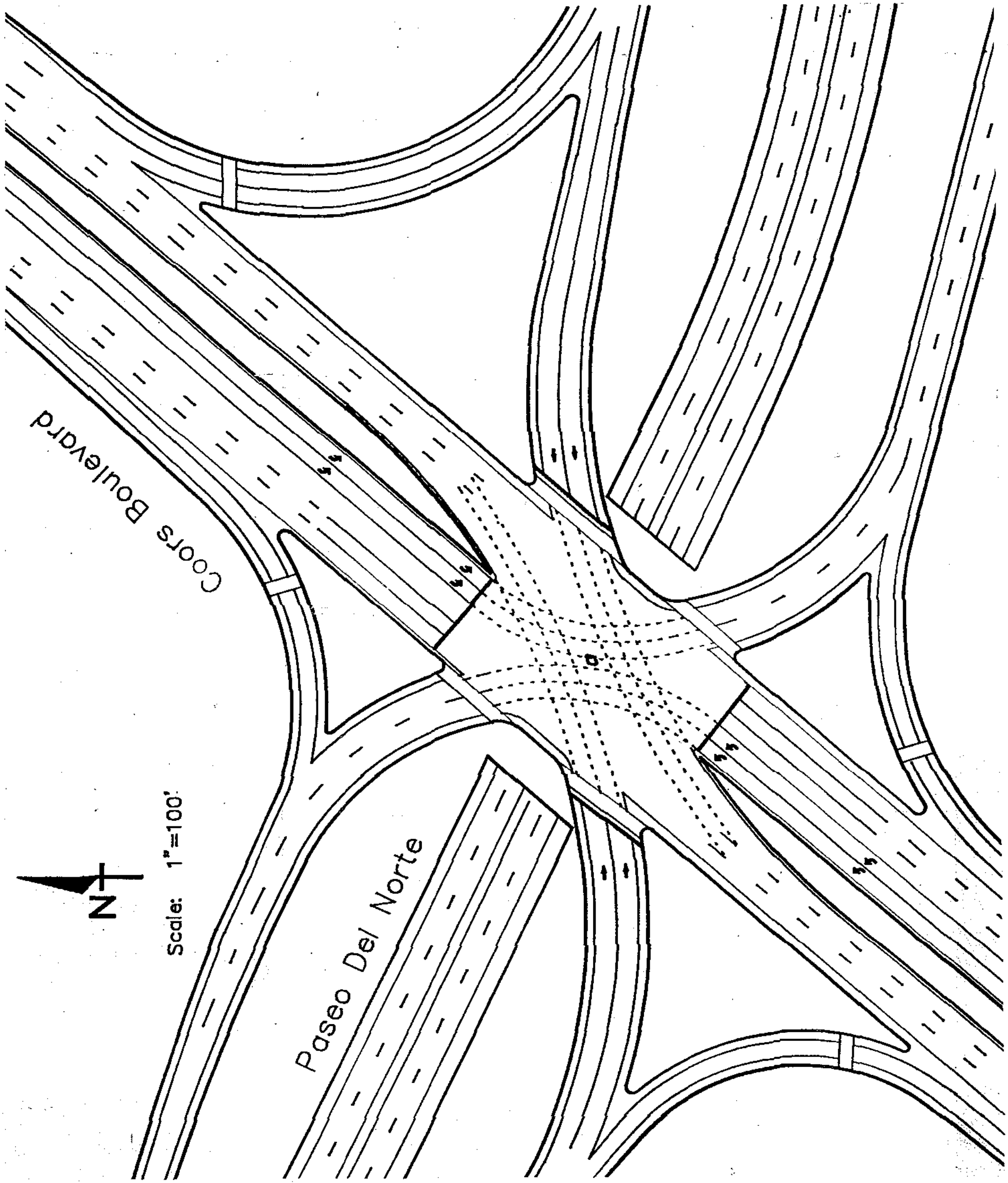


Figure A-6. Paseo Del Norte & Coors Boulevard, Albuquerque, New Mexico.