parameters (e.g., saturation flow rate), in order to consider the effect on performance. Along these lines, Research Problem Statement 1 in this Circular addresses basic characteristics of interchange area operations and the modelling of them. That research, which will be funded in 1994 under the National Cooperative Highway Research Program, should develop appropriate analysis techniques to address many of these concerns.

SURVEY OF STATE DOT PERSPECTIVES ON INTERCHANGES

Kent Lall, Portland State University; James L. Powell, Felsburg Holt & Ullevig; and Michael Church, California Department of Transportation

Introduction

The Interchange Subcommittee (Highway Capacity and Quality of Service Committee A3A10 Transportation Research Board) undertook to document the types of interchanges currently in operation in order to learn from the experience that has been gained from their performance. The ultimate objective will be to develop procedures for the determination of the capacity of interchanges similar to other highway elements embodied in the *Highway Capacity Manual*. This will be achieved through defining research objectives, preparing a scope of work and identifying funding sources, while building on existing experience. The survey was intended to identify knowledge gaps in both interchange characteristics and specific operational features, to help set priorities for future research and development. A related area is the need for new evaluation techniques for operations of other closely-spaced intersections near ramp terminals.

In the nomenclature used in the AASHTO "Green Book", the facilities under consideration are service interchanges, as opposed to system interchanges (i.e., freeway/freeway). Specifically, a service interchange is the grade-separated junction of a through roadway with a typically lower classification roadway, and includes the at-grade intersections between through roadway ramps and the lower classification roadway. Freeway/arterial interchanges are the typical configuration, though arterial/arterial interchanges are also included. The at-grade intersections are the primary focus here, and can be either signalized or unsignalized, even in urban areas.

The questionnaire/survey was sent to thirty-two traffic engineers in twenty six states, based on a list of AASHTO Traffic Engineering Subcommittee members (Highway Design Committee) and personal contacts through the Interchange Subcommittee. The goal was to reach primarily state level individuals from geographically diverse areas who were responsible for planning and operational functions. Twenty-four questionnaires were returned, which represents a 75% response rate (see Figure 1). A full text of the questionnaire is included as Appendix A.

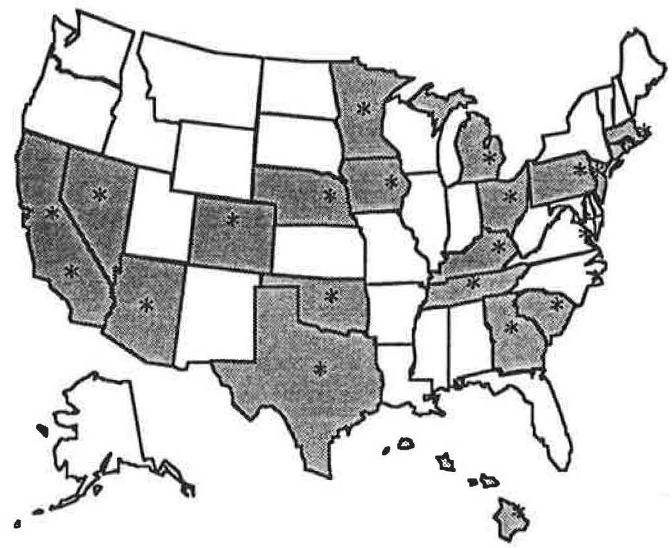


FIGURE 1 Distribution of questionnaire and responses.

Classification of Interchange Types In Use or Under Consideration

Based on a compilation of the survey results, it appears that the following interchange types are currently in operation (Question #1):

TABLE 1: INTERCHANGE TYPES IN USE

TYPE	NO. OF RESPONSES
Conventional diamond	24
Partial cloverleaf	23
Full cloverleaf	20
Trumpet	18
Split diamond	17
Directional	16
Tight diamond	15
Single point diamond interchange*	8
Three level diamond	6
Half diamond	2
Partial diamond	2
Semi-directional	2
Partial turban	1
Button hook	1
Slip ramp	1

*Also known as single point urban, urban diamond, or sometimes urban interchange.

It should be noted that a large number of states *(16)* indicated use of directional interchanges, despite the fact that directionals are normally system interchanges, not service interchanges that were the survey focus. Apparently respondents did not make this distinction in completing both Questions #1 and #3.

Of the interchanges currently in operation, the most "common" types (see Question #1) appear as follows:

TABLE 2: MOST COMMON INTERCHANGE TYPES IN USE

TYPE	NO. OF RESPONSES
Conventional diamond	19
Partial cloverleaf	16
Tight diamond	8
Full cloverleaf	6
Directional	4
Trumpet	3
Split diamond	1
Three level diamond	0
Other	0

Thus the two most common types appear to be conventional diamond, followed by partial cloverleaf. Tight diamond occupies a distant third place. It comes as no surprise that these types also dominate what is considered for new construction or reconstruction as indicated by the following responses (Question #3):

TABLE 3: INTERCHANGE TYPES CONSIDERED FOR NEW CONSTRUCTION OR RECONSTRUCTION

TYPE	NO. OF RESPONSES
Conventional diamond	22
Partial cloverleaf	17
Directional	14
Tight diamond	12
Single point diamond	10
Split diamond	10
Trumpet	10
Full cloverleaf	9
Three level diamond	3
Semi-directional	2
Button hooks	1
Diamond-type ramps	1
Partial turban	1
Diamond with flyover ramps	1

Conventional diamond leads the candidate list in new construction or reconstruction followed by partial cloverleaf. Directional interchanges appear to have gained popularity in the new construction/ reconstruction, but probably only when a system interchange is under consideration, as discussed following Table 1. Single point diamond interchanges, as expected, are also frequently being considered. Split diamond and trumpet are being considered about as frequently as the tight diamond or full cloverleaf. It is of note that the full cloverleaf has dropped a good deal from future consideration, especially compared to the list of interchanges in use (i.e., from third place in Table 1 to eighth place in Table 3). This point will be discussed further.

The factors that are considered in the selection of interchange type for new construction/reconstruction are listed as follows (Question #4):

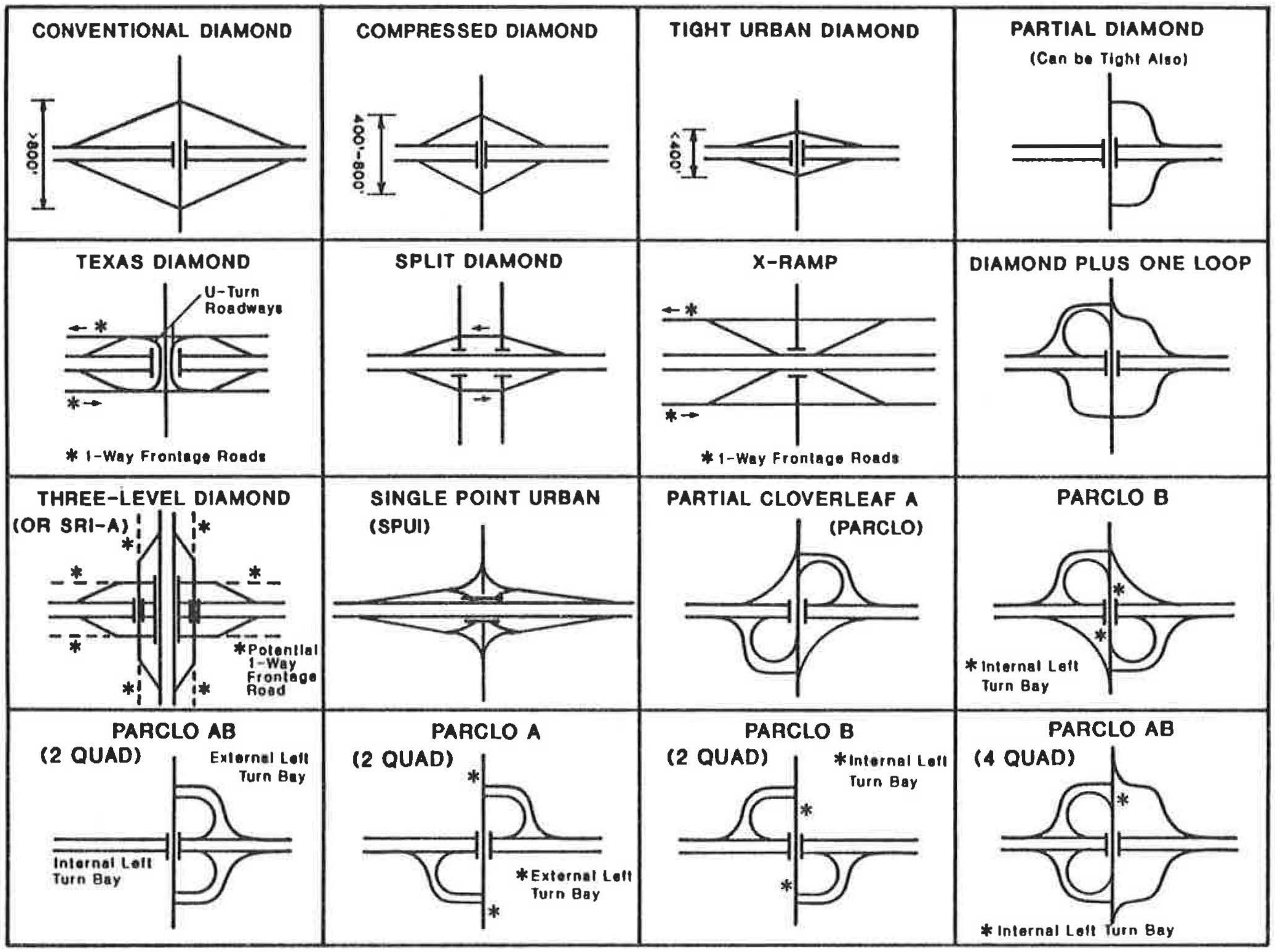
TABLE 4: FACTORS CONSIDERED IN SELECTING INTERCHANGE TYPE

FACTORS	NO. OF RESPONSES
ROW	24
Environmental/Socioeconomic	24
Operations	23
Cost	23
Topography	21
Design Features	20
Constructability	20
Other	5

As expected, a large number of factors weigh about equally in the choice of interchange type.

Operational Experience

The literature provides little information on the subject of interchanges, particularly with respect to operational experience on the local street side. This survey deals with basic aspects of interchanges such as configuration, operational characteristics and evaluation techniques to aid in design and construction of key elements in future projects. It is important to define operational experience by looking at the interchange area comprehensively with the surrounding street system. Almost every interchange is unique and all are influenced by external factors. Traffic engineers appear to favor providing the motorist as consistent a driving experience as possible in terms of



NOTE: ADAPTED FROM MICHIGAN DOT & AASHTO

FIGURE 2 Basic interchange types ***(continued on next page).***

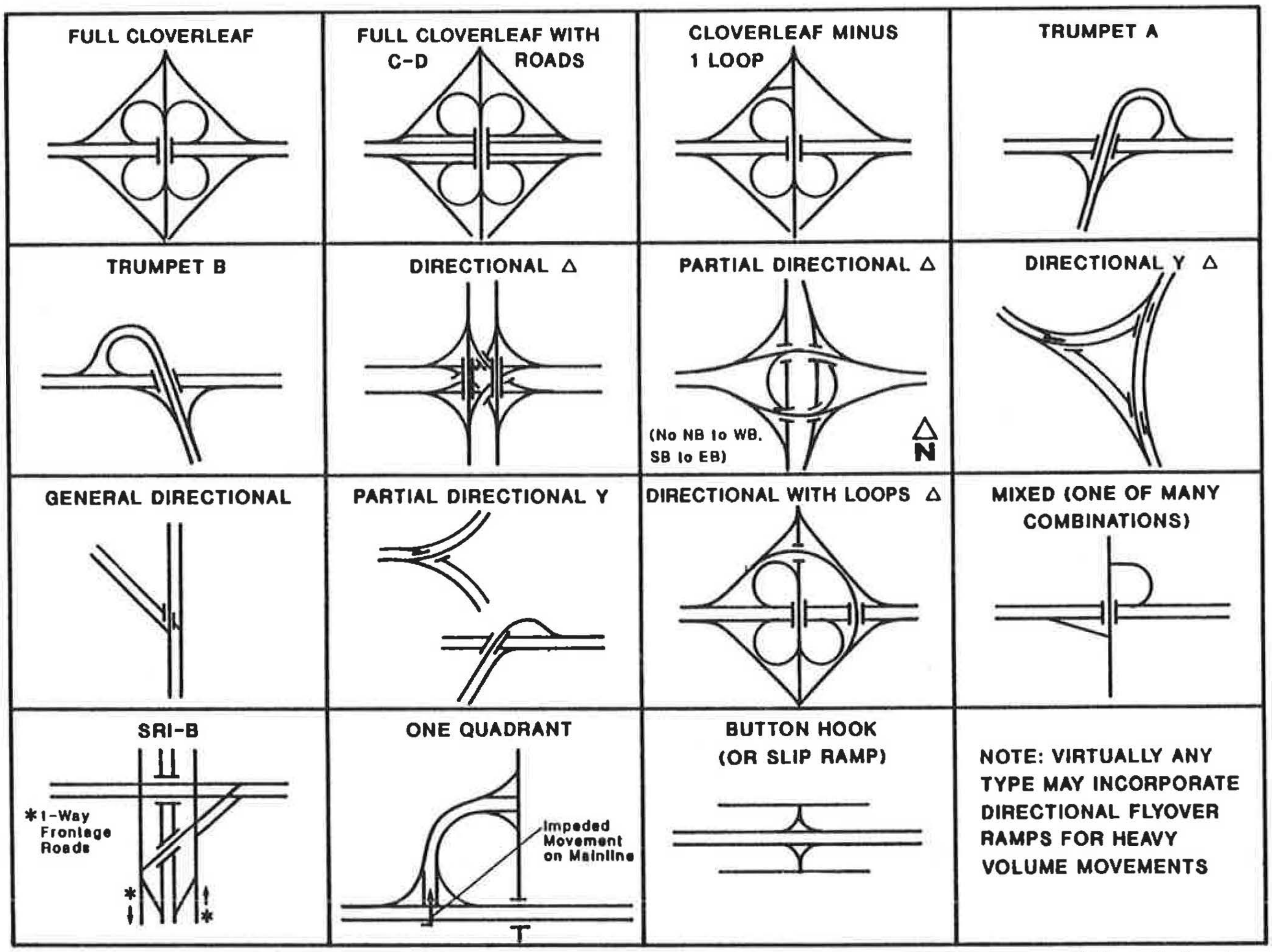
configuration to meet driver expectancy. There also appears to be an effort to eliminate weaving or at least provide sufficient lengths to accommodate it. Operational experience of commonly used interchange types is described below, based on summaries of the qualitative and descriptive portions of Questions One and Two. The responses are grouped by interchange type.

It should be noted that this survey predated the description of distinct types of diamond interchanges discussed earlier in this Circular. The definitions used here are not consistent with that discussion, rather the discussion below generally distinguishes between a tight diamond with very closely spaced ramps (under 250 ft.) and diamonds with wider spacing. These definitions did not seem to cause confusion among survey respondents, though there clearly is a need for uniform terminology when discussing interchanges.

For reference, Figure 2 illustrates a variety of basic interchange types. This figure is based on a graphic provided by the State of Michigan.

Conventional Diamond

Arizona indicates the conventional diamond as the most common type of interchange, which has a high motorist familiarity. California recognizes it as the basic type and favors it because it can be designed for expansion and adding loops generally at a minimum cost. However, it requires good signal synchronization to be flexible with respect to traffic demand. Connecticut lists this as the preferred type. The conventional diamond appears as a standard in Georgia as it meets driver expectancy. It is best used in conjunction with an arterial divided by a median. Problems are reported to occur at high volumes or if driveways and side-streets are in close proximity.



Δ Normally Considered a Systems (Freeway-to-Freeway) Interchange

FIGURE 2 Basic interchange types *(continued)*.

Iowa reports the conventional diamond as the most understood type and economic in design, and considers it efficient and safe unless high volumes exist. Kentucky favors it as the best type for its operations. It is the most common type in Nebraska in rural areas, where the operation is typically unsignalized. Nevada conveys that ninety percent of the interchanges in the state are conventional diamonds. Problems are reported if adjacent intersections are closely spaced or high volumes exist, where it leads to storage and capacity difficulties.

Ohio links its choice of type and configuration of interchange to the volume. For low-to-medium volumes, conventional diamond is the standard. A cloverleaf is favored for medium-to-high volume. However, weave problems are reported with this type at very high volumes, in which case a "super diamond" with extra lanes is the recommended type. Oklahoma indicates the conventional diamond is the most common and the most understood interchange. At some locations there are on/off ramps to/from two-way frontage roads, where problems have been reported. Backups have occurred onto freeways sometimes.

South Carolina recommends the conventional diamond as the most common type. If there are heavy left turns at the location, double left turn lanes are generally used. Tennessee, in rural areas, uses 600 ft to 1000 ft spacing between ramps. Loops are added instead of signalization if heavy turning traffic arises. Drivers appear to understand the operation well and few problems are reported.

Based on the responses, the following common features emerge for the conventional diamond:

• Most understood by drivers regarding proper lane positioning;
• Most efficient and safest design, and usually has minimum construction cost;
• Provides low level of service at high volume locations, but it is adaptable to a wide range of traffic volumes, sometimes by adding loops to make a partial cloverleaf; and
• Restricted left turn storage length on the cross road sometimes may create a problem, adversely affecting ramp operation. Possible remedies include double left turn lanes or full length (ramp-to-ramp, side-by-side) left turn lanes. Traffic operations improve if cross road is divided by a median.

Overall, the conventional diamond appears to be the basic design against which to compare other types. Diamonds seems to enable provision of a high standard of alignment and treatment of turning maneuvers, and they are also seen as adaptable to a wide range of traffic volumes.

Tight Diamond

California uses tight diamond interchanges in locations which are heavily developed and/or if the freeway is either elevated or depressed, but feels it provides the least capacity and sometimes has storage and sight distance problems. The sight distance problems can occur due to the presence of support piers. Storage and capacity problems are also reported by Minnesota and spacing problems are reported by Kentucky.

Pennsylvania reports that intersections at tight diamonds are usually unsignalized, where sight distance problems have been reported sometimes. When used with signalized intersections, storage problems have been noted.

The respondents' experience with the tight diamond are summarized as follows:

• May be appropriate if right-of-way is greatly constrained;
• There can be storage and capacity problems for both the left turns and the through movements when traffic volumes are high. Back-to-back left turn lanes can be troublesome; and
• The presence of crest vertical curves and bridge rail can sometimes limit sight distance.

Overall, the impression left by respondents is that the tight diamond is limited by basic capacity and storage constraints. It is worthwhile to note that the recent research and discussion on interchange types (*Single Point Urban Interchange Design and Operations Analysis*, by C.J. Messer, J.A. Bonneson, S.D. Anderson and W.F. McFarland, NCHRP 345, 1991) states that as long as good signal timing is employed, the capacity of a tight (urban) diamond interchange should be similar to that of a single point urban interchange (pp. 47-48). Apparently, many practicing engineers are unaware of the signal timing concepts appropriate to tight diamonds embodied, for example, in the PASSER III program (see Bibliography, References *10*, *16*, *18* and *34*). An important requirement for tight diamonds is that the signals be timed to assure no internal stacking and spillback problems. Two or three basic phase plans, depending on volume conditions, can be used to coordinate signal operations to meet the requirement.

Regarding the broader question of capacity of tight diamonds relative to single point diamonds, the literature unfortunately has been confused by inappropriate before-and-after comparisons. Frequently, basic lane capacity has been added to an after case along with a change in form, making it nearly impossible to compare interchange forms alone. Research Problem Statement 1 in this Circular should provide tools to address the question fully.

Single Point Diamond (Urban) Interchange (or SPUI)

Arizona reports single point diamond interchanges becoming commonplace, particularly in the Phoenix area. Single points are favored for handling heavy volumes with a minimum right-of-way. No storage problems are reported and it appears to provide good capacity with a minimum number of signal phases. Kentucky appears to have had success with their use so far, and more of this type are being built. Kentucky also reports requiring minimum right of way and no storage problems.

Tennessee reports increased construction of single points lately, experiencing good capacity and storage relative to tight diamonds. The design also appears flexible to changing or time-varying traffic demands. Tennessee's experience also indicates that it costs less in right-of-way dollars than tight diamonds, although construction costs are often higher.

Colorado indicates favorable experience with a small number of single points, observing good delay and capacity performance. The state notes that following an "initiation" period, drivers have adapted well, and likes the fact that the number of signals is reduced. Nebraska also is experimenting with them and feels positive with their first such design.

The following observations based on the responses can be made about the single point diamond interchange:

• May be appropriate if right-of-way is greatly constrained;

• Accommodates large turning movements (with large left turning radii); see Bibliography, Reference 9 for further discussion;

• Eliminates left turn storage within the interchange, and reduces the number of signals or signal phases; and

• May increase the capacity of the cross road.

Partial Cloverleaf (Parclo)

It can be noted that the survey did not distinguish between Parclos types. Responses covered a range of Parclos illustrated on Figure 2 and discussed in Sevice Interchange Section of this Chapter.

California finds the partial cloverleaf utilizing a loop on-ramp (Parclo A) provides the best local service. The Parclo provides high capacity and is sometimes used with unsignalized intersections in California. However, free-flow right onto arterials have sometimes been eliminated due to pedestrian concerns. Connecticut reports that in their use of (2 quad) Parclo B's, drivers sometimes are confused by on/off ramps at the point of entry from the arterial (see Figure 3). Hawaii also favors Parclo's.

Georgia finds the application very useful for dealing with heavy left turn volumes, though it does result in occasional weaving problems. This design is also sometimes required due to topographic constraints (e.g., an immediately adjacent river or railroad). Iowa also uses a Parclo when right-of-way requirements or topography suggest it and it is also a favored design where high left turn volumes are encountered. Iowa indicates that placement of signs is sometimes made more complex due to right side and left side entrances onto the freeway, and recommends avoiding weaving sections.

Nebraska uses a Parclo A where topography or right-of-way requires it. Driver expectancy on the freeway is felt to be violated with a Parclo B, apparently due to concern with two separate egress ramps. New Jersey uses partial and full cloverleafs exclusively, especially on intersections along major arterials or expressways. To avoid left turns at signalized intersections between two arterials, New Jersey often uses a "jug handle" (converting all turns to right turn maneuvers). There are weave concerns, including weaves involving nearby driveways on arterials. Oklahoma reports that in their use of partial cloverleafs, they find weave problems to be a function of signal spacing.

South Carolina finds that the Parclo can help eliminate some problems associated with heavy left turns, but suggests avoiding the Parclo AB due to arterial weaving. Tennessee favors avoidance of weaves and also reports driver confusion on half clovers similar to Connecticut's experience noted earlier.

Colorado notes the fact that Parclo intersections typically operate with simple two-phase signalization. The state is currently converting several diamond and full cloverleaf interchanges to partial cloverleafs.

The following characteristics appear to emerge regarding the Parclo:

• The Parclo provides a good design when right-of-way is restricted in one or two quadrants or when left turn volume has a significant impact on the operation of the basic diamond intersections;

• Weaving sections can be created by adjacent loops. These should be avoided, or provided adequate length to complete the maneuver; and

• Motorists' confusion can occur if the on ramps and off ramps meet at one point on the cross road (i.e., in a 2 quad configuration) and are not properly channelized. At some locations, signing can be somewhat complex if drivers are unfamiliar with the layout.

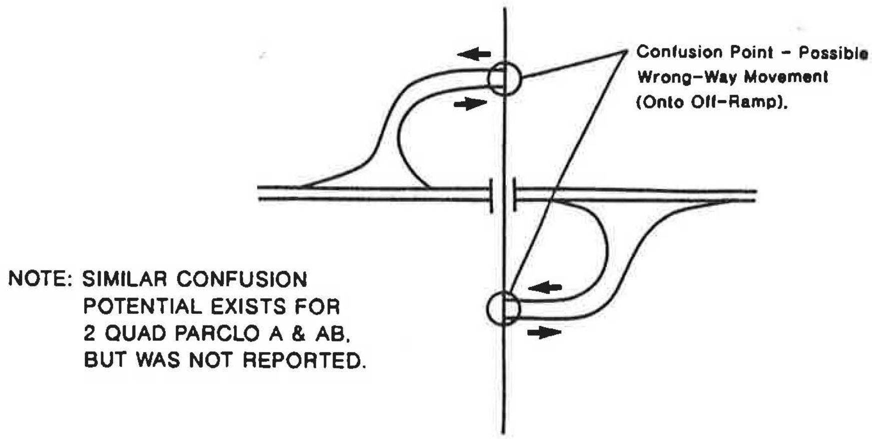
The at-grade confusion problem is discussed earlier in this Circular, where it is indicated that 2 quad Parclo A's and B's are considered in new designs only where topography or right-of-way require them.

Full Cloverleaf

Both California and South Carolina report weaving problems associated with a full cloverleaf. California's experience indicates that it can handle high volumes, however, sideswipe and rear end accidents have been reported. Also problems are noted for left turns at the downstream intersection due to the need to weave across arterial through lanes. Iowa would not use a full cloverleaf unless a collector-distributor road is provided, and does not see it as a local service interchange.

In the same vein, Kentucky is eliminating use of the full cloverleaf because of weaving problems. Massachusetts similarly is eliminating its use due to merge conflicts. Nebraska reports that increasing traffic volumes lead to capacity and weaving problems. As noted previously, New Jersey uses full and partial cloverleafs exclusively, especially at intersections between major arterials and expressways. However, concerns remain about weaving, including with nearby driveways on arterials. Tennessee also observes that weave problems exist unless a collector-distributor road is provided. Colorado considers the full cloverleaf a "dinosaur."

2 Quad Parclo B



Standard Parclo B (4 Quad) Eliminates Problem (where Topography/ROW permit):

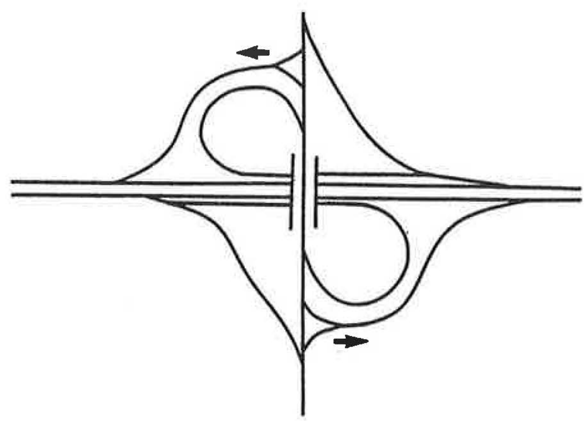


FIGURE 3 Reported parclo confusion.

Some general observations about the full cloverleaf are as follows:

- Maximum right-of-way is typically required;
- A full cloverleaf often presents weaving problems on the freeway, local street or both, particularly during peak hours, thus reducing capacity; and
- It is a good practice with this form to include collector-distributor roads along the freeway to reduce the weaving problem.

Trumpet

Arizona uses trumpet type interchanges in rural areas. Hawaii indicates that their engineers favor the directional features of the trumpet.

Other

Arizona reports that it occasionally uses turban (a form of directional) interchanges. Georgia also uses the directional type for freeway-to-freeway interchanges. A flyover is sometimes used on ramps to/from a major arterial.

General Comments/Responses

Georgia reports that weaving cross-over problems exist if traffic needs to make a left turn at nearby downstream intersections after exit maneuvers. Minnesota similarly indicates that closely spaced intersections cause problems. Minnesota is also interested in ramp metering implications and high occupancy vehicle (HOV) lane accommodations, such as by-pass lanes. Texas favors a consistency in design and provision of adequate lengths for weaves and merges. Virginia reports one case of a single point diamond with three other closely spaced (300' to 650') signalized intersections that works very well.

Analysis Techniques and Concerns

Question #5 elicited information on how operations were considered in selecting a new interchange type or evaluating an existing one. A summary of the techniques used for analysis/evaluation is given as follows:

TABLE 5: OPERATIONAL ANALYSIS METHODS

ANALYSIS TECHNIQUE	NO. OF RESPONSES
HCM	23
Software Programs	13
Critical lane	12
Other	6

More specific information was compiled from the responses to determine what software is being used in analysis or evaluation, as follows:

TABLE 6: OPERATIONAL ANALYSIS SOFTWARE

ANALYSIS TECHNIQUE	NO. OF RESPONSES
Highway Capacity Software (HCS)	21
Passer II & III	4
TRAF-NETSIM	1
TRANSYT-7F	1

It would appear that the Highway Capacity Software is being used primarily. It is interesting to compare these results with those of Figure 1 in the Chen, Lieu and Santiago paper earlier in this Circular chapter. There, TRANSYT-7F came out as the most common software for evaluating interchanges. The differences probably lie in the survey groups; the Chen survey queried TRB committee members (Freeway Operations and the Interchange Subcommittee) who tend to be research oriented, while this survey covered practicing state engineers.

In addition to the occasional use of other software, the following analysis concerns or techniques were mentioned: driver expectancy, weaving, merging, and lane balance; storage length (specifically using 1967 Jack Leisch technique); and benefit versus cost analysis.

In response to Question #7 asking if interchange operations were a major area of research need, only five reported in the affirmative. The wording of this question (asking to identify persons to contact for funded research) may have discouraged a more positive response.

TABLE 7: MAJOR RESEARCH NEED ON INTERCHANGES?

RESPONSES	NO. OF RESPONSES
Yes	5
No	9
Did not respond	10

Overview

It is appropriate to combine some of the survey planning/operations responses with our own observations regarding interchange planning, design and operations, as follows.

Major items that need to be addressed in interchange planning include:

- Travel demands: volumes, origin/destination patterns, vehicle classifications (with differing vehicle acceleration/deceleration characteristics), and pedestrian considerations;
- Driver characteristics: work load/stress, gap acceptance behavior, merging and weaving behavior;
- Functional characteristics: laneage (e.g., free right versus dual right turn; dual left turn provision), signage and pavement markings; and
- Signal timing and operational MOE's: delay and spillback, and their relationship to signal optimization.

These items should be considered together with the many design and environmental aspects of interchanges.

Specific performance characteristics that should be considered in evaluation include:

- Capacity and level of service:
  Ability to handle changing travel demands,
  Number of lanes and distance before lane drop,
  Signalized vs. unsignalized operation, and
  Signal coordination and resulting throughput along a series of closely spaced intersections (ramps and adjacent intersections);

- Safety:
  Driver expectancy,
  Signing, and
  Sight distance;
- Storage and spacing:
  Ramp intersection spacing and spacing to adjacent intersections and
  Access control along the cross road; and
- Weaving:
  Between freeway off ramp and on ramp, along the arterial and
  Between off ramp and next downstream intersection on the arterial, to make a turn.

Evaluation may be a part of initial planning for a new interchange, or it may relate to review or problem identification for an existing interchange. Many of these items cannot be considered separately from design and cost issues.

For the future, current trends and recent developments suggest areas for additional research:

- Ramp metering accommodation, with potential interconnection to interchange signals;
- HOV accommodation (e.g., by-pass lane treatment), to service transit needs; and
- Integration with advanced traffic control concepts associated with Intelligent Vehicle Highway Systems (IVHS).

Overall the topic of service interchange operations is an evolving field in which a good deal has been learned, but a good deal more needs to be understood and put into practice.

Acknowledgements

Assistance provided by Khaled Mudarres & Kostaman Thayib, both graduate students at Portland State University, in the preparation of this paper is greatly appreciated.

APPENDIX A: SURVEY FORM

Interchange Subcommittee
Committee on Highway Capacity and Quality of Service
Committee A3A10 Transportation Research Board

The Interchange Subcommittee is undertaking to document the types of interchanges currently in operation and learn from the experience that has been gained from their performance. The ultimate objective is to develop procedures for the determination of the capacity of interchanges similar to other highway elements as embodied in the Highway Capacity Manual. While we define the research objectives, state the scope of work and identify funds for any research, we expect to build on existing experience. This questionnaire is brief with a view to limiting your time and effort in completing it, yet it may call for certain coordinating effort on your part within your organization. Any effort you spend will be a very useful contribution to the advancement of knowledge in this area.

Interchanges *here are meant to be the at-grade junction of a through roadway, usually a freeway, with a lower classification road and can be either signalized or unsignalized. Arterial/arterial interchanges are also included. The operational focus is on the lower classification road and its intersections with the on/off ramps, and not on the merge/diverge features of the through roadway.*

1. What type of interchanges are currently in operation for your agency? Please check types below, and put an asterisk next to the three most common types.

☐ Conventional Diamond
 (Ramp spacing greater than 250 ft.)
☐ Tight Diamond
 (Ramp spacing less than 250 ft.)
☐ Split Diamond
☐ Partial Cloverleaf (One, two or three quadrant)
☐ Full cloverleaf
☐ Trumpet
☐ Three level Diamond
☐ Directional
☐ Other (Please list):

On the back of this sheet, please briefly summarize your operational experience (that is, operations on the lower classification road) with the three most common types in use. If you so choose, please feel free to describe your operational experience with types other than the three most common in use.

2. For the types of interchanges in use, are there any design or operational characteristics that you feel are unique? Please briefly summarize and supply related sketches, figures or photographs.

____
____
____
____
____

3. What interchange types are you considering for any new construction or reconstruction?

☐ Conventional Diamond
(Ramp spacing greater than 250 ft.)
☐ Tight Diamond
(Ramp spacing less than 250 ft.)
☐ Split Diamond
☐ Partial Cloverleaf (One, two or three quadrant)
☐ Full cloverleaf
☐ Trumpet
☐ Three level Diamond
☐ Directional
☐ Other (Please list):

4. In interchange construction or reconstruction, what factors do you consider in selection of type? Check those that apply.

☐ Right-of-Way
☐ Cost
☐ Operations
☐ Design features (for example, design speed)
☐ Constructability
(for example, disruption/construction difficulty)
☐ Topography
☐ Environmental/Socio-Economic Impacts
☐ Other (Please list):

Do you have a procedure for considering and trading off the factors? If so, please briefly describe (or supply a sample application).

____
____
____
____
____
____

5. How do you consider operations in selecting a new interchange type or evaluating existing conditions? Please check off the analysis techniques you use.

☐ Critical lane
☐ Highway Capacity Manual
(with or without modifications to account for interchange characteristics)
☐ Software programs (Please list):
☐ Other (Please list):

If possible, include document(s) that outline your approach. We are particularly interested in special considerations related to interchanges, for example, spill back between ramps or onto the freeway, signal timing, weaving on the arterial or interactions with adjacent intersections.

6. State the three most important aspects of interchange operations (from your point of view) that we need to understand and analyze better.

____
____
____
____
____
____

7. Does your agency consider interchange operations a major area of concern justifying new research attention?

____

If yes, please supply the name/title/phone number of person or persons we should contact regarding the possibility of funded research or contributed manpower.

____
____
____
____
____
____

8. Please provide any further comments regarding interchanges.

____
____
____
____
____

9. Name/address/telephone no. of person(s) responding to this survey.

(Note: This is a condensed version of the survey.)

DISCUSSION: NEEDED RESEARCH

Following the presentations, each of the presenters was asked to identify the most critical research needs in both short-range and long-range perspectives. Following is a summary of their comments.

Dan Fambro identified six areas of needed research or clarification, including:

• Establishment of criteria for level of service determination; most likely more than one measure will be needed, i.e., more than delay only;

• The potential need for other metrics besides, or in addition to, level of service when comparing or evaluating alternative interchange forms. In other words, a complete framework that includes level of service, safety, cost and environmental factors at a minimum, when considering interchange alternatives;

• The need to better define and validate storage ratio as a level of service measure, as used in the PASSER III program;

• Better understanding and characterization of weaving on arterials near interchanges;

• More thorough research into progression effects at interchanges, since with limited platoon dispersion, progression/timing effects will be at a peak; and

• Guidance to analysts regarding values of lost time and saturation flow rate for use at various interchange forms.

Hobih Chen took a somewhat different tack:

• The need to look at adaptive signal control technology for use at closely-spaced interchange intersections; FHWA is conducting research to develop self-calibrating strategies and algorithms that will optimize performance in a traffic responsive mode. These may be useful at interchanges.

Jim Lee suggested the following:

• The need for a comprehensive capacity analysis technique for diamond interchanges and

• Better methods for comparing and evaluating basic interchange forms; he mentioned the tendency in Arizona to regard the single point urban interchange as the best in all circumstances, when this may not be the case. Economic analysis should be an important part of the evaluation technique.

B. Kent Lall mentioned some of the same ideas as Dan Fambro and Jim Lee:

• Focus on performance and level of service measures, though in a set order of priority, i.e., perhaps conventional diamonds first, parclos second, etc., and then on to less common interchange types.