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JHRP-75-1

STUDY OF COLLECTOR-DISTRIBUTOR ROADS

Ronald S. Hansell

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

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Final Report
STUDY OF COLLECTOR-DISTRIBUTOR ROADS

TO: J. F. McLaughlin, Director February 4, 1975
Joint Highway Research Project
Project: C-36-68C
FROM: H. L. Michael, Associate Director
Joint Highway Research Project File: 3-6-3

The attached Final Report "Study of Collector-Distributor Roads" is for the HPR Part II research study of the same title. It has been authored by Mr. Ronald S. Hansell, Graduate Assistant in Research on our staff under the direction of Professor G. T. Satterly, Jr.

The purpose of this study was to summarize and evaluate information on characteristics of collector-distributor roads as used at interchanges to permit wiser design and use of such facilities. Findings indicate collector-distributor roads reduce weaving-type accidents and are cost beneficial where high volumes of traffic occur.

The Report is presented to the Board for acceptance as fulfillment of the objectives of this Study. It also will be forwarded to ISHC and FHWA for review, comment and similar acceptance.

Respectfully submitted,

Harold L. Michael
Associate Director

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16. Abstract <p>It was the purpose of this study to provide information about the design and the use of collector-distributor equipped interchanges.</p> <p>A review of state design standards and policies and review of the literature was made. A study was made of the operation and accidents at four interchanges equipped with C-D roads and three interchanges without C-D roads in Indiana. Operations were filmed and erratic maneuvers counted. Costs for construction, maintenance, and operation were calculated for typical examples of C-D and non-C-D interchanges.</p> <p>The results showed agreement among design experts favoring C-D road use as a design ideal to minimize weaving, improve operation, and generally to improve design. Analysis of accident rates for 100 million vehicles by total number and by type showed only weaving-type accidents to be significantly different, with C-D sites experiencing fewer accidents than non-C-D sites. Construction costs were higher for C-D interchanges, as were maintenance costs. Operating costs were not different at low volumes, yet based on assumptions of likely higher volume operating conditions, the C-D interchange would have lower operating costs.</p>			
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by

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Graduate Assistant in Research

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The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, Indiana
February 4, 1975

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I stand on their shoulders, but I do not hold them responsible for my faulty vision.

-- John Raser

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ABSTRACT

Hansell, Ronald S. M.S.C.E., Purdue University, August 1974. Study of Collector-Distributor Roads. Major Professor: G. T. Satterly, Jr.

It was the purpose of this study to provide information about the design and the use of collector-distributor equipped interchanges. It is generally expected by design engineers that the use of collector-distributor roads at an interchange will increase highway cost because of several additional design elements but that operating costs will decrease under certain operating conditions sufficiently to warrant C-D road use on a basis of lower overall costs.

A review of state design standards and policies and review of the literature was made. Questions on the use of C-D roads were asked in interviews with design engineers in several states and questionnaires concerning C-D roads were sent to design engineers and consultants. A study was made of the operation and accidents at four interchanges equipped with C-D roads and three interchanges without C-D roads in Indiana. Operations were filmed and erratic maneuvers counted. Costs for construction, maintenance, and operation were calculated for typical examples of C-D and non-C-D interchanges.

The results showed agreement among design experts favoring C-D road use as a design ideal to minimize weaving, improve operation, and generally to improve design (such as the single exit policy, minimized signing, etc.). Analysis of accident rates for 100 million vehicles by total number and by type showed only weaving-type accidents to be significantly different, with C-D sites experiencing fewer accidents than non-C-D sites at the $\alpha = 0.75$ level for the relatively low volumes using the interchanges studied. Erratic maneuvers provided additional information about potential conflicts, showing C-D sites to experience more erratic maneuvers than non-C-D sites ($\alpha = .025$). Construction costs were higher for C-D interchanges, as were maintenance costs. Operating costs were not different at low volumes, yet based on assumptions of likely higher volume operating conditions, the C-D interchange would have lower operating costs.

C-D roads were beneficial from a cost-effectiveness standpoint, although high volume traffic conditions were not to be found at all study sites. Annual amortized construction and annual maintenance cost increase for the average C-D interchange were small compared to total interchange cost. Based on assumptions of operations at peak or near peak hour volumes the cost of operating over a typical C-D interchange was lower than the cost of operating over a typical non-C-D interchange. The lower

operating costs result in lower overall annual costs, even when time and accident costs are excluded to produce a conservative test.

CHAPTER I

INTRODUCTION

"A collector-distributor road is an auxiliary roadway, separated laterally from but generally parallel to the expressway through roadway. It serves to collect and distribute traffic from several access connections between selected points of ingress to and egress from the through traffic lanes." (1, p. 583)*

Whether a particular road is determined to be a collector-distributor road is certainly more dependent upon function than upon design, and the above use-oriented definition is generally valid. Common application of collector-distributor roads occurs under three main design conditions:

1. within an interchange
2. through two adjacent interchanges
3. continuous along a freeway through several interchanges

The intended function of collector-distributor roads within a cloverleaf (type) interchange is to reduce weaving maneuvers associated with the standard cloverleaf

*The numbers in parentheses indicate reference to numbered bibliographic references; p. ** indicates page(s) from which specific excerpts are taken.

design. Simultaneously, conflicts produced by differential speeds between through traffic and exiting or entering traffic can be eliminated by separating through traffic and maneuvering traffic by a physical barrier, such as a guardrail or lane separator.

Traffic conditions in urban areas frequently demand adjacent interchanges at spacings which are too close to avoid serious weaving maneuvers. When ingress and egress ramps are separated by only a short distance, driver decision points become closer than the recommended 1,000 feet (29). The use of a C-D road to separate faster moving through traffic from slower decision-making traffic eliminates or transfers driver decision points to less critical areas.

Finally, collector-distributor roads are used along a high volume facility which has frequent exits and entrances. Two-mile spacing of interchanges has not been found acceptable in larger urban areas, since there is always local pressure to design any new facility to accommodate local traffic distribution. Frequent interchanges interfere with through traffic, but collector-distributor roads will insulate through traffic from the marginal friction produced by the interchanging traffic. Several design manuals propose that interchanges could be spaced closer together with a C-D design because of slower weaving and maneuvering speeds and therefore shorter weaving distance requirements.

Continuous C-D roads provide the buffer between through roadway traffic and slower maneuvering traffic and allow enough egress points to serve local traffic.

This study was undertaken in September, 1971, for the purpose of establishing the justifiability of collector-distributor road use and determining the conditions under which justification exists for their use.

CHAPTER II

REVIEW OF THE LITERATURE

Collector-distributor roadways have a relatively short history of design application and, consequently, literature about their design, construction, and operation is not extensive. Review of the literature consisted of a library search of completed studies, analyses, and remarks concerning collector-distributor (C-D) roads. A computerized literature search by the Highway Research Information Service (HRIS) did not provide additional important information on in-progress research on C-D roads.

The distinction between frontage roads, auxiliary lanes and collector-distributor roads must be made explicit before further comments can be presented. From "A Policy on Design of Urban Highways and Arterial Streets", (1) the following definitions are excerpted:

(1) "A collector-distributor road is an auxiliary one-way roadway usually of limited length, separated laterally from but generally parallel to and connecting with the freeway through roadway. The purpose of the collector-distributor road is to eliminate weaving on the traveled way and to reduce the number of points of ingress and egress on the freeway. This transfers most of the turbulence to the collector-distributor road and results in a safer freeway with greater capacity and higher speeds. A collector-distributor road is distinguished from a frontage road in that it does not provide direct access to abutting property." (1, p. 583)

(2) "A frontage road is a local street or road auxiliary to and located on the side of an arterial highway for service to abutting property and adjacent areas and for control of access. The frontage road has acquired several other commonly-used names including auxiliary road, service road and access road. The term frontage road is more commonly used and is used throughout this policy. The function of the frontage road is to control access to the traveled way for through traffic, to provide access to the property adjoining the highway and to maintain circulation of traffic on the street system on each side of the highway. In lieu of terminating crossroads with cul-de-sacs, all or many of the cross streets may connect into the frontage roads. A frontage road also adds substantial flexibility to the operation of a freeway, including use as an alternate route for through traffic in emergency situations." (1, p. 152)

(3) "Auxiliary Lane - The portion of roadway adjoining the traveled way for parking, speed change, or for other purposes supplementary to the through traffic movement. (includes acceleration lanes, deceleration lanes, parking lanes, and climbing lanes)." (1, p. 686)

In addition to these terms, a glossary of various traffic separators precedes discussion of the problem. The following definitions are from the 1965 Highway Capacity Manual (16). The reader should familiarize himself with these definitions before reading the text, for adherence to strict and concise definitions is essential to the development and presentation of many of the arguments.

(1) Median - That portion of a divided highway separating the traveled ways for traffic in opposite directions (16).

(2) Lane separator - A separation between traffic streams moving in the same direction where the service rendered by the roadways on either side of the separator is essentially of the same character, as distinguished from that of a frontage road (16).

(3) Outer separator - A separator between a frontage road and the roadway of a controlled-access highway or major street (16).

(4) Traffic island - An island provided in the roadway to separate or direct streams of traffic; includes both divisional and channelizing islands (16).

A collector-distributor road is shown in Figure 1b, "Weaving on Collector-Distributor Roads of C-D Equipped Cloverleaf," which also shows the difference between four-quadrant cloverleaf interchanges without C-D roads (Figure 1a) and those with C-D roads (Figure 1b). Note that Figure 1b shows the weaving movement physically separated from through freeway operations.

An assistant engineer of design in California in a 1970 paper (13) gives three common solutions to weaving problems:

- "...a) Add auxiliary lanes to increase weaving capacity
- b) Provide a collector (-distributor) road - adds lanes and moves weave off freeway proper
- c) Provide a braid-eliminate weaving conflict entirely." (13, p. 17)

In this same paper on interchange design, the author states:

..."Collector(-distributor) roads will always be provided on four-quadrant cloverleaf interchanges"... (13, p. 10)

FIGURE 1a : WEAVING ON THROUGH LANE OF CLOVERLEAF
WITHOUT COLLECTOR-DISTRIBUTOR

FIGURE 1b : WEAVING ON COLLECTOR-DISTRIBUTOR ROADS
OF C-D EQUIPPED CLOVERLEAF

FIGURE 1 : TYPICAL (IDEALIZED) FOUR-QUADRANT
CLOVERLEAF INTERCHANGES

There are other references which propose collector-distributor road use as a design objective, citing weaving theory and geometric design policies as warrants for implementation under certain conditions. One objective study was performed by Cirillo, Dietz, and Beatty (6) based upon twelve full cloverleaf interchanges that had one or more collector-distributor roadways compared with 186 interchanges that had no C-D roadways. They made the following observations:

"On the average it is noted that a full cloverleaf interchange with at least one C-D road has

- a. Fewer accidents/million vehicles
- b. Fewer number of accidents per interchange, and
- c. Considerably less injuries and amount of property damage per interchange than does a full cloverleaf without a C-D roadway." (6, p. 39)

In this carefully designed study, however, quantitative results were not conclusive. The "fact" than an interchange would average 4.7 fewer accidents per year if a C-D roadway were included and all other variables remained the same was found not to be statistically significant (t statistic = 1.3).

The study by Cirillo, Dietz, and Beatty is accompanied by information on accident rates by type of interchange unit, type of freeway ramp, type of accident, and length of weaving area, as depicted in Figures 2, 3, and 4 and Table 1.

¹ ACCIDENT RATE / 100,000,000 VEHICLE MILES OF TRAVEL

FIGURE 2: ACCIDENT RATE BY TYPE OF INTERCHANGE UNIT (7, p.74)

FIGURE 3: RAMP ACCIDENTS BY TYPE (30, p.54)

RAMP TYPE	ACCIDENT RATE		
	ON	OFF	ON & OFF
1. DIAMOND RAMPS	0.40	0.67	0.53
2. CLOVERLEAF RAMPS WITH COLLECTOR-DISTRIBUTOR ROADS	0.45	0.62	0.61
3. DIRECT CONNECTIONS	0.50	0.91	0.67
4. CLOVERLEAF LOOPS WITH COLLECTOR-DISTRIBUTOR ROADS	0.38	0.40	0.39
5. BUTTONHOOK RAMPS	0.64	0.96	0.80
6. LOOPS WITHOUT COLLECTOR- DISTRIBUTOR ROADS	0.78	0.88	0.83
7. CLOVERLEAF RAMPS WITHOUT COLLECTOR-DISTRIBUTOR ROADS	0.72	0.95	0.84
8. TRUMPET RAMPS	0.84	0.85	0.85
9. SCISSORS RAMPS	0.88	1.40	1.28
10. LEFT SIDE RAMPS	0.93	2.19	1.91
AVERAGE	0.59	0.95	0.79

TABLE 1: ACCIDENT RATES BY TYPE OF FREEWAY
RAMP (ACCIDENTS PER MILLION VEHICLES
USING INTERCHANGE) (25, p.116)

FIGURE 4: ACCIDENT RATE AND LENGTH OF WEAVING AREA (8,p.21)

Cirillo, et al, (6) also found different traffic patterns in collector-distributor equipped interchanges than in those without C-D roads.

"On the average less vehicles traveled on the mainline but more vehicles entered and exited from an interchange with at least one C-D roadway. In fact, this type of interchange had the highest percentage of vehicles entering or exiting." (6, p. 39-40)

The Cirillo report, however, does not explain whether the different travel patterns at interchanges with collector-distributor roads were due to the presence of C-D roads or whether C-D roads had been used under different design conditions, such as heavier volumes of non-through movements. This study also included the relationships between accidents and the geometric and traffic characteristics of the interstate system (6). Full cloverleaf interchanges (with no C-D roadway) had by far the most dangerous record in terms of the number of accidents per interchange, the number of injuries per interchange, and the amount of property damage per interchange, as well as the highest accident rate (the number of accidents per million vehicles). The results of this analysis are given in Tables 2 and 3 (6, p. 44). Table 2 also shows that when at least one C-D roadway was used at a full cloverleaf interchange the average number of accidents dropped from 19.3 to 14.3 and the accident rate dropped from 1.69 to 1.45 per million vehicles.

TABLE 2

Average Number of Accidents and Injuries per Year for Interchanges, Average Amount of Property Damage per Year per Interchange, and Average Number of Accidents per Interchange				
Model Number	Intersection	Average Number of Accidents	Average Number of Injuries	Average Amount of Property Damage (in Hundreds of Dollars)
14	Full Cloverleaf with No C-D Roadway	19.3	12.9	132
-	Full Cloverleaf with At Least One C-D Roadway	14.3	6.2	92
15	Partial Cloverleaf	5.3	3.7	33
16	Three-Leg or T-Intersect	4.0	2.6	32
17	Full Diamond	4.2	2.3	29
18	Half Diamond	2.9	2.0	20
19	Full Slip Ramp Diamond	9.9	3.5	43
-	Half Slip Ramp Diamond	4.9	1.3	21

(6, p. 44)

TABLE 3

Means and Standard Deviations of the Components of Independent Variables Used in Final Model Analysis.

Variable Number	Variable Description	Full Cloverleaf with C-D Roadway (1)		Partial Cloverleaf Model 14		Partial Cloverleaf Model 15		Turned-Left or Turned-Right Model 16	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
X ₁₀₁	ADT mainline	20000		25900	23500	17400	16300	15100	13400
X ₁₀₂	Daily exit volume	6350		5200	4760	1560	1650	2100	1890
X ₁₀₃	# businesses/100 feet	.03		.05	.06	.04	.07	*	*
X ₁₀₄	1 = rural 2 = urban	.50		.46	.50	.57	.50	.71	.45
X ₁₀₅	% commercial volume day	18		17	5.1	19	6.0	19	6.0
X ₁₀₆	% commercial volume night	24		21	13	25	12	22	12
X ₁₀₇	Size of Interchange (feet)	1200		1220	390	490	160	770	370

* No model developed; only 12 observations.

An analysis by Leisch of the use of C-D roads with full cloverleaf interchanges in both rural and urban settings showed improved weaving when C-D roads were used (23). Leisch found an increase in weaving capacity of from 20 percent to 35 percent, with weaving volumes from 1,200 vph to 1,350 vph for a two lane C-D road and up to 1,500 vph for a three lane C-D road. In urban areas, Leisch predicted that C-D roads could increase the weaving capacity as much as 50 percent, from 1,000 vph to 1,500 vph.

Leisch says that because the ramps connect to the C-D road which has slower speeds, the number of ramps may be increased due to the shorter maneuver and weaving area lengths required (23). At least one study, however, found that at least part of the time the basic assumption of slower speeds on C-D roads is invalid.

An Institute of Transportation and Traffic Engineering (ITTE) Graduate Report states:

"Design standards provided on these two-mile sections of collector-distributor road are less than would have been provided adjacent to the through freeway lanes. The average spacing between interchanges is only one-half mile. In several cases, the available lengths provided for weaving conflicts is only 600 feet between concrete noses. Many of the ramp acceleration lanes and other lane drops are from 200 feet to 400 feet in length.

These standards were considered appropriate on the assumption that traffic would travel at slower speeds on the collector-distributor road. This would be the case where, say a collector-distributor road was provided on a four-quadrant interchange. However, on this long Santa Monica Freeway section, speeds

similar to those on the through roadway are commonplace. Rapid lane changes are, therefore, occurring on sections of the collector-distributor road where differential speeds between vehicles are quite high." (21)

This California study also analyzed the weaving patterns within weaving sections of collector-distributor roads and found the effective weaving length within those sections to decrease as traffic volumes increase. The 425 feet long weaving section in the test site was judged "adequate" in length (21, p. 11). Volumes ranged from 700 to 2750 vehicles per hour in that analysis. Under different vehicle operating conditions (related to on-ramp designs), Fukutome and Moskowitz found similar tendencies for increases in ramp traffic from 480 to 960 vehicles per hour to cause reductions in median weave length of 390 to 300 feet, 480 to 420 feet, and 430 to 300 feet (12, p. 38).

Pinnell and Buhr discuss collector-distributor roads in an analysis of capacities of loop ramps when weaving becomes the determining factor for capacity (44). They observe that while the capacity of an isolated single lane loop ramp is approximately 800 vehicles per hour, two adjacent loop ramps (Figure 5a) are restricted to a total capacity of 1,000 vehicles per hour due to the influence of weaving maneuvers. When a collector-distributor road is used, the weaving capacity and thus the ramp capacity increases to about 1,500 vehicles per hour (Figure 5b).

Figure 5a. Adjacent Loop Ramps

Figure 5b. Loop Ramps with C-D Roads

FIGURE 5
LOOP RAMPS WITH AND WITHOUT COLLECTOR-DISTRIBUTOR ROADS

Pinnell and Buhr showed in their study an actual improvement in capacity with collector-distributors between adjacent loop ramps. The studies of both Leisch and Pinnell and Buhr emphasized the utility of C-D roads under near-capacity conditions and showed increased capacity in a large number of cases when weaving is the determining constraint on capacity.

A highway research report prepared by D. B. Martin, L. Newman, and R. T. Johnson, entitled "Evaluation of Freeway Traffic Flow at Ramps, Collector Roads and Lane Drops (The Collector Road Study)" contains some pertinent conclusions. One major conclusion of this study, presented in 1972, was that freeways with auxiliary lanes have greater flexibility than freeways with collector road systems with the same number of lanes (26, p. 1). Their conclusion was that such freeways also have "greater capacity and more efficient operation" (26, p. 1).

The review of literature associated with the implementation of collector-distributor roads showed optimism on the part of experts on design theory and of researchers for collector-distributor roads for their ability to improve freeway traffic operations and capacity under near-capacity volumes where weaving maneuvers are a determining capacity restraint.

CHAPTER III

THE PURPOSE AND SCOPE OF THE STUDY

Collector-distributor roads may be used under several complex highway design conditions to improve safety and operational flexibility. Within four-quadrant cloverleaf interchanges, between adjacent interchanges where conflicts impede through traffic movement, or where traffic is to be collected and distributed from several points of access, the collector-distributor road performs the function of an extra freeway lane but also limits points of ingress to and egress from the through freeway lanes while separating faster through traffic from interchanging traffic.

It is generally expected by design engineers that the use of collector-distributor roads at an interchange will increase highway cost because of increased span length of structures, increased right-of-way requirements and additional pavement. An important question in highway design, therefore, is when will C-D roads decrease the operational cost sufficiently to warrant the additional construction cost of an interchange. The question posed for a C-D road is whether or not the increased (if it is increased) expense can be justified economically (through fewer accidents and less serious accidents) or

operationally (through more efficient operation and economy of design). No established warrants are accepted as a basis to justify the expected additional construction cost in providing the higher level of service possible with C-D roads. Such a warrant would be useful to serve as a guideline for applications of C-D roads. Although consistency in design is desirable from a design and operational standpoint, this may not be sufficient justification when a design alternative increases the construction cost of an interchange by several hundred thousand dollars. Numerous state design manuals and consultants appear today to rely on the improved geometric design resulting from collector-distributor facilities as sufficient justification for their use.

Previous studies of collector-distributor roads have shown near-capacity interchanges with C-D roads to operate approximately as they had been predicted to operate in theory. The justification for C-D facilities on current low volume facilities is apparently dependent on the expected increase in volume to capacity conditions in or near the design year.

Freeway capacity may, however, be less with a C-D road in place of an additional freeway auxiliary lane because alternatives for operators to avoid conflicts or to opt for the lane with the least amount of resistance may be fewer (26).

Justifying the use of C-D roads for their benefit in reducing property damage and personal injury accidents has been previously addressed by Cirillo et al, showing fewer accidents with the C-D design, but results were subject to large variations and were not found to be statistically significant (6). Transferring conflict points to exit and entrance ramps between the freeway and C-D road may also result in exceeding the capacity of these ramps.

These many problem areas in selection of a C-D design for or between complex interchanges of freeways resulted in this research. The specific purpose of this study of collector-distributor roads was to determine the cost-effectiveness of C-D roads. The results of such a study could be applied to determine when, where, and how the C-D roads should be designed and employed.

Objectives which were to be met in the study were

1. To determine, from the standpoint of traffic operations and safety, the conditions under which a collector-distributor road is the most advantageous design consistent with traffic volumes, travel speeds and other pertinent operational considerations.
2. To establish cost comparisons between interchanges with collector-distributor roads and alternate forms of design without C-D roads.

3. To develop design standards for C-D roads commensurate with anticipated travel speeds and traffic volumes.

The scope of the study included:

1. A review of as many current design manuals of state highway departments as could be obtained by correspondence with state highway officials.
2. An analysis of replies to questions on C-D facilities which had been included in questionnaires submitted to state highway departments and major consulting design engineers in conjunction with another highway research project of the Joint Highway Research Project at Purdue University on interchange designs and policies. Portions of interviews with selected officials and consultants performed as part of the interchange study which concerned C-D facilities were also reviewed and studied.
3. An operational and cost study of all pertinent C-D roadways in the state of Indiana.

CHAPTER IV

REVIEW OF DESIGN MANUALS AND RESPONSES FROM DESIGN ENGINEERS

In developing the work plan for this study, it was felt a valuable source of information on criteria for use of C-D roads and their design would be the design manuals of the several states and the experience of design engineers. As a result the study included a review of as many design manuals as could be obtained by correspondence and a review of responses of design engineers to questions on C-D roads contained in a questionnaire and in interviews conducted for an interchange study made at Purdue in 1973.

Review of Design Manuals

The fifty state highway departments and commissions were contacted and forty replied by sending appropriate sections of design manuals or the entire manual. The investigators were able to add four more from various sources, bringing to forty-four the number of manuals reviewed. Of this number, only twenty-three made specific reference to interchanges and only nine included any reference to collector-distributor roads.

The New York State Department of Transportation Highway Design Manual outlines preferred design principles for interchanges and specifics where collector-distributor roads can be used to improve speed and capacity (37).

"Minimum weaving - weaving sections severely reduce speed and capacity and, on high-speed, high-volume highways, cause sharply increased accident rates and congestion. In general, on rural freeways, the distance between any entrance and the following exit should be sufficient to eliminate weaving as a design control. On urban freeways and rural multi-lane primary highways, some weaving may be tolerated. However, the Quality of Flow as shown in Figure 7.4 on page 166 of the 1965 Highway Capacity Manual should be a minimum of II and for freeways, the absolute minimum distance between any entrance and the following exit shall be 1,800 feet. ...On collector-distributor (C-D) roads and the weaving sections of rotary interchanges, the Quality of Flow should be III absolute minimum IV in urban areas." (37, p. 6-48)

"As can be seen from the foregoing, direct cloverleaf interchanges with associated short weaving sections are not acceptable on freeways and undesirable on multilane rural primary highways. Cloverleafs with C-D roads may be used on these facilities provided all other criteria are met." (37, p. 6-48)

"With single exit interchanges, the driver has only one decision to make while on the freeway in the midst of high-speed, high-volume traffic; to exit or not. His second decision is made off the freeway among lower-speed, lower-volume traffic on the ramp of C-D road. It is recognized that incorporation of single exit designs will increase construction costs in many cases due to the need for additional and/or wider structures. This increase in cost can normally be justified by the added safety and the improvement in traffic flow." (37, p. 6-49)

The State of Washington Design Manual (1972) describes basic interchange patterns and includes several references to collector-distributor roads, even detailing design criteria for C-D roads (48).

"Either parallel auxiliary roads or collector-distributor roads should be considered when it is necessary to facilitate the operation of near-capacity volumes between closely spaced interchanges or ramp terminals. Where inner loops are involved or where a series of interchange ramps which cannot be cross separated may otherwise require overlapping of the speed change lanes, collector roads may be required. (48, p. 3-25.01)

"Cloverleaf designs often incorporate a collector-distributor road to minimize signing difficulties and to reduce weaving conflicts where speed change lanes of the inner loop overlap." (48, p. 3-25.01-.02)

"Weaving between closely spaced loop ramps when adjacent to high speed highways, will be accomplished by using C-D roads. Weaving without C-D roads will be allowed on the low speed crossroad." (48, p. 3-25.05(1))

Design standards for on and off connections are detailed in the Washington State Design Manual and are included in Appendix A. This manual recognizes, as do other references, that collector-distributor roads improve traffic operations under high volume or near capacity conditions.

The Florida State Roadway Design Manual recommends that full cloverleaf interchanges not be used for high density highways because of unfavorable weaving conditions introduced between loop ramps.

"If this type interchange is proposed, collector-distributor roads should be considered." (11, p. 28-1)

The Oregon State Design Manual states:

"Collector-distributor roads may be used to reduce traffic friction from several entrance and exit connections, thereby permitting higher speeds in the through traffic lanes." (39, p. 158)

New Mexico's, Nevada's, and Colorado's design manuals in the same words propose collector-distributor roads to counteract the disadvantages of four quadrant cloverleaf interchanges (36, 35, 9).

"A four-quadrant clover-leaf pattern may incorporate a collector-distributor road in the design, which will minimize signing difficulties as well as weaving conflicts where the inner-loop speed-change lanes overlap. A collector-distributor road is essentially a weaving section physically separated from the through lanes, and whose termini are joined to the through lanes by exit and entrance connections. Collector-distributor roads also may be used as an adjunct to a series of interchanges, when close spacing of entrances and exits would require overlapping of speed-change lanes." (36, p. 7-503.3; 35, p. 2-602; 9, p. 5-3)

Several design manuals which detail collector-distributor road standards allow shorter merging or weaving sections when C-D roads are employed. The distance between successive ramp terminals is also generally described in a Northwestern University Traffic Institute Publication as follows:

"Minimum distances are predicated on the principle of not allowing the maneuver influence length of one ramp to overlap the maneuver influence length of the succeeding ramp." (38, p. 9)

A more specific quantitative standard to promote this design objective is also stated:

"In the case of two successive exits or entrances on freeways, the spacing should not be less than 1200 feet. Minimum distances of 800 to 1200 feet in conjunction with collector-distributor or major interchange roadways are appropriate." (38, p. 9)

Within the weaving sections of roadways the Traffic Institute Publication suggests greater allowances when C-D roads are used:

"Lengths of weaving sections should also be checked for required minimum distance between successive ramps. In the case of a weaving section - an entrance ramp followed by an exit ramp - the minimum distance should be predicated on two non-overlapping maneuver influence lengths; this calls for twice the indicated lengths of 600 to 1200 feet, or weaving section lengths on the order of 1800 to 2400 feet should be considered as minimum, and on high-type collector-distributor (C-D) roads, lengths of 1200 to 1500 feet. Weaving may be removed from the freeway by the use of C-D roads, or weaving may be completely eliminated by introducing a grade-separation structure." (38, p. 10)

Furthermore, the publication quotes the AASHO definition of a collector-distributor road and states that "it (the C-D road) provides greater capacity and permits higher speeds to be maintained on the through traveled way." (38, p.10) and outlines general concepts to guide interchange spacing.

"Ramp frequency may be increased by: Criss-cross ramp arrangements; Ramp groupings; Use of C-D roads; and by a combination of these." (38, p. 12)

The Highway Capacity Manual dedicates one chapter (seven) to weaving problems and design objectives. Operating characteristics of weaving sections are expressed graphically and relationships between basic roadway levels of service and quality of flow on weaving sections show a lower quality of flow to be satisfactory on C-D roads (as opposed to the highway proper) for the same level of service.

The AASHO policy on design of urban highways and arterial streets (1973) follows its definition of a collector-distributor road with design applications:

"Collector-distributor roads may be provided within a single interchange, through two adjacent interchanges, or be continuous for some distance along freeways, through several interchanges. Care must be taken that the connecting roadways between the freeway and the collector-distributor road are properly located and designed to assure that the points of exit from the freeway to the collector-distributor road and the points of entry to the freeway from the collector-distributor road do not become so overburdened with traffic that freeway operation is adversely affected." (1, p. 583)

Where ramp terminals are closely spaced and where there is weaving over inadequate distances on the freeway, the AASHO Policy recommends C-D roads to remove the weaving. Describing these conditions, the AASHO policy states:

"Unless the volume of traffic entering and leaving the freeway is very light, there will be a considerable amount of interference with through traffic at locations such as these. Such interference can be alleviated by utilizing a collector-distributor road." (1, p. 583)

The rural counterpart to the above policy statement for urban highways is AASHO's "Policy on Geometric Design of Rural Highways" (1965). That policy states that where high speed or high volume, or both, must be accommodated, traditional forms of interchange design may be "inadequate".

"In such case, the interference to through traffic of the weaving and maneuvering of entrance and exit traffic along a substantial length may be eliminated by provision of a separate one-way roadway. This arrangement is known as a collector-distributor road and has a definite advantage by removing the weaving from the through lanes. Operationally it is superior to the other arrangements. This also has the advantage of placing the exit ramp terminal on the rear side of the structure, which arrangement may be desirable to maintain a uniform pattern of exits along a freeway. However, the cost is greater since it normally requires longer overhead structures and additional paving." (2, p. 543)

The several references to the C-D concept and design in the state design manuals show extensive agreement about the purposes and uses of collector-distributor roads. Many of the state criteria for C-D roads are from the two AASHO policy books. For weaving capacity design, the states typically reference the Highway Capacity Manual. The design policies suggested by the HCM and the AASHO publications are generally accepted as state design policy for collector-distributor roads in those states that include C-D roads in their design manuals.

Review of Interviews with Design Engineers From
Six State Highway Departments

In conjunction with another Joint Highway Research Project at Purdue University, interviews were held with design engineers from six highway departments. The purpose of the interviews was to review interchange design principles in the six (Indiana, Illinois, Michigan, Ohio, Texas, and California) states. One question asked during each interview was "What are your opinions toward the use of collector-distributor roads?" The answers to that question are summarized here.

Design engineers in the State of Michigan indicated a preference for single-lane exits and entrances on freeways. To achieve this objective and in order to take weaving off through lanes, collector-distributor roads are utilized. The Highway Capacity Manual was referenced for evaluation of weaving problems.

Ohio design engineers indicated a dislike for two exits and entrances because of resulting "tying up" of the through roadways at cloverleafs without C-D roads. Ohio engineers felt the tendency was toward increased use of collector-distributors with cloverleaf designs in suburban areas. The last several interchanges designed, they reported, have been cloverleaf type designs and generally with C-D roads.

It was the opinion of one design engineer that if lane balance were strictly followed on three lane expressways with C-D roads at almost every interchange, the needed lanes would vary on the mainline from three to two and then back to three. He indicated that this type of design tends to force some drivers to use the C-D road as a through lane. However, lane balance theory is also dependent upon a basic requirement for a certain number of lanes. Had three lanes been continued through the interchange, the problem of using the C-D roads as through lanes might not have arisen. In other words, lane balance theory does not dictate a lane drop through the interchange, as was implied by the engineer. Another design engineer pointed out that signing problems were fewer when C-D roads were applied.

Engineers from the State of Illinois felt that the cloverleaf interchange with C-D roads was very costly, because of the extra bridge cost, extra pavement cost and right of way cost. Therefore, the only accepted reasons for building C-D roads tend to be needed extra capacity and to bridge closely spaced ramps. The criterion for capacity is weaving volumes above 1200 vehicles per hour. Collector-distributor roads are never used on partial cloverleaves for uniformity; however the C-D is not necessarily used on full cloverleaves to achieve uniformity. C-D roads are used primarily for two purposes:

1. To collect ramps in close proximity for signing and to improve operations,
2. Or, as on the Dan Ryan Expressway, an integrated system of C-D roads to isolate interference from through traffic.

The C-D is favored as an ideal to make cloverleafs more acceptable because they remove weaving from the main-line. In cases where improvement was needed on cloverleafs, the C-D design was preferred over directional ramps as a more practical solution. Closely spaced ramps such as those found in urban areas were cited as another application of C-D roads.

In Texas it was generally felt that even with C-D roads, cloverleafs do not provide enough capacity in urban areas except for minimal traffic conditions. However, two engineers expressed opinions that C-D roads should be standardized. They noted that collector-distributor roads will protect movements on main lanes only but when such protection improves overall performance, it is an acceptable warrant. When dual-dual type, continuous C-D roads, were used Texas preferred the possible infrequent connections to the through lanes. Weaving was evaluated by a level of service analysis and weaving capacity derived from the Highway Capacity Manual.

California has been using C-D roads in conjunction with cloverleafs more frequently than most states, and several

design engineers praised C-D roads "when used in the right situations". One engineer said that C-D roads were being provided in almost all cloverleafs so that loop movements and weaving could be accomplished at slower speeds on the C-D. Collector-distributor roads were also used to handle large volumes of interchanging traffic, but engineers pointed out that they did not like short weaving sections on the C-D road. Minimum criteria for driver decision points was 600 feet to 800 feet, based on driver reaction and signing. One design expert said that there was a serious weaving problem associated with cloverleaf interchanges but that weaving does not produce accidents, as a majority of accidents occur at gore areas. Another engineer said that all cloverleafs now either have C-D roads or are designed for future C-D roads. He promoted the single exit policy, indicating that there should be no cloverleafs without C-D roads. Where acceptable weaving distances (1600') were not obtainable, C-D roads were recommended, with a 600' minimum requirement for signing. Two of the major concerns in determining the use of C-D roads were room and money. One engineer expressed the preference to have the C-D lanes contiguous to the freeway for flexibility. His preference was for 1700' weave sections but he noted that it was not uncommon to have 400' weave sections. He felt that this was "entirely inadequate". He said that since it was impractical to get adequate weaving lengths at four-quadrant

cloverleafs, at least the C-D performed the function of isolation of traffic by operation (weaving and non-weaving) and speed (through versus maneuvering). C-D roads were not generally thought appropriate on local low-volume interchanges.

Review of Questionnaires of Consultants

The review of design manuals and interviews with state design officials was supplemented by results of a questionnaire sent to twenty-one consultants who specialize in highway design. The questionnaire also was done in conjunction with the already noted other Joint Highway Research Project on Interchange Design. Again the one question "When would you use C-D roads?" provided answers to some of the objectives of this study.

Of the nine respondents, three appeared to define the term C-D roads as a type of frontage road. The remaining six consultants indicated that situations in which collector-distributor application might be beneficial were (the numbers indicate number of consultants providing that answer):

- a) Improved weaving patterns - 4
- b) Improved capacity - 4
- c) Improved speed - 1
- d) Higher turning volumes (capacity) in conjunction with cloverleafs - 3

- e) Low volume, freeway-to-freeway interchanges - 1
- and f) To remove weaving from the freeway - 2.

CHAPTER V

DATA COLLECTION AND DESIGN OF THE OPERATIONAL STUDY

Collector-distributor roads are in operation at the following locations in the state of Indiana: (Figure 6, Location Map)

1. I-65 and 38th Street in Indianapolis (between interchanges)
2. I-65 from Eastern Boulevard, Clarksville, to the Ohio River (1.5 miles - continuous) (SB and NB: one exit and one entrance from the through roadway.)
3. I-65 and US-52 Northwest of Lebanon (protection of weaving maneuver)
4. I-465 and 10th Street, West of Indianapolis (Cloverleaf with C-D on West side)
5. I-69 and Ind. 32 and Ind. 67 between Anderson and Muncie (Chesterfield - between closely spaced interchanges)
6. I-465 and Ind. 100 and 56th Street (complex interchange)
7. I-69 and S.R. 37 (Fishers at 116th Street - separating weaving maneuver at the junction of two major arterials)

FIGURE 6 LOCATION MAP DEPICTING FIVE INCLUDED (1-5) AND TWO EXCLUDED (9,10) SITES AND THREE (6-8) NON C-D INTERCHANGES

Upon examination of traffic volumes at the 38th Street facility (Kessler Boulevard) and by observation of its operation, this interchange, although by definition C-D equipped, was dropped from the study of C-D roads. The volumes of traffic at the four cross-over points (one ingress and one egress per each of two C-D roads) were very low in comparison with the traffic on both I-65 (38th St.) and on C-D lanes (Figure 12a). Operationally, this facility performed more as two parallel roads than a C-D equipped freeway. In addition, an intersecting local street (Guion Road) on both the north and south C-D roads added the possibility of completely different conflicts and travel characteristics on those sections of roadway. The site was not representative of a C-D road for the purposes of this study.

The Louisville site was peculiar in that it was much longer (1.5 miles) than any other C-D road in the state and was continuous through two interchanges, both of which had fairly light volumes (Figure 12b). The design conditions included a high proportion of weaving movements and very heavy pulsed traffic flow (commutation to or from Louisville, depending upon the time of day) across the Clark Memorial Bridge.

The weaving movements at this Louisville site were seen to be numerous lane changes, more than were associated with entrances and exits at the two interchanges. During

peak hours there was relatively more traffic using the interchanges, indicating that much of the traffic is commuting from Jeffersonville, Indiana. The C-D roads at Jeffersonville were also thought by ISHC engineers to carry a number of through movements for I-65 and the difference in scale of the C-D facility and the fact that it was in an urban area made it impractical for comparison of costs for the economic justification study. Although the peculiarities were sufficient to warrant special design considerations, they also made the facility so much different from the other C-D sites in Indiana that it was eliminated from the C-D sample. The collector-distributor roads and interchanges at this location, however, may provide an excellent model for a case study of C-D roads on a subjective basis due to its unique design and function.

Thus, five C-D equipped interchanges remained in the study sample to represent collector-distributor design and use. The facilities and sites are as follows:

1. I-465 and Ind. 100 and 56th Street (East of Indianapolis) (Figure 7)
2. I-465 and 10th Street (West of Indianapolis) (Figure 8)
3. I-69 and S.R. 37 (Fishers) (Figure 9)
4. I-69 and S.R. 32 and S.R. 67 (Chesterfield) (Figure 10)
5. I-65 and U.S. 52 (Northwest of Lebanon) (Figure 11)

FIGURE 7: AERIAL PHOTOGRAPH OF INTERCHANGE I465
AND 56th STREET WITH S.R. 100

FIGURE 8: AERIAL PHOTOGRAPH OF INTERCHANGE I 465
AND 10th STREET

FIGURE 9: AERIAL PHOTOGRAPH OF INTERCHANGE I69
AND S.R. 37

FIGURE 10: AERIAL PHOTOGRAPH OF INTERCHANGE I69,
S.R. 32 AND S.R. 67

FIGURE II: AERIAL PHOTOGRAPH OF INTERCHANGE I65
AND U.S. 52

FIGURE 12a: AERIAL PHOTOGRAPH
OF INTERCHANGE I 65 AT
JEFFERSONVILLE

FIGURE 12b: AERIAL PHOTOGRAPH
OF INTERCHANGE I 65 AND 28th
STREET

FIGURE 12: THE TWO C-D INTERCHANGES EXCLUDED FROM
THE STUDY

The five collector-distributor equipped interchanges were chosen as the population of sites in Indiana at which a C-D design has been implemented because of design peculiarities, e.g., where weaving movements were thought to be exceptionally critical. Three interchanges were also chosen to compare with the C-D equipped interchanges (Figure 6, location map):

6. I-74 West at I-465 (Figure 6, #6)

7. I-69 and Ind. 37 at I-465 (Figure 6, #7)

8. I-70 East of Indianapolis at I-465 (Figure 6, #8)

Sampling for the above was not randomized because it was intended that this study apply to a generalized type of collector-distributor road which is defined by its operation and not by its physical design. The three interchanges chosen to represent non-C-D equipped interchanges were selected intentionally and not at random because of the necessity of duplicating operation and design conditions between C-D and non-C-D sites as much as possible.

Interchanges were selected for the "null-alternative" (without C-D roads) sample with the advice of ISHC design engineers. Airphotos, traffic volumes, construction plans and cost figures were collected and analyzed for both C-D and non-C-D interchanges.

A pilot study was designed for the purpose of testing data collection procedures and defining investigation methods. The pilot study was conducted at one of the

collector-distributor locations during the month of May, 1973, to develop the procedure for noting and recording. The incidents analysis was also to serve as additional information about the actual quality of operation.

The site chosen for the pilot study was the I-465 interchange with 56th Street and State Road 100, east of Indianapolis. The 56th Street site had sufficient volume of traffic for the study and is a fairly typical configuration for a collector-distributor road.

After completion of the pilot study, the remaining sites were studied in random order by implementing the techniques which had been finalized during the pilot study.

Traffic volumes are collected and reported regularly on freeway through movements and ramp movements at every interchange along Interstate highways and state roads in Indiana by the Indiana State Highway Commission. The file containing these data is periodically revised and is current and well organized. Counts are taken by a pneumatic tube-activated traffic volume recorder and are raw counts (48 hour count, divided by 2).

Accident data were collected from the Indiana State Police Department, Accident Records Division, whose records of accidents on interstate highways have been filed by (a) the interstate highway on which the accident occurred (including ramps at interstate highway interchanges), (b) the county in which the accident occurred, (c) townships,

and (d) chronological order, separated by year. The fatal accidents are kept in a separate file with the same arrangement of data. The basis for collecting three years' (January 1, 1971 to December 31, 1973) accident data was a study by May (27) which states that a three year accident history is required to reduce the possibility of encountering unusual results, and that little confidence is gained by further increasing the period of observation.

Although the quality of operation is roughly indicated by accident records for each interchange under study, the number of reported accidents during three years (the period of accident study) was too small in comparison to the number of vehicles using the interchange to get a statistically valid comparison between interchanges. In an attempt to circumvent the inability of reported accident data to give the desired information, photographic equipment (Appendix B) was used to record erratic maneuvers within the zone of influence of each interchange. It was believed such maneuvers, which might lead to incidents, near misses, minor and unreported accidents, or in more serious and rare cases to reportable accidents, would more closely parallel driver difficulty. Hence, an analysis of erratic maneuvers was included as an element of operational evaluation.

Data collection on erratic maneuvers was completed in November, 1973, using a time-lapse photographic unit

(recording on 16 mm color film at 1-second intervals) to record traffic operations which do not end up on the accident ledgers, but may indicate that some problem or void in signing or design may exist.

The difficulties usually inherent in ground-mounted oblique photography were overcome by taking advantage of the ramp design to elevate and at the same time to conceal the photographic equipment, since it was thought that knowledge of the camera's presence might effect a driver's approach or reaction to the interchange. This assumption was borne out to some extent, in that occasionally vehicles approaching the camera would use their horns and/or wave to the camera operator or otherwise indicate that the camera was visible. There was no evidence that those moving away from the camera knew of the camera's presence or reacted as if they did, with the exception of the vehicles entering the C-D from the ingress ramp. The camera was sometimes exposed to observation from this vantage point, but since it was almost impossible to hide the camera from every lane of traffic it was thought that these vehicles would be moving more slowly and, upon entering the possible conflict of a merge or weaving maneuver, would not dwell upon the camera's presence, checking their speed or braking as might those on the C-D or freeway through lanes.

Filming was not begun until after several observations of operations at each interchange. A stop watch was used to record progressive changes in traffic volumes to determine approximately the peak and off-peak periods at each interchange. It was thought by investigators that using the same time of day for each interchange for filming would not necessarily show peak vs. non-peak conditions, because several of the interchanges were rural in nature and were various distances from the sources of peak hour volumes. After this determination was made for each of the eight study sites (5 C-D and 3 non-C-D interchanges), several points from which to film were selected and the position which gave the most comprehensive picture of operations was chosen from these. All filming was done from the upstream side of traffic in order to provide a view of brake activation, as indicated by time and duration of brake light activation.

The time-lapse camera was usually activated for periods of one hour or slightly longer than one hour. Both off-peak and peak hours were included in the erratic maneuver analysis in equal amounts and were pooled to provide a view of average erratic maneuvers per hour. At least one observation (hour) each was taken of peak and off-peak traffic on two separate days at each of the eight study sites. Only two days' data, however, were analyzed for each site (approximately four hours of operation per

site). The numbers of vehicles observed during these periods at their respective sites are tabulated in the Analysis section of this report.

Construction costs associated with the five collector-distributor equipped interchanges and the three non-C-D interchanges utilized in this study were collected and analyzed for economic purposes. Construction costs are maintained by the Indiana State Highway Commission on ISHC Comparison of Estimates Construction Records (Form IC642), but there was little continuity in the information listed. Methods of reporting varied greatly, as did the quality of reporting. Nevertheless, all pertinent information was obtainable from those records and is presented in a comparison of initial construction costs of both collector-distributor and non-collector-distributor interchanges. This comparison was intended to provide a determination in economic terms of the amount of increase in construction costs induced by the addition of a C-D facility.

CHAPTER VI

ANALYSIS

Traffic Volumes

Traffic volumes at the study interchanges were obtained for the period for which accident data were analyzed. These volumes appear in Figures 13 through 22 and in Table 4. The base data from which the ADT volumes were estimated were traffic volume counts taken by the Indiana State Highway Commission during the years 1971 and 1972. Factors from the state's permanent counters on interstate highways were used to adjust the data to 1972 volumes, the mid-year of the accident data. The same volumes were used in the erratic maneuver analysis although these data were collected in 1973. Adjustment of the volumes to 1973 levels would have resulted in so little change that it was felt to be insignificant.

Accident Analysis

The analysis of collector-distributor roads included a study of accidents occurring at the five C-D locations and three locations without collector-distributor roads. Indiana law requires that accidents be reported if property damage exceeds one hundred dollars, or if any

FIGURE 13 TRAFFIC VOLUMES AT INTERCHANGE I-65 AND S.R. 100

FIGURE 14: TRAFFIC VOLUMES AT INTERCHANGE
I-465 & TENTH ST. (SITE NO. 2, ADT)

FIGURE 15: TRAFFIC VOLUMES AT INTERCHANGE
I-69 & S.R. 37 (SITE NO.3,ADT)

FIGURE 16: TRAFFIC VOLUMES AT INTERCHANGE
I-69 & S.R. 67 & S.R. 32 (SITE NO. 4, ADT)

FIGURE 17: TRAFFIC VOLUMES AT INTERCHANGE
I 65 AND US 52 (SITE NO.5, ADT.)

FIGURE 18 TRAFFIC VOLUMES AT INTERCHANGE I-65 & 38 TH ST.

**FIGURE 19: TRAFFIC VOLUMES ON INTERSTATE ROUTE 65
AT JEFFERSONVILLE (ADT)**

FIGURE 20: TRAFFIC VOLUMES AT INTERCHANGE

I-465 & I-74 (SITE NO.6,ADT)

FIGURE 21: TRAFFIC VOLUMES AT INTERCHANGE
I-465 & S.R. 37, I-69 (SITE NO. 7, ADT)

FIGURE 22: TRAFFIC VOLUMES AT INTERCHANGE
I-465 & I-70 (SITE NO.8, ADT)

TABLE 4
TRAFFIC VOLUMES (1972 ADT) AT THE EIGHT
STUDY SITES (FIVE C-D AND THREE NON-C-D INTERCHANGES)

SITE	LOCATION	1972 ADT
1	I-465 at 56th St. and S.R. 100	51,111
2	I-465 at 10th St.	87,183
3	I-69 at S.R. 37	24,143
4	I-69 at S.R. 67 and S.R. 32	25,515
5	I-65 with U.S. 52	23,656
6	I-465 at I-74	75,211
7	I-465 at I-69 and S.R. 37	47,122
8	I-465 at I-70	79,274

personal injuries are sustained in the accident. However, accident records indicated that a small number of the reported accidents showed neither property loss nor personal injury. There were also undoubtedly accidents occurring in the time span covered by this study which should have been reported, but were not, because those involved either misjudged the extent of damage or neglected to report it. In spite of these expected inconsistencies, the accident data were assumed to be complete and accurate for the purpose of this analysis.

During the accident study, it became evident that the facility at the I-65-US 52 interchange at Lebanon (Figure 17) was not a typical C-D interchange. The C-D roadway operated also as a parallel road for US 52, carried very low volumes and hence had little weaving, the crossroad structures were outside the C-D roadway and did not provide their typical influence on design and operation and the number of accidents on the C-D facility was zero for the three-year period. As a result this C-D equipped interchange was removed from the C-D sample and further analysis.

The total number of accidents during the three year period was 402, distributed by year at the seven interchanges as shown in Table 5. Fatalities resulted in 1.3 percent of the accidents (eight persons died in five accidents) and 22.8 percent resulted in injuries (92 accidents resulted in 116 injuries).

TABLE 5

THE TOTAL NUMBERS OF REPORTED ACCIDENTS BY YEAR (1971-1973) AND BY INTERCHANGE (SITE)

Site No.	With at Least One C-D Roadway				Without C-D Roadway			Total
	1	2	3	4	6	7	8	
Location	I-465 at 56th St. and S.R. 100	I-465 at 10th St.	I-69 at S.R. 37	I-69 at S.R. 67 and S.R. 32	I-465 at I-74	I-465 at I-69 and S.R. 37	I-465 at I-70	
Year								
1971	9	33	8	13	20	29	41	153
1972	6	30	7	16	12	14	37	122
1973	13	35	3	13	10	13	40	127
Total	28	98	18	42	42	56	118	402

The total number of accidents at each interchange remained fairly stable over the three year observation period. Traffic volume increase on Indiana highways has been approximating a four percent growth in traffic volumes per year, but if there was such increased traffic it did not show up in increased accidents. On the contrary, 1971 was the year of the largest number of accidents (153), while the accidents in 1972 and 1973 were close (122 and 127 respectively). The reduction cannot be explained in terms of the relative newness of the C-D facilities, either, because the biggest difference in accidents by year occurred at two of the three non-C-D interchanges.

The accident data were displayed on collision diagrams of the seven interchanges and were classified by type. It was found that all of the accidents could be classified into four general types:

- 1) Lost control
- 2) Merging
- 3) Rear end collision
- 4) Weaving

The data for all three years were pooled to produce the accident percentages shown in Table 6, "The Percentage of Total Reported Accidents by Type at Each Study Site" and Table 7, "Accident Rates by Type (Number of Accidents Per 100 Million Vehicles)."

Table 6

THE PERCENTAGE OF TOTAL REPORTED ACCIDENTS BY TYPE
AT EACH STUDY SITE

Site No.	Description: Location	Lost Control	Merge	Rear End	Weave	Total
1	I-465 at 56th St. and S.R. 100	3.5	1.0	2.5	0.0	7.0
2	I-465 at 10th Street	10.9	4.0	6.9	2.5	24.3
3	I-69 at S.R. 37	2.5	1.0	1.0	0.0	4.5
4	I-69 and S.R. 67 and S.R. 32	5.9	1.5	2.5	0.5	10.4
All C-D Sites		22.8	7.5	12.9	3.0	46.2
6	I-465 at I-74	4.0	3.5	2.0	1.0	10.5
7	I-465 at I-69	9.4	0.5	3.0	1.0	13.9
8	I-465 at I-70	15.4	4.0	3.5	6.5	29.4
All Non-C-D Sites		28.8	8.0	8.5	8.5	53.8

TABLE 7

ACCIDENT RATES BY TYPE (NUMBER OF ACCIDENTS PER 100 MILLION VEHICLES)

Site No.	With at Least One C-D Roadway				Without C-D Roadway		
	1	2	3	4	6	7	8
Location	I-465 at 56th St. and S.R. 100	I-465 at 10th St.	I-69 at S.R. 37	I-69 at S.R. 67 and S.R. 32	I-465 at I-74	I-465 at I-69 and S.R. 37	I-465 at I-70
<u>Occurrence</u>							
Lost Control	25.01	46.09	37.83	85.90	19.85	73.65	71.43
Merge	7.15	16.76	15.13	21.48	17.37	3.88	18.43
Rear End	17.87	29.33	15.13	35.79	9.92	23.26	16.13
Weave	0.00	10.48	0.00	7.16	4.96	7.75	29.95
Total Accidents	50.03	102.66	68.09	150.33	52.10	108.53	135.94

The numbers of injuries and fatalities at each of the interchanges were also recorded, but these numbers were so small that their statistical value is questionable. However, because of their relative importance to the public and to highway officials, injuries and fatalities were listed and categorized in the study. The rates of accidents, injuries and fatalities (per 100 million vehicles) are given in Table 8, "The Rates of Accidents, Injuries and Fatalities for the Period January, 1971 - December, 1973".

Figure 23 is a graphical representation of the relationship between accidents for the three-year period (1971-1973) and ADT at the seven interchanges and Figure 24 depicts the relationship of accident rates to ADT.

An evident feature of Figure 23 (showing the number of accidents versus volume) is that the two populations of interchanges seem to follow the same trend. Accident rate (expressed in accidents per 100 million vehicles), however (Figure 24), shows no apparent trend relative to ADT. That is, the higher volume interchanges did not experience more accidents per 100 million vehicles than did lower volume interchanges in the range from approximately 20,000 vehicles per day to 90,000 vehicles per day. The Figures do show the considerable variability in numbers of accidents and in accident rates when compared with ADT.

Table 8

THE RATES OF ACCIDENTS, INJURIES AND FATALITIES (PER 100 MILLION VEHICLES) AT THE
SEVEN FINAL STUDY SITES FOR THE PERIOD JANUARY 1971 TO DECEMBER 1973

Site No.	Location	1972 ADT	Type of Occurrence	Occurrences Per 100 Million Vehicles
1	I-465 and 56th Street with S.R. 100	51,111	Accidents Injuries Fatalities	50.03 10.72 7.15
2	I-465 with 10th Street (West)	87,183	Accidents Injuries Fatalities	102.66 50.28 0.00
3	I-69 with S.R. 37 at 116th Street	24,143	Accidents Injuries Fatalities	68.09 0.00 0.00
4	I-69 with S.R. 67 and S.R. 32	25,515	Accidents Injuries Fatalities	150.33 0.00 0.00

TABLE 8 (continued)

Site No.	Location	1972 ADT	Type of Occurrence	Occurrences Per 100 Million Vehicles
6	I-465 with I-74 (West)	75,211	Accidents Injuries Fatalities	52.10 26.71 0.00
7	I-465 with I-69 and S.R. 37	47,122	Accidents Injuries Fatalities	108.53 31.01 7.75
8	I-465 with I-70 (East)	79,274	Accidents Injuries Fatalities	135.94 27.65 0.00

FIGURE 23: NUMBER OF ACCIDENTS vs. ADT AT INTERCHANGE

FIGURE 24: NUMBER OF ACCIDENTS / 100 MILLION VEHICLES AT INTERCHANGE vs. ADT AT INTERCHANGE

The next step in the analysis was to compare accident rates at the C-D equipped interchanges with those at the non-C-D equipped facilities. The t-test was used for a statistical comparison of the accident rates. Use of this test requires that the variances of the populations being sampled be equal.

Before checking the variances for equality, the accident distributions were plotted for normality. In such small sample sizes as in this study, judgement of the population distribution can be based upon either the distribution of the study sample or can be inferred from past observations of larger populations. Accident distributions for all interchanges of these types were not available, therefore the Shapiro-Wilk W test was used to test accident rates per 100 million vehicles and the distribution of accident rates for both interchange types was found to be normal at the $\alpha = 0.10$ ($W = 0.916$).

The accident rate data were checked for homogeneity of variance and were found to be not significantly different. The hypothesis that the four collector-distributor interchanges had equal population means was not rejected at the $\alpha = 0.05$ level (t statistic = 2.571 versus t calculated 0.396). This indicates that the mean accident rate per year at the collector-distributor equipped interchanges (92.78) was not significantly different than the mean accident rate per year where C-D roads were not employed (98.86), at the $\alpha = 0.05$.

In comparing the difference in accident rates by type, no significant differences were found in lost control, rear end, or merging accidents. The difference between means of weaving accident rates also was not found to be significant at the $\alpha = 0.05$ nor 0.10 levels, but it was judged significant at the $\alpha = 0.15$ level of significance. The t statistic was found to be 1.34 with a pooled standard deviation of 7.30.

Calculations for injury and fatality occurrence were similar to those for accidents and produced no significant differences in the numbers of injuries and fatalities. The number of injuries at collector-distributor road interchanges averaged 30.50 per interchange, compared to a 56.92 average for non-C-D locations. This 87 percent higher number of injuries at non-C-D over C-D sites hardly seems coincidental, however the calculated t statistic for injuries was $t = 0.93$, (not significant at $\alpha = 0.20$).

A second comparison of the accident data was based on fitting a common straight line by the method of least squares to accidents for both interchange types and predicting the number of accidents that would occur

at a common volume. The regression equation for the fitted line was not forced through zero and it was neither extrapolated to low (under 20,000) nor high (over 90,000) ADTs.

The mean value of ADT for all interchanges was 51,700 with a standard deviation of 26,300 for the seven cases. To project all accidents at a standard interchange volume of 50,000 ADT, which is a close approximation of the mean ADT value, the actual values of Y (accidents) were projected either up (for negative residuals) or down (for positive residuals) a line through the original data points and with the same slope as the prediction regression line. The purpose of this was to compare the accident histories of the interchanges if the number of accidents were based on the same interchange volume for all cases. Accident rates are different than those computed for the 1972 interchange traffic volumes. The estimated numbers of accidents at the respective interchanges are shown graphically in Figure 25 and quantitatively in Table 9.

The mean of adjusted accidents is 50.53 (accidents per interchange at 50,000 ADT) with standard deviation 24.84. The number of accidents at the seven study sites was adjusted to a base ADT of 50,000 by the formula:

$$\# \text{ Acc}_{50} = \# \text{ Acc}_x + \text{Slope} \cdot (50,000 - x)$$

FIGURE 25: THE PREDICTED NUMBERS OF ACCIDENTS AT THE SEVEN INTERCHANGES, BASED UPON 50,000 ADT

TABLE 9

THE PREDICTED NUMBER OF ACCIDENTS AT 50,000 ADT FOR THE SEVEN INTERCHANGES

Site No.	1	2	3	4	6	7	8
Location	I-465 at 56th St. and S.R. 100	I-465 at 10th St.	I-69 at S.R. 37	I-69 at S.R. 67 and S.R. 32	I-465 at I-74	I-465 at I-69 and S.R. 37	I-465 at I-70
1972 ADT at Inter- change	51,111	87,183	24,143	25,515	75,211	47,122	79,274
Predicted Number of Accidents in Three Year Period at 50,000 ADT	26.64	52.64	49.54	71.88	11.24	59.52	82.28

where x is the actual ADT at an interchange, $\# \text{Acc}_x$ is the number of accidents at x ADT, and $\# \text{Acc}_{50}$ is the predicted number of accidents at ADT 50,000.

Therefore, if the (x) ADT was greater than 50,000 the difference $(50,000-x)$ was negative and the number of accidents at 50,000 ADT was less than the number of accidents at (x) ADT.

The mean number of accidents adjusted to base 50,000 ADT was 50.18 for the sample of four C-D equipped interchanges and 51.02 for the non-C-D sample of three. That the C-D interchanges were predicted to experience an average of 0.84 fewer accidents per interchange over a three year period (0.28 per year) was not found to be statistically significant (at the $\alpha = 0.05$ level).

This finding is in agreement with the earlier studies by Cirillo et al (6) of accident rates on collector-distributor facilities with higher volumes.

Analysis of Erratic Maneuvers

The results of the accident data comparison showed that the sample sizes used were too small for data with such large variances. In order to show a statistically

significant difference between means of accidents of ten accidents in the three year observation period at the C-D and non-C-D interchanges with the observed variances, the available sample sizes would have to be approximately 100 interchanges of each type ($\alpha = 0.10$, $\beta = 0.10$) or a minimum of 35 of each type at $\alpha = 0.10$ if the probability of a type two error is 50 percent ($\beta = 0.50$). This comparison cannot be found in Indiana, as it has collector-distributor roadways at only seven interchanges. This problem of comparison was expected to exist at the outset of the study and a more meaningful measure of driver difficulties was sought to replace accident data.

A study of erratic maneuvers was designed to be a more sensitive indicator of the quality of traffic operation at the seven study sites and analysis of such maneuvers was sought as a meaningful representation of driver difficulty. Time-lapsed films were taken of peak and off-peak hours of traffic operations and the selected hours of film were reduced by identifying and counting the number of erratic maneuvers, evasive actions, irregular braking activity, and other abnormal traffic operations. Some of the operations which were thought to be erratic were easily identified and could be objectively qualified by type. Such typical erratic maneuvers, evasive actions, and peculiar driving behavior which were observed in analysis of operations of the study sites were:

- Type 1. Stopping on the C-D or ramp
2. Stopping on the mainline
 3. Backing on the C-D (including wrong-way maneuvers)
 4. Backing on the ramp (including wrong-way movements)
 5. Backing on the mainline (including wrong-way movements)

Determination of vehicle operations which fit each of the above descriptions was fairly concise and would be consistent among several analyzers of the same data. One gray area was in determination of whether the stopping part of a backing movement should be included as a separate movement. After several such movements were viewed, stopping only and stopping with backing were seen to be different maneuvers and were separated and the stopping part of a backing movement was not enumerated as a separate stopping maneuver. Only one bona-fide wrong way movement was observed during the many hours of filming, therefore, wrong way movements were included in the backing categories.

Unfortunately, additional erratic maneuvers were seen during reduction of the film data which could not be defined in a manner which would be determined reasonably the same by more than one analyst of the data. The subjective nature of these categories of data was considerable, making them difficult to compare between interchanges but neither

could they be ignored. All erratic maneuvers of these categories were recorded under several headings, but in the final analysis they were grouped together. An example of one type of such subjective erratic maneuver which might also show the difference of these data from the "hard and fast" objective categories was a merging maneuver. An operator might effect such a maneuver in a very short distance and not jeopardize the stability of his vehicle. However, should such an action on his part interfere with the safe operation of other vehicles, his maneuver would be defined by most observers as erratic. If his maneuver was not unsafe, yet another operator decelerated or braked, agreement on which maneuvers were erratic and which were not would be difficult to establish. The only way to adequately determine such categories would be to interview all of the operators involved. Since such interviews were impossible to obtain, the determination of erratic maneuvers in such cases was the subjective opinion of the film investigator. Maneuvers which were included in these subjective categories were large differential speed between vehicles (marginal friction), very short headways relative to travel speed, erratic brake activation, and improper or unsafe changes of lanes, weaving, etc.

Another difficulty in the erratic maneuver analysis was the inability of the investigators to quantify the general types of erratic movements for their relative

potential to cause driver difficulties. Some of the movements may have higher probabilities than others to cause difficulties and different degrees of difficulties may arise from different maneuvers. However, with the method of analysis used, the movements could not be objectively weighted for their probability to cause difficulties, and they were simply totaled.

The lengths of the collector-distributor interchanges also posed difficulties in stationing the photographic equipment in a way that equivalent data could be collected at each interchange to form a base for comparison of C-D and non-C-D interchanges. All non-C-D interchanges were relatively short and it was possible to observe all movements in one direction throughout the entire length of the interchange. At several of the collector-distributor interchanges, however, the lengths were much longer or alignment, topography, or man-made structures interfered with one camera's being able to record all through operations for the total distance of the interchange. In some instances even two cameras could not have recorded all of the desired information. At some of the sites, operation of an individual vehicle could be traced throughout the entire interchange, yet at others only a portion of the total movement could be seen. To compare interchanges on such a basis would have been unrealistic, for it would in effect have compared all of the erratic

maneuvers at one interchange with part of those at another. It was found that the five categories described as "objective" almost always occurred at portions of the interchanges which were observed.

Visual observation of the operation of the seven interchanges showed a very large proportion of the stopping "movements" over which the driver had some control (excluding mechanical difficulties, that is) to occur on the mainline at or just after the core area or directly under a structure and stopping on C-D roads and ramps to occur at the earliest possible opportunity after the ingress. Thus, the same basis for stopping maneuvers was available. In the cases of backing movements, most of these also occurred just after an exit. It was apparent in a few of these instances that drivers had missed their intended exit and tried to correct their error. All observed backing movements occurred within one or two hundred feet of the exit gore.

A table of erratic maneuvers by type was produced from the data and is presented in Table 10 with the samples of vehicles observed. Approximately one-tenth of the ADT at each study site was used for the sample for erratic maneuver data, then the observed sample size was used to factor the observed number of erratic maneuvers to a typical interchange ADT. The numbers of erratic maneuvers could not be based upon the same 100 million vehicles as

TABLE 10
ERRATIC MANEUVERS BY TOTAL
NUMBER AND BY TYPE PER INTERCHANGE

Site No.	1	2	3	4	6	7	8
Location	I-465 at 56th St. and S.R. 100	I-465 at 10th St.	I-69 at S.R. 37	I-69 at S.R. 67 and S.R. 32	I-465 at I-74	I-465 at I-69 and S.R. 37	I-465 at I-70
ADT	51,111	87,183	24,143	25,515	75,211	47,122	79,274
Number Vehicles Observed	4837	8184	2221	1309	8068	4450	5645
Erratic Maneuver Type							
1	6	11	6	2	11	3	6
2	1	5	4	4	11	3	3
3	2	0	0	0	3	1	5
4	1	0	1	2	3	1	5
5	0	0	1	2	1	0	1
Subtotal	10	16	12	10	26	7	15
All Other Types of Erratic Maneuver	15	8	7	4	10	7	23

were accidents because accidents are less frequent and are based on a much larger population of vehicles than are erratic maneuvers. In order to compare erratics rates which are on the same basis, the approximate average ADT volume for the study sites (50,000) which was used in the second accident comparison was also used for erratic maneuvers comparison. The rates of erratics relative to this base ADT are depicted in Table 11.

The rates of stopping and backing movements were highest in two of the interchanges which had the lowest volumes. A possible explanation for this occurrence might be in the rural nature of these two interchanges. Because of lower volumes at these two sites and because of the increased opportunity to stop at the C-D interchanges, operators possibly found stopping to be convenient or less restricted than it would be at a busy interchange. In addition, it may be that the proximity of service stations, rest areas, etc. to most urban interchanges encourages drivers to use those facilities instead of taking the chance of being involved in some conflict.

The less objectively defined erratic maneuvers were also relatively high at the two low-volume interchanges, yet one high-volume interchange experienced by far the highest number of this type of erratic maneuver. This non-C-D interchange which had the highest number of erratics had a short weaving section on an unlighted and topographically

TABLE 11
ERRATIC MANEUVER RATES BASED ON OCCURRENCES
PER 50,000 VEHICLES (ADT)

Site No.	With at Least One C-D Roadway				Without C-D Roadway		
	1	2	3	4	6	7	8
Location	I-465 at 56th St. and S.R. 100	I-465 at 10th St.	I-69 at S.R. 37	I-69 at S.R. 67 and S.R. 32	I-465 at I-74	I-465 at I-69 and S.R. 37	I-465 at I-70
Subtotal Types 1-5	103.37	97.75	270.15	381.97	161.13	78.65	132.86
All Other Types of Erratic Maneuvers	155.05	48.88	157.59	152.79	61.97	78.65	203.72

rolling site. The numbers of accidents at the same site were also very large, especially those accidents associated with weaving in that particular section of the interchange.

The average numbers of erratic maneuvers was larger at the C-D sites (213.31 per interchange of types 1-4) than it was at non-C-D interchanges (124.21). However, if the two low-volume interchanges are not included, the averages are less with C-D roads (100.56).

Analysis of Interchange Costs

The plan to compare the construction costs of a typical interchange having a collector-distributor road with the construction costs for a typical interchange (for instance, a four-quadrant cloverleaf) without a collector-distributor proved difficult to design. The small sample size of interchanges with collector-distributor roads and the variation between the designs, their size and complexity, traffic distribution requirements, and topography produced little confidence in averages based upon the observed interchanges. Although the size of the sample of interchange without C-D roads was even smaller (three observations), it was subject to less variation due to the process of selection.

The economic factors which were considered for the interchange were (1) initial costs, (2) maintenance costs, and (3) vehicle operating costs. These three factors served as the basis for the economic justification study.

Analysis of Construction Costs

Review of the literature pertaining to collector-distributor road use did not reveal a detailed study of two alternative designs, one interchange equipped with C-D roads and the other without. Likewise, no two such alternatives could be found in the State of Indiana which experienced the same topographic, locational, or traffic situations. The most ideal comparison was not available, therefore, in which designs could be compared for differences solely because of the influence of an added C-D road. Some of the major design features which were recorded for the seven study sites are summarized in Table 12, showing differences between interchanges within both types as well as between types of interchange. The features common to more than one interchange are also shown.

Construction cost comparisons were made preliminarily from the same sample of four collector-distributor interchanges versus three non-C-D interchanges, based upon unit price bids and final quantity estimates of 111 commonly used contract bid items.

TABLE 12
DESIGN FEATURES OF THE SEVEN STUDY SITES

Site No.	1	2	3	4	6	7	8
Number of Lanes of Freeway Pavement on Each Side of Median	3	2	2	2	2	2	3
Area of Interchange (Acres)	121.0	68.5	60.0	57.0	52.3	62.9	73.5
Length of Interchange (Feet)	7500	3000	6000	3500	3000	3500	4000
Length of Weaving Section (Feet)	630	775	1690	613	830	--	680
Number of Lanes in Cross Structure	4	4	2	4	4	4	6
Number of C-D Roads	2	1	2	2	0	0	0
Number of Lanes in Each C-D Road	2	1	1	2	--	--	--
Length of C-D Roads (feet)	6800	3000	5300	4156	--	--	--
Entrances to C-D	6	2	3	4	--	--	--
Exits from C-D	6	1	3	4	--	--	--
Entrances to Freeway	2	3	2	2	4	4	4
Exits from Freeway	2	3	2	2	4	4	4

Contract items are specified in detail by the Indiana State Highway Commission, thus expediting the reporting and comparison of phases of construction by contract item. It was found in this stage of the construction cost comparison that a wide range of essentially similar or equal contract items which are acceptable to the ISHC may be used in a specified application. For instance, there are several types of guardrail, pipe, or inlet which may satisfactorily serve a given application. This condition and the present contract bid item reporting system made computer comparison of construction costs virtually impossible. The recorded unit prices and quantities of the 111 contract bid items are presented in Appendix C.

Upon examination of the average project construction costs, the C-D equipped interchange was found to suffer a cost disadvantage. The average total cost of the four C-D equipped interchanges was \$6,046,000 versus \$3,507,000 for the three non-C-D interchanges. Ranges were from \$3,780,000 to \$8,576,000 in the first category and \$2,336,000 to \$4,679,000 in the second. Because of the large variance in total project costs because of site conditions, a comparison of the 111 contract bid items typically included was made. This also provided information on which items produced large or significant differences in quantities with various designs.

The sum of the average unit prices of the 111 contract bid items multiplied by the average quantities of the same bid items to obtain the average cost of C-D and non-C-D interchanges differed slightly from the average of the total cost of the interchanges for the two samples.

The sum of average unit prices multiplied by average quantities for the C-D interchanges was \$3,620,886 or \$804,664 (29 percent) more than the sum of those costs for non-C-D facilities (2,816,222). When unit prices were multiplied by quantities for each interchange and then averaged, C-D interchange costs were found to be slightly higher (under 5 percent) than the total of the averages, while in non-C-D facilities the cost figures thusly was \$700,000 or 20 percent more than the total of the averages.

The average area required for non-C-D interchanges was 62.90 acres while C-D equipped facilities averaged 67.15 acres. The average width of C-D facilities (less ramps) was only 80 feet greater than that of non-C-D equipped interchanges. Interchanges with C-D roads were wider in the C-D sections when the same total number of lanes were present due to the lane separator.

After the collection of unit bid prices and final quantity estimates on contract items for the seven interchanges (4 with C-D and 3 without C-D) under study, a comparison of these items was to produce objective evidence to support or to contradict the assumption (which was thought

to be a safe one) that longer span lengths on structures, more pavement, and more right-of-way on C-D roads produced a more costly design. As it turned out, the assumption was not always true and discussion with Indiana State Highway Officials explained why this was the case. Unit prices bid and paid are highly dependent upon the amount of work of a certain type within a region and how badly the bidding contractors want the contract. As quantities increase the unit cost may decrease, depending upon available technology and contracting methods. For example, the per length cost of a structure may decrease if no extra spans are required to span an increased distance. This does not mean that an absolute decrease in total price necessarily occurs but the total cost increase may not be as great as it might appear. One structure at a C-D site was less costly to construct than a shorter structure at a non-C-D site which was constructed to approximately the same standards and at approximately the same time and in the same regional location.

ISHC design engineers indicated that the cost of pavement, longer structure span lengths, additional right-of-way, etc., required for just the C-D portion of a C-D equipped interchange could not be assumed to account for all of the increased cost of a C-D facility over that of a non-C-D interchange. Since none of the existing designs provided the needed total comparison under similar design conditions,

it was decided that an idealized cloverleaf interchange on level topography would be easier to both visualize and to quantify while serving as a model from which more specific design conditions might also be compared.

A second comparison, therefore, was made of construction cost differences of two idealized interchanges, one with a collector-distributor road on both sides of the major freeway at a four-quadrant cloverleaf interchange and a similar interchange without C-D roads. The values applied in the comparison were derived from average lengths and widths of pavement, R.O.W., etc. found in the two design types in this study.

Cross sections were generated for every minor change in mainline cross section and estimates were made of bid items by quantity and average price per foot of roadway. Representative cross sections for the C-D equipped interchange and cross sections for the standard four-quadrant cloverleaf interchange are included in Figure 26.

Figure 27 shows major measurements of the two idealized interchanges. Figure 27a has three twelve feet wide through lanes and a twelve feet wide weaving section. Figure 27b has two twelve feet wide collector-distributor lanes to the right of three twelve feet wide freeway lanes on each side of the median. In addition, the collector-distributor interchange is equipped with a sixteen feet wide lane separator and double-faced guardrail.

FIGURE 26a NON C-D INTERCHANGE

FIGURE 26b C-D INTERCHANGE

FIGURE 26: TYPICAL CROSS SECTION OF TYPICAL C-D AND NON-C-D INTERCHANGES AT MEDIAN OF CROSSING ROADWAY

FIGURE 27 a WITHOUT C-D ROADS

FIGURE 27 b WITH C-D ROADS

FIGURE 27 MEASUREMENTS ON TWO IDEALIZED CLOVERLEAF INTERCHANGES

The first cross section was taken at the center of the major cross structure. Half of this cross section is depicted in Figure 26 and typical differences between the two designs are listed in Table 13. The pavement dimensioned by "A" in both figures is three 12' freeway through lanes for a total width of 36 feet. "B" in Figure 26 is a 12' wide weaving lane. The pavement labeled "C" represents a two-lane C-D road. The section labeled "D" in the lower figure depicts the 16 feet wide lane separator and its appurtenances. Because of the span length, an extra pier is included in the C-D interchange.

The cross section width for the C-D interchange, taken along the median of the intersecting roadway, was 2520 feet including the loop and outer ramps. For the non-C-D design it was also 2520 feet, 2440 of which was within the interchange and an additional 40' section of highway on each side to provide the same overall width of 2520 feet. Additional cross sections were drawn at every major change in cross section and quantities and costs of construction items were determined.

The typical collector-distributor interchange was found to cost \$4,045,000 for its 4900 feet length. For the 3500 feet long non-C-D facility plus 1400 feet of freeway (to make the comparison correctly) those costs were \$3,493,000. The C-D interchange required \$552,000 more of initial construction costs than the non-C-D interchange.

TABLE 13
DESIGN DETAILS OF CROSS-SECTION OF TWO
INTERCHANGE TYPES AT CENTER LINE OF CROSS STRUCTURES

- a) Features common to both.
 - 1. Number of freeway lanes on each side of mediam -- three.
 - 2. Width of lanes -- 12 feet.
 - 3. Average radius of interior (left-turning) ramps -- 200 feet (199.87 feet).
 - 4. Width of all ramps -- 16 feet.
 - 5. Average length of right-turning ramps -- 1,275 feet.
 - 6. Width of median -- 32 feet.
- b) Features required for only C-D interchange.
 - 1. Two 12 foot C-D lanes per side.
 - 2. One 16 foot lane separator.
 - 3. Double-faced steel or aluminum guardrail or double-faced parabolic concrete guardrail per side.
 - 4. 56 feet longer cross structure.
 - 5. 56 feet wider right-of-way at center line of cross structure.
 - 6. 4.25 acres more R.O.W.
 - 7. Span lengths -- maximum length, 25 feet shorter (number of spans required was also different).

Analysis of Maintenance Costs

Maintenance cost figures were not available for the four C-D interchanges and three non-C-D interchanges included in this study. Because of the additional pavement, guard-rail, and span lengths, the collector-distributor interchange will experience higher maintenance costs than will the non-C-D equipped interchange. Since construction costs were found to be higher, annual maintenance costs might be expressed in terms of a percentage increase over the initial construction cost.

Winfrey gives maintenance and non-road user operating expenses for interstate highways in Illinois of \$5300 per centerline mile per year (1965). The cost of maintaining interchanges would obviously be higher and for through roadways would be less. The estimated 1964 maintenance expenses for the 48 contiguous states and the District of Columbia were \$3,233 per mile for rural interstate highways and \$6,677 per mile for urban interstate highways, with average per mile maintenance costs for both \$3,772 (48, p. 253).

Winfrey also includes complete highway construction costs by census division and shows cost per centerline mile to range from \$500,000 to \$1,200,000 for interstate rural highways and from \$1,700,000 to \$5,700,000 for interstate urban highways (1965) (48, p. 251). Based upon the maintenance costs for the state of Illinois and the average per

mile construction cost for the north central census districts (\$652,000), annual maintenance costs average very close to one-half percent (0.49 percent) of total initial construction costs, therefore, the expected maintenance costs for C-D interchanges average \$4000 (14.3 percent) higher per year than for non-C-D interchanges.

Analysis of Operating Costs

Operating costs per 100 million vehicles over collector-distributor equipped interchanges were thought to have potential for being less than those on a similar but non-C-D equipped facility, if speed reduction, maneuvering or braking of through vehicles is less with C-D roads. The elimination or reduction of weaving conflicts also should reduce braking and erratic driving which thus decreases fuel use and tire wear. The C-D concept and design predicts less constrained movement at C-D equipped interchanges which might result in decreased operating costs.

Operating distances for interchanges were taken between the most extreme points of ramps on C-D egresses from the through roadway, and 1400 feet of freeway were added to the length of the non-C-D interchange to produce a corresponding distance for comparison.

The ADT values applied to the idealized interchanges for user cost comparison were estimates which were based upon the higher current volumes found at the study sites,

rounded to the nearest 100 vehicles. Assumed ADT volumes are shown in Figure 28.

Most important to the comparison is that the volumes at both typical interchanges were the same. The freeways on both designs carried identical volumes of traffic and cross traffic volumes were equal. Where two exits carried 3,000 and 1,300 vehicles per day on the non-C-D interchange, the single exit to the C-D road collected 4,300 vehicles and distributed them to their proper exit. This condition of equal traffic for both the C-D and non-C-D sample was not to be found within the sample of actual study sites, but was fabricated here for a comparison of user costs. The interchanges were made as identical as possible in geometric design and traffic operations (see Figures 27 and 28). The only difference was the existence of a C-D road on one facility while the other facility had none. The same two idealized interchanges which provided a basis for construction cost analysis then provided a comparison of operating costs for the two types of interchange.

Two costs which are associated with operating costs require basic assumptions which are debatable. Since it was found that there was no significant difference between accidents at C-D versus non-C-D sites, it would be unfair to assign accident dollar costs which are different for the two typical sites.

WITH C-D ROAD

WITHOUT C-D ROAD

FIGURE 28 THE ASSUMED DISTRIBUTION OF TRAFFIC VOLUMES ON TWO TYPICAL INTERCHANGES

Similarly, time costs associated with these operations were difficult to evaluate because the amount of time saved by traveling at a higher speed is relatively small, yet real, over these short operating distances. The time required to travel at 70 miles per hour (assumed for C-D interchanges) for the 4900 feet length of interchange is 8 seconds less than to travel the same distance at 60 miles per hour (assumed for non-C-D interchanges). The assumed difference of 10 mph operating speed on the freeway through the interchange was based upon observation from the films and in the field that speeds on the freeway lanes during high volumes were higher on the C-D equipped interchanges than on the non-C-D interchanges. The 10 mph value was taken as a reasonable one.

The question arises whether or not the time saved is usable time and what value should be placed upon it. A common value often used for time costs determination is \$2.50 per hour per vehicle. The maximum time savings would probably apply only to those peak hour and near-peak hour vehicles which would be affected by the near capacity to capacity conditions. The peak hour for freeways such as these carries from twelve to fifteen percent of the ADT. If an additional ten per cent of near-peak vehicles are similarly affected, the value of time lost at \$2.50 per hour would exceed \$26,000 in a year for an ADT of 50,000. Several methods were tried to determine

basic differences in vehicle operating costs.

The first procedure was based upon passenger vehicles only and assumed that the speeds of vehicles in the interchanges were the design speeds of the several sections of the interchange facilities except for the non-C-D interchanges where the 10 mph difference previously discussed was assumed for peak and near peak conditions (25% of ADT = 80,000) see Figure 29). The basic differences in speeds were on the freeway through lanes and between weaving vehicles in the C-D and non-C-D interchanges. The assumed decrease in speed on the non-C-D freeway was due to marginal friction.

Operating speeds were limited by curve radii on loop ramps to a maximum of 30 or 35 miles per hour. Land acquisition costs prohibit curve radii which are large enough to improve operating speeds very much above these limits. Therefore the operating conditions and costs were identical for the non-tangent sections of both interchanges. All differences in operating conditions, speed, and therefore costs occurred on tangent, level sections of roadway under these assumptions. These assumptions of travel speeds through the two interchanges allowed the use of tables on running costs to be used which were based on level tangent sections of roadway (see Table 14). The overall running costs at each interchange could not be found by this method with those figures, but differences

WITHOUT C-D ROADS

WITH C-D ROADS

FIGURE 29 OPERATING SECTION ASSOCIATED WITH DESIGN ELEMENTS
UNDER EQUAL TRAFFIC CONDITIONS

TABLE 14
 RUNNING COST AT UNIFORM SPEED ON LEVEL TANGENT
 PASSENGER CARS

Speed (Miles/Hour)	Dollars Per 1000 Veh. Mi.	\$ Cost/100 Million Vehicles Per Ft.
10	62	1174.24
20	50	946.97
30	47.5	899.62
40	47	890.15
50	47.5	899.62
60	49	928.03
70	53	1003.79
80	58	1098.48

(From NCHRP #133)

between the two interchange types were available. Although a percentage increase could not be found, the absolute difference in running costs between the two typical interchanges was based on the minimum number of different assumptions and minimized the probability of making untenable or inconsistent assumptions, which might decrease confidence in the results.

Running costs decrease as speed increases from zero to about 40 miles per hour for passenger cars (Table 14). As speed increases above 40 miles per hour, running costs increase even faster. At the same time, the time saved increases in direct proportion to increase in speed.

A number of factors influence the average running speed, especially when volumes are high. Weaving is one factor which increases marginal friction (inhibits through operation as a result of traffic within the weaving section) and decreases capacity, as well as operating speed. According to design experts and design manuals, the use of C-D roads should improve both capacity and speed in weaving sections and thus overall operations should benefit.

On this basis, average running speeds of 10 mph less were assigned to the tangent sections on the non-C-D free-ways based upon a lower level of service during peak or near-peak volumes, assuming marginal friction caused reduction of through speeds. Speeds, however, would have

to be reduced to less than 40 miles per hour on the free-way without C-D roads before running costs would increase. At the low volumes seen in this study, through traffic seldom decreased to under 50 miles per hour, even during peak periods when weaving was relatively heavy.

Based on these assumptions and by the procedures which are summarized in Tables 15 and 16, running costs were found to be slightly higher with the collector-distributor design because at the low traffic volumes speeds remained high or even increased.

On the basis of running costs alone, the collector-distributor interchange was found to cost \$11,800 more per year than the non-C-D interchange.

Different assumptions about operating conditions produced different results in determination of operating costs. Winfrey shows "dollars excess cost" (Including fuel, tires, engine oil, maintenance, and depreciation) to be greater when an initial speed of 70 miles per hour is followed by a speed change cycle of 60 miles per hour and then back to the initial speed than maintaining the initial speed would be. Such a condition exists in the interchange examples of this study. Using Winfrey's value of \$17.83 per 1000 cycles would produce, with the same assumptions on travel volumes and speeds (including 25% of the ADT) as before over \$240 per day additional operating costs for the non-C-D interchange over the C-D interchange.

TABLE 15
 RUNNING COSTS PER 100 MILLION VEHICLES
 OPERATING OVER INTERCHANGE WITHOUT C-D ROADS

Section	Section Length	Ave. Speed	Cost/100 Mil. Pass. Cars/Ft.	Cost 10 ⁸ Pass. Cars/Section	ADT Volume	Section Cost/Day
C	1250	60	928	1,160,000	6,750	78.30
		70	1004	1,255,000	20,250	254.14
E	500	40	890	445,000	29,500	131.28
G	1250	60	928	1,160,000	7,050	81.78
		70	1004	1,255,000	21,150	265.43
K	550	40	890	489,500	9,500	46.50
M	1400	70	1004	1,405,600	30,000	421.68
N	80	50	900	72,000	10,000	7.20
Running Cost Per Day Subtotal =						\$2,573
Running Cost Per Year Subtotal =						\$ 939,006

TABLE 16
RUNNING COSTS PER 100 MILLION
VEHICLES OPERATING OVER INTERCHANGE WITH C-D ROADS

Section	Section Length	Ave. Speed	Cost/100 Mil. Pass. Cars/Ft.	Cost 10 ⁸ Cars/Section	ADT Volume	Section Cost/Day
B	700	50	900	630000	4,300	27.09
C	4400	70	1004	4417600	25,700	1135.32
E	1250	50	900	1125000	1,300	14.63
G	500	40	890	445000	3,800	16.91
I	1250	50	900	1125000	2,500	28.13
K	7700	50	900	630000	4,300	27.09
N	630	40	890	560700	9,500	53.27

Running Cost Per Day Subtotal = \$2605

Running Cost Per Year Subtotal = \$950,781

On the basis of "dollars excess cost", the collector-distributor interchange was found to cost \$87,900 less per year than the non-C-D interchange.

Operating costs for truck traffic, which amounts to 12-15 percent of the ADT on Indiana freeways, were not calculated separately in this study. If they had been, for the running costs method the results would have increased the difference in operating costs slightly for the C-D interchange over the non-C-D interchange. For the "dollars excess cost" method, operating costs differences would have increased slightly for the non-C-D facility over the C-D facility. In either case the use of passenger car operating costs was the conservative value and was the only one calculated.

Total differences between C-D and non-C-D interchanges were calculated using the averages of 111 contract bid items as the basis for initial costs, average regional maintenance costs to predict maintenance costs, and "dollars excess cost" to predict operating costs.

Assuming a rate of five percent interest on the initial investment and an interchange life of 25 years, the increased construction cost of C-D interchanges was \$71,200 per year. Annual maintenance cost increase for C-D interchanges was \$4000. Operating costs were \$87,900 less per year for collector-distributor interchanges when most real operating expenses (excluding time expenses)

are included. Based on the same assumptions, time savings would also occur with the C-D design when compared with the non-C-D design. Sensitivity analysis of the value of time was not required because the savings in operating costs per year were \$12,600 greater than the yearly amortized construction cost and the yearly maintenance cost increases with the C-D design. Any value applied to time would increase the operating benefits of C-D facilities over non-C-D facilities which operate at volumes which would produce the assumed differences in travel conditions and speeds.

CHAPTER VII

SUMMARY OF RESULTS

Summary of Design Concepts

From a review of design manuals, results of interviews with design engineers, and results of questionnaires to highway design consultants, a general preference toward the use of C-D roads was evident among respondents whose policies included statements about C-D roads. Briefly summarizing, those policies are:

1. The primary reason for the use of collector-distributor roads was described as minimizing (or eliminating from the freeway through lanes) weaving. There were 13 responses which indicated this policy preference.
2. The next most preferred justification for C-D roads was to facilitate capacity at near-capacity volumes, which eight respondents favored. Two added improved speed (at near-capacity volumes) for a total of ten who cited improved operations at high volumes with C-D roads.

3. Four respondents favored C-D roads to promote single-exit policy as a design ideal. Four also discussed minimizing signing with C-D roads. Two of the respondents mentioned both, bringing to a total of eight the responses that C-D roads promote more efficient design for exits and signing.
4. Four preferred to use C-D roads as an adjunct to a series of interchanges when close spacing of entrances and exits requires overlapping speed-change lanes.
5. One said that the increased construction cost was justified by improved safety and improved traffic flow.
6. The exit-entrance spacings preferred for freeways ranged from "not less than 1200 feet" to "1600 feet minimum", "700' preferred" to "absolute minimum 1800 feet" and "1800-2400 minimum", but with C-D roads used the allowable spacings dropped to 800'-1200'; "less than 1800' with C-D if all other criteria are met", and "1200'-1500' on C-D".

Summary of Accident Analysis

The results of a comparison of accidents at the four C-D and the three non-C-D interchanges in this study by total accidents at each interchange and by types of accidents occurring at each interchange showed no significant

difference between the average number of accidents at the collector-distributor interchanges and the non-C-D interchanges. The numbers of accidents were slightly fewer at C-D sites and the mean number and rate per 100 million vehicles of accidents over a three year period was a little lower at the average C-D site, yet variation within samples was large and results could not be judged statistically significant.

In a comparison of four types of accidents (lost control, merging, weaving, and rear end collisions), none were found to be statistically significant in the differences in means between C-D and non-C-D sites except weaving accidents, which were judged significantly different at the $\alpha = 0.15$ significance level. Accidents have been shown generally to be poor predictors of driver difficulties and a previous study of total accidents at C-D and non-C-D interchanges also was unable to find statistically significant differences between the two interchange types.

Summary of Erratic Maneuvers

The collector-distributor interchanges in the study experienced more erratic maneuvers than did those interchanges without C-D roads. On the other hand there was some evidence that the collector-distributor road interchanges which operated at high volume conditions had, on the average, fewer erratic maneuver occurrences than did

similar volume non-C-D sites. The erratic maneuver analysis did not provide the statistically different results that were desired, but did provide supplementary information. The variances of erratic maneuvers between interchanges (both between and within types of interchanges) were very large for the small sample sizes and no significant results could be found at any reasonable level of significance.

Summary of Cost Differences

Construction costs were greater on the average for collector-distributor interchanges than for interchanges without C-D roads. The average cost of four C-D equipped interchanges was \$3,621,000, based on average unit bid prices and average quantities of 111 common contract bid items. The C-D interchange costs were \$805,000 or 29 percent, greater than non-C-D facilities. Because of large differences between interchanges within types, a construction cost comparison based on typical designs of C-D and non-C-D interchanges was made. The designs differed only as a result of the C-D roads at one and not at the other. The typical C-D interchange was \$4,045,000, which was \$552,000 or about 16 percent more in initial construction cost over the non-C-D interchange (\$3,493,000).

Maintenance costs were also slightly higher for C-D road interchanges because of increased construction elements which require periodic or continual maintenance. Maintaining a collector-distributor equipped interchange was estimated to be 14.3 percent more costly (\$4000 per year more) than non-C-D interchanges.

Operating costs were \$87,900 less per year for collector-distributor interchanges than for typical non-C-D interchanges. Dollars excess cost analysis produced this result and was used in the overall cost comparison. Time and accident benefits are not included in the indicated value, the first because of controversy relative to the value of time, and the second because no difference in accidents was found.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

Conclusions

This study indicated that idealized interchanges are able to provide better bases for comparison between C-D and non-C-D interchanges than are existing interchanges in the state of Indiana. There are at present only seven sites in the state of Indiana where C-D roadways are in operation, and only three of the sites have begun to experience high traffic volumes for which collector-distributor roads are intended to facilitate overall operations.

C-D roads were beneficial from a cost-effectiveness standpoint, although high volume traffic conditions were not to be found at all study sites. The annual construction and maintenance cost increases for the average C-D interchange were small compared to total interchange cost. Based on assumptions of operations at peak or near peak hour volumes the cost of operating over a typical C-D interchange was lower than the cost of operating over a non-C-D interchange. The lower operating costs result in lower overall annual costs, even when time and

accident costs are excluded for a conservative test.

Highway design engineers and consultants favor the use of C-D roadways as a design ideal to minimize weaving, improve operation, and generally to improve design (such as the single exit policy, minimized signing requirements, etc.).

In an analysis of accident rates per 100 million vehicles, by total rates of occurrences and by type (lost control, merging, rear end, and weaving) only weaving accidents showed a statistically significant difference between C-D and non-C-D designs, with the average of this type of accident at C-D sites less than at non-C-D sites ($\alpha = 0.15$).

Erratic maneuvers provided additional information about the potential conflicts which was not available from accident analysis. The average numbers of erratic maneuvers were larger at C-D sites than they were at non-C-D interchanges. Yet when only the higher volume C-D interchanges were compared, erratic maneuvers were less at the C-D interchanges.

Recommendations for Further Research

It is recommended that study of collector-distributor interchanges be continued. The work should be extended to concentrate on study of high volume, high conflict conditions, where the use of C-D roads would provide maximum benefits.

As present volumes and distributions change, so will the conditions from which results of this study were drawn. It is recommended that a program be established to monitor conditions and evaluate benefits at the sample of interchanges studied in this project.

Costs of adding collector-distributor roadways at the time of construction of low-volume facilities should be weighed against costs of reconstruction or adding C-D roads at a point in time where volumes warrant the addition. Research of collector-distributor interchanges and alternative geometric designs should be continued to establish more definitive guidelines for selection of optimum designs.

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APPENDIX A

Figure A1: Washington State Design Manual Specifications for Collector Road On Connections (46)

APPENDIX B

APPENDIX B

PHOTOGRAPHIC EQUIPMENT SELECTION

For the recording of traffic operations at the study sites, a Kodak K-100 16 mm movie camera was selected. (Figure B1) The camera was equipped with a spring driven advance mechanism and can be operated in single frames by an external release lever. Another accessory was a Sam Berthoit zoom lens with a focal range of from 17.5 mm to 70 mm which incorporated a through-the-lens viewing system which showed the image as it would appear in the finished film (Figure B2).

Color film was found to be a practical necessity to distinguish between vehicles and to record brake light activation, so Kodachrome II daylight color film was used.

A battery-powered electronic timer regulated the exposure of individual frames, spacing exposures every 1 (one) second $\pm$ 0.01 second, and a digital counter was added to record the number of frames (Figure B1).

Data were reduced with a 16 mm Zeiss-Ikon Moviskop film recorder.

Figure B2 (above) is a detail of the camera in Figure B1 (right), which shows the photographic equipment used in collection of erratic maneuver data.

APPENDIX C

TABLE C1

AVERAGE VALUES FOR 111 CONTRACT BID ITEMS

ITEM	AVERAGES WITH C-D ROADS			AVERAGES WITHOUT C-D ROADS		
	Unit*	Quantity	Total**	Unit*	Quantity	Total**
1. Common Excavation	0.81	723,824	586,297	0.88	510,681	449,399
2. Special Borrows	1.04	479,280	498,451	0.97	214,792	208,348
3. Overhaul	0.0001	-0-	-0-	0.0301	148,321	4,457
4. Added Haul	0.0001	-0-	-0-	0.07	205,484	14,384
5. Grade "B" Special Borrow	2.13	28,835	61,419	2.38	8,100	19,278
6. Pavement Removal	0.95	16,300	15,485	0.73	7,326	5,348
7. Combined Curb & Gutter Removal	0.48	553	258	0.75	1,280	960
8. Guard Rail Salvage	0.73	1,175	.858	---	---	---
9. Subbase Type I or II	1.89	53,046	100,257	3.25	35,167	114,293
10. RCP 10"	5.93	113,145	670,950	5.83	116,520	679,312
11. RCP 9"	5.59	19,363	108,239	7.25	200	1,450
12. RCP 8"	5.61	8,486	47,604	---	---	---
13. Plain Concr. 9"	5.91	10,063	59,472	---	---	---
14. Plain Concr. 7"	5.60	17,549	98,273	---	---	---
15. Reinf. Steel for Pavement	0.15	44,254	6,638	0.13	40,128	5,217
16. D-1 Contraction Joints	1.27	34,648	44,003	1.23	26,107	32,111
17. 1" Preformed Joint Filler	1.19	248	295	0.50	347	174
18. 1 1/2" Preformed Joint Filler	0.75	-0-	-0-	0.60	110	66

TABLE C1 (Continued)

ITEM	AVERAGES WITH C-D ROADS			AVERAGES WITHOUT C-D ROADS		
	Unit*	Quantity	Total**	Unit*	Quantity	Total**
19. 1" Expansion Joint w/Load Transfer	2.00	2,274	4,548	2.00	1,611	3,222
20. 3" Expansion Joint	4.00	-0-	-0-	2.00	58	116
21. Aggregate for Comp. Aggregate Base	3.15	9,353	29,462	2.50	3,022	7,556
22. Water for Comp. Aggregate Base	8.90	2,610	23,227	8.67	2,187	18,958
23. Bituminous Matl. for Prime	58.50	56	3,247	55.00	89	4,895
24. Hot Asphalt Concrete Base	7.00	456	3,192	7.50	394	2,955
25. Hot Asphalt Conc. Surface Type A	7.00	654	4,578	7.00	450	3,150
26. Salvage Road Matl. for Approaches	4.00	2,007	8,028	4.00	2,007	8,028
27. Comp. Agg. Base for Bit. Shoulders	5.94	19,977	118,661	6.00	25,642	153,350
28. Bit. Shoulder	7.76	31,794	246,725	7.50	63,449	476,115
29. Bit. Matl. for Seal Covering	41.50	142	5,893	52.50	230	12,075
30. Aggregate	4.60	1,958	9,007	5.58	2,122	11,839
31. Comp. Agg. Shoulder	3.36	63,069	211,912	3.67	45,683	167,504
32. Calcium Chloride	90.00	27	243	86.50	53	458
33. Bit. Shoulder Mix for Approaches	8.63	1,581	13,646	9.25	1,221	11,294

TABLE C1 (Continued)

ITEM	AVERAGES WITH C-D ROADS			AVERAGES WITHOUT C-D ROADS		
	Unit*	Quantity	Total**	Unit*	Quantity	Total**
34. Pipe Class I 12"	4.18	5,106	21,352	2.60	126	328
35. Pipe Class I 15"	4.95	210	1,038	3.30	-0-	-0-
36. Pipe Class I 18"	6.05	617	3,731	4.40	-0-	-0-
37. Pipe Class I 24"	7.68	756	5,806	6.30	132	832
38. Pipe Class I 30"	9.99	108	1,079	9.00	122	1,098
39. Pipe Class I 36"	13.08	353	4,614	13.50	174	2,349
40. Pipe Class I 42"	15.86	160	2,538	16.50	84	1,386
41. Pipe Class I 48"	19.95	199	3,965	19.30	133	2,573
42. Pipe Class III 24"	7.53	228	1,715	7.50	200	1,500
43. Pipe Class III 42"	15.78	201	3,168	16.00	172	2,747
44. Pipe Class III 54"	22.10	1,295	28,620	22.83	159	3,638
45. FBCCS/Paved Invert 12"	4.09	1,250	5,110	4.33	1,496	6,478
46. " 15"	4.89	114	557	5.48	583	320
47. " 18"	5.94	194	1,149	6.33	101	637
48. " 24"	7.95	127	1,006	8.17	92	749
49. Pipe: Sewer 6"	1.50	919	1,379	1.47	529	776
50. " 8"	1.89	65	122	1.82	236	430
51. " 10"	2.30	144	330	2.13	225	479
52. Pipe: Class II 2.8' ²	7.10	99	701	7.42	112	829
53. " 4.2 ft ²	8.47	254	2,149	9.03	114	1,032
54. " 11.3 ft ²	17.60	105	1,852	18.52	82	1,519

TABLE C1 (Continued)

ITEM	AVERAGES WITH C-D ROADS			AVERAGES WITHOUT C-D ROADS		
	Unit*	Quantity	Total**	Unit*	Quantity	Total**
55. Pipe: Drintile 6"	1.38	1,016	1,401	1.30	330	429
56. " 8"	1.78	187	332	1.67	240	401
57. " 10"	2.26	31	69	1.90	200	379
58. Class VII for Subsurface Drain 6"	0.77	83,367	64,192	0.95	66,711	63,376
59. Agg. for Subsurface Drainage	5.06	5,151	26,065	4.85	984	4,771
60. Catch Basin Type A-4	441.11	1	441	456.83	1	608
61. Catch Basin Spec. Type 7 Casting	466.50	-0-	0	454.17	-0-	-0-
62. Inlets, Type A-3	187.75	5	939	126.67	7	887
63. " D-7	220.40	6	1,278	206.67	3	623
64. " E-7	186.20	30	5,512	168.33	12	1,964
65. " F-7	175.00	4	700	182.50	4	669
66. " K-11	241.25	25	6,031	218.30	13	2,911
67. " M-11	238.33	5	1,192	245.00	5	1,225
68. " A-9	173.75	2	304	185.83	2	362
69. " A-8	169.33	1	169	184.17	1	245
70. Manholes, Type B 4	475.00	1	475	506.67	4	2,027
71. B For Casting in Place	338.75	1	339	350.00	2	700
72. Concrete Class D for Structures	69.25	1,042	72,141	72.83	764	55,674

TABLE C1 (Continued)

ITEM	AVERAGES WITH C-D ROADS			AVERAGES WITHOUT C-D ROADS		
	Unit*	Quantity	Total**	Unit*	Quantity	Total**
73. Reinf. Steel for Structures	0.15	49,622	7,443	0.15	49,507	7,426
74. Automatic Drainage Gates	6.00	-0-	100	---	---	---
75. 12" Handlaid Riprap	9.09	318	2,892	8.67	217	1,879
76. Placing 6" Handlaid Riprap	9.60	2,212	21,233	9.17	706	6,477
77. Standard Lip Gutter	3.63	2,866	10,548	2.87	6,504	18,666
78. Paved Side Ditch Type "A"	2.98	7,223	21,524	3.07	3,916	9,258
79. " Type "B"	3.41	478	1,630	3.88	75	291
80. " Type "C"	4.25	476	2,023	4.22	106	447
81. " Type "G"	8.76	1,819	15,937	8.58	263	2,259
82. Integral Concrete Curb	2.22	1,303	2,892	2.50	280	701
83. " Type "B"	1.64	6,567	10,740	1.83	2,067	3,783
84. " Type "C"	1.79	2,690	4,815	1.72	1,393	2,397
85. Bit. Curb.	1.01	4,552	45,970	0.92	5,173	4,759
86. Concrete Center Curb Type "C"	9.90	283	2,799	10.92	315	3,440
87. " Type "D"	7.45	403	3,000	8.42	328	2,765
88. Concrete Curb	3.35	438	1,467	3.60	1,342	4,830
89. Concrete Gutter	2.96	122	360	3.77	242	911

TABLE C1 (Continued)

ITEM	AVERAGES WITH C-D ROADS			AVERAGES WITHOUT C-D ROADS		
	Unit*	Quantity	Total**	Unit*	Quantity	Total**
90. Class F Concrete for Integral Curbwalk	75.63	12	917	66.67	11	758
91. Special Integral Concrete Curb	2.08	206	428	2.28	201	459
92. Furnishing & Installing 2" Conduit	3.16	489	1,544	3.77	483	1,821
93. Steel Beam Guard Rail	3.42	7,878	26,941	3.22	9,115	29,351
94. Double Faced Steel Beam Guard Rail	5.08	1,727	8,772	3.75	1,300	4,874
95. Guard Rail	2.78	1,036	2,881	2.10	1,635	3,533
96. Guide Post Type "A"	8.22	14	113	8.27	25	204
97. " Type "B"	8.22	10	81	8.27	16	135
98. Sign #131	108.00	10	1,080	115.00	3	345
99. Barricades, Type "A"	140.86	7	986	195.00	6	1,105
100. " Type "B"	220.00	9	2,068	148.33	5	692
101. Typical Sign Standard	63.50	32	2,045	61.67	31	1,932
102. R.O.W. Markers	14.14	117	1,657	10.97	77	844
103. Monuments, Type "D"	48.00	1	53	52.67	1	70
104. Bench Mark Posts	57.50	1	69	61.67	3	18,083
105. Sodding	0.66	52,202	34,505	0.65	27,820	18,083
106. Furnishing & Placing Agricultural Limestone	8.77	196	1,716	7.83	167	1,307

TABLE C1 (Continued)

ITEM	AVERAGES WITH C-D ROADS			AVERAGES WITHOUT C-D ROADS		
	Unit*	Quantity	Total**	Unit*	Quantity	Total**
107. Furnishing & Placing Fertilizer	110.81	33	3,707	96.67	30	2,904
108. Furnishing & Placing Seed	1.12	10,549	11,815	1.12	8,070	9,012
109. Furnishing & Applying Mulching Material	80.15	312	24,994	75.67	260	19,684
110. Fence, Chain Link Type	1.50	44,138	66,207	1.55	28,054	43,484
111. Maintaining Traffic		Lump Sum	18,500		Lump Sum	21,467
Total of 111 Items			\$3,620,886			\$2,816,222
Total Contract Averages			\$6,234,500			\$3,507,437

*Unit Cost (or price) in Dollars.

**Total cost per item.

COVER DESIGN BY ALDO GIORGINI