NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 175

FREEWAY LANE DROPS

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FREEWAY LANE DROPS

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Areas of Interest
Highway Design
Highway Safety
Traffic Control and Operations

Transportation Research Board
National Research Council
Washington, D.C. 1976
Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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This report will especially interest highway design engineers, traffic engineers, and all other highway officials concerned with improving traffic operations and safety on freeways. The report contains the findings of a survey of current design and operational practice at freeway lane drop sites in selected states across the nation. Most importantly, it contains recommendations and guidelines for lane drop design in the form of eight principles applicable to several types of lane drop conditions.

It is necessary in some circumstances to reduce the number of travel lanes on a freeway. The requirement may occur under a variety of operating and geometric conditions, and a variety of possible lane drop configurations may be applied. Thus, sound criteria are needed for the selection of appropriate lane drop designs.

The initial NCHRP research in this subject began in 1969 with the threefold objective of determining the effectiveness of existing designs, determining the effects of the significant design parameters, and recommending suitable lane drop configurations. System Development Corporation undertook this research by intensively studying traffic behavior at three sites with differing configuration. The findings from those studies were reported in NCHRP Summary of Progress Through 1971.

The research reported here had the same three objectives and was also conducted by System Development Corporation with an added objective of recommending remedial treatments for existing mainline lane drop situations. The eight design principles that were developed have evolved after a review of the design and operational characteristics of 65 lane drop sites. The validity of the principles has been demonstrated to a degree by their evaluation with respect to before-and-after traffic behavior at two sites where design changes were effected during the course of the study. The report suggests, however, that further validation and research would be desirable before definite design dimension can be recommended.
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FREEWAY LANE DROPS

SUMMARY  Research into the definition and extent of the freeway lane drop problem has yielded considerable knowledge regarding the operational characteristics of existing lane drop locations throughout the country. In general, it has been observed that existing lane drop design standards fail to provide an effective means of warning drivers of the presence and location of the impending lane drop. Very little standardization of lane drop geometric design or traffic control device treatment exists in the field, resulting in much driver confusion regarding lane drop maneuvers. In many instances lane drops are not physically well defined; they can be difficult to see because they might blend into their background or be hidden over the crest of a grade. In addition, advance warning traffic control devices are many times misleading or obscure.

A well-designed lane drop will inform an approaching driver, in a timely manner, of three very important facts: (1) that a lane drop situation is ahead; (2) how far ahead; and (3) what action the driver must take.

As a result of this research, the following eight principles have been developed to serve as guidelines for lane drop design:

1. The lane drop should be placed where the surface of the roadway remains visible continuously for a significant amount of time.
2. The lane drop should be placed away from attention-dividing conditions, such as ramps or complicated directional signing.
3. The lane drop taper should provide adequate visual cues that inform a driver that his lane is ending and should allow a smooth lane change transition in the taper area.
4. The lane drop should be placed on the side of the freeway that is better with respect to given traffic and geometric conditions.
5. The lane should appear to end on the same side of the freeway as the operational lane drop.
6. When a lane drops at an exit ramp, an escape area of adequate dimensions should be provided to allow for a smooth transition into through lanes.
7. When a lane is added at an on-ramp and dropped at a nearby off-ramp, the entering drivers should be notified that the lane they are traveling in is not a continuous lane for through travel.
8. Consistent and appropriate traffic control devices (TCDs) should be used in advance of a lane drop.

Five different lane drop situations, based on design functions, have been identified:

1. Outlying situations—designed to accommodate reduced demand at the perimeter of a metropolitan area.
2. Add-drop situations—designed to accommodate temporarily increased demand at a weaving section.
3. Drop-add situations—designed to accommodate reduced demand through a major interchange.

4. Step-over situations—designed to reduce problems caused by left-hand ramps.

5. Lane split situations—designed to accomplish major route connections.

Applications of the design principles to each of the functional situations are discussed in this report.

Applications of the design principles have been also applied to lane drop design changes at two sites. Before-and-after operations analyses were performed on these two sites, and the results were compared with the conclusions obtained from application of the design principles.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

A nine-month research task was undertaken to determine the definition and extent of the freeway lane drop problem. By means of personal visits and a survey of over 20 major metropolitan areas, several hundred lane drop sites were observed and 65 were selected for more detailed evaluation. This document reports the findings of the survey along with conclusions and recommendations for lane drop design. Also included are suggestions for further research which involves the verification, amplification, and quantification of the design principles set forth in this report.

RESEARCH APPROACH

The research approach consisted of dividing the task into four major subtasks:

1. Conduct a telephone survey of traffic engineers to determine the number of lane drops and associated problems in many areas of the country.

2. Collect lane drop information by interviewing traffic engineers and observing lane drop sites. Information collected includes data on the geometrics, accident experience, and operational characteristics of selected sites; interviews with traffic engineers concerning lane drop problems; and solutions and design standards currently in use.

3. Analyze the survey findings to determine whether patterns exist in lane drop design and, if so, their operational characteristics.

4. Report these findings, lane drop design recommendations, and suggested further research.

The remainder of this report details the findings of this effort and indicates areas where additional research might be conducted. In addition, detailed descriptions of 65 lane drop sites located throughout the United States are presented in Appendix A.
CHAPTER TWO

FINDINGS

This chapter briefly describes some current lane drop design standards at the Federal and state levels, provides a classification scheme for basic lane drop situations, rates lane drop sites observed in the field according to a three-point scale standard, offers some major reasons for operational problems at lane drop sites, and presents eight design principles for lane drop situations.

EXISTING LANE DROP DESIGN STANDARDS

Lane drop design standards are not comprehensively covered in existing highway engineering manuals. The survey indicates that even published standards are frequently not followed at lane drop sites. Several reports, published by the American Association of State Highway Officials (AASHO), the Federal Highway Administration (FHWA), and the Highway Research Board (HRB), have briefly treated lane drop designs and recommended standards. A summary of the reports includes:

1. AASHO Report by the Special Freeway Study and Analysis Committee (1)—indicates lanes should not be dropped at exit ramps because this results in driver confusion, where through lanes are dropped downstream of ramps, a long merging lane should be provided.
2. Highway Capacity Manual (2)—gives warrants for number of lanes, but does not discuss lane drop transitions.
3. AASHO A Policy on Geometric Design of Rural Highways (3)—indicates lanes should be dropped beyond an exit terminal; also specifies lane and taper distances for several design speeds (by referring to acceleration lane tables).
4. Report of the Special AASHO Traffic Safety Committee (4)—indicates lanes should be dropped on the same side as and downstream of an exit ramp; taper rate should be not less than 70.1.
5. FHWA Handbook of Highway Safety Design and Operating Practices (5)—indicates taper rates should be at least 50:1 or 100:1, lanes should be dropped downstream of an off-ramp, signing and striping are important.
6. Manual on Uniform Traffic Control Devices (6)—illustrates several signs for lane drops and recommends sign locations, describes and recommends use of black-on-yellow EXIT ONLY advisory signs; taper length should be lane width times design speed (or 85th percentile off-peak speed), illustrates left-side pavement drop with striping to merge two right lanes.

In addition, design standards collected from many states are listed below. The Institute of Traffic Engineers has conducted a mail survey of standard practices for application of traffic control devices at freeway lane drops, which should provide information in addition to the following concerning standard practices in a number of states.

California

California standards are being revised. The following comments were derived from interviews with California Department of Transportation personnel:

1. Do not drop a lane at the same location as a ramp end.
2. Do not present a driver with successive decisions too quickly.
3. Coordinate geometry and striping, if possible.
4. Avoid drops on curves.
5. Consider traffic volumes by lane and composition.
6. Do not drop lanes at an off-ramp connection, unless more than 50 percent of vehicles exit.
7. Through lanes should not be dropped at a local ramp.
8. Taper should begin about 600 ft downstream from a ramp.
9. Taper length should be about 800 to 1,000 ft.

With respect to item 7, field observation indicates that through lanes in California are frequently dropped at a local ramp.

Connecticut

Published standards for pavement design are presented in Figures 1 and 2. Stated signing standards are those of the MUTCD, but there is much variation in existing signing.

Michigan

The following comments were derived from interviews with Michigan highway personnel.

1. Most lane drops occur at exit ramps, currently provided with an escape lane tapering from 22 ft wide.
2. Future design may reduce the escape lane to 14 ft.
Michigan treats add and drop lanes less than 2,600 ft long as auxiliary lanes, using different-colored pavement.

Minnesota

Minnesota standards are published in a manual and in staff memos (see Figs 3 and 4). These sources note that escape lanes should be considered.

1. Following the auxiliary lane between cloverleaf loops where the loops are immediately adjacent to the mainline roadway, the suggested escape lane design consists of 200 ft of tangent 12-ft lane followed by a 50:1 taper, provided that the taper would end at least 300 ft in advance of the nose for the following entrance leg.
Granite Slope Curbing only if required for drainage

600' Minimum

Double Barrier Line

Reduce median width at a rate of 50 ft

600' Minimum

General Note
Transitions between two-lane highways and four-lane highways shall be designed to direct drivers approaching the divided section into the intended path to the right of the median without any appreciable change in direction. Any significant change in direction shall be made by drivers leaving the divided section.

FOUR LANES DIVIDED INTO TWO LANES UNDIVIDED

1000' Minimum

General Note
normally, the lane drop will take place on the right in the direction of traffic. Transitions shall be avoided before interchanges and at locations with horizontal and/or vertical sight distance restrictions.

ROADWAY LANE DROP

Figure 1. Connecticut design standard for a lane drop away from an interchange

Varies

1000' Minimum

General Notes
A reduction in the number of lanes at an interchange is an appropriate layout only where the traffic warrants for a considerable section of the expressway beyond the interchange do not require the greater number of lanes. Because of the difficulty of predicting the daily and hourly fluctuations of traffic on low volume ramp movements, the number of lanes should not be reduced within the interchange area, such as between successive "off" and "on" ramps.

Length of parallel section beyond ramp terminal varies to meet special considerations. Transition should occur on tangent section wherever possible and should avoid locations with horizontal and vertical sight distance restrictions.

Figure 2. Connecticut design standard for a lane drop at an interchange
2. Following the auxiliary lane between interchanges, where the auxiliary lane length between noses measures from 1,000 to 2,000 ft, the escape lane should consist of a 50:1 taper beginning at the exit nose and having a width at the nose of 14 ft. This design may vary depending upon the projected volumes on the ramps and on the mainline lanes.

3. Following a short auxiliary lane (less than 1,000 ft between noses). Normally the escape lane should consist of 400 ft of tangent 12-ft lane followed by a 50:1 taper.

The suggested dimensions may be considered applicable in most instances; however, in all cases the projected volumes on the mainlines, ramps, loops, and weaving areas should be considered to determine the appropriate design.

For comparison, it should be noted that Minnesota's present standard for a major exit, which involves the dropping of a mainline lane, specifies that the escape lane shall consist of a 400-ft length of tangent 12-ft lane followed by a taper having a ratio of the design speed of fifty to one.

Missouri

The following is abstracted from a letter from Robert N. Hunter, Chief Engineer, Missouri State Highway Commission.

Missouri has no published specifications because lane drops occur infrequently. Normal practice is to drop the outside lane at a ramp exit. Missouri has experienced some problems when inside lanes were dropped; these situations have been corrected by restriping and signing to drop the right lane. Missouri favors the black-on-yellow EXIT ONLY sign, a solid stripe from 500 ft upstream of the exit gore through the gore area, and a 70:1 taper rate downstream of the gore. On those few sites away from ramps, an overhead RIGHT LANE ENDS 1500 FT, lane drop symbol (4-2), and LANE ENDS MERGE LEFT.

New Jersey

The following comments were derived from interviews with New Jersey personnel:

1. If a lane is dropped at an exit, a standard acceleration lane (600-ft full lane width, 600-ft taper) should be provided past the exit gore as an escape area.

2. A standard taper length of 70:1 should be used at a non-exit lane drop site.

Figure 3. Minnesota design standard for a lane drop at a major highway fork.
Figure 4. Minnesota design standard for a lane drop at an interchange.
6° Max. If curve is less than 300 feet in length, retain the 0.02 ft. per ft. cross slope throughout.

**TABLE A**

OFFSET FROM EDGE OF MAINLINE PAVEMENT TO EDGE OF STRIPING

<table>
<thead>
<tr>
<th>DISTANCE</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>150, 250</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFFSET</td>
<td>1.00</td>
<td>1.07</td>
<td>1.28</td>
<td>1.63</td>
<td>2.00</td>
<td>2.50</td>
<td></td>
</tr>
</tbody>
</table>

For super elevation see Fig. A-3-91L 264

Where mainline is curved plot offsets and connect points with smooth curve.

**Y LANE DESIGN**

**ESCAPE LANES AT MAJOR RAMP EXITS**
New York

According to the Deputy Chief Engineer, the following extracts from New York's published standards reflect the results of a California study of a few years ago:

5 05 06 Lane Drops

At diamond, cloverleaf, or other conventional types of interchanges, do not drop a lane at the exit terminal and subsequently pick it up again at the next entrance terminal. Instead, carry the outside lane through the interchange area.

When capacity-dictated lane drops are necessary on multi-lane divided highways, it has been found in one California study that dropping the striped and constructed lane on the median side resulted in two-thirds of the accident rate resulting from a lane drop on the right side.

It has also been shown that lane drop transitions on curves result in from two to ten times the accident rate as for tangent transitions.

Therefore, capacity-dictated lane drops for multi-lane facilities should be made on the median side, on tangents, and away from the influence of the interchange ramps.

The lane drop transition should begin at least one-half mile beyond the nearest exit or entrance ramp nose. The length of taper should then be "Design Speed × Lane Width".

In direct connection interchanges, where a reduction in the number of through lanes is indicated by capacity analysis, these locations should be designed as major forks, with appropriate advance and gore signage that give specific and clear lane assignments to guide the driver.

Ohio

The following priority system is used in determining the placement of lane drops in Ohio:

1. Continue the drop lane through an interchange and begin the taper approximately ½ mile past the final exit ramp.
2. Continue the drop lane past the final exit ramp, terminating the taper prior to the next entrance ramp.
3. Begin the lane drop taper approximately 12 ft beyond the exit ramp gore.

Right-hand lane drops are accomplished by reducing the pavement width from the left-hand side, with the pavement markings for the through lanes placed parallel to the pavement taper through the transition zone. Signing for a drop away from a ramp includes a black-on-yellow RIGHT LANE ENDS 1 MILE, and a black-on-yellow RIGHT LANE ENDS MERGE LEFT at the start of the taper, both signs are overhead. The EXIT ONLY panel is used for ramp drops, with an EXIT LEFT 1 MILE for a left-hand ramp.

Oregon

The State of Oregon has published plans for guidance in the development of lane drop standards (see Fig. 5).

WASHINGTON

The following is extracted from a State of Washington manual (Figs. 6 and 7):

\[
L = \frac{V T}{2}
\]

where \( L \) = length of transition (ft)
\( V \) = design speed (MPH)
\( T \) = tangential offset (ft.)

Transitions occurring at turning roadways, and tapers into existing pavement widths on low speed conditions should normally have a tangential rate of change of 1.25 or flatter. Nevertheless, the number of tapers should be held to a minimum.

CLASSIFICATION OF BASIC LANE DROPS

Lane drops, as defined by highway personnel, can generally be categorized into one of five basic types. (Fig. 8 shows typical configurations of lane drop types) Appendix A is arranged by these five types of lane drops and can serve as a guide to examples of current sites.

Outlying Drop Situation

The most familiar type of lane drop site is located at the perimeter of a metropolitan area. The lane drop is produced when the basic number of lanes is no longer required to carry the traffic generated from an urban center. This lane drop type has been designated as an outlying drop situation.

A subcategory of outlying lane drops has also been identified. In some cases, lanes have been dropped to accommodate a downstream physical constraint, such as a narrow bridge. Such sites have been included in this category because the problems and design of these lane drops generally reflect those of the remainder of the category.

Add-Drop Situation

A second major lane drop type is the add-drop situation. In many cases a lane is added at an on-ramp and dropped shortly thereafter at a downstream off-ramp. The observed distance between the lane addition and the lane drop has been as short as 1,500 ft or as long as more than 6,000 ft.

Drop-Add Situation

A counterpart of the add-drop situation is the drop-add situation, which has generally been observed at major freeway-to-freeway interchanges. This type of drop is installed for several reasons. First, traffic exiting from the freeway may be extremely heavy, indicating a need for two or more exiting lanes. Thus, if one full lane of traffic exits to travel to the other freeway, the additional lane is no longer needed for through traffic. Further, by dropping a

* Unpublished standards based on a Deleuw, Cather and Company study, by Jack E. Leisch, published in the 1965 Canadian Good Roads Association Proceedings
Figure 5 Oregon design recommendations for lane drops

lane through the interchange, vehicles entering on the other side of the interchange have a "free" lane in which to enter the freeway; they do not have to merge with faster-moving through traffic. It thus seems reasonable to drop a lane through a major interchange.

Step-Over Situation

A fourth type of lane drop situation that results in many problems is called the step-over lane drop. In this situation, a freeway step-over is accomplished by adding and dropping, or dropping and adding, a lane on opposite sides of

Figure 6. Washington design standards for a lane drop at an interchange (single-lane exit).
Two-Lane Off Connection

Figure 7. Washington design standards for a lane drop at an interchange (two-lane exit).

Lane Split Situation

The fifth type of lane drop, a lane split, is found on a freeway that divides into two or more legs where the design speed on each leg is generally higher than the conventional off-ramp which goes to a surface road. The point at which the division takes place is called a lane split. It is difficult to characterize a lane split because many factors must be taken into consideration. A few of these are (a) the number of lanes on the freeway prior to the split; (b) the number of lanes on each leg after the split; (c) the traffic demands on each leg downstream of the split; and (d) the hierarchy of route designations of the freeway upstream of the split or downstream of the split. In many cases, drivers are forced to change lanes to continue in their chosen direction of travel. Thus, some of the problems and some of the solutions pertinent to other categories of lane drops are found at lane splits.

Classification and Grading of Field Data Observations

A rough three-point scale was used to rate the relative effectiveness of the sites observed. The factors used in the grading scheme included (1) the number and severity of erratic movements, (2) lane change behavior, (3) speed change behavior, (4) opinions of state and local highway engineers, and (5) amount of citizen complaint regarding the site. A site was judged good if the number of erratic movements seemed small, if most lane changing was accomplished in advance of the taper or gore area, and if highway engineers thought that the site was currently not
a problem. A site was judged passable if no serious problems occurred, but indications of problem-producing maneuvers were frequent. A site was judged bad if many erratic movements were observed, if congestion was apparent in the lane drop area even if the general area was flowing at below capacity, or if highway engineers or citizens expressed awareness of serious problems.

It must be remembered that some sites are considered problems because they are peak-hour bottlenecks. If the traffic demand at peak-hour is above downstream capacity, the lane drop will become congested regardless of how it is designed. In cases where such a condition exists, the site was observed in off-peak-period operation. If it worked well under these conditions, the site was judged good regardless of the fact that during peak-hour operation breakdown occurs in the vicinity of the drop.

Each of the 65 sites observed and catalogued in Appendix A was graded by the researchers and categorized into one of the five basic lane drop types described previously. The categorization scheme is not necessarily all-inclusive or mutually exclusive. A few lane drops will defy being classified into any of the five categories; a few others will fit more than one category. However, most lane drops can be effectively classified into one category. Table 1 presents the ratings of the various sites.

**OPERATIONAL PROBLEMS**

The categorization scheme allows for ease in treating the situations from a design or remedial treatment standpoint. From a purely operational or driver’s-eye standpoint, some of these categories can be grouped together. Thus, problems associated with exit ramp drops at a drop-add situation may be similar to those of a lane split, or the apparent conditions facing a driver entering a freeway from an on-ramp at an add-drop situation may be similar to those experienced by a driver entering the freeway on the lane-add of a drop-add situation. The problems associated with each type of basic lane drop situation are discussed, with the understanding that many problems overlap category boundaries.

### TABLE 1

**RATINGS OF LANE DROP SITES**

<table>
<thead>
<tr>
<th>LANE DROP CONFIGURATION</th>
<th>GOOD</th>
<th>PASSABLE</th>
<th>BAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlying</td>
<td>02, 05, 14, 19, 23, 26, 27, 34, 38, 39, 53, 58, 59</td>
<td>08, 16, 28, 36, 44, 47, 48, 52, 57, 60</td>
<td>04, 17, 20, 25, 31, 35, 51, 61, 65</td>
</tr>
<tr>
<td>Drop-add</td>
<td>41</td>
<td>42, 55</td>
<td>30, 40, 49, 50, 54</td>
</tr>
<tr>
<td>Add-drop</td>
<td>18, 62, 63, 09, 21, 32, 33</td>
<td>14, 23, 38, 24, 37, 45</td>
<td></td>
</tr>
<tr>
<td>Split</td>
<td>64</td>
<td>43</td>
<td>06, 22</td>
</tr>
<tr>
<td>Step-over</td>
<td>15</td>
<td>03, 11</td>
<td>01, 10, 29, 46, 56</td>
</tr>
</tbody>
</table>

### TABLE 2

**RATINGS OF OUTLYING LANE DROP CONFIGURATION SITES**

<table>
<thead>
<tr>
<th>OUTLYING LANE DROP CONFIGURATION</th>
<th>RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GOOD</td>
</tr>
<tr>
<td>Right taper</td>
<td>05, 19</td>
</tr>
<tr>
<td>Left taper</td>
<td>14, 23, 38, 39, 53</td>
</tr>
<tr>
<td>Right ramp</td>
<td>02, 26, 27, 34, 58, 59</td>
</tr>
<tr>
<td>Left ramp</td>
<td></td>
</tr>
</tbody>
</table>
suits were poor. The three sites studied were all designed
differently and the characteristics of sites 17, 65, and 13
are shown in Figures 11, 12, and 13, respectively. The
pavement at site 17 ends on the left, and the two right lanes
are merged together by moving the four left lanes towards
the right lane. The pavement at site 65 ends on the right
just downstream of a right-hand on-ramp, and the three
right lanes are moved toward the left lane. The pavement
at site 13 moves toward the right as the median widens and
the pavement tapers into lane two.

The difference between sites 65 and 13 is that the site 65
lane lines do not follow the longitudinal pavement joints,
whereas the site 13 lane lines are in accordance with the
pavement joints. In all cases, the sites have been indicated
to be confusing to the driver.

The situations highlight two main points for considera-
tion. First, it is difficult for the driver in the median lane
to understand that he must move out of his lane because
of an impending lane drop when he can “see” that the
pavement in front of him continues; all his cues and past
experience tell him that his lane is still there. Second, even
if he moves out of this lane the first time through, the com-
muter learns quickly enough that, had he chosen to stay in
his lane, he would get where he was going just as well. That
sets up a perfect stage for “freeway roulette” in which the
driver in the inner lane fights to remain in his lane which,
according to the lane lines, moves over slightly, while the
driver in the outside lane is sure that his lane continues as
well.

Though there have been numerous complaints of driver
confusion over who has the right-of-way at site 13, the
first lane drop study (7) concluded that site 65 experienced
a much greater amount of turbulence than at the other two
sites in that study.

A corollary to this difficult lane drop situation is that the
sites are also difficult to sign. The standard lane drop signs
(W4-2) have been changed several times due to citizen
complaints that the merge indicated is in the wrong direc-
tion; each time the state has made a sign change, they have
received complaints. A new type of sign (Fig. 14) has been
installed to try to eliminate this driver confusion.

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**Figure 9. Site 31.**

**Figure 10. Site 04.**
Clearly, this type of lane drop configuration is undesirable using current techniques. One state highway department has eliminated two opposite taper lane drops, one by extending the dropped lane, and the other by moving the operational lane drop upstream a few hundred feet and converting it to an exit ramp drop.

Several outlying-type sites have been designated "problem" sites by state agencies or as a result of citizens' complaints because congestion occurs during peak-hour traffic. Geometric design procedures or traffic control devices cannot eliminate a lane drop problem that is a result of insufficient downstream capacity. Site 34, shown in Figure 15, is an example of this situation. This 3-2 right-hand exit lane drop functions well during off-peak hours, but it routinely breaks down every week-day afternoon because of above-capacity demand downstream. In general, if a site suffers from this type of problem, the solution is either to continue the additional lane until there is sufficient capacity for the demand; to reduce demand by upstream control, such as on-ramp metering, or to accept the occurrence of the bottleneck.

Add-Drop Situation

Almost half of the 13 add-drop sites were given bad ratings. Most of these have one common problem—poor sight distance. If drivers cannot see the lane drop in time to make a smooth transition out of the dropping lane, erratic maneuvers may result. Sites 24 and 37, respectively shown in Figures 16 and 17, both less than 1,500 ft long, are good examples. Sight distance is very restricted due to the presence of vertical curves; the lane is dropped just beyond the crest of the grade. Both sites have one sign in the add-drop lane pertaining to the lane drop, an EXIT ONLY panel on a directional sign several hundred feet in front of the gore of the off-ramp. Even if a driver is looking for a directional sign at this point—which he probably isn't because he just entered the freeway—by the time he is able to read the sign he is probably close to being committed to an erratic maneuver to get out of the lane before it veers off the freeway.

The operational problems at add-drop locations generally seem to stem from the driver's confusion over whether he is in a through lane or not. At most add-drop sites, normal lane lines begin just after the lane add and continue until just before the lane drop. Sometimes a solid white line replaces the lane line, yet normally it occurs too late to let the driver avoid an erratic maneuver if he wishes to remain on the freeway. One additional operational problem exists for right-lane drivers. It has been observed several times that drivers who normally travel in the right lane enter an
add-drop lane from the through lanes only to find themselves trapped by the lane drop.

In general, add-drop lanes cause significant operational problems, possibly because drivers are unaware that the lane is a “special” one and not for through travel.

**Drop-Add Situation**

The drop-add situation occurs most frequently at major freeway-to-freeway interchanges. As has been stated previously, the normal reason for this configuration involves the expected high volume of exiting and entering traffic at the interchange. Theoretically, dropping a lane through the interchange is a good plan if the predicted volume distribution does split as intended, and if advance signing is adequate so that through drivers do not become entangled with exiting vehicles and end up on the wrong freeway. Because trucks and other slower moving vehicles are usually in the right lane, the engineer must be convinced from an operational standpoint that the benefits of dropping and adding a lane outweigh the disadvantages of moving the slower vehicles out of the right lane and back into the right lane on the other side of the interchange.

Site 50, shown in Figure 18, suffers from an unfortunate volume split. A lane was dropped on the freeway northbound at the interchange to the other freeway because it was believed that a large percentage of the traffic would be exiting the northbound freeway at that point in order to use the other freeway. However, for years the other freeway has remained incomplete and only a short section is operational. Thus, fewer vehicles than predicted utilize that freeway, and more vehicles remain on the northbound freeway. A peak-hour capacity problem has, therefore, developed on the reduced lane section through the interchange. A study at this interchange has been completed by the state highway department and construction has been approved to continue the lane through the interchange.

Enforcement of an operationally dropped lane is difficult to carry out but not impossible. Two sites were judged bad because many drivers violated an operation drop-add by remaining in the dropped lane, regardless of warning signs and pavement markings. It must be noted that, even though compliance with the lane drop restrictions at these sites was not total, general operations in the area improved. However, because some operational lane drops do work well from a compliance standpoint, it appears that additional improvement in operations can be made at these sites.

**Step-Over Situation**

Generally, operations at step-over lane drop sites are no better, and many times worse, than the average lane drop site. Step-over lane drops suffer from the same operational problems as other types of lane drops. However, the situations that have required step-over lane drops to be built could probably be avoided. Two bad step-over lane drops (sites 29 and 46, respectively shown in Figs. 19 and 20), involve left-hand off-ramps. Site 46 is also at a tangent off-ramp, compounding the problem. The lane drops are placed so that it is difficult, if not impossible, to do an adequate advance signing job. This, combined with poor geometries, allows for a very poor accident history.
In another instance, two step-over drops were constructed to accommodate high-volume right-hand ramps. A lane was added on the left and all traffic was forced to move left one lane by means of changes in striping. The on-ramp traffic was given a "free" lane. Then shortly downstream, a high-volume off-ramp siphoned off right-lane traffic and the added left lane was dropped, which forced the two left lanes of traffic to merge. The sites were reconstructed in this manner because of geometric restrictions on the right; a weaving lane could have been added on the right. On one of the sites, a downstream restriction (a narrow two-lane bridge) prevented the added left lane from continuing. This section of freeway has a severe problem basically because of the high-volume ramps and insufficient weaving area. The forced lane drops do not work well because they are too close to the weaving section and not enough distance is available for adequate warning and smooth transition.

Lane-Split Situations
Operational problems at the few lane splits observed by the researchers indicate driver confusion over which route to travel and, in some cases, poor sight distance. Site 06, shown in Figure 21, has relatively adequate sight distance, but is a very complex interchange. Traveling eastbound on the freeway, the driver finds that the three left lanes exit onto a surface street just downstream of the interchange while the two right lanes split into an east-west directionally signed freeway that physically runs north-south at the interchange. Thus, a driver must be in one of the two right lanes in order to make an effective left-turn to travel north. Many last-minute maneuvers were observed by the researchers, including one in which a driver stopped his vehicle in the gore area and consulted a road map. This indicates that many operational problems at lane splits are not due to simple inattention to road signs.

The more complex problem at lane splits seems to be directional guidance. However, this is a problem which
needs an entire study to itself. In the present research effort, lane splits are treated briefly and in a manner comparable to other lane drops. Thus, lane splits are considered from a geometric design viewpoint with regard to sight distance, construction, and the like.

Traffic Congestion-Related

When traffic demand exceeds the capacity of the freeway lane drop downstream, congestion and eventual breakdown occurs. From the observation of lane drop operations that approach freeway breakdown near lane drop locations, it appears that the most likely point of breakdown will be downstream of the lane drop rather than at the lane drop itself. Flow levels exceeding 2,000 vehicles per lane per hour for the lanes in the downstream section have been observed at lane drop sites. At those flow levels, some vehicles had difficulty finding acceptable gaps in order to move out of the dropped lane, but total breakdown did not result from such maneuvers. If freeway breakdown did occur at a lane drop site, the breakdown point was downstream of the actual lane drop, usually at the first ramp.

Driver Behavior-Related

A lane drop site may be a problem even though demand remains below downstream capacity. In general, an operational problem exists if a significant number of drivers make erratic maneuvers in the area of the lane drop. Erratic maneuvers include sudden speed changes; abrupt lane changes; and lane changes that require driving through a ramp gore area, an escape lane, or a lane drop taper. Some of these erratic maneuvers can result in unsafe conditions or even accidents, many may result in increased driver anxiety.

Although some of these maneuvers may involve a deliberate attempt by a driver to gain some advantage in traffic position, most maneuvers probably result from the driver's failure to recognize the requirements to negotiate the lane drop area until it is too late for him to reach his desired lane without making the erratic movement.

The requirements for negotiating a lane drop are (a) an awareness of an impending lane drop, (b) a knowledge of the location of the lane drop, and (c) an ability to decide upon an appropriate maneuver and the ability to execute the maneuver. When a driver is in the vicinity of a lane drop, the longer that information regarding these three requirements is withheld from him, the fewer the options he
has for making a smooth transition through the area. Therefore, lack of important information necessary for negotiating the lane drop may be seen as the source of driver behavior-related operational problems at lane drop locations.

Solutions

Two solutions to congestion-related operational problems caused by demand exceeding downstream capacity are fairly straightforward, although not easy to accomplish. They are (a) to extend the lane until demand is reduced to a level below lane reduction capacity, and (b) to reduce upstream demand. The 1965 AASHO manual (3) indicates a design capacity of 1,200 vehicles per hour (vph) on suburban freeways and 1,500 vph on urban freeways. If the demand predictions hold true, then a lane can be dropped without creating a geometric bottleneck when demand reaches the design capacity volume of the downstream section of the lane drop location.

Solving operational problems caused by erratic driver behavior is not straightforward. Three requirements for negotiating a lane drop (i.e., indication of presence, indication of location, and indication of appropriate action) form the basis for design policy in the construction of the lane drop. Once a decision has been made that the level of demand or geometric design constraints indicate a lane drop is desirable or necessary, then work can begin on the physical design of the lane drop, such as deciding where to place it, how to construct it, how to inform drivers of it. Solutions to the design of an effective, safe lane drop involve all of those aspects. The goal of lane drop design policy is to develop a lane drop that gives a driver the appropriate timely information necessary to allow him to make a smooth transition through the lane drop area.

Probably the most important factor in the geometrics of a lane drop is in designing its location such that it can be seen by drivers approaching the area. The most direct visual cue a driver can receive is that of the roadway geometry itself, which shows him that the lane in which he is traveling either ends or leads him in a direction contrary to his intended direction of travel. Geometric conditions continuously provide the driver with cues that he uses to negotiate his chosen path of travel. Traffic control devices, on the other hand, can provide advance warning of the impending lane drop, enhancement of the visibility of the actual lane drop area, and directional information when a choice of traveled way must be made.
DESIGN PRINCIPLES

Eight principles of lane drop design have been identified. Discussion of the principles and their applications emphasizes the clarity with which geometric cues must be presented.

1. Provide continuous visibility—The lane drop should be placed where the surface of the roadway remains continuously visible for a significant amount of time. The first design principle indicates that roadway surface continuity is important because it provides the most reliable visual cue to the driver. Surface continuity stipulates that the entire roadway surface must be visible from the beginning of the lane drop to the end of the lane drop and must remain in continuous view as the driver traverses the section. In rolling terrain, a lane drop located just over the crest of a grade or just beyond a horizontal curve is not desirable because the visual cue is lost to the driver. On the other hand, a lane drop located at the end of a sag vertical curve or on an upgrade can be seen by the driver in time for him to take proper action even in the absence of appropriate advance signage.

The distance required for a driver to (a) perceive that a lane is ending, (b) evaluate alternative courses of action, and (c) maneuver to an adjacent lane, if desirable, is the minimum distance that should be “in-view” to a driver approaching a lane drop. Perception-reaction times as reported in the Transportation and Traffic Engineering Handbook (7) can be as much as 3 to 4 sec for complicated situations. The AASHO standards (3) assume the perception time value to be 1.5 sec and the total of perception and brake reaction to be 2.5 sec. At a lane drop, brake reaction time is probably not appropriate because that is not a desirable reaction. AASHO also indicates that a normal lane change is accomplished at a rate of ½ sec per foot of lateral movement, or 4 sec for 12-ft lanes. An unforced freeway lane change has been observed to average 2 to 3 sec. However, it has been observed that lane changes associated with moving out of a lane drop situation average 7 sec. Additional data are required before average maneuver time for leaving a lane drop is determined. If one assumes that under nonrestrictive conditions it is desirable to move all vehicles out of the lane before the beginning of the taper, or before the operational gore, the minimum surface continuity distance is:

\[
\text{“in-view” distance} = \text{maneuver time} \times \text{design speed} \quad (1)
\]

where “in-view” distance is the distance of surface continuity to the beginning of the lane drop taper or operational gore.

Some questions arise: Is in-view distance a practical parameter? Can a driver on a straight and level section of freeway see a lane drop nearly one-quarter mile distant? Can roadways be designed to accommodate a lane drop subject to such restraints? The answers to these questions should be explored in future research.

2. Minimize attention-dividing conditions—The lane drop should be placed away from attention-dividing conditions, such as ramps or complicated directional signing. This principle states that conditions that divide the attention of the driver should be minimized in a lane drop area. This improves the likelihood that the driver will concentrate on the roadway in front of him and that he will be required to make only one decision at a time.

Ideally, no extraneous attention-dividing conditions exist in a lane drop area; practically, this is nearly impossible to achieve in urban areas. Some common distractions include (a) additional ramps other than those directly involved with the lane drop, (b) directional signs requiring imminent decisions to be made downstream of the lane drop, (c) service information, and (d) warning signs pertaining to other geometric conditions. Site 07, shown in Figure 22, illustrates such distractions in the nature of a left-hand curve and several on-ramps, which interfere with the lane drop.

To achieve the objective of minimizing distractions from a construction standpoint, a lane drop should be built where the complete sequence of lane drop information can be given to the driver without interruption. Thus, if lane drop design standards indicate that advance signing for the lane drop should begin one-half mile upstream of the lane drop, no additional ramps or other distractions should be constructed within that distance.

3. Provide adequate transition cues—The lane drop taper
should allow for a smooth transition for drivers to make a lane change in the taper area and should provide adequate visual cues that inform the driver that his lane is ending. The third principle indicates that the taper should be long enough to allow for "fail-safe" maneuvers for drivers who enter the taper area with no prior knowledge of the lane drop, this may occur even at lane drops with well-designed visibility. A visually observable taper is probably the most reliable cue available for informing drivers of an impending lane drop.

Stub-end lane drops and too-short tapers should be avoided Where a stub-end is desirable from a construction standpoint, it should be disguised by forming an artificial taper. This can be accomplished by covering upstream pavement with dirt and adding a removable-type curbing to form an appropriate taper. A too-short taper is shown in Figure 23 Although the visual lane-ending cues are dramatic, the situation forces drivers to make undesirable panic lane changes or speed changes.

On the other hand, a too-long lane drop taper may cause a driver to miss important visual cues that tell him the lane is ending. At some unspecified point, called the closure threshold, a driver is unable to visually perceive that the lane is narrowing. The threshold has not been established.

Further research should be conducted to define the numerical range of the "happy medium" for a standard-length lane drop taper. Lane drops with a taper should be designed to provide a "fail-safe" factor in terms of the lateral rate at which a full-speed motorist is forced over by the pavement edge line. If a motorist has failed to understand the advance signs and special pavement markings, he should be led to merge gradually enough so that he and motorists in the adjacent lanes can safely adjust. In other words, the motorist who for any reason is unresponsive to all else may be guided by the edge line (right or left). It may also be desirable to create a buffer zone beyond the edge line before the errant driver reaches the actual edge of the pavement and/or shoulder.

4. Create lane drops on better freeway side—The lane drop should be placed on the better side of the freeway for given traffic and geometric conditions. This principle addresses whether to build a lane drop taper on the left or the right. There seems to be no definitive answer to this question. One argument states that the left-hand drop is advantageous because (a) the left two lanes usually carry less traffic, (b) it is away from the influence of ramp turbulence on the right, and (c) vehicles generally flow at a more uniform speed in the left lanes because there are few slower commercial vehicles. The opposing argument states that

![Figure 22. Site 07.](image)

![Figure 23. Site 11.](image)
the right-hand drop is advantageous because (a) drivers are accustomed to having lanes (i.e., acceleration lanes) end on the right and they can merge better from right to left than left to right, (b) traffic is generally slower in the right lanes and would make the merge at slower speeds, and (c) the right lanes usually carry less traffic.*

* Driver lane preference seems to be a regional phenomenon. Several states have laws that make it mandatory to remain in the right lane except to pass, others do not. Thus, some areas experience different lane distributions than others.

To help determine which lane to drop from a freeway, the following factors should be considered:

1. What type of lane distribution is expected? It is preferable to merge the two most lightly traveled lanes.
2. What type of traffic composition is expected? If a large percentage of heavy trucks or recreational vehicles is expected, consideration should be given to merging the two left lanes.
3. What other geometric features, such as ramps, are nearby? Lane drops generally work better away from the influence of ramp turbulence.
4. Will the sight distance be significantly better on one side than the other? Sight distance is always critical.
5. Will it be more difficult to sign a lane drop on one side than the other? Appropriate signing can significantly improve a bad situation.

By examining these factors, an engineer can then make a reasonable judgment concerning which side of the freeway should have the lane drop.

5. Coordinate visual and operational drop—The lane should appear to end on the same side of the freeway as the operational lane drop. In some cases it is physically advantageous, yet not operationally desirable, to drop a lane on a particular side of the freeway. A case of this sort can occur when the dropped lane has a high probability of future continuation, as in site 17 (see Fig. 11). From a construction viewpoint, it is desirable to drop the left lane by stubbing off the pavement. However, from an operations view, this handling of a lane drop is far from optimum. To correct the situation, merging the right two lanes is accomplished through striping and signing. (Appendix C describes the results of such a change in markings.) Theoretically, this solves the problem; practically, the results of such situations are less than optimum. For example, such treatment sets up a right-of-way problem for two drivers.
who arrive simultaneously at the lane drop and also results in the loss of valuable information cues. A practical solution to this problem should be sought.

A design solution to the problem has been proposed by the California Division of Highways and is shown in Figure 24. To a driver approaching this lane drop, the visual cues from the shoulder of the freeway indicating an impending lane drop are seen at point 1 on the illustration. At point 2 the driver only sees a slight curving of the roadway alignment. Ideally, point 2 and point 1 should not be in view simultaneously. Figure 25 shows perspective views from points 1 and 2 shown on Figure 24.

The main requirement for placement of the operational lane drop is the undetectability of the physical lane drop. Even repeat users should not be readily aware of the occurrence of the physical lane drop; this is the one lane drop that should be hidden. The operational lane drop should be constructed so that the lane looks as if it is ending. This may be accomplished through the use of a temporary curbing, filling in the unused pavement with dirt, or making the surface similar to the shoulder treatment. The downstream drop can be stubbed-off and treated in the same manner. This technique obviously requires the laying of pavement and then not using it, but the increase in operational efficiency more than offsets the cost of the unused pavement. The "after" configuration described in Appendix D is a good example of how a bad situation can be improved by disguising the physical drop from the operational drop.

6. Provide adequate escape area—When a lane drops at an exit ramp, an escape area of adequate dimensions should be provided to allow for a smooth transition into through lanes. The sixth design principle defines the nature of the escape area as just that—an area for merging into the through lane once the driver is too close to the exit gore to make a normal lane change.

Figure 26 shows a plan view and a perspective view of a suggested exit ramp lane drop configuration. There is a definite indication that the lane is not continuing past the interchange, but the configuration does allow a driver to safely change to a through lane even if he does not begin his lane change until entering the operational gore area, which should be plainly visible to the driver. The shoulder has been eliminated at the physical gore, to be picked up again as the pavement tapers.

A full acceleration lane is not needed because the driver is probably traveling at or near freeway speed. A full lane width plus shoulder width can confuse the driver by providing too wide an area. From a construction standpoint, it may be desirable to stub off the pavement at the gore and allow traffic to use the shoulder as the escape area. This is reasonable if pavement markings resembling a taper can be made permanently as visible as a pavement taper. The ideal taper length has not yet been determined for this situation, but it is reasonable to hypothesize that the taper should begin at the physical gore and should resemble a standard taper.

Figure 26. Perspective and plan views of an exit ramp lane drop
7. Notify driver that lane is not continuous—When a lane is added at an on-ramp and dropped at a nearby off-ramp, the entering drivers should be notified that the lane they are traveling in is not a continuous lane for through travel. The seventh principle pertains to add-drop lanes used when an on-ramp/off-ramp pairing warrants an additional lane for weaving and capacity through the section. However, steps should be taken to inform drivers entering the freeway at this point, as well as informing the through traffic, that the lane is only a temporary addition to the freeway. Traffic control devices (TCDs) must perform the information function when sight distance restrictions prevent drivers from observing the lane drop from the lane add point. These conditions are shown in site 62, Figure 27.

Normal lane lines should not be used to delineate the two adjacent lanes because they would reinforce the concept that a through lane has been permanently added. Instead, the special lane should be as different as possible from the through lane. Three methods accomplish this: (a) contrasting pavement, (b) special-purpose lane delineations, and (c) signing. Ideally, some combination of these methods would be used. Figure 28 shows several warning methods that can be employed at an add-drop location. Views B, C, and D give the message that this is

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**Figure 27. Site 62.**

A. No warning device: Normal lane lines

B. Warning device: Special lane lines

C. Warning device: Black-on-yellow over-head sign

D. Warning device: Contrasting pavement

**Figure 28. Warning information systems at lane add-drop locations.**
a special lane. Additionally, an add-drop lane should have normal minimum sight distance to the lane drop gore and an escape area, as previously described.

Use adequate traffic control devices—Consistent and appropriate traffic control devices (TCDs) should be used in advance of a lane drop. The last design principle indicates that consistent and appropriate traffic control devices should be used in advance of a lane drop. The package of traffic control devices used at a lane drop should inform the driver (a) what is going to happen, (b) where it is going to happen, and (c) what he should do about it.

At the present time, many sites have incomplete or misleading information. The driver may be told to merge left but, in actuality, the other lanes may move into his lane, such as in the situation where a lane is operationally dropped on the opposite side of the freeway from the physical drop. At some sites where a right-hand lane drop occurs, messages such as SLOWER TRAFFIC KEEP RIGHT appear just prior to the lane drop. Occasionally missing information is detrimental to lane drop performance. For example, a simple ROAD NARROWS sign does not inform the driver of two very important facts: (a) it does not tell him how far before the road narrows, and (b) it does not tell him whether he is supposed to change lanes. Devices should not confuse the driver with additional information unrelated to the task of traversing the lane drop section.

Obviously, different TCD packages are necessary for different lane drop situations. The manual (6) designates four lane drop signs; however, over 50 significantly different lane drop signs have been observed in twenty metropolitan areas visited during the conduct of this project, and that does not even begin to consider the combinations and placement variations put into practice.

CHAPTER THREE

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Safe driving consists of managing a vehicle in its committed zone to avoid obstacles. A vehicle's committed zone is the area in which the driver is committed to travel based on current velocity and deceleration characteristics and geometric constraints. This task can become quite complex when there is impairment of the driver's ability to predict, or to anticipate, what lies ahead. Driver expectation can be impaired by loss of vision due to fog, snow, rain, dust, or by missing or misleading visual cues. Highways must be designed to provide visual cues sufficient to make up for these losses, often through the use of traffic control devices.

Drivers have learned to expect certain visual cues far enough in advance of hazards, or potential hazards, to enable him to safely manage his committed zone and avoid contact with obstacles.

There are only two things drivers can do to alter their committed zone: change direction or change speed. A safe trajectory is considered to be one that reveals that the driver has seen the available visual cues, has correctly interpreted them, and has adjusted his path smoothly and well in advance of the obstacle. The driver's trajectory should be such that there is evidence he was not taken by surprise and that he was able to allow a comfortable margin for error without having to adjust his speed.

Field observations at over 60 lane drop sites have led to the conclusion that lane drops that operate successfully have resulted in safe motoring trajectories, while lane drops that do not operate successfully reveal the opposite types of motoring trajectories—namely, abrupt path changes as well as changes that occur closer to the obstacles, often accompanied by speed changes.

It is not unexpected that many drivers appear to be surprised or confused at lane drops. Although lane drops have been classified in five basic design categories, over 50 different signs have been observed as well as so many different combinations of TCDs that almost no two sites have the same treatment.

From the analysis of site observations, discussions with engineers in many state agencies, and at meetings of AASHTO, ITE, and TRB, a set of principles for the design of lane drops have been developed. The design principles have been translated into tentative application procedures, but further experiments are needed to test these procedures.

SUGGESTED RESEARCH

Further research will be required to translate design procedures into practical procedures for implementation. For example, several different values of taper length and ratio have been proposed; experiments to determine the minimum and maximum taper values would be desirable. Also, many different traffic control device treatments are in use for each lane drop category; properly designed experiments should be conducted to select the best treatments for each category. Other items that need testing include the length and width of escape areas at exit ramp drops, the best locations for warning signs, and the best location for the operational taper if it is to be on the opposite side of the roadway.
from the physical lane end. In addition to developing criteria for ideal lane drops and new construction, methods for improving existing conditions are needed.

Additional basic research is needed into driver reaction and the time needed for lane changing at freeway lane drops, sight distance requirements for advance warning signs and for pavement markings, and enhancement of taper and gore marking visibility.

The ideal method for conducting lane drop research would be to collect detailed field observations on existing lane drop sites at which conditions can be controlled, and to continue an iterative process of making small changes in the sites and measuring the resulting changes in traffic operations. However, this approach is impractical both from a cost standpoint and the risk involved for highway users. Additionally, it is impossible to control essential conditions such as weather, seasonal shifts in driver population, and nearby distracting geometric conditions, such as ramps.

A more practical approach involves collecting field data to support the development of some of the basic hypotheses and, concurrently, conducting a series of laboratory experiments to test these hypotheses. The laboratory experiments can also be used to compare a large range of solutions to specific problems and to select that alternative which appears most promising for field application.

An objective procedure is needed for evaluating traffic operations at lane drops so that the engineer can measure the effect of any changes he may implement and determine how a site compares with others of its type. In this regard, variations in lane change behavior and in the rate of erratic maneuvers are the most important differences in traffic operations among lane drops.

REFERENCES

1. AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS, Report by the Special Freeway Study Analysis Committee to the Executive Committee (1960).
APPENDIX A - A SAMPLE OF LANE DROP SITES ACROSS THE COUNTRY

Sixty-five freeway lane drop sites were selected for inclusion in this study. The purpose of this appendix is to document the study sites visited and to provide a compilation of existing lane drop configurations. The schematic drawings are not to scale. The Appendix is organized by lane drop category.

CLASSIFICATION AND GRADING OF FIELD DATA OBSERVATIONS

A rough three-grade scale was developed to rate the relative effectiveness of the sites observed. The factors used in the grading scheme included (1) the number and severity of erratic movements, (2) lane change behavior, (3) speed change behavior, (4) opinions of state and local highway engineers, and (5) amount of citizen complaint regarding the site. A site was judged good if the number of erratic movements seemed small, most lane-changing was accomplished in advance of the taper or gore area, and highway engineers thought that the site was not presently a problem. A site was judged passable if no serious problems occurred, but indications of problem-producing maneuvers were frequent. A site was judged bad if many erratic movements were observed, if congestion was apparent in the lane drop area even if the general area was flowing at below capacity, or if highway engineers or citizens expressed opinions of serious problems.

A-2

It must be remembered that some sites are considered problems because they are peak-hour bottlenecks. If the traffic demand at peak-hour is above downstream capacity, the lane drop will become congested regardless of how it is designed. In cases where such a condition exists, the site was observed in off-peak-hour operation. If it worked well under these conditions, the site was judged good regardless of the fact that during peak-hour operation breakdown occurs in the vicinity of the drop.

Each of the 65 sites observed and catalogued in this appendix was given a grade and categorized into one of the five basic lane drop types described in the previous report body. The categorization scheme is not necessarily all-inclusive or mutually exclusive. A few lane drops will defy being classified into any of the five categories, and few lane drops will fit more than one category. However, most lane drops can be effectively classified into one category. The sight distance at a site is taken from the point where the actual (operational and/or physical) lane drop is visible to an approaching driver.

A-3

<table>
<thead>
<tr>
<th>Site</th>
<th>Type</th>
<th>Sight Distance</th>
<th>Vertical Curvature</th>
<th>Horizontal Curvature</th>
<th>Tangent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 MILE</td>
<td>LEFT LANE ENDS</td>
<td>1/2 MILE</td>
<td>EXIT 3/4 MILE</td>
<td>EXIT 1 ONLY</td>
<td></td>
</tr>
<tr>
<td>1/4 MILE</td>
<td>RIGHT LANE ENDS</td>
<td>1/2 MILE</td>
<td>EXIT 3/4 MILE</td>
<td>EXIT 1 ONLY</td>
<td></td>
</tr>
</tbody>
</table>

Figure A-1

NOT TO SCALE
Operational Characteristics: Traffic volumes were fairly light. Most traffic was out of the lane well before the taper area. Lane drop works well under present traffic volumes.

Figure A-2

Figure A-3

Operational Characteristics: The speeds on each lane remain approximately constant until two-thirds of the way through the lane drop taper. After a gradual-like decrease in speeds is observed, this uniformity in speed decrease is all lanes suggests that the cause of the decrease is not the lane drop itself but rather a geometric feature (the leveling out of a long downgrade). The movement of vehicles out of the drop lane can be seen to be smooth and gradual with almost no cars in lane 1 near the end of the taper.
Sight Distance: 700'

Vertical Curvature: Slight upgrade - beginning 3,300' upstream and crossing 700' upstream.

Horizontal Curvature: Straight

Pavement Type: Concrete

ADT: 160,000

5-Minute Count

<table>
<thead>
<tr>
<th>Time - 3:30 PM</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trucks</td>
<td>48</td>
<td>2%</td>
</tr>
<tr>
<td>Lane 1</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Lane 2</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>Lane 3</td>
<td>149</td>
<td></td>
</tr>
<tr>
<td>Lane 4</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>Ramp</td>
<td>82</td>
<td></td>
</tr>
</tbody>
</table>

Accident Experience: Lane drop was installed June of 1972. No information available yet.

Operational Characteristics: Site does not work very well. Many vehicles do not respond until lane drop is visible, some 700' before the end of the ramp. Some drivers never move out of right lane since they know the pavement continues.

Site was changed to an exit lane drop in late January 1973. It is reevaluated with this configuration in Appendix C of this report.

Figure A-4

Sight Distance: 700'

Vertical Curvature: Level

Horizontal Curvature: Right - head curve beginning 2 miles upstream of right lane end.

Pavement Type: Concrete

ADT: 160,000

5-Minute Count

<table>
<thead>
<tr>
<th>Lane</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td></td>
</tr>
<tr>
<td>Lane 2</td>
<td></td>
</tr>
<tr>
<td>Lane 3</td>
<td></td>
</tr>
<tr>
<td>Lane 4</td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
</tr>
</tbody>
</table>

Accident Experience: Lane drop was installed June of 1972. No information available yet.

Operational Characteristics: The results for Site 65, in which lane 3 is merged into lane 4, show a uniformity of behavior at all flow levels. The two lanes that merge at the lane drop show a severe decrease in speed, however, lane 4 virtually no speed drop and lane 2 drops only slightly. The data indicated that vehicles in lane 4 follow the signals and start to merge right upstream of the lane drop, then are forced back to the left by the pavement markings in the lane drop taper area. Flows in lanes 1 and 2 remain relatively undisturbed, except for the influx of a very few vehicles from the on-ramp upstream of the lane drop. The slight speed increase in lanes 1 and 2 at the upstream end of the lane drop taper was observed during all three periods, but no explanation of its cause has been found.

Figure A-5
**Site 25**

<table>
<thead>
<tr>
<th>Sight Distance</th>
<th>Type</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 miles</td>
<td>4-3</td>
<td></td>
</tr>
</tbody>
</table>

**Horizontal Curvature**
- Sight reverse curve

**Vertical Curvature**
- Crest of upgrade 500' upstream
- Taper on slight downgrade

**Pavement Type**
- Asphalt

**ADT**
- One-Way: 45,000
- Two-Way: 45,000

**5-Minute Count**

<table>
<thead>
<tr>
<th>Time - 8:00 a.m.</th>
<th>Total</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
<th>Lane 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>559</td>
<td>60</td>
<td>205</td>
<td>132</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td>35</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Operational Characteristics**
- Work well during off-peak hours.
- Downstream congestion causes breakdown during peak a.m. hour.
- Commuters in left lane take advantage of unloaded lane drop area and cause merging problem. Several near-miss incidents were observed.

**Accident Experience**
- Per correspondence with the State Department of Highway, there were no lane drop related accidents from November 12, 1971 to Sep. 1, 1973.

---

**Site 26**

<table>
<thead>
<tr>
<th>Sight Distance</th>
<th>Type</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5-4</td>
<td></td>
</tr>
</tbody>
</table>

**Horizontal Curvature**

**Vertical Curvature**

**Pavement Type**

**ADT**
- One-Way: 18,000
- Two-Way: 18,000

**5-Minute Count**

<table>
<thead>
<tr>
<th>Time - 11:40 a.m.</th>
<th>Total</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
<th>Lane 5</th>
<th>Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>264</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Operational Characteristics**
- A significant amount of last minute maneuvering occurs at lane drop.

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**Figure A-8**

**Figure A-9**

**Figure A-10**

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**Figure A-11**

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**Figure A-12**

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**Figure A-13**

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**Figure A-14**

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**Figure A-15**

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**Figure A-16**

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**Figure A-17**

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**Figure A-18**

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**Figure A-19**

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**Figure A-20**

---
Sight Distance 06 miles
Vertical Curvature

Horizontal Curvature

Pavement Type

ADT
One-Way
Two-Way 20,150

5-Minute Count Time 4:35 PM
Total 7
Lane 1 81
Lane 2 132
Lane 3 50
Lane 4
Lane 5

Accident Experience Accident experience in lane.

Operational Characteristics A few lane drivers were all the way before merging in through lane. Operating fairly well at below capacity volume.

Figure A-10

---

Sight Distance 25 miles
Vertical Curvature Level

Horizontal Curvature Straight

Pavement Type Asphalt

ADT
One-Way
Two-Way

5-Minute Count Time - 11:10 A.M
Total 100
Trucks 1
Lane 1 22
Lane 2 51
Lane 3 17
Lane 4
Lane 5

Operational Characteristics Many vehicles crossed the solid white line at the gore and continued in the long escape area for some distance. Some vehicles did not seem disturbed about traveling in this lane for some time. Traffic volume are fairly light.

Figure A-11

---

NOT TO SCALE
### Site 51

<table>
<thead>
<tr>
<th>Sighting Distance</th>
<th>Vertical Curvature</th>
<th>Horizontal Curvature</th>
<th>Pavement Type</th>
<th>ADT</th>
<th>One-Way</th>
<th>Two-Way</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sight Distance</td>
<td>Vertical Curvature</td>
<td>Horizontal Curvature</td>
<td>Pavement Type</td>
<td>ADT</td>
<td>One-Way</td>
<td>Two-Way</td>
</tr>
<tr>
<td>Sight Distance</td>
<td>Vertical Curvature</td>
<td>Horizontal Curvature</td>
<td>Pavement Type</td>
<td>ADT</td>
<td>One-Way</td>
<td>Two-Way</td>
</tr>
<tr>
<td>Sight Distance</td>
<td>Vertical Curvature</td>
<td>Horizontal Curvature</td>
<td>Pavement Type</td>
<td>ADT</td>
<td>One-Way</td>
<td>Two-Way</td>
</tr>
</tbody>
</table>

- **Sight Distance**: Type 4 - Right
- **Type 5 - Sight Distance**
- **Type 6 - Sight Distance**
- **Type 7 - Sight Distance**
- **Type 8 - Sight Distance**
- **Type 9 - Sight Distance**
- **Type 10 - Sight Distance**

### Accident Experience

Operational Characteristics: Site very confusing, poor delineation of

Operational Characteristics: Site very confusing, poor delineation of

Operational Characteristics: Site very confusing, poor delineation of

### Figure A-12

- Toll Bridge
- Only
- 1 Mile

### Figure A-13

- Merging Left
- 300'
- 2500'

### Figure A-14

- Toll Bridge
- Only
- 1 Mile
Accident Experience_ Serious accidents at the lane drop have been reported.

Operational Characteristic_A lot of last-minute lane changes are made in the right pavement (shaded area). The site is currently under construction and is being changed from a taper lane drop to an exit ramp lane drop.

**Accidents/Million Vehicle Miles**

<table>
<thead>
<tr>
<th>Year</th>
<th>1964</th>
<th>1965</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>41</td>
<td>10</td>
</tr>
<tr>
<td>Lane 1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Fatality Rate**

<table>
<thead>
<tr>
<th>Year</th>
<th>1964</th>
<th>1965</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lane 5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Accident Experience** Accident rate _1.12 accidents per million vehicles_.

Operational Characteristic_Mean speeds ranged from 48-53 mph during study. Overall erratic movement rate = _4,100/million vehicles_, overall brake light rate = _57,600/million vehicles_.

---
Site 46
Type: 3 = 2 Ramp
Sight Distance
Vertical Curvature 1.3% grade upstream of lane drop/2.48% grade just downstream of lane drop
Horizontal Curvature Straight Section
Pavement Type: Concrete
ADT
One-Way 17,718 (1971)
Two-Way
5-Minute Count Average hourly volumes
Total 830
Trucks 260
Lane 1 200
Lane 2 100
Lane 3 100
Lane 4 100

Accident Experience Accident Rate 0.77 accidents per million vehicles (1971)
6.0 Attached
Operational Characteristics See attached - Erratic maneuver counts and spot speeds

Figure A-16

Figure A-16

SOUTH
SOUTH

SOUTH

SOUTH

SOUTH

JET 1 1/2 MILES

NOT TO SCALE

A-35
ACCIDENT SUMMARY

STUDY PERIOD - January 1, 1971 - December 31, 1971

ACCIDENT RATE - 0.77 accidents per million vehicles

INJURY RATE - 0.46 injury accidents per million vehicles

TOTAL PERCENT

NUMBER OF ACCIDENTS 5 100

ACCIDENT TYPES

- Rear-End 40
- Multiple Rear-End 20
- Lost Control 20
- Sidewipe 20

ACCIDENTS INVOLVING INJURY 3 60

TOTAL NUMBER INJURED 6

TOTAL INJURIES 6

LIGHT CONDITION

- Daylight 60
- Dark 20
- Dawn or Dusk 20

PAVEMENT CONDITION

- Wet 0
- Dry 100

Figure A-16.
A-37

Southbound

AUTOS

Initial Delineators 78
Stripes 72
1, 6 Delineators 72

Initial Delineators 77
Stripes 60
5, 6 Delineators 66

TRUCKS

Initial Delineators 63
Stripes 65
5, 6 Delineators 61

Initial Delineators 62
Stripes 60
5, 6 Delineators 58

SPEED LIMIT - 70

AUTOS

Initial Delineators 73
Stripes 68
1, 6 Delineators 70

Initial Delineators 68
Stripes 65
5, 6 Delineators 66

TRUCKS

Initial Delineators 63
Stripes 64
5, 6 Delineators 67

Initial Delineators 62
Stripes 60
5, 6 Delineators 58

... BRACKETS DENOTE STATISTICALLY SIGNIFICANT MEAN SPEED DEVIATIONS...

Mean Speeds at the Single Lane Exit with Taper

Figure A-16.
Figure A-17

A-39

Figure A-18

A-40

A-41
Figure A-19

Operational Characteristics: Heavy afternoon traffic. A few on-ramp vehicles have trouble merging into through traffic before lane ends due to heavy traffic and short weaving area.

Figure A-20

Operational Characteristics: Many vehicles cross pavement striping near gore area. Some vehicles entering freeway just upstream of lane drop have difficulties merging into a through lane before the lane drop area.
Figure A-21. | Figure A-22

**Site 04**

- **Type:** 3 - 2 Right Taper
- **Sight Distance:** 2/4 mile or more
- **Vertical Curvature:** Level
- **Horizontal Curvature:** Slight left-hand curve in taper area
- **Pavement Type:** Concrete

<table>
<thead>
<tr>
<th>ADT</th>
<th>One-Way</th>
<th>41,600 (1970)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Way</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5-Minute Count</th>
<th>Time - 7:30 A.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>267</td>
</tr>
<tr>
<td>Trucks</td>
<td>6</td>
</tr>
<tr>
<td>Lane 1</td>
<td>133</td>
</tr>
<tr>
<td>Lane 2</td>
<td>115</td>
</tr>
<tr>
<td>Lane 3</td>
<td>19</td>
</tr>
<tr>
<td>Lane 4</td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accident Experience</th>
<th>Light</th>
</tr>
</thead>
</table>

**Operational Characteristics:** On peak hour carries the most traffic during a typical day. Speeds steady through entire area, 55-60 mph. Some vehicles use trapped lane to gain an advantage because it is empty wall in advance. 3000-4000 feet. Those vehicles usually travel quite fast; have no trouble squeezing in because volume is below capacity. No visible pavement markings other than strip white.

---

**Site 02**

- **Type:** A - 3 Trap Right
- **Sight Distance:** |
- **Vertical Curvature:** |
- **Horizontal Curvature:** |

<table>
<thead>
<tr>
<th>ADT</th>
<th>Three-Way</th>
<th>52,700 (1970)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Way</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5-Minute Count</th>
<th>Time - 5:10 P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>379</td>
</tr>
<tr>
<td>Trucks</td>
<td>12</td>
</tr>
<tr>
<td>Lane 1</td>
<td>153</td>
</tr>
<tr>
<td>Lane 2</td>
<td>125</td>
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<tr>
<td>Lane 3</td>
<td>101</td>
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<tr>
<td>Lane 4</td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accident Experience</th>
<th>Low</th>
</tr>
</thead>
</table>

**Operational Characteristics:** Downstream congestion backing up into area caused slowdowns, Stoppages noted. During peak 5-minute period speeds varied from 45 to 25. Some vehicles using escape lane get hooked up, but generally merge were smooth. Shock waves in right-hand lane take longer to dissipate. Generally, operation must be considered quite acceptable. Metered freeway demo will have effect when implemented in 1973. Signed for this lane drop is entirely temporary, as state engineers overlooked that aspect in original contract. Solid white line virtually gone already for this winter.

---

**Figure A-22** | **Figure A-22**
<table>
<thead>
<tr>
<th>Site</th>
<th>Type 3 - 2</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
<th>Lane 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>Taper, right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sight Distance</td>
<td>3 miles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Curvature</td>
<td>slight up-grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal Curvature</td>
<td>sharp left</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement Type</td>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADT</td>
<td>One-Way</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two-Way</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
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<td></td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Operational Characteristics: Operates poorly; capacity problem during peak hours. When freeway was originally designed, the right lane was continued to the second exit causing problems between through drivers, exit traffic, and traffic entering from the loop connection. Hence, the right lane was striped closed creating a land drop at the first exit. Some vehicles ignore the operational drop causing downstream conflicts.

* Dramatic increase between 1969 and 1970 has not yet been explained.

---

<table>
<thead>
<tr>
<th>Site</th>
<th>Type 3 - 2</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
<th>Lane 5</th>
</tr>
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<tbody>
<tr>
<td>53</td>
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<tr>
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<td>2 miles</td>
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<td></td>
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<td>Vertical Curvature</td>
<td>slight up-grade</td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Pavement Type</td>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ADT</td>
<td>One-Way</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Two-Way</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5-Minute Count</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
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<tr>
<td>Trucks</td>
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<td></td>
<td></td>
</tr>
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<td>Percentage</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Accident Experience: Slight, slight increase in number of accidents over the years, probably due to increased volumes.

Operational Characteristics: At 4:20 P.M. the site had capacity problems. Operates poorly during peak hours; capacity problem.

---

NOTE: NOT TO SCALE
Site 44

Type 4 - 3 Exit Right

Sight Distance 1 mile

Vertical Curvature - Slight upgrade

Horizontal Curvature - Slight right-hand curve - .65, Slight left - .1

Pavement Type Concrete

ADT

One-Way 36,625 (1970)

Two-Way

5-Minute Count

Total

Trucks 12

Lane 1 122

Lane 2 111

Lane 3 No Counts Available

Lane 4

Lane 5

Accident Experience 1970 accident rate 2.07 accidents/million vehicle mile

Operational Characteristics Site works OK at light volumes

Figure A-25.

Site 24

Type 3 - 2 Typ. right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type Asphalt

ADT

One-Way 43,750 approaching, 4,750 exiting

Two-Way

5-Minute Count

Time - 3:45 p.m.

Total 268

Trucks 12

Lane 1 122

Lane 2 111

Lane 3

Lane 4

Lane 5

Accident Experience Site works well during off-peak hours. Breakdown occurs during peak hour due to a downstream capacity restriction

Operational Characteristics Site works OK at light volumes

Figure A-26

A-55

A-56

A-57
### Site 33

- **Type:** A-3 Right at Ramp
- **Sight Distance:** 2 miles
- **Vertical Curvature:**
- **Horizontal Curvature:**
- **Pavement Type:** Concrete
- **ADT**
  - One-Way: 28,200 approaching, 6,300 exiting
  - Two-Way: 5-Minute Count
    - **Total:** 132
    - **Trucks:** 9, Percentage: 7%
    - Lane 1: 71
    - Lane 2: 21
    - Lane 3: 24
    - Lane 4: 21
    - Lane 5: 21
    - Ramp: 26
- **Accident Experience:** Light accident experience
- **Operational Characteristics:** Many erratic maneuvers observed in merge area after gore.

---

### Site 36

- **Type:** A-2 Right to ramp
- **Sight Distance:**
- **Vertical Curvature:**
- **Horizontal Curvature:**
- **Pavement Type:** Asphalt
- **ADT**
  - One-Way: 39,100 approaching, 6,300 exiting
  - Two-Way: 5-Minute Count
    - **Total:** 292
    - **Trucks:** 22, Percentage: 7%
    - Lane 1: 114
    - Lane 2: 76
    - Lane 3: 38
    - Lane 4: 39
    - Lane 5: 39
    - Ramp: 39
- **Accident Experience:** Most accidents seem to be congestion related, only a few near lane drop
- **Operational Characteristics:** This site operates with a minimum of disturbance, A few vehicles were observed making last-minute maneuvers

---

![Figure A-27](image-url)

---

![Figure A-28](image-url)
Site 20

Type: 4 - 3 Taper, right

Sight Distance: 1 mile
Vertical Curvature: -0.30% grade
Horizontal Curvature: No curve

Pavement Type: Concrete

ADT
One-Way:

Two-Way:

5-Minute Count:

<table>
<thead>
<tr>
<th></th>
<th>Trucks</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Accident Experience: Light - 9 accidents over last 3 years at first off ramp, 3 accidents at lane drop off ramp

Operational Characteristics: Traffic moves fairly well through section, some last minute maneuvers

Figure A-29.

Site 21

Type: 4 - 3 Taper, left

Sight Distance: 1.5 mile
Vertical Curvature: -1.06% to +1.06% (400' vertical curve)
Horizontal Curvature: No curve

Pavement Type: Concrete

ADT
One-Way:

Two-Way:

5-Minute Count:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Accident Experience: Only a few accidents indicated

Operational Characteristics: This left-hand taper works rather well. Most vehicles seem to make a smooth transition into the other lanes. Only 4% of the total volume of traffic was in the left lane 3 miles upstream of the lane drop

Figure A-30.
**TYPE B — ADD-DROP SITUATIONS**

**Sight Distance** 21 miles

**Vertical Curvature**

**Horizontal Curvature**

**Pavement Type** Concrete

**ADT**

- **One-Way:**
  - Time: 12:00 noon
  - Total: 104
  - Trucks: 20
  - Percentage: 19%

- **Two-Way:**
  - Time: 9:00 AM
  - Total: 633
  - Trucks: 24
  - Percentage: 3%

**Accident Experience**

Operational Characteristics: Vehicles tend to wait until the last minute to merge right, regardless of traffic. Slight upgrade and the fact that there are few problems in finding a suitable gap in traffic may be responsible for this behavior. The proximity of a upstream on-ramp and the fact that there are few problems in finding a suitable gap in traffic may be responsible for this behavior. The State Highway Commission indicated that the site has been a problem and the extensive signing has been largely successful in solving the problem.

**Figure A-31**

**SITE 31**

**Lane Drop Left**

**5-Minute Count**

- **Total:** 104
- **Trucks:** 20
- **Percentage:** 19%

**ADT**

- **One-Way:**
  - Time: 12:00 noon
  - Total: 104
  - Trucks: 20
  - Percentage: 19%

- **Two-Way:**
  - Time: 9:00 AM
  - Total: 633
  - Trucks: 24
  - Percentage: 3%

**Accident Experience**

Operational Characteristics: Very few erratic maneuvers were observed, however, 9:00 AM commuter traffic may well make up the majority of vehicles.

**Figure A-33**

**RIGHT LANE MUST EXIT**

**THRU TRAFFIC MERGE LEFT**

**LEFT ONLY**

**NOT TO SCALE**
**Site 27**

**Type** 3-4 Trap-right

Sight Distance

Vertical Curvature

Horizontal Curvature

Pavement Type

ADT

One-Way: 30,000

Two-Way:

5-Minute Count

Time: 11:40 A M

Total: 467

Truck: 62

Percentage: 11%

Lane 1: 25

Lane 2: 60

Lane 3: 21

Lane 4: 61

Lane 5: 62

**Accident Experience**

Operational Characteristics: A significant amount of last minute maneuvering occurs at lane drop

---

**Site 62**

**Type** 3-2 Trap-right

Sight Distance: 1 mile

Vertical Curvature: Right downgrade begins 6 miles

Horizontal Curvature: Right left hand curve at lane add

Pavement Type: Concrete

ADT

One-Way:

Two-Way:

5-Minute Count

Time: 3:55 P M

Total: 203

Truck: 16

Percentage: 7%

Lane 1: 76

Lane 2: 70

Lane 3: 59

Lane 4: 52

Lane 5: 24

**Accident Experience**

Operational Characteristics: The site looks quite well even though geometric conditions are far from optimum. Both erratic maneuvers were caused by vehicles attempting to exit the freeway

---

**Accident Experience**

Operational Characteristics: The site looks quite well even though geometric conditions are far from optimum. Both erratic maneuvers were caused by vehicles attempting to exit the freeway

---

**Accident Experience**

---

**Figure A-32**

**Figure A-34**

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**Figure A-36**

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**Figure A-38**

---

**Figure A-40**
**Site:** A-76  
**Type:** Trap. right  
**Sight Distance:** 1 mile  
**Vertical Curvature:** Level  
**Horizontal Curvature:** Fairly sharp left curve ending at 3 miles upstream, followed by a sharp right curve  
**Pavement Type:** Concrete  

**ADT:**  
- **One-Way:**  
- **Two-Way:**  

**5-Minute Count**  
- **Time:** 4:30 P.M.  
  - **Total:** 269  
  - **Trucks:** 17  
  - **Percentage:** 6.3%  
  - **Lane 1:** 16  
  - **Lane 2:** 116  
  - **Lane 3:** 137  
  - **Lane 4:**  
  - **Lane 5:**  

**Operational Characteristics:** Traffic volume was quite heavy; very few erratic maneuvers were observed even though sight distance is minimal.

**Accident Experience:**

- **Accidents/Million Vehicle Miles:** 1964 - 0.32, 1965 - 0.32
- **Fatality Rate:** 1964 - 1.15, 1965 - 1.26

**Operational Characteristics:** Many vehicles stop or nearly stop at lane drop. Vehicles from ramp just before lane drop have much difficulty merging into through lanes.

---

**Site:** A-76  
**Type:** Trap. add-on left  
**Sight Distance:** 0.9 mile  
**Vertical Curvature:** Level  
**Horizontal Curvature:** Straight but lane drop tapers in a sharp left-hand curve about 40' downstream of lane on-ramp  
**Pavement Type:** Concrete  

**ADT:**  
- **One-Way:**  
- **Two-Way:**  

**5-Minute Count**  
- **Time:** 1:00 P.M.  
  - **Total:** 454  
  - **Trucks:** 55  
  - **Percentage:** 12.1%  
  - **Lane 1:** 64  
  - **Lane 2:** 99  
  - **Lane 3:** 123  
  - **Lane 4:** 134  
  - **Lane 5:** 24  

**Operational Characteristics:** Many vehicles stop or nearly stop at lane drop. Vehicles from ramp just before lane drop have much difficulty merging into through lanes.

---

**Figure A-35**

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**Figure A-36**

---

**Figure A-37**

---
Site 09

Sight Distance
Type 4 - 3 Taper, Right
Vertical Curvature - 7.3 upgrade ends
Horizontal Curvature - Slight left-hand curve
Pavement Type - Concrete
ADT
One-Way
Two-Way 77,797 (1972)

5-Minute Count
Total
Trucks
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5

Percentage

Accident Experience
Operational Characteristics Direct observation was not available, due to inaccessibility of site

Figure A-37

Site 12

Sight Distance 3 miles
Vertical Curvature - Long - up grade
Horizontal Curvature
Pavement Type
ADT
One-Way
Two-Way 30,223 (1971)
5-Minute Count
Total
Trucks
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5

Percentage

Accident Experience Several possible lane drop related accidents indicated
Operational Characteristics The second lane drop is difficult to see until just before the taper begins. Vehicles entering from the on-ramp must merge rapidly into the two through lanes to avoid being trapped and slowed in the lane drop area

Figure A-38
Site 45

Type 4 - 3 Trap, right

Sight Distance: 2

Vertical Curvature: Slight upgrade, creasing at 1 mile

Horizontal Curvature: Right hand curve beginning 4 miles upstream

Pavement Type: Concrete

ADT

One-Way: 3,010

Two-Way: 7,250 (1971)

5-Minute Count

<table>
<thead>
<tr>
<th>Truck</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>28</td>
</tr>
<tr>
<td>Lane 2</td>
<td>30</td>
</tr>
<tr>
<td>Lane 3</td>
<td>133</td>
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<tr>
<td>Lane 4</td>
<td>131</td>
</tr>
<tr>
<td>Lane 5</td>
<td>160</td>
</tr>
</tbody>
</table>

Accident Experience: 1970 accident rate = 7.68 accidents/million vehicle miles

Operational Characteristics: Much use of the escape lane is made. Traffic was quite heavy and definite merge problems occur in the lane drop area. Some vehicles are almost slowed to a stop before finding a gap to merge into the through lanes.

Figure A-40

---

Site 46

Type 4 - 3 Trap, right

Sight Distance: 2

Vertical Curvature: Slight upgrade, creasing at 1 mile

Horizontal Curvature: Right hand curve beginning 4 miles upstream

Pavement Type: Concrete

ADT

One-Way: 3,010

Two-Way: 7,250 (1971)

5-Minute Count

<table>
<thead>
<tr>
<th>Truck</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>28</td>
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<tr>
<td>Lane 2</td>
<td>30</td>
</tr>
<tr>
<td>Lane 3</td>
<td>133</td>
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<tr>
<td>Lane 4</td>
<td>131</td>
</tr>
<tr>
<td>Lane 5</td>
<td>160</td>
</tr>
</tbody>
</table>

Accident Experience: 1970 accident rate = 7.68 accidents/million vehicle miles

Operational Characteristics: Much use of the escape lane is made. Traffic was quite heavy and definite merge problems occur in the lane drop area. Some vehicles are almost slowed to a stop before finding a gap to merge into the through lanes.

Figure A-40

---

Figure A-39

NOT TO SCALE
Accident Experience: Accident experience is heavy.

Operational Characteristics: The site is considered to be a hazardous location by many. Collision attenuators have been installed in the gore area. Many vehicles were observed to make last-minute lane changes.

---

Operational Characteristics: The site is considered to be a hazardous location by many. Collision attenuators have been installed in the gore area. Many vehicles were observed to make last-minute lane changes.

---

Figure A-41

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Figure A-42

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Figure A-43

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Figure A-44
A-90

Site 24

Type: 4 - Trap, right

Sight Distance: 0.03 mile

Vertical Curvature: -2.09% to +5.5% (1000' vertical curve)

Horizontal Curvature: 3 = 3° 31' 56" Re, D = 2° 30' 00" E = 2291.03

Pavement Type: Asphalt

ADT

One-Way

Two-Way

5-Minute Count

Total: 81

Trucks: 4

Percentage: 5%

Accident Experience: Several gore-located accidents have occurred

Operational Characteristics: Lane drop is a problem even though volumes are light. Vehicles entering from upstream ramp think they have a thru lane to travel in. It abruptly ends. Last minute maneuvers were mostly to avoid leaving freeway.

Figure A-43

A-91

EXIT 1 MILE

EXIT ONLY

RIGHT LANE MUST TURN RIGHT

A-92

Site 32

Type: 4 - Trap, right

Sight Distance: 0.03 mile

Vertical Curvature: Long upgrade creating 3000' upstream, beginning of descent at -1.98% and leveling out at lane drop.

Horizontal Curvature: Slight Curve to right downstream

Pavement Type: Concrete

ADT

One-Way

Two-Way

5-Minute Count

Total

Trucks

Percentage

Lane 1

Lane 2

Lane 3

Lane 4

Lane 5

Accident Experience: Few accidents; area general may be lane drop related.

Operational Characteristics: Traffic volumes were fairly light during mid-day. Some erratic maneuvers were observed near the gore area.

Figure A-44

A-93

EXIT 2 MILES

EXIT ONLY

NOT TO SCALE
**A-94**

<table>
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<th>Site</th>
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<td>Vertical Curvature</td>
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</tr>
<tr>
<td>ADT</td>
<td></td>
</tr>
<tr>
<td>One-Way</td>
<td></td>
</tr>
<tr>
<td>Two-Way</td>
<td></td>
</tr>
<tr>
<td>5-Minute Count</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
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<tr>
<td>Trucks</td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td></td>
</tr>
<tr>
<td>Lane 2</td>
<td></td>
</tr>
<tr>
<td>Lane 3</td>
<td></td>
</tr>
<tr>
<td>Lane 4</td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td></td>
</tr>
</tbody>
</table>

**A-96**

**TYPE C — DROP-ADD SITUATIONS**

<table>
<thead>
<tr>
<th>Site</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Sight Distance</td>
<td>1 mile</td>
</tr>
<tr>
<td>Vertical Curvature</td>
<td>Very slight downgrade and upgrade, 3%, at A</td>
</tr>
<tr>
<td>Horizontal Curvature</td>
<td>Slight right curve 40° - Sharp left curve 24°</td>
</tr>
<tr>
<td>Pavement Type</td>
<td>Concrete</td>
</tr>
<tr>
<td>ADT</td>
<td></td>
</tr>
<tr>
<td>One-Way</td>
<td></td>
</tr>
<tr>
<td>Two-Way</td>
<td></td>
</tr>
<tr>
<td>5-Minute Count</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
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<tr>
<td>Trucks</td>
<td></td>
</tr>
<tr>
<td>Lane 1</td>
<td></td>
</tr>
<tr>
<td>Lane 2</td>
<td></td>
</tr>
<tr>
<td>Lane 3</td>
<td></td>
</tr>
<tr>
<td>Lane 4</td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td></td>
</tr>
</tbody>
</table>

Accident Experience: A three year study of accidents reveals 38 accidents occurred of which 3 were considered lane drop related.

Operational Characteristics: Traffic volumes are fairly light much maneuvering was observed in the section, however, direct observation of erratic maneuvering was not possible over a long period of time.

Accident Experience: High accident location.

Operational Characteristics: Many erratic maneuvers and operational problems have occurred at this site. Site is due to be reconstructed to alleviate the lane drop.

---

**A-95**

**Figure A-45**

---

**A-97**

**Figure A-46**

---
A-98
Site: 52
Type: 4 - 3 left
Right Distance
Vertical Curvature
Horizontal Curvature: Straight
Pavement Type: Concrete
ADT
One-Way
Two-Way
5-Minute Count
Total
Trucks
Lanes
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5

Accident Experience

Operational Characteristics: Construction barriers indicate that this is a construction zone and site operates accordingly. Traffic is generally light.

Figure A-47

---

A-100
Site: 40
Type: 4 - 3 Trap, w/escape route
Right Distance
Vertical Curvature: Slight down grade
Horizontal Curvature
Pavement Type: Concrete
ADT
One-Way: 52,600
Two-Way:
5-Minute Count
Total: 216
Trucks
Lanes
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5

Accident Experience:

Accidents per 100,000,000 vehicles = 171.88 - see attached
Operational Characteristics: Capacity is exceeded during peak-hour afternoons. Many vehicles use the escape lane. It is being proposed that the fourth lane be continued through the interchange.

Figure A-48

---

A-99

---

A-101

NOT TO SCALE
Accidents Attributable to Bottleneck

1) Total accidents between I---- and ---- Lane Drop

2) Total Accidents occurring during the peak hours (3 pm to 7 pm)

A. Accidents attributable to the bottleneck and upstream delays

1) Accidents occurring at the bottleneck
   a) Rear End
   b) Lane Change or Sideswipe
   c) Out-of-Control

2) Accidents occurring upstream from the bottleneck
   a) Rear End
   b) Lane Change or Sideswipe
   c) Out-of-Control

1. Injury
   a) Injury
   b) Property Damage

Accidents per 100,000,000 vehicles = 20.67

Operational Characteristics: Some vehicles tend to travel in the long captive lane for quite a distance. The cross-hatching at the gore area does not necessarily cause drivers to merge into the through lanes.
**Figure A-50**

Accident Experience: Heavy (per state estimate). Many accidents in area, primarily due to other factors, principally road curvature (compound curve).

Operational Characteristic: Severe congestion in area due to causes other than lane drop. Likewise, lane drop is not prime cause of accidents. Although it probably contributes speed limit recently lowered from 60 to 55 through the area. Personal observation is that traffic is smoother - less speed differentials between vehicles.

**Figure A-51**

Accident Experience: Many vehicles make last-minute maneuvers. Traffic composition included percentage of taxi-cabs.
### Site 50

**Type:** 4 - 3 Trap - Right

<table>
<thead>
<tr>
<th><strong>Sight Distance</strong></th>
<th>3 miles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal Curvature</strong></td>
<td>Sharp right, slight left curve</td>
</tr>
<tr>
<td><strong>Pavement Type</strong></td>
<td>Concrete</td>
</tr>
<tr>
<td><strong>ADT</strong></td>
<td>One-Way</td>
</tr>
</tbody>
</table>

#### 5-Minute Count

<table>
<thead>
<tr>
<th>Lane</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

**Trucks Prohibited**

**Operational Characteristic:** Many erratic maneuvers occur at this site. Violations of the operational lane drop are noticeable during peak hour traffic.

---

### Site 62

**Type:** 3 - 2 Trap - Right

<table>
<thead>
<tr>
<th><strong>Sight Distance</strong></th>
<th>1 mile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal Curvature</strong></td>
<td>Left hand sweeping curve ending 1 mile</td>
</tr>
<tr>
<td><strong>Pavement Type</strong></td>
<td>Concrete</td>
</tr>
<tr>
<td><strong>ADT</strong></td>
<td>One-Way</td>
</tr>
</tbody>
</table>

#### 5-Minute Count

<table>
<thead>
<tr>
<th>Lane</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

**Operational Characteristic:** A number of erratic maneuvers were observed.

---

**Figure A-52**

**Figure A-53**

**Figure A-54**
Site: 30

**Type**: 4 - 3 Trap, right

**Sight Distance**: 1 mile

**Vertical Curvature**

**Horizontal Curvature**

**Pavement Type**: Concrete

**ADT**

- **One-Way**: 72,000
- **Two-Way**: 

**5-Minute Count**

<table>
<thead>
<tr>
<th>Lane</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>47</td>
</tr>
<tr>
<td>Lane 2</td>
<td>95</td>
</tr>
<tr>
<td>Lane 3</td>
<td>127</td>
</tr>
<tr>
<td>Lane 4</td>
<td>44</td>
</tr>
</tbody>
</table>

**Operational Characteristics**: Any last minute lane changes were observed. Sight distance is restricted.

**Accident Experience**: 1971 accident rate per M.V. = 2.1, only one accident was judged to be lane drop related; 18 were congestion related.

**Operational Characteristic**: Any last minute lane changes were observed. Sight distance is restricted.

---

**Type B — Step-Over Situations**

Site: 13

**Type**: 4 - 3 Trap right, add-on left

**Sight Distance**: 1,500'

**Vertical Curvature**

**Horizontal Curvature**

**Pavement Type**: Concrete

**ADT**

- **One-Way**: 144,000 (1968) peak hour 11,200

**5-Minute Count**

<table>
<thead>
<tr>
<th>Lane</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>56</td>
</tr>
<tr>
<td>Lane 2</td>
<td>140</td>
</tr>
<tr>
<td>Lane 3</td>
<td>122</td>
</tr>
<tr>
<td>Lane 4</td>
<td>105</td>
</tr>
<tr>
<td>Lane 5</td>
<td>247</td>
</tr>
<tr>
<td>1 - 2</td>
<td>222</td>
</tr>
</tbody>
</table>

**Operational Characteristic**: The results from the first lane drop contract for this site, in which the two lanes are merged, show a uniformity of behavior at all flow levels. The two lanes that merge at the lane drop show a severe decrease in speed; however, the right lane has virtually no speed drop and Lane 2 drops only slightly. The disturbances in speed in all lanes increases as the flow increases. The traffic flow rate curves indicate that vehicles in the left lane follow the signing and start to merge right upstream of the lane drop, then are forced back to the left by the pavement markings in the lane drop taper area. Flows in the right two lanes remain relatively undisturbed, except for the influx of a very few vehicles from the on-ramp upstream of the lane drop.

The slight speed increase in the right two lanes at the upstream end of the lane drop taper was observed during all three film periods, but no explanation of its cause has been found.
**Type 3-2 Trap-Left**

**Sight Distance**: 0.5 mile

**Horizontal Curvature**: Slight curve to the right 22°

**Pavement Type**: Concrete

**ADT**

- One-Way
- Two-Way

<table>
<thead>
<tr>
<th>Lane</th>
<th>5-Minute Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>120</td>
<td>6%</td>
</tr>
<tr>
<td>Lane 2</td>
<td>129</td>
<td>6%</td>
</tr>
<tr>
<td>Lane 3</td>
<td>17</td>
<td>1%</td>
</tr>
<tr>
<td>Lane 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Operational Characteristics**

- Minimal sight distance causes many last minute maneuvers.
- Gore area is not very well defined.

**Accident Experience**

- Number of accidents 1971: 14 (5 were in the immediate lane drop area.)

**Operational Characteristics**

- This site is heavily congested during the AM peak hour. Many last minute maneuvers were observed.

---

**Type 3-2 Trap-Left**

**Sight Distance**: 22 miles

**Horizontal Curvature**: Straight

**Pavement Type**: Concrete

**ADT**

- One-Way
- Two-Way: 48,500 (1971)

<table>
<thead>
<tr>
<th>Lane</th>
<th>5-Minute Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>130</td>
<td>6%</td>
</tr>
<tr>
<td>Lane 2</td>
<td>129</td>
<td>6%</td>
</tr>
<tr>
<td>Lane 3</td>
<td>17</td>
<td>1%</td>
</tr>
<tr>
<td>Lane 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Operational Characteristics**

- This site is heavily congested during the AM peak hour. Many last minute maneuvers were observed.

---

**NOT TO SCALE**

**NOT TO SCALE**
**A-123**

**Site:** 11

**Type:** 3 - 2 Taper, left

**Vertical Curvature:** Slight downgrade (0.5)

**Horizontal Curvature:**

**Pavement Type:** Concrete

**ADT:**

One-Way: 48,500 (1971)

Two-Way: 75,325

**5-Minute Count:**

<table>
<thead>
<tr>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trucks</td>
<td>8</td>
</tr>
<tr>
<td>Lane 1</td>
<td>23</td>
</tr>
<tr>
<td>Lane 2</td>
<td>110</td>
</tr>
<tr>
<td>Lane 3</td>
<td>109</td>
</tr>
<tr>
<td>Lane 4</td>
<td>94</td>
</tr>
<tr>
<td>Lane 5</td>
<td></td>
</tr>
</tbody>
</table>

**Accident Experience:** Number of accidents 1971 - 5 - at least one might be considered lane drop related.

**Operational Characteristics:** This site is comparable to site 10, they are at the same location on opposite directions of travel. Many last minute, erratic maneuvers were observed, even at low traffic volumes.

---

**Figure A-59**

---

**A-125**

**Site:** 05

**Type:** 3 - 2 left

**Vertical Curvature:**

**Horizontal Curvature:**

**Pavement Type:** Concrete

**ADT:**

One-Way: 51,500 (1970)

Two-Way: 75,325

**5-Minute Count:**

<table>
<thead>
<tr>
<th>Time: 3:00 P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Trucks</td>
</tr>
<tr>
<td>Lane 1</td>
</tr>
<tr>
<td>Lane 2</td>
</tr>
<tr>
<td>Lane 1</td>
</tr>
<tr>
<td>Lane 4</td>
</tr>
<tr>
<td>Lane 5</td>
</tr>
</tbody>
</table>

**Accident Experience:** Light to moderate (average) - Few accidents.

**Operational Characteristics:** Originally good operation considering swapped lane is around a horizontal curve, over a vertical curve, has limited sight distance to the gore, and exit is on the left. Speeds affected by relatively heavy truck volumes in left lane. (Left exit leads to a truck terminal area).

Geometry due to restricted R/W & planned connection to future cross-town freeway extending across the river.

---

**Figure A-59**

---
Accident Experience: Accident rate in 1970 = 4.8 accidents/million vehicle miles

Operational Characteristics: This site is known to be a service accident location. The left lane seems to be unloading well before the lane drop but congestion was apparent at 4:30 p.m. Breakdown may be due to capacity problems. The left tangent off-ramp lane drop combined with a sharp curve on the ramp produces a key hazardous location.

Figure A-60
Operational Characteristics: The site is considered to definitely be a high-accident location. There is no escape lane from the trapped lane at the off-ramp. Collision attenuators have been placed in the gore area. Signing is poor because another left-hand exit to the freeway's express lanes is located only 150' upstream of the lane drop. The signs located on the right probably are not terribly effective. Hence the only two signs prior to the lane drop are within one-fifth mile of the exit.

Figure A-61

| Accident Experience | See attached |

Accident Experience

Drop Lanes 1971 Accidents

<table>
<thead>
<tr>
<th>Location</th>
<th>NB off</th>
<th>SB off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milepost</td>
<td>165.10 - 165.60</td>
<td>168.30 - 168.80</td>
</tr>
<tr>
<td>Property Damage Accidents</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>Injury Accidents</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Fatal Accidents</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total Accidents</td>
<td>39</td>
<td>36</td>
</tr>
<tr>
<td>Persons Injured</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>Fatalities</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Property Damage</td>
<td>$31,000</td>
<td>$27,000</td>
</tr>
<tr>
<td>Economic Loss</td>
<td>$141,000</td>
<td>$107,000</td>
</tr>
<tr>
<td>Accidents per MM</td>
<td>4.0</td>
<td>2.1</td>
</tr>
<tr>
<td>ADT</td>
<td>52,900</td>
<td>72,200</td>
</tr>
<tr>
<td>Drop Lane Related Accidents</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rear-end Accs Due to Congestion</td>
<td>29</td>
<td>18</td>
</tr>
</tbody>
</table>

1971 average statewide rate for urban interstate roadway is 2.1.

Figure A-61
Type E — Lane Split Situations

Site: 64

Type: 3 - (2-1) Split

Sight Distance: 0.2 mile

Vertical Curvature: Slight downgrade

Horizontal Curve: Right hand curve

Pavement Type: Concrete

ADT

One-Way: 159,700

Two-Way: 159,700

5-Minute Count:

Total:

Trucks: 559

Percentage: 1

Lane 1:

Lane 2:

Lane 3:

Lane 4:

Lane 5:

Accident Experience:

Operational Characteristic: The site had operational problems when the middle lane was an optional lane forming a 3 to 2-2 split. The majority of the traffic used the left fork of the split. The site was restriped to force the left two lanes left only and the right lane right only. According to the Department of Transportation, operations have improved considerably since the restrriping.

Accident Experience:

Accidents/Million Vehicle Miles 1964 = 86 1965 = 67

No. of Fatalities 1964 = 6 1965 = 7

Fatality Rate 1964 = 0.79 1965 = 0.92

Operational Characteristic: This site has congestion problems throughout most of the day. Many last minute lane changes were observed. Ramp traffic unable to merge downstream back-up into lane drop site.

Figure A-62

Figure A-63
Site 43

Type 3 - (2-2) Split

Sight Distance: 39 miles

Vertical Curvature: Slight upgrade cresting at .94 mile upstream, slight downgrade leveling off at .59 mile upstream.

Horizontal Curvature: Slight

Pavement Type: Concrete

ADT:

One-Way

5-Minute Count: Total 222

Trucks: 5, Percentage: 2%

Lane 1: 61
Lane 2: 105
Lane 3: 56
Lane 4: 
Lane 5: 21

Right Fork: 101

Accident Experience:

Operational Characteristics: Traffic volume splits evenly. There were a few erratic maneuvers observed, however, traffic generally flowed smoothly.

Figure A-64

Site 22

Type 4 - (2-2) Split

Sight Distance: 1 mile

Vertical Curvature: +0.52% grade

Horizontal Curvature: No curve

Pavement Type: Concrete

ADT:

One-Way

Two-Way

5-Minute Count: Total 256

Trucks: 21, Percentage: 8.5%

Lane 1: 160 to I-18
Lane 2: 
Lane 3: 96 to I-80
Lane 4: 
Lane 5: 

Right Fork: 27

Accident Experience: High accident experience indicated. No actual data obtained.

Operational Characteristics: The curve area seems to appear very suddenly (almost unexpected). Last-minute maneuvers were observed with some frequency.

Figure A-65
APPENDIX B - DATA COLLECTION FORMS USED IN PHASE I SITE VISITS

Appendix B consists of data forms developed for gathering lane drop information from State and Metropolitan agencies and at lane drop sites during Phase I efforts.

PHONE INTERVIEW SHEET

State __________________ Date __________ Phone No __________
Person contacted __________________ Position __________________

Approximately how many lane drops are in your state? __________________

Are any of them considered to be problems, in terms of high accident rates or unusual congestion? __________________ How many? __________________

Which ones? __________________

How does your state determine problem locations?

________________________________________

Does your state have any documented lane drop design policies and practices?

________________________________________

How do problem locations deviate from the established design policies and practices?

________________________________________

B-2

Can SDC obtain plans of lane drops, accident and traffic counts, photographs, or other data?

________________________________________

Is there anyone else in your state (in a regional office perhaps?) who might have knowledge of lane drops there?

________________________________________

Can we visit you to collect data, discuss design policies and observe traffic at some of your lane drops?

Date of personal interview __________________

Areas in state to be visited __________________

Letter sent __________

Comments

B-3

OPERATIONS FORM

Organization __________________ Date __________
Interviewed __________________ Location __________________
Name __________________ Title __________________

1

2

3

4

5

6

7

8

9

10

Where are your problem sites located?

1

2

3

4

5

6

7

8

9

10

Have you done any studies at these sites? If so, what kind, and what were the results?

________________________________________

Do you have any sites which you feel work well? __________________

If so, where are they located?

1

2

3

4

5

What type of accident record information and volume information can be made available for these sites (good and bad)?

________________________________________

What is the best method for obtaining this information?

________________________________________
**POLICIES & PROCEDURES FORM**

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Date**

**Incervled**

**Location**

---

Do you conform to the AASHTO's red book guidelines?

Do you have a State Manual on Signing, striping, and geometric design and does it conform to current practice?

Are there any lane drop sites in your state which conform to current design specifications? If so, where are they?

What has been your experience with their operating characteristics?

Briefly describe current guidelines for striping, signing & geometric design (Attach handouts)

---

**LOCATION State**

**Route Designation**

**City**

**Route No**

**Characteristics upstream of lane drop**

**Geometric Design**

Distance to closest ramp

Name of ramp

Type of ramp (on, off, direct, loop, etc)

Number of freeway lanes, Width of lane

Width of median, Width of shoulder

Gradient

Length of graded section

Begin point, End point

Curvature

Begin point, End point

Pavement type

Sight Distance (to end of taper or lane)

**Characteristics downstream of lane drop**

**Geometric Design**

Distance to closest ramp

Name of closest ramp

Type of ramp (on, off, direct, loop, etc)

Number of freeway lanes, Width of lane

Width of median, Width of shoulder

Gradient

Length of graded section

Begin point, End point

Curvature

Begin point, End point

Pavement type

Sight Distance (to end of taper or lane)

Lane drop characteristics

Which lane physically dropped?

Which lane operationally dropped?

Type of lane drop

Type of lane split

Length of physical taper

Length of operational taper

Provide sketch of area
### Operational Characteristics

<table>
<thead>
<tr>
<th>Site No</th>
<th>Route Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location State, City</td>
<td>Route No, Direction</td>
</tr>
<tr>
<td>ADT for the year</td>
<td>Overall accident experience</td>
</tr>
</tbody>
</table>

Date of site visit ____________  
Day of week ____________ Time of day ____________ to ____________

#### Time

<table>
<thead>
<tr>
<th>Lanes</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 5-minute counts

#### Odometer readings & speeds

<table>
<thead>
<tr>
<th>Time of day</th>
<th>1st pass</th>
<th>2nd pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Speed</td>
<td>Speed</td>
</tr>
<tr>
<td>Nearest upstream ramp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beginning of taper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>End of taper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp gore (trapped lane)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearest downstream ramp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign location 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign location 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign location 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign location 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sign location 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sight distance to end of taper or gore</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments about operational characteristics of site

### Signing

<table>
<thead>
<tr>
<th>Type</th>
<th>Message</th>
<th>Color background, letters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size width, height</td>
<td>Location above ground</td>
<td></td>
</tr>
<tr>
<td>Location in relation to freeway (l-r, right, overhead)</td>
<td>Distance to lane drop</td>
<td></td>
</tr>
</tbody>
</table>

### Pavement Markings

<table>
<thead>
<tr>
<th>Location begin point</th>
<th>end point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of marking</td>
<td>Color</td>
</tr>
</tbody>
</table>

APPENDIX C - BEFORE/AFTER STUDY AT A METROPOLITAN LANE DROP LOCATION

A "before-and-after" study was conducted at an urban lane drop site to determine if traffic operations and safety at the site could be improved through the implementation of traffic control devices.

In June 1972, a left-hand lane drop was created near an off-ramp of a northbound freeway. Because traffic volumes are very heavy in the left lanes during peak-hour operations, it was decided that the lane drop should be accomplished by operationally merging the right two lanes upstream of the physical lane drop. An operational right-lane taper was installed for this purpose. Subsequent problems with this configuration resulted in the transforming of this lane drop into an operational exit ramp drop in January 1973. Both "before" and "after" data were collected at the site. The data support the subjective opinion that improvement in operations and an apparent lessening of driver confusion resulted from the change.

"Before" Site Configuration

The lane drop was created when a fifth lane was added in the median of a four-lane section of freeway. The fifth lane was continued from a left-hand on-ramp connection from another freeway approximately three miles upstream of the selected off-ramp. The lane was physically dropped on the left, but operationally the two right lanes were merged by moving the four left lanes of traffic to the right one lane-width through pavement striping. Advance signing and pavement markings instructed an approaching driver in the right lane to merge left. Figure C-1 illustrates the geometric configuration and traffic control devices at the lane drop site.

"After" Site Configuration

On January 28, 1973, the site was reconfigured to drop the right lane operationally at the selected off-ramp. An existing short up-grade between the off-ramp and the beginning of the old operational taper was effectively used to hide the physical continuation of the right lane from the approaching right lane driver. Figure C-2 illustrates the "after" design configuration.

Analysis of Configurations in Terms of Lane Drop Design Principles

In the main body of the report, eight lane drop design principles were outlined. It was expected that if these principles were violated, poor traffic operations would result; conversely, if these principles were obeyed, lane drop operations would be satisfactory. A listing of the design principles and the adherence of both design configurations to these principles follows.

1. The lane drop should be placed where the surface of the roadway remains visible continuously for a significant amount of time.

   - Before - Sight distance is 650'; a vertical curve hides the operational lane drop.
   - After - Sight distance is 3650'; the operational lane drop is on a slight up-grade.
THE LANE DROP SHOULD BE PLACED AWAY FROM ATTENTION-DIVIDING CONDITIONS, SUCH AS RAMPS OR COMPLICATED DIRECTIONAL SIGNING.

**Before**

The off-ramp is situated in the middle of the lane drop signing sequence, 600' upstream of the beginning of the taper.

**After**

The off-ramp is now part of the lane drop, an on-ramp 3850' upstream of the lane drop might cause problems for entering drivers. If so, an additional sign on or near the on-ramp might help.

THE LANE DROP TAPER SHOULD ALLOW FOR A SMOOTH TRANSITION FOR DRIVERS TO MAKE A LANE CHANGE IN THE TAPER AREA AND SHOULD PROVIDE ADEQUATE VISUAL CUES WHICH INFORM THE DRIVER THAT HIS LANE IS ENDING.

**Before**

The 50' taper is probably adequate but visual cues are very misleading, the lane physically continues in a straight line.

**After**

Not applicable, lane drop is at an exit ramp.

WHEN A LANE DROPS AT AN EXIT RAMP, AN ESCAPE AREA OF ADEQUATE DIMENSIONS SHOULD BE PROVIDED TO ALLOW FOR A SMOOTH TRANSITION INTO THROUGH LANES.

**Before**

Not applicable

**After**

The operational gore extends for 300' and the unused old through lane continues for 650' before the beginning of the physical taper area.

CONSISTENT AND APPROPRIATE TRAFFIC CONTROL DEVICES (TCOs) SHOULD BE USED IN ADVANCE OF A LANE DROP.

**Before**

TCOs inform the driver that his lane is physically ending, which is inconsistent with the fact that the lane is visible after the lane drop. The first TCO is 1300' upstream of the beginning of the taper, not much notice to make a smooth transition out of the lane.

**After**

Signage, which begins just over 1 mile upstream, and skip-striping, which begins 1/2 mile upstream, give adequate and consistent warning that the lane is for exiting vehicles only. Notice that there is no mention of the lane physically ending, only that the lane is reserved for exiting vehicles.

Presentation of Data

"Before" data were collected on two different occasions. On Thursday, July 20, 1972, afternoon peak-hour traffic was observed, and on Wednesday, January 24, 1973, midmorning off-peak traffic was observed. Volume counts, lane distributions, traffic composition, and ramp volumes were collected on both days. Due to the development of new data collection and analysis techniques in the interim between the two data collection efforts, peak-hour counts were made 600 feet downstream of off-peak hour counts.

Peak-hour and off-peak-hour data were again collected at the site after the changes were made. Since a change in configuration (from a taper to a ramp drop) was made, approximately four weeks was allowed for the settling down of the site before data were collected.

Table C-1 summarizes average six-minute volume counts, lane distributions, traffic composition, and ramp volumes both before and after the change during peak-hour and off-peak-hour operation.

In summary, the original lane drop violated several of the design principles, but the current lane drop seems consistent with most of these principles.
In addition, lane change information was obtained in the off-peak data collection activity. For this purpose, the site was divided into three regions. Region 1 contained the area from the selected exit gore to the end of the taper area, Region 2 contained the area from the LANE ENDS MERGE LEFT sign to the exit gore, Region 3 contained the area from 2000 feet upstream of the taper to the sign. These regions are illustrated in Figure C-2. Six-minute counts were made of vehicles changing either into or out of the lane drop lane for each region. These average counts are contained in Table C-2. If a vehicle did not move out of lane 1 by the end of the taper area, it was still counted as moving out of lane 1 in region 1.

### Table C-1 - "Before" and "After" Average Six-Minute Counts

<table>
<thead>
<tr>
<th></th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
<th>Lane 5</th>
<th>Off-Ramp</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Off-Peak-Hour</td>
<td>809</td>
<td>157</td>
<td>179</td>
<td>166</td>
<td>191</td>
<td>116</td>
<td>22</td>
</tr>
<tr>
<td>1/24/73 (Wed) 10:30-11:00 AM</td>
<td>831</td>
<td>173</td>
<td>178</td>
<td>187</td>
<td>103</td>
<td>90</td>
<td>21</td>
</tr>
<tr>
<td>After Peak-Hour</td>
<td>773</td>
<td>107</td>
<td>131</td>
<td>183</td>
<td>175</td>
<td>179</td>
<td>20</td>
</tr>
<tr>
<td>1/24/73 (Wed) 10:30-11:00 AM</td>
<td>84</td>
<td>111</td>
<td>107</td>
<td>103</td>
<td>73</td>
<td>44</td>
<td>32</td>
</tr>
<tr>
<td>Before Off-Peak-Hour 2/23/73 (Fri) 10:30-11:30 AM</td>
<td>48</td>
<td>50</td>
<td>105</td>
<td>122</td>
<td>106</td>
<td>85</td>
<td>44</td>
</tr>
</tbody>
</table>

*These counts were made approximately 600' downstream of the other counts.*

Erratic maneuvers were observed with some frequency. These maneuvers were generally either reduction in speed (indicated by brake light illumination) or the acceptance of small gaps to accomplish a lane change just prior to, or in, the taper area. It is felt that several factors caused drivers to misunderstand what was expected of them and, therefore, made erratic maneuvers to compensate.

First, advance warning was accomplished by a LANE ENDS MERGE LEFT sign approximately 1750 feet upstream of the taper and 750 feet upstream of the exit ramp. In addition, several white pavement arrows were located between the exit ramp and the lane drop taper. Apparently the advance warning did not effectively inform the drivers of the impending lane drop, because many vehicles, including large commercial trucks, did not move out of the lane in advance of the lane drop area.

Secondly, sight distance was restricted by the presence of a short up-grade beginning at the exit-ramp gore and clearing near the beginning of the lane drop taper. This sight distance, approximately 650 feet, does not allow many drivers to observe and react to the lane drop without making an erratic maneuver.

Finally, the lane drop itself could be misleading to a driver because he can see that a through traffic lane continues in his line of sight downstream of the lane drop. This may cause confusion as to whether he should believe the traffic control devices and merge left or believe his eyes and continue straight.
Many drivers in this situation continued straight through the lane drop area, causing a second type of operational conflict. The straight-through traffic forced a fight for lane position with the drivers following lane lines and, therefore, moving over from the left. In some cases when two vehicles in adjoining lanes arrived simultaneously at the lane drop merge area, an erratic maneuver was committed by one or both drivers to avoid an accident. The change in configuration seems to have improved the lane drop site considerably. Drivers appear to be moving out of the drop lane further upstream and in a safer manner.

Traffic volumes, traffic compositions and off-ramp volumes were consistent between the "before" and "after" data collection activities. The lane distributions did change somewhat, but this is to be expected if drivers are moving out of the drop lane earlier.

In addition, it should be noted that although drivers moved out of the drop lane well in advance of the gore area in off-peak period operations, many conflicts and lane changes were observed during peak-period operation. This is probably due to the lack of suitable gaps for merging in heavy traffic, but the number of such instances was sharply reduced after the lane drop was reconfigured.

A graph, as shown in Figure C-3, of cumulative percent lane changes out of the drop lane was produced for several metropolitan area lane drops. A more convex curve indicates that most drivers are leaving the drop lane well in advance of the taper or gore area and thus is considered a well-working lane drop. Conversely, a concave curve will indicate a poorly working lane drop. In this study, three curves were generated, representing the "before" condition, the "after" condition using regions identical to the "before" condition, and the "after" condition using regions similar in nature, but not location, to the "before" condition. These curves are superimposed over similar curves for other lane drop sites.

A quick comparison of the curves indicates the relative effectiveness of the site before and after change in configuration. Two different curves are developed for the "after" configuration, because the location of the operational lane drop was changed. It is felt that when the location of the lane drop is changed, that two sets of curves should be developed, one comparing the "after" configuration directly with the "before" configuration by using the same region boundaries locations and the other to compare the relative effectiveness of the configurations using region boundary locations appropriate for each configuration. It can be seen from the three curves that an improvement in lane change behavior was made by the change in configuration. In addition, by comparing the "before" and "after" configurations to other lane drops in the area, it can be seen that the site improved relative to other sites as well.

Conclusions

A right-hand operational merge at a left-hand physical lane drop located just downstream of the selected exit of the freeway in the area resulted in several problematic maneuver patterns during both peak and off-peak period operations. The major problem seemed to stem from two sources, 1) little advance warning, compounded by an interfering right-hand exit ramp located 650' upstream of the beginning of the operational taper, and 2) the visual continuation of the operational drop lane past the merge area. Many drivers made last minute or erratic lane changes out of the operational taper area, and many additional drivers continued through the operational taper forcing a downstream conflict with traffic moving from the left into their path of travel.

A change in configuration using traffic control devices transformed the operational taper lane drop into an operational exit lane drop at the off-ramp. A short up-grade which formerly impaired the lane drop taper sight distance became the focal point of an operational gore extending 300' upstream of the physical gore. The up-grade also aided in hiding the physical lane continuation from approaching right lane drivers.

Data collected before and after the change in configuration during both peak and off-peak period operations confirm the subjective opinion that most through drivers now leave the right lane well upstream of the lane drop. In addition, drivers only rarely remain in the right lane beyond the operational gore area. Merging conflicts were still observed during peak-period operations after the change in configuration, but were most likely the result of the near-capacity volumes rather than the configuration. Finally, it should be noted that the improvement in site operations is not necessarily due to one configuration type being inherently better than the other (i.e., an exit lane drop vs. a taper lane drop). More likely, the improvement results from the adherence to the design principles.
A "before-and-after" study was conducted at a lane drop site in a moderate-size city to determine the effect of the implementation of changes in traffic control devices upon traffic operations and safety. In March, 1973, a left-hand lane drop was changed to a right-hand lane drop through the use of traffic control devices. This change was prompted by the observation by the Division of Highways that during peak-hour flow, Sunday afternoon returning recreational traffic, an uneven lane distribution was causing premature capacity breakdown at the location.

"Before" and "after" data were collected at the site during off-peak hour operation as well as peak-hour operation. The change in traffic control devices had a significant effect on both peak and off-peak operations, causing peak hour operations to improve considerably but causing many conflicting driver patterns, at times with undesirable results, to emerge during off-peak operations.

"Before" Site Configuration

The lane drop was created due to a stage construction on a three-lane freeway. Two lanes of the freeway were initially constructed along the eastern length of the section. A third lane is being constructed in stages. From a construction point of view, it was wise to add pavement in the freeway median, thus deceasing a left-hand physical lane drop. Figure D-1 illustrates the lane drop as it appeared in December 1972.

"After" Site Configuration

On March 9, 1973, the site was reconfigured to improve an uneven lane distribution observed during peak hour operation. The physical lane drop remained on the left but resigning and striping operationally attempted to merge the two right lanes. Figure D-2 illustrates the "after" configuration.

Analysis of Configurations in Terms of Lane Drop Design Principles

Right tentative lane drop design principles were outlined in the main body of the report. It was expected that if these principles were violated, poor traffic operations would result. Conversely, if the principles were obeyed, lane drop operations should be satisfactory. A listing of the design principles and the adherence of both design configurations to these principles follows:

1. The lane drop should be placed where the surface of the roadway remains visible continuously for a significant amount of time.

   - Before: Yes, sight distance is about 1/2 mile. The lane drop is on a level section of freeway after a downgrade.
   - After: Same as "before".

   "NOT TO SCALE"

Figure D-1. Schematic Drawing of "Before" Configuration

Figure D-2. Schematic Drawing of "After" Configuration
2 THE LANE DROP SHOULD BE PLACED AWAY FROM ATTENTION-DIVIDING CONDITIONS, SUCH AS RAMPS OR COMPLICATED DIRECTIONAL SIGNING.

-Before-
YES Closest upstream on ramp is 1 mile.
Closest downstream off-ramp is 1600 feet.

-After-
YES Same as "before".

3 THE LANE DROP TAPER SHOULD ALLOW FOR A SMOOTH TRANSITION FOR DRIVERS TO MAKE A LANE CHANGE IN THE TAPER AREA AND SHOULD PROVIDE ADEQUATE VISUAL CUES WHICH INFORM THE DRIVER THAT HIS LANE IS ENDING.

-Before-
YES The 50' taper length results in smooth transitions for most drivers making lane changes in the taper area.

-After-
NO Visual cues are contradictory to signing and striping cues.

4 THE LANE DROP SHOULD BE PLACED ON THE BETTER SIDE OF FREEWAY FOR GIVEN TRAFFIC AND GEOMETRIC CONDITIONS.

-Before-
YES The physical and operational lane drop are both on the left.

-After-
NO Signing informs the right lane driver that his lane ends. It does not, and does not appear to do so.

5 WHEN A LANE DROPS AT AN EXIT RAMP, AN ESCAPE AREA OF ADEQUATE DIMENSIONS SHOULD BE PROVIDED TO ALLOW FOR A SMOOTH TRANSITION INTO THROUGH LANES.

-Before-
Not applicable.

-After-
Not applicable.

6 CONSISTENT AND APPROPRIATE TRAFFIC CONTROL DEVICES (TCDS) SHOULD BE USED IN ADVANCE OF A LANE DROP.

-Before-
YES TCDS correctly indicate that the left lane ends and that the traffic in this lane should merge right.

-After-
NO Signing informs the driver in the right lane that his lane ends, but he can see it does not. Striping indicates that the center lane is merging into the right lane and the longitudinal pavement joints indicate that both the right and the center lane continue.

Table D-1 summarizes average six-minute volume counts, lane distribution and traffic composition both before and after the change during peak-hour and off-peak hour operation.
TABLE D-1 - "BEFORE" AND "AFTER" AVERAGE SIX MINUTE COUTS

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Trunks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before off-peak</td>
<td>207</td>
<td>76</td>
<td>110</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>12/20/72 (Wed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 00-12 00 Noon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After off-peak</td>
<td>214</td>
<td>51</td>
<td>96</td>
<td>65</td>
<td>32</td>
</tr>
<tr>
<td>1/21/73 (Mon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 00-12 00 Noon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After off-peak</td>
<td>171</td>
<td>130</td>
<td>61</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4/16/73 (Tues)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 00-11 00 Noon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After peak</td>
<td>315</td>
<td>172</td>
<td>143</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1/18/73 (Sun)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 00-4 00 PM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before peak</td>
<td>312</td>
<td>108</td>
<td>202</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2/4/73 (Sun)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 00-4 00 PM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lane 1 is the shoulder lane.
These counts were taken 1500' upstream of the lane drop transition
These counts were taken downstream of the lane drop transition

In addition, in the off-peak data collection activities lane change information was produced. In one experiment the test site was divided into three regions: Region 1 contained the area from the location of the third rumble strip to the overcrossing, Region 2 contained the area from the first rumble strip to the third rumble strip (see Figure D-1 for relative locations). Six minute counts were made of vehicles changing either into or out of the lane drop lane for each region. These average counts are contained in Table D-2.

If a vehicle did not move out of the drop lane by the end of the taper area, it was counted as moving out of the drop lane in Region 1.

TABLE D-2 - "BEFORE" AND "AFTER" SIX MINUTE DROP LANE CHANGE COUNTS BY REGION

<table>
<thead>
<tr>
<th>Region 1</th>
<th>Region 2</th>
<th>Region 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Into</td>
<td>Out of</td>
<td>Into</td>
</tr>
<tr>
<td>Drop Lane</td>
<td>Drop Lane</td>
<td>Drop Lane</td>
</tr>
</tbody>
</table>

Before off-peak
12/20/72 (Wednesday)
10 00-12 00 Noon

After off-peak
4/10/73 (Tuesday)
10 00-12 00 Noon

Because several distinct lane change patterns were observed in the "after" configuration, additional counts were obtained.

During the "after" data collection activities, it was observed that the traffic in lane 2 (the center lane) could be divided into several distinct traffic patterns. Counts were taken of the number of vehicles traveling in each of the patterns. It was found that during off-peak operations, 9% of the lane a vehicles made definite lane change maneuvers into lane 1 (the outside lane), 75% of the vehicles followed their left lane line pavement marking, thereby gradually merging into the physical lane 1 (as defined by the longitudinal pavement joints), 9% of the lane 2 vehicles remained physically in lane 2, thus following the straight line of sight and pavement joints and crossing over the lane line pavement markings into the left-hand operational lane (the downstream median lane), and 7% of the center lane vehicles choose to make definite lane changes into lane 3 (the upstream median lane) and then gradually merge back into the physical lane 2 when the

Figure D-3. Traffic Patterns
physical lane 3 was ended. Figure D-3 illustrates these various traffic maneuvers.

Analysis of "Before"/"After" Data and Site Observations

"Before" traffic operations during off-peak hours were judged to be satisfactory even though the lane distribution was uneven. Almost all drivers moved out of the left lane well in advance of the lane drop taper. The uneven lane distribution did not cause significant problems as traffic volumes were low and opportunities to merge were numerous. However, during peak-hour operation, the uneven lane distribution caused significant problems for returning Sunday afternoon recreational traffic. Capacity was quickly reached in the median lane, even when the shoulder lane was running well below capacity. This caused a premature breakdown of the system.

The change in configuration improved this peak-hour situation by merging the two lighter traveled lanes of traffic. The lane distribution was almost equal (55% lane 1; 45% lane 2). Much less queuing was observed and fewer shock waves were noticed. Eventually, breakdown did occur from the downstream off-ramp congestion backup.

During off-peak hour operation, the change in configuration apparently caused confusion to drivers and led to a situation of unpredictability. Two major changes in traffic behavior were noticed. First, the majority of the drivers in the shoulder lane did not merge out of that lane, as requested by the advance warning signs, but instead continued straight through the lane drop area, forcing the center lane traffic to compete with them for the shoulder lane.

Secondly, several traffic patterns were observed in this configuration. Whereas in the "before" configuration only one traffic pattern was observed (i.e., almost all vehicles in the median lane changed lanes into the center lane and almost all traffic in the shoulder and center lanes remained in their respective lanes). As noted above, the majority of the traffic in the shoulder remained on that lane throughout the lane drop area. However, a small fraction of the drivers did obey the advance warning signs and merged into the center lane. Thus, two distinct traffic patterns were observed for the shoulder lane drivers. The center lane traffic can be divided into four traffic patterns. These have been described in the previous section of this report and are illustrated in Figure D-3.

Conclusions

The analysis of the data indicates that the uneven lane distribution which adversely affected peak-hour operations has been corrected by the change in configuration. However, since the lane drop site has been reconfigured, an increase in traffic patterns through the section has been observed. This increase obviously reduces the predictability of any vehicle traveling through the section. It is thus desirable to determine a method for lessening the off-peak hour driver confusion observed in this configuration while maintaining the peak hour operation improvement experienced with this configuration.

It is apparent then that the two right lanes of traffic should remain those to be merged. In the design principles outlined earlier in this paper, it was seen that the "after" configuration violated three of these principles. A solution to the problems encountered in the "after" configuration may be found in the following discussion.

Driver confusion is probably the main source of the varying patterns of traffic behavior. In other words, the site is ambiguous. Many different cues, often conflicting, are presented to each driver. The shoulder lane driver's first cue is the advance warning signs warning that the right lane is ending and that he should merge left. The next cue he receives is from the roadway itself which appears not to end at all. Additional cues may also be received from the behavior of other vehicles. The center lane driver's first cues are also the advance warning signs, but in his case the signs indicate that the lane he occupies is continuous and that he should expect shoulder lane traffic to merge into his lane. The next cue the center lane driver receives is from the lane line pavement marking which begins gradually moving to the right into the shoulder lane. In addition, at the same time, the longitudinal pavement joints indicate that both the shoulder and center lanes continue in a straight line. Other vehicles may also provide cues.

The situation violates the design principles by not providing adequate visual cues which inform the driver that his lane is ending (principle 3), by not making the lane appear to end physically as well as operationally (principle 5), and by not providing consistent and appropriate traffic control devices (principle 8).

The solution should be found by correcting the difficulties described in the preceding paragraphs. One apparent method is described in Appendix C. The site will then line up affirmatively with all design principles. As at the site described above, the left lane was physically dropped and the two right lanes were merged. To correct the current deficiencies of this site the two right lanes should be merged upstream as illustrated in Figure 24.
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To share in the tasks of furthering science and engineering and of advising the federal government, the National Academy of Engineering was established on December 5, 1964, under the authority of the act of incorporation of the National Academy of Sciences. Its advisory activities are closely coordinated with those of the National Academy of Sciences, but it is independent and autonomous in its organization and election of members.