FREEWAY DATA COLLECTION FOR STUDYING VEHICLE INTERACTIONS - TECHNICAL REPORT

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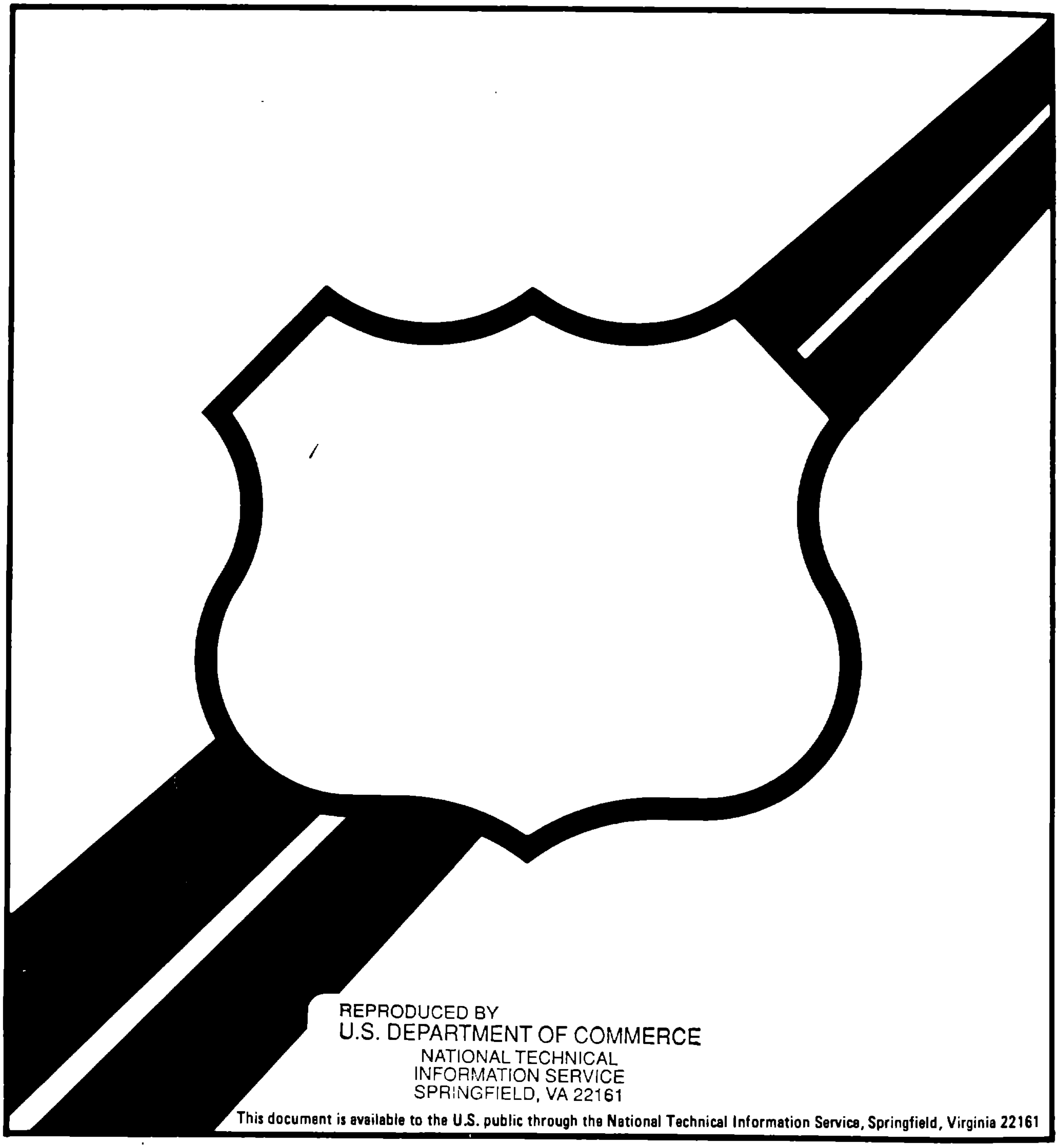

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16. Abstract

The purpose of this study was to develop a series of data sets on microscopic vehicular traffic flow for selected types of freeway bottleneck sections. The methodology used to develop these data sets involved digitizing vehicle positions from time-lapse aerial photography for a series of freeway sites under various geometric configurations. Six types of freeway geometry were of interest: ramp merges, weaving sections, upgrade sections, reduced width sections, lane drops, and horizontal curves.

The aerial photography involved the use of a full-frame 33 mm motion picture camera mounted in a fixed-wing, short-takeoff-and-landing (STOL) aircraft. The sites were filmed at one frame per second, with the aircraft flying clockwise at a slow speed around each site at altitudes ranging between 2,500 and 4,500 feet (760 and 1,370 m). Data were reduced for one hour of the film at each site, with sites ranging between 1,200 and 3,200 feet (370 and 980 m) in length.

The data reduction method involved a microcomputer-based digitizing system, producing complete vehicle trajectories for all vehicles passing through the sections studied. The data sets are expected to be useful for both empirical research on freeway traffic flow and for the validation of freeway simulation models. The data sets are being made available to those conduction research in these areas. Appendices H and I, contained in a separate volume, describe the set-up for the digitizing system and present the source code for the computer program.

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METRIC CONVERSION FACTORS

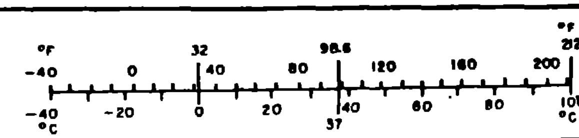
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

OVERVIEW AND OBJECTIVES OF THE STUDY

This report describes the results of the Federal Highway Administration research study entitled "Freeway Data Collection for Studying Vehicle Interactions." The purpose of this study was to develop a series of data sets on vehicular traffic flow for selected types of freeway sections. The methodology used to develop these data sets involved digitizing vehicle positions from time-lapse aerial photography for a series of freeway sites under various geometric configurations. Six types of freeway geometry were of interest:

- Ramp merges.
- Weaving sections.
- Upgrade sections.
- Reduced width sections.
- Lane drops.
- Horizontal curves.

There were several reasons for selecting these types of sections for study. These types of geometric configurations are the most frequent causes of bottlenecks or congestion points on freeways; therefore, a study of these types of sections is likely to provide the greatest benefit to overall freeway operations. In addition, these types of sections represent some of the more difficult situations to accurately model in the simulation of freeway traffic flow. Data on microscopic vehicle movements through such sections is expected to be useful in enhancing freeway simulation models, which in turn can be used to study how traffic operation through these types of sections might be improved.

The aerial photography involved the use of a full-frame 35 mm motion picture camera operating in time-lapse mode, mounted in a fixed-wing, short-takeoff-and-landing (STOL) aircraft. The sites were filmed at one frame per second, with the aircraft flying clockwise at a slow speed around each site at altitudes ranging between 2,500 and 4,500 feet (760 and 1,370 meters). Data were reduced for 1 hour of film (3,600 frames) at each site, with sites ranging between 1,200 and 3,200 feet (370 and 980 meters) in length.

The data reduction method involved a microcomputer-based digitizing system. The most important components of the system were the mathematical techniques for computing vehicle position and the method of vehicle matching, which yielded complete vehicle trajectories for all vehicles passing through the sections studied.

The objective of the study was to develop data sets which could be used in the study of these sections and not to perform the analysis of the traffic flow itself. The data sets are being made available to other researchers who will use the data to study particular aspects of traffic flow which are of interest to them. Information on how to request a copy of a data set is presented later in this report. The remainder of this introduction discusses the operational characteristics of freeway bottleneck sections and the current need for data on vehicle interactions, as developed in this study.

Overview of Freeway Operations

The Interstate Highway System and other limited access highways carry a large proportion of all travel on U.S. highways. In urban areas, it is estimated that 28 percent of the vehicle miles of travel occur on such highways, even though they comprise only about 2 percent of urban highway miles (Ref. 1). Thus, the density of travel on freeways (or the volume per lane-mile) tends to be considerably higher than on non-limited access highways. Drivers are attracted to such facilities due to the avoidance of delays at traffic signals and because of the generally higher speeds.

It has been increasingly difficult to construct new freeways or add width to existing freeways in recent years. Highway agencies are therefore taking a closer look at ways to increase the capacity of existing freeways and other facilities through operational improvements within the existing right-of-way. The obvious place to look for a payoff in making such improvements is at capacity-constrained sections, or freeway "bottlenecks." Such sections are usually characterized by discontinuities in the geometry of the highway which require drivers to change their speed or path, disrupting regular traffic flow. Changes to the geometry or other operational improvements can increase the capacity of the bottleneck and result in an increase in the overall throughput of the facility. Investing financial resources on these short sections of highway to improve the overall operation would seem to be a prudent way to achieve the much-needed increases in system capacity, particularly if other options are not feasible.

Operation of Freeway Traffic Bottlenecks

The six types of freeway bottleneck situations investigated have already been listed above. For each of these situations, drivers are faced with conditions which do not permit them to continue driving in a "steady-state" fashion, as they are usually able to do on straight, level sections between interchanges. Each driver is affected directly by changes in alignment or lane width and either directly or indirectly in sections where merging or weaving takes place (directly, when the driver must take the initiative to merge or weave, and indirectly when a merge or weave is made by a driver nearby).

Not enough is known about the dynamics of traffic flow through freeway bottleneck sections. Each maneuver can be a complex string of events that cannot be completely described by any of our current theories of traffic flow. Drivers may employ different techniques for negotiating a congested section, and the level of cooperation among drivers is an important determinant in how traffic will flow. For these reasons, a comprehensive analysis of vehicle interactions in bottleneck sections is necessary.

It should also be noted that there tends to be a threshold in the volume-capacity relationship at which the flow of traffic breaks down from continuous fluid flow prevalent at lower volume levels. Once this threshold of volume is exceeded, speeds tend to be lowered to the point where smooth, fluid flow no longer occurs but traffic is often in a wave-like stop-and-go movement, with throughput greatly reduced. It has been estimated that once flow takes on this pattern, the per-lane capacity of a freeway section is reduced from 2,000 vehicles per hour to 1,500 to 1,700 vehicles per hour (not accounting for the effect of the geometry of the bottleneck situation itself). The flow of traffic within bottleneck sections is frequently in this mode, so that study of congested flow in such sections is an important area of research.

Each of the six bottleneck situations can be described in terms of its geometry and traffic operational characteristics. A brief overview of the operational characteristics of each situation is presented below. The primary traffic data required to distinguish such situations from each other and from nonbottleneck sections follow directly from the type of traffic operation at each. These data requirements dictated the type and method of data collection employed later in this study. In the discussion of each of the situations presented below, only the primary traffic data requirements are listed. A summary of all geometric, traffic control device, and traffic performance data required is presented at the end of this section. A bibliography on past research in these areas is presented at the end of the report.

Reduced Lane Width/Shoulder Usage Sections

This type of bottleneck is created by a lateral constriction of the travel lanes and/or shoulders. The 1965 Highway Capacity Manual (HCM-Ref. 2) recognizes the potential capacity-reducing effect of narrow lanes and reduced lateral clearances and includes factors to account for the effect of such restrictions on service volumes. The factors range from a three percent reduction in capacity for 11-foot (3.4 m) lanes on four-lane freeways with obstructions on both sides six feet (1.8 m) from the edge of the traffic lane, to a 34 percent reduction for 9-foot (2.7 m) lanes and obstructions at the very edge of the lanes. Table 1 indicates the factors recommended in the HCM. These factors are also adopted in the more recent document, Freeway Capacity Procedures (Ref. 3). These reductions in volume are said to be brought about by vehicles being forced to travel closer to each other (laterally) than normal. Drivers compensate for this by driving more cautiously and allowing greater longitudinal spacing between vehicles. Reductions in speed normally are a by-product of the driver's sense of the need for greater caution. Thus, volume, speed and traffic density or spacing should be considered key data to describe traffic operation on reduced-width sections on freeways.

Ramp Merges

According to the HCM, a ramp is a roadway that permits traffic to transfer from one highway to another. At entrance ramp junctions or merges, "...the ramp vehicle driver has the task of evaluating the freeway stream and making speed adjustments necessary for merging into a chosen gap. Some limited assistance by lane-one vehicle

Table 1. Combined Effect of Lane Width and Restricted Lateral Clearance on Capacity and Service Volumes of Divided Freeways and Expressways with Uninterrupted Flow

DISTANCE FROM TRAFFIC LANE EDGE TO OBSTRUCTION (FT)	ADJUSTMENT FACTOR,* *W*, FOR LANE WIDTH AND LATERAL CLEARANCE							
	OBSTRUCTION ON ONE SIDE OF ONE-DIRECTION ROADWAY				OBSTRUCTIONS ON BOTH SIDES OF ONE-DIRECTION ROADWAY			
	12-FT LANES	11-FT LANES	10-FT LANES	9-FT LANES	12-FT LANES	11-FT LANES	10-FT LANES	9-FT LANES
(a) 4-Lane Divided Freeway, One Direction of Travel								
6	1.00	0.97	0.91	0.81	1.00	0.97	0.91	0.81
4	0.99	0.96	0.90	0.80	0.98	0.95	0.89	0.79
2	0.97	0.94	0.88	0.79	0.94	0.91	0.86	0.76
0	0.90	0.87	0.82	0.73	0.81	0.79	0.74	0.66
(b) 6- and 8-Lane Divided Freeway, One Direction of Travel								
6	1.00	0.96	0.89	0.78	1.00	0.96	0.89	0.78
4	0.99	0.95	0.88	0.77	0.98	0.94	0.87	0.77
2	0.97	0.93	0.87	0.76	0.96	0.92	0.85	0.75
0	0.94	0.91	0.85	0.74	0.91	0.87	0.81	0.70

* Same adjustments for capacity and all levels of service.

Source: Highway Capacity Manual, 1965, p. 256.

drivers may be given in that some of these drivers may speed up or slow down to widen gaps, crowd over toward the left edge of lane one while in the merging area, or even move into adjacent lane two."[1] This is somewhat analogous to fluid flow where two streams meet and produce a turbulent effect. In a freeway setting, a ramp merge creates an abnormally high traffic demand for the lane or lanes closest to the merge. Many drivers on the mainline, warned by an information system of the ensuing imbalance in demand, will shift lanes upstream of the merge area. Nevertheless, the upstream lane-shifting may often not be adequate to counter the effect of merging vehicles, and the on-ramp may add more vehicles to the mainline than it can adequately service, resulting in congested flow.

The type of operation described above indicates a number of measures of traffic performance which are necessary to describe the impact of freeway on-ramps. Volume, lane distribution of vehicles by distance from the merge area, lane change frequency, lane change and merge gap acceptance characteristics, speed, and acceleration profiles would seem to be the primary measures required.

Weaving Sections

Weaving is the crossing of traffic streams moving in the same general direction. In simple weaving, a single merge point is followed by a single diverge point. In multiple weaving, there are two or more merge points combined with a single diverge point or two or more diverge points with a single merge point. Weaving sections may also be classified as one- or two-sided. In a one-sided weave, the weaving maneuvers take place only on one side of the highway, while, in two-sided weaves, many vehicles from one traffic stream must completely cross the other traffic stream. A right-side on-ramp followed by a left-side off-ramp would be an example of a two-sided weave.

The document Freeway Capacity Procedures makes a distinction between ramp-weaves (one-lane on-ramp followed by a one-lane off-ramp) and major weaves (at least three of the entry and exit legs involve multiple lanes). In the latter, vehicles are not generally expected to accelerate or decelerate through the section. Ramp-weaves are treated in the "Ramps" chapter of that document. The analysis in this study is limited to one- and two-sided simple weaving sections.

The operation of a weaving section is somewhat similar to a ramp merge, but is made more complex by the addition of a diverge movement. Consequently, the measures of performance required to describe weaving area operation are similar to those described above for ramps.

Grades/Rollercoaster Sections

This type of site has to do with the vertical alignment of a freeway mainline, affecting the speeds which can be attained by certain vehicles, primarily trucks, buses, and some recreational vehicles. Passenger cars are generally acknowledged to be able

1 Highway Capacity Manual, 1965, p. 190.

to maintain higher speeds for most grades which would exist on freeways. The effect of sustained grades on a traffic stream consisting predominantly of automobiles should not be ignored, however, as upgrades in underwater tunnels have been shown to be subject to bottleneck conditions. The reduced speeds of heavier vehicles on sustained grades influences the speed and lane changing behavior of other vehicles, and subsequently, the service volume or capacity of the section. In both the HCM and Freeway Capacity Procedures, Passenger Car Equivalents (PCE's) are computed based on the percent and length of grade and percentage of trucks.

In both of the above documents, downgrades are treated as level sections with the caveat that where substantial down-shifting is required by trucks, special studies should be undertaken. Freeways with frequent and drastic changes in vertical alignment may have more restrictive effects, but are probably found much less often than a single sustained grade. The primary measures necessary to describe the traffic performance of grades include vehicle classification, volume, speed distributions by lane, and lane changing behavior.

Horizontal Curves

Existing freeway capacity analysis procedures in the U.S. do not account for the effects of horizontal curvature, and little research has been done in this area. However, observation of certain freeway sections with unusually high degree curves, particularly reverse curves, would suggest that horizontal curvature can be the cause of freeway bottleneck conditions. In some cases, the design speed of the curve is less than the prevailing speed limit, requiring vehicles to reduce speed. Lane changing may also be inhibited, as drivers must be concerned with lateral placement within a lane concurrently with searching for gaps acceptable for a lane change. These added demands may cause drivers to maintain greater longitudinal spacing between vehicles, resulting in reductions in volume through the section. Thus, volume, speed, and lane changing behavior appear to be measures of primary interest in describing such a situation.

Lane Drops

Lane drops are locations where one of the freeway mainline lanes is terminated. For the purposes of this study, the lane termination may be at an off-ramp or on the mainline itself. For a mainline termination, vehicles in the terminated lane are required to move into one of the through lanes, and the geometry is usually similar to an acceleration lane for an on-ramp. In fact, the operation of traffic at a mainline lane drop is quite similar to that at a ramp merge, except that vehicles merging onto the mainline from an off-ramp need to accelerate up to mainline traffic speeds.

Where a lane is dropped at an off-ramp, there is often a major exiting flow on the ramp, but demand may still be greater than capacity for the remaining mainline lanes. Merging operations from the dropped lane at an off-ramp are similar to a mainline drop, except that there is usually no formal merging area for a lane dropped at an off-ramp. Traffic performance measures needed to describe lane drop operation are nearly identical to those required for ramp merges.

Combinations of Situations

Many combinations of the above situations can exist on a freeway section. Furthermore, there are so many geometric and traffic variables that one could say with a fair degree of certainty that each freeway bottleneck site is unique.

Unfortunately, there is no inventory available of sufficient detail to define the population of each type of situation. Ramp merges, weaving sections, and lane drops could not exist together, by definition, but each of these could conceivably be combined with reduced width, grade, or curve sections. Grades, curves and reduced width sections could all occur in combination themselves. Isolating the effect of a single geometric factor on a site with multiple geometric conditions would be difficult. In selecting sites for filming in this study, an effort was made to avoid sites in which a bottleneck was created because of multiple geometric factors.

There are numerous instances in which congestion on a freeway is caused by traffic backing up from a traffic signal or geometric deficiency on a surface street. Such a bottleneck is not within the scope of this study.

NEED FOR DATA ON VEHICLE INTERACTIONS

As discussed in the previous section, a thorough understanding of traffic operations on freeway bottleneck sections is critical to the design of cost-effective solutions to freeway congestion problems. Traffic operations in such sections is a highly complex phenomenon, and it is not adequate to view the problem simply in terms of demand and capacity. If effective solutions are to be devised, the detailed interactions of vehicles must be more thoroughly understood, with the goal of optimizing traffic flow without large capital expenditures. Potential low-capital traffic management strategies which could be applied to freeway bottleneck sections include:

- Reducing lane widths and using shoulders to increase the number of lanes.
- Ramp control strategies.
- Mainline freeway control strategies.
- Diversion systems such as IMIS (Integrated Motorist Information System).
- Lane occupancy control strategies.
- Reversible lanes.
- Restriping and use of signs and markings.
- Minor geometric changes.

Many of these strategies have already been employed with some degree of success. But it has been difficult to determine when such measures are justified, and additional enhancements may be possible.

The impact of freeway traffic management strategies can be assessed in two primary ways: 1) through direct measurement of changes in traffic performance; and 2) through simulation of traffic performance. Both techniques have been used in the past, but efforts in the simulation area have increased in recent years. Given that the simulation of a highway section is sufficiently realistic, it can permit the evaluation of many freeway improvements which would be too costly to evaluate using field data collection techniques. Some of these improvements are too difficult or risky to be evaluated in the field at all.

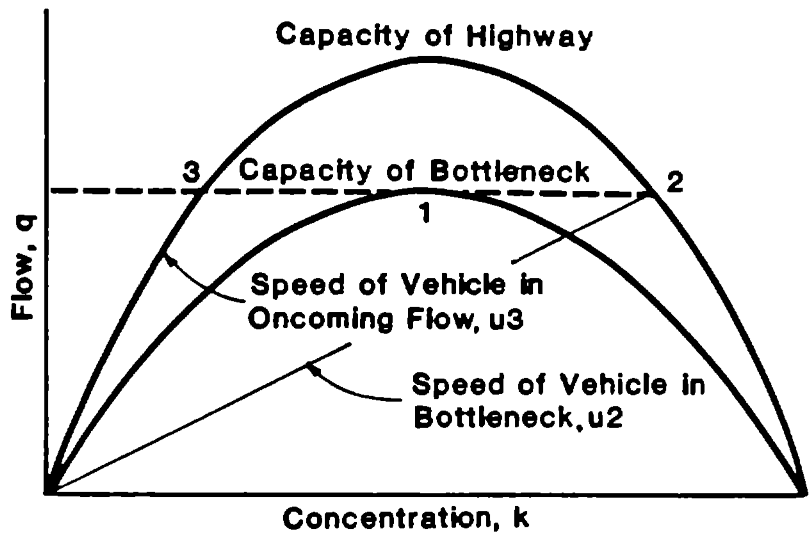
Data on vehicle interactions are thus needed to calibrate and validate simulation models as well as to directly assess the impact of freeway traffic management strategies for a range of bottleneck situations. Data needs for both these approaches are discussed below.

Data Needs for General Purpose Research and Evaluation of Traffic Management Strategies

Substantial effort has been invested in the past toward the development of theories that describe traffic behavior on freeways, particularly at bottlenecks. A good recent summary of progress to date can be found in TRB Special Report 165, (Ref. 4) "Traffic Flow Theory". There is a great deal of evidence that freeway traffic flow under congested conditions is dramatically different from high-volume non-congested flow. As volume builds up to capacity, there comes a point where speeds drop, the density of vehicles in a section increases, and throughput is significantly degraded. Once over this threshold point of breakdown, the full capacity of the bottleneck section is lost. This is illustrated by the flow-concentration curve in Figure 1. Studies by VERAC using detector data confirm this finding. Volume increases toward capacity, speeds then drop, concentration (or density) increases, and the section can no longer sustain the flow rates as they existed before the breakdown occurred. One of the strategies designed to maintain the traffic speeds and densities to achieve optimum flows is freeway surveillance and control, usually involving the restriction of traffic flow at on-ramps under certain traffic conditions. Unfortunately, not enough is known about how to maintain this delicate balance in demand. In addition, many other potential countermeasures for improving traffic flow through bottlenecks have impacts which are uncertain. If more can be understood about vehicle interactions under these conditions, engineers will be better equipped to devise cost-effective solutions.

Appendix A lists some of the questions which must be more fully answered about traffic operations in freeway bottleneck sections. Several additional example applications of improved knowledge of bottleneck traffic flow are cited below:

- Prohibition of lane changing through certain sections may increase or decrease capacity depending on the circumstances. To assess this measure, lane-changing frequencies must be known, as well as to what extent the lane changes are necessitated by origin-destination patterns or by the efforts of drivers to reduce their own individual delays.



Note: Speed $= \frac{\Delta q}{\Delta k}$

Figure 1. Typical Flow-Concentration Curve Illustrating Degradation of Capacity Under Congested Flow

- Development of techniques for easier measurement of certain traffic performance measures. For example, placing detectors in certain locations may enable one to estimate lane change frequency accurately and cheaply.

- Development of sampling procedures to estimate many traffic performance measures at reduced cost. For example, suggested sampling techniques for estimating vehicle headways, speed, density, lane changing, etc. could be developed by analyzing the statistical accuracy of alternative techniques using a comprehensive research data base.

Data Needs for Traffic Simulation of Freeway Bottleneck Sections

In addition to the need for data for the overall understanding of traffic operations in freeway bottlenecks and the evaluation of traffic management strategies, data are required for the calibration and validation of simulation models. Required here are the more microscopic measures of traffic operation (e.g., acceleration/deceleration profiles, car-following headways, lane change and merge gap acceptance) for the calibration of model parameters. Other macroscopic measures (throughput volume, travel time, lane change frequency) are needed for checking the realism of model outputs.

The data developed in this study was particularly concerned with microscopic freeway simulation models as opposed to macroscopic models. Although the data can be used in the development of macroscopic freeway simulation models, there was a particular need to address the requirements of calibrating and validating microscopic models, since microscopic traffic flow data are currently lacking.

Articles by Gibson and May in TRB Special Report 194, "The Application of Traffic Simulation Models" (Ref. 5) summarize the historical development of both macroscopic and microscopic freeway simulation models. Early microscopic models were developed in the mid-1960's, with the most recent development being INTRAS (INtegrated TRAffic Simulation), which stochastically models both the freeway and surrounding surface streets (Ref. 6). It incorporates the PITT car-following algorithms, but much of the logic is newly developed. INTRAS is clearly the most advanced microscopic freeway simulation model in existence and is receiving additional support in its development from FHWA, with the ultimate goal of integration into the TRAF family of models sponsored by FHWA. Therefore, INTRAS will be used as the basis for determination of data requirements for simulation model calibration and validation. It must be remembered, however, that INTRAS may itself undergo modifications which could impact data requirements.

The data requirements for calibrating and validating INTRAS are listed in Table 2. They are classified as required model inputs (either geometric, traffic control or traffic characteristics); changeable internal parameters (i.e. not requiring input from the user, but may be specified by the user if desired); and model outputs (traffic performance and other measures). There are also some internal parameters that cannot be modified by the user without actual modification to the software (e.g., vehicle lengths, car-following algorithm, lane changing logic). These could also be a cause of the model's failure to adequately replicate traffic behavior under certain conditions.

Table 2. **Highway and Traffic Data Requirements for Running, Calibrating and/or Validating the Freeway and Ramp Portions of INTRAS**

Inputs	Changeable Internal Parameters
Geometric	
Link node numbers	Vehicle acceleration by veh. type by grade by speed
Link lengths	Vehicle deceleration by type by grade by speed
Link types (freeway or ramp)	Mean speed by lane
No. thru lane by link	Percent of commercial vehicles by lane
Grade by link	Time to complete a lane change
Nodes receiving thru and turning traffic	Min. time separation for generaton of freeway vehicles
Curve radius	Lane change probability
Auxiliary lane type	Minimum acceleration
Auxiliary lane length	Percent drivers desiring to yield ROW
Location of physical barriers	Time lag to accel. or decel.
Superelevation	Fuel consumption characteristics
Pavement type and wetness	Maximum deceleration
Lane numbers to which ramps are connected	Factors for car-following law
Turning percentage at off-ramp	
Traffic	**Outputs**
Mean desired free-flow speed	Mean and distribution of spot speeds
Mean queue discharged headway (for off-ramps)	Space mean speed and travel time on a link
Flow rate (demand)	Volume per lane
Percent of vehicles by type	Density and lane occupancy
Percent of vehicles by lane	Queue delay
Incident Specifications	Mean and distribution of headways
	Number of lane changes by time period and link
Traffic Control	Fuel consumption by vehicle type and link
Location at which drivers react to advance warning signs	Vehicle emmisions by vehicle type and link
Location of freeway data stations	Time/Space trajectories of vehicles
Ramp metering specifications	
Detector locations	

As can be determined from the table, the data requirements for making a microscopic freeway simulation model fully operational and able to replicate real-world traffic behavior are quite large. Based on the requirements of INTRAS and availability of existing data, the need for additional data for specific bottleneck conditions can be determined. These requirements are summarized below.

Summary of Data Requirements for Bottleneck Situations

Table 3 lists the geometric, traffic control, and traffic performance data required to adequately describe the six bottleneck situations being investigated. They are classified by independent and dependent variables depending on whether they are viewed as being a cause or effect. The requirements are further classified as primary or secondary. The primary data are those which would describe the major distinguishing features between one type of situation and another. The secondary data are those which are expected to offer less discriminatory power. The difference between primary and secondary is highly qualitative, but helps to highlight the more important data elements.

The data requirements listed in Table 3 respond to the questions listed for each bottleneck situation in Appendix A. Data collection techniques and the resulting traffic data sets were designed to enable the user of the data sets to obtain all the traffic measures listed in the table, if so desired.

Table 3. Summary of Data Requirements by Situation

Measure	Reduced Lane Width	Ramp Merges	Weaving Areas	Grades	Horiz. Curves	Lane Drops
INDEPENDENT VARIABLES						
Geometric						
No. Lanes	P	P	P	P	P	P
Lane Width	P	S	S	S	S	S
Shoulder Width	P	S	S	S	S	S
Vertical Grade Percent	S	S	S	P	S	S
Vertical Grade Length	S	S	S	P	S	S
Horizontal Curve Radius	S	S	S	S	P	S
Horizontal Curve Length	S	S	S	S	P	S
Cross-Slope/Superelev.	N	N	N	N	P	N
Location of on/off ramps	P	P	P	P	P	P
Length of Accel./Decel. Lanes	S	P	P	S	S	S
Type/Location of Barriers	P	S	S	S	S	S
Pavement Condition	N	N	N	N	N	N
Traffic Control						
Speed Limit	S	S	S	S	S	S
Lane Striping	S	S	P	S	S	S
Ramp Control	S	P	P	S	S	S
Signing	S	P	P	S	S	P
Traffic						
Vehicle Class	P	P	P	P	P	P
Vehicle Length	S	S	S	S	S	S
Demand Volume	P	P	P	P	P	P
DEPENDENT VARIABLES (All Traffic Perf. Vars.; All Required by Lane And Vehicle Class)						
Throughput Volume	P	P	P	P	P	P
Time Headway	P	P	P	P	P	P
Space Headway	S	S	S	S	S	S
Time Mean Speed	S	S	S	S	S	S
Space Mean Speed	P	P	P	P	P	P
Lane Change Frequency and Direction	P	P	P	P	P	P
Lane Change Time	P	P	P	P	P	P
Speed Changes (Accel/Decel)	P	P	P	P	P	P
Lane Change Gap Acceptance Distribution	P	P	P	P	P	P
Merge Gap Acceptance Distribution	S	P	P	S	S	S
Lane Occupancy*	S	S	S	S	S	S
Traffic Density*	S	S	S	S	S	S
Driver "Cooperation"	S	P	P	S	S	P
Queue Length	P	P	P	P	P	P
Traffic Delay	P	P	P	P	P	P

KEY: INDEPENDENT VARIABLES:

P = Data element expected to be primary distinguishing factor in traffic operation.

S = Data element expected to be secondary distinguishing factor in traffic operation.

N = Data element expected to be negligible distinguishing factor in traffic operation.

DEPENDENT VARIABLES:

P = Data element expected to have primary effect on traffic operation.

S = Data element expected to have secondary effect on traffic operation.

N = Data element expected to have negligible effect on traffic operation.

*Not required by vehicle class.

2. DATA COLLECTION AND REDUCTION METHODOLOGY

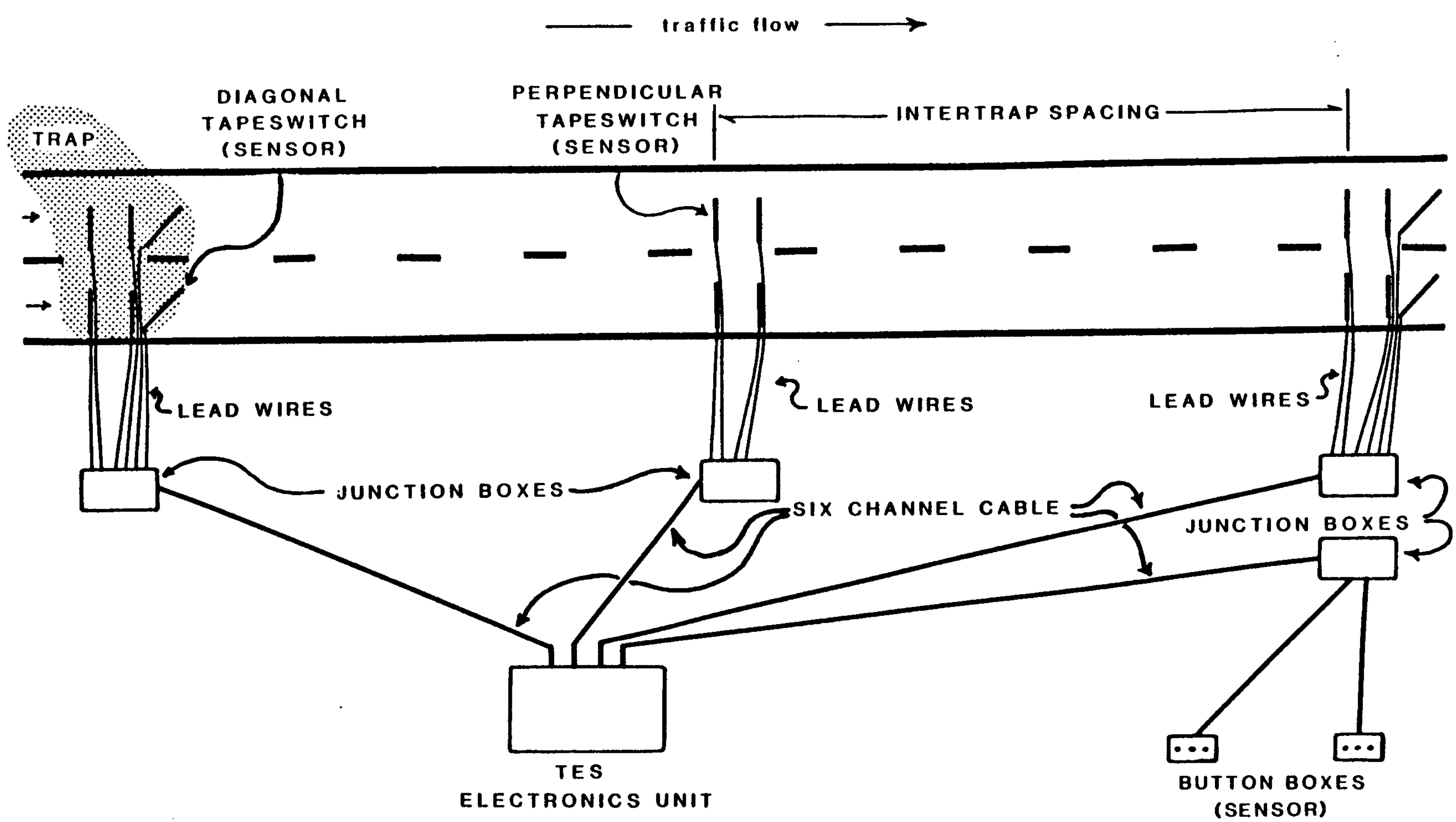
Chapter 2 discusses the development of the data collection and reduction system. It first provides a review of past approaches to developing vehicle trajectory data, followed by a description of the development of both the aerial photography and digitizing systems.

REVIEW OF APPROACHES TO DEVELOPING VEHICLE TRAJECTORY DATA

The collection of data for studying microscopic traffic flow in freeway bottleneck sections implies the need for detailed data on vehicle trajectories. This is the most difficult type of traffic data to obtain since the position of all vehicles must be known for short time increments (one to three seconds) and vehicles must be completely traced through the section.

There are two basic approaches to developing detailed vehicle trajectory information. The first approach involves the placement of closely-spaced pairs of axle detectors on the roadway. The detectors are used to record the exact time of each axle crossing which then enables the identification of vehicles by axle characteristics and the matching of these characteristics from one detector to the next, thus tracing the vehicles through the section. Devices such as FHWA's Traffic Evaluator System (TES) have been used to develop vehicle trajectories using this method. However, the number of detectors required to track vehicles through a section in short time increments is not practical for the lengths of sections required in this study. Detector stations would be needed at frequent spacings (probably every 50 to 100 feet (15 to 30 m)) on each lane to collect microscopic traffic flow data under congested conditions. With three axle detectors per station (two parallel, one diagonal), some 250 to 500 detector inputs would be needed to cover the lengths and widths of sections to be studied. In addition, the TES software has not been designed for vehicle matching under congested flow conditions. Figure 2 illustrates a typical detector layout for the TES.

The second approach to developing vehicle trajectory data involves the tracing of vehicles through a section using photographic means. In this approach vehicles are tracked though the section of interest and their positions recorded at discrete points in time. This approach has also been attempted in the past with varying degrees of success. One of the methods used for matching vehicles in these photographic methods has been to record the position of vehicles at short time increments (e.g., one second) and to match vehicles from one frame to the next using a computer algorithm based on the vehicles' position and on known speed and lane changing behavior. This method was used in a study by UCLA and System Development Corporation (Ref. 7) to reduce vehicle trajectory data from aerial 70 mm films. Data were collected at three sites and the data reduced by the transformation of vehicle positions into digitized form. However, numerous problems were encountered in the vehicle matching algorithm, and an evaluation of the UCLA/SDC experience by Raudseps (Ref. 8) did not provide a great deal of optimism for this approach. This technique was also used in a study by Garner and Mountain in the U.K. (Ref. 9), but an approximate 85 percent matching rate was reportedly all that could be achieved.



Source .: Sequin, et. al., Traffic Evaluator System Users Manual, Volume 1-Overview and Field Acquisition Guide, FHWA Report FHWA/RD-82/078, February, 1983.

Figure 2. Typical Detector layout for Traffic Evaluator System

The data collection and reduction method adopted for this study involved an aerial photographic approach in conjunction with a microcomputer-based digitizing system. The key to the success of the system was the method of vehicle matching, which yielded complete vehicle trajectories for all vehicles passing through the sections studied. The matching method involved the digitizing of all vehicles within defined section limits on successive frames of film taken at one-second intervals. The system relied on the operators' ability to match vehicles based on four key characteristics:

- The order of the vehicles in the previous frame.
- The color of the vehicle.
- The type of vehicle.
- The vehicle's lane in the previous frame.

The operator was assisted in the matching process by error checks built into the computer software. The operator matching approach (with computer assist) is superior to the computer matching approach, as the operator/computer interaction allows many potential errors to be caught prior to entry of data into the working data files.

Some researchers have suggested that a fully automated system might be employed using the image recognition capabilities of video recording methods. While this method is conceptually attractive, both eliminating the need for operator matching and potentially accelerating the data reduction process, major advances need to be made in video resolution, image recognition, and matching algorithms before this technique would be feasible for the lengths of freeway sections being studied here. It is possible that video methods may be developed for application dealing with considerably larger scale images.

The aerial photography method employed in this study involved the use of a full-frame 35 mm motion picture camera operating in the time-lapse mode mounted in a fixed-wing, short-takeoff-and-landing (STOL) aircraft. The sites were filmed at one frame per second, with the aircraft flying clockwise at a slow speed around each site at altitudes ranging between 2,500 and 4,500 feet (760 and 1,370 m). Data were reduced for 1 hour of the film at each site, with sites ranging between 1,200 and 3,200 feet (370 and 980 m) in length. The sites included all six of the types of sections discussed in the introduction. The sections below describe the filming and data reduction procedures in detail.

AERIAL PHOTOGRAPHY

Initial Experiments

A series of pilot tests was conducted to test the aerial photography procedures prior to production filming. An overview of the pilot study filming is presented here, followed by a detailed account of the final aerial photographic procedures. Appendix B describes the procedures and results of the pilot study tests in more detail.

The aerial photography proved to be one of the more difficult aspects of the study, given the stringent filming requirements and the budget limitations. The purpose of the pilot study was to test various combinations of film formats and aircraft until an optimum filming method was achieved. Requirements for the filming were as follows:

- The same section had to be filmed continuously at one frame per second for approximately 1 hour and 15 minutes; 1 hour of data was to be actually reduced; sites were expected to be in the range of 2,000 feet (610 meters).

- The photography had to be as nearly vertical as practical to maximize the accuracy of the measurements of vehicle position.

- The film format had to be as small as possible for reasons of economy and yet be of high enough resolution for all vehicles to be distinguished.

Experimentation with the photography was begun with the concept of a light plane circling in a tight radius and testing both 16 mm and half-frame 35 mm film formats. (Note that a "half-frame" 35 mm film frame is half the size of a standard 35 mm slide, while a "full-frame" 35 mm film frame is the same size as a 35 mm slide.) A camera mount was constructed and affixed to the floor of the aircraft enabling the camera to be angled toward the ground as the aircraft was banked in a continuous circle around the freeway section being photographed. In this first experiment it was found that the aircraft (a Cessna 206) did not provide a stable enough platform and could not fly sufficiently slow to enable the photographer to keep the camera continuously on the section. The 16 mm film format was clearly unacceptable for the length of sections studied. The 35 mm half-frame format, although considerably better, was still insufficient to obtain the resolution required.

A brief experiment was also conducted using a hovering helicopter and 35 mm half-frame format. This configuration was also found to be impractical. Although 1 hour of film could conceivably be obtained with this method, ideal conditions of wind velocity and direction would be needed at every site to avoid overheating of the helicopter engine. These highly restrictive requirements, the cost of helicopter rental, and the inability to find commercial helicopter companies willing to fly under such conditions all contributed to the elimination of this method from further consideration. If it were possible to film safely and economically from a helicopter, that would be preferable to the circling technique used with a fixed wing aircraft, as accuracy in the digitizing process is easier to achieve when the section is being continuously filmed from approximately the same point. However, an alternative to the helicopter and the small fixed wing aircraft had to be sought.

The final experiment involved the use of a Heli Porter STOL (Short Take-Off and Landing) aircraft with a full-frame 35 mm film format. This aircraft proved to be considerably more stable as a filming platform than the Cessna and was able to hold a tighter radius around the site. Combined with the larger film format, this configuration proved to meet all of the filming requirements and was therefore adopted as the method to be used. Enough test film was shot in October 1982 to allow further development of the data reduction process. Although 70 mm film was considered in these experiments, the cost of the film and of projection equipment was substantially higher than 35 mm film, and only 40 minutes of continuous 70 mm filming could be obtained with the available film magazine size.

Final Filming System

The actual filming was undertaken in the spring of 1983 on freeway sections in both the Washington, DC and the Los Angeles metropolitan areas. A Helio-Courier STOL aircraft was used along with the 35 mm full-frame camera and a 1,000-foot film magazine. This magazine size enabled two sites to be filmed back-to-back in one flight, speeding up the filming process and reducing filming costs considerably. The camera was a Flight Research Model 207, equipped with an industrial grade Nikkor 35 mm focal length lens and auto exposure control. The auto exposure control was an important feature since angle of photography with respect to the sun was continuously changing. The frame number was superimposed on the film image. The camera was angled out the rear right-side door, and the camera operator was responsible for keeping the freeway section continuously in view. Figure 3 shows the aircraft, and Figure 4 illustrates the camera mounted in the aircraft.

The Helio Courier STOL aircraft was similar in characteristics to the Heli Porter aircraft referred to earlier, having a long wing span and wide wings, enabling it to fly safely at speeds as low as 30 to 40 knots. Wind speeds during the filming were generally maintained between 60 and 90 knots.

Appendix B discusses the analysis of film types for use in the aerial photography. A 35 mm color negative film (Eastman 5247) with a 250 ASA rating was selected. Color photography was needed to enable the operator of the digitizing system to distinguish vehicle color, as an aid in matching vehicles from one frame to the next. A negative, rather than a color reversal film was selected because:

- The workprint (positive), made from the negative, could be used in the projection equipment, enabling the original to be safely stored should the working copy be damaged.
- There is greater latitude in the exposure settings of color negative film.
- Additional high quality copies could be made, if desired.
- The per frame costs of purchasing and processing the film were actually less than for color reversal film (approximately $0.08 per full-frame 35 mm frame).

A relatively fast film was needed to allow the use of a rapid shutter speed (1/500 s) to minimize the blurring effects of both aircraft vibration and vehicular motion.

Site Selection

The sites selected for filming were chosen with the ultimate uses of the data sets in view. A set of criteria was established in summer 1982 for the purpose of selecting sites which would be most profitable for future research. The characteristics of both the site itself and the traffic conditions on the site were important. The site selection criteria were as follows:

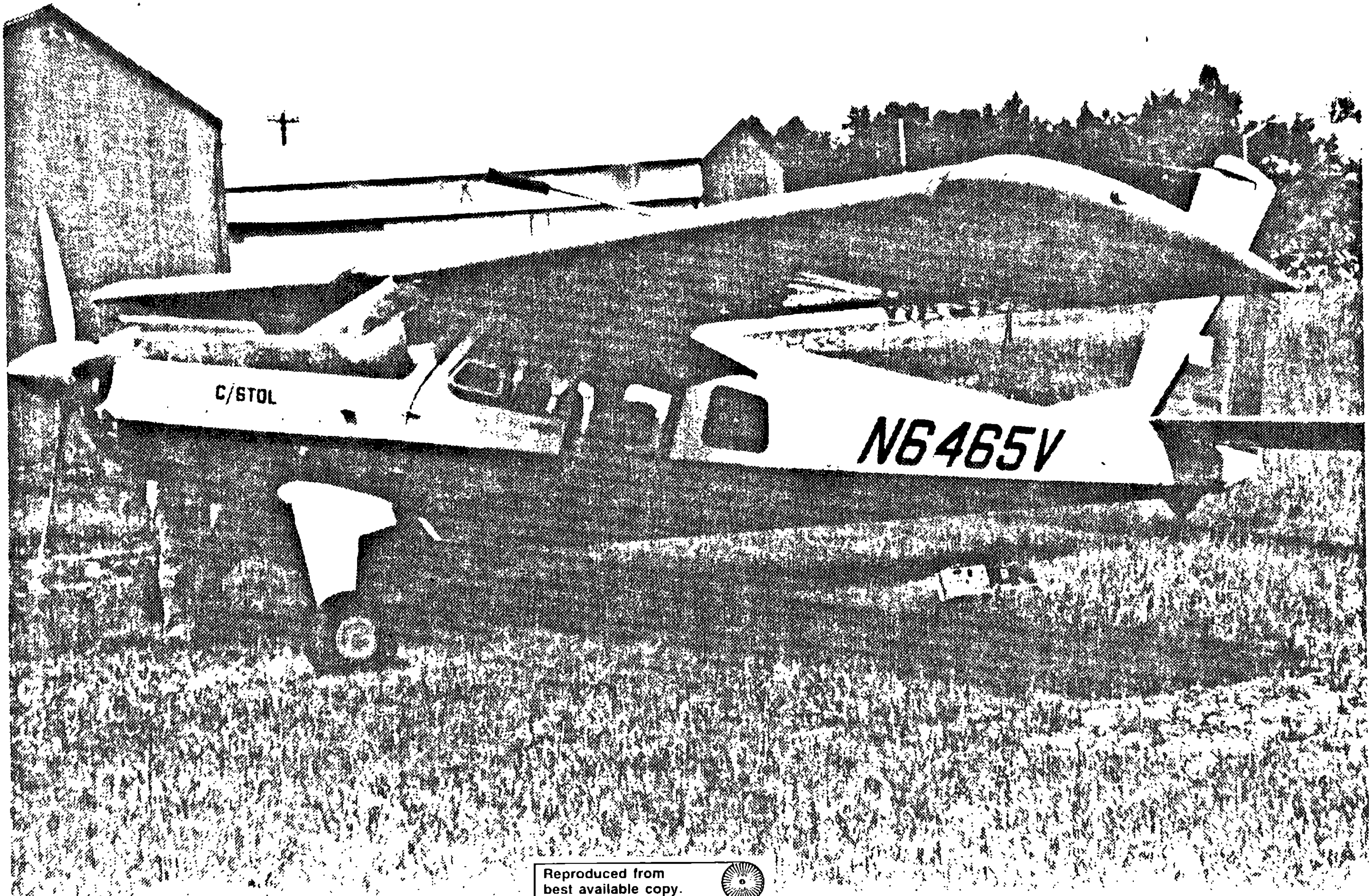


Figure 3. STOL Aircraft

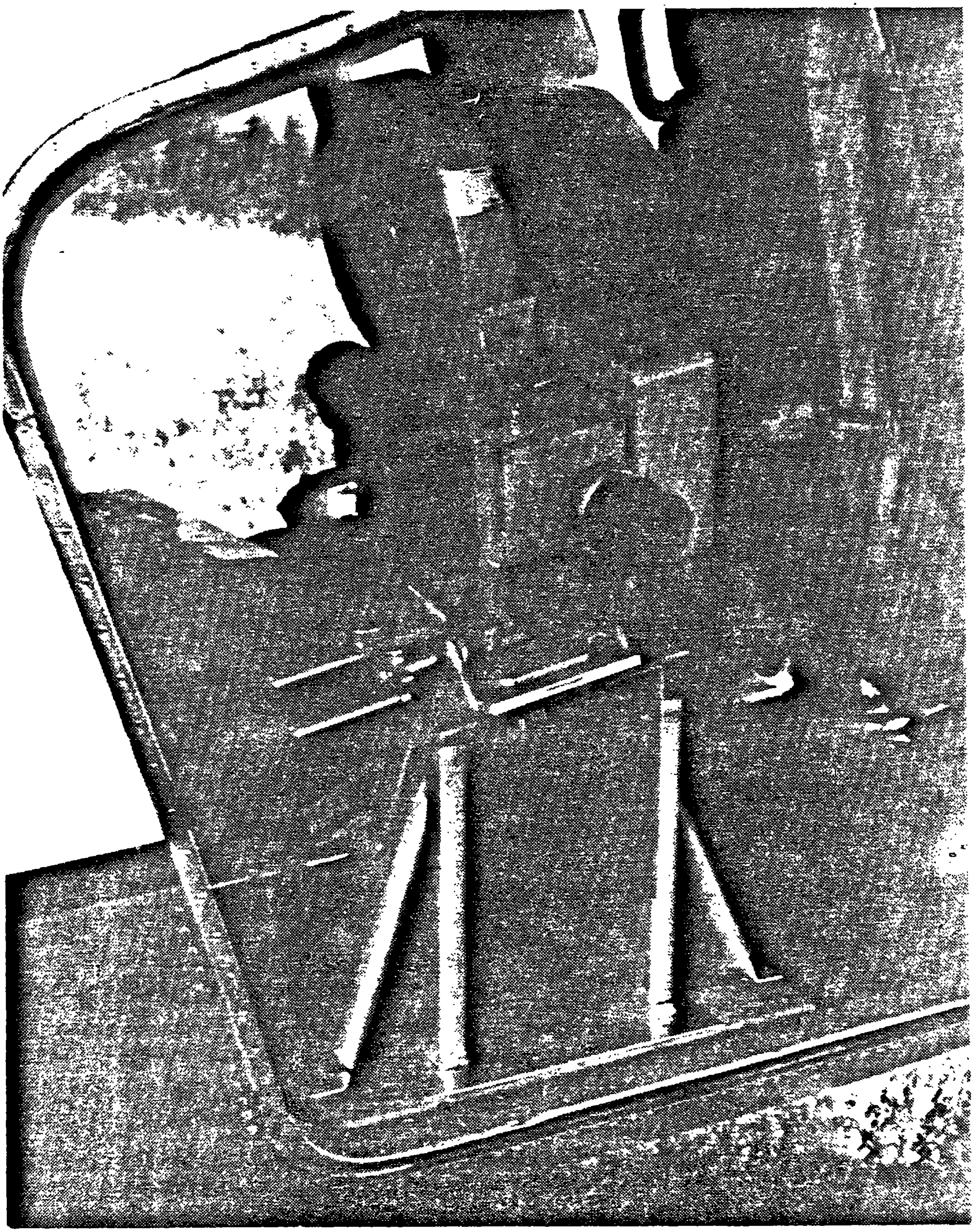


Figure 4. 35 mm Camera Mounted in Aircraft

- The site must consist of one or more of the following six geometric features: horizontal curvature, lane drop, ramp merge, reduced lane width and shoulder usage section, weaving section (one- or two-sided) or vertical grade.

- The geometric feature or features should be fully or partially the cause of recurrent traffic congestion. Where no congestion-causing site for one of the six geometric features can be found, a site with high traffic demand may be substituted.

- Traffic levels of service should be in the C to E range, depending on the type of site. For most sites an effort was made to include the transition period from uncongested flow to congested flow.

- There must be no condition downstream of the site which influences congestion within the site. In other words, there can be no backup from a downstream location into the site area.

- There should be few or no bridge structures passing over the site, and those that are present should not be so wide as to obscure vehicles from view in the films.

- For best film resolution, the site should generally be no longer than 3,000 feet (914 m). The average site was approximately 1,800 feet (548.4 m) long.

- The peak traffic time to be filmed must occur at a time when light conditions for filming are favorable. Film quality significantly deteriorates with low sun angles.

- Suitable locations must exist for establishing and placing control points.

- The site should not be so incident-prone that it is unlikely to be able to obtain satisfactory film footage of incident-free traffic flow.

Two metropolitan areas, Washington, DC and Los Angeles, California, were designated as the areas for which to look for acceptable filming sites. The site selection process included an initial identification of 54 sites, which were later screened down to the 18 sites which were actually filmed. Figures 5 and 6 show the locations of the sites initially identified in Washington and Los Angeles. The site numbers are keyed to Table 4, which indicates the characteristics of each site. Field reviews of the sites were conducted, and relevant traffic and geometric data were obtained in August 1982. Decisions on sites to be filmed were deferred until the pilot study was completed and the actual filming schedule was established. Table 4 indicates which of the candidate sites were actually filmed.

Filming Procedures

The pilot study filming was completed in October 1982. Following this, it was desired to more fully develop the data reduction system and demonstrate the feasibility of the entire data collection and reduction process prior to conducting more filming. In addition, the low light conditions and sun angles which prevail during the

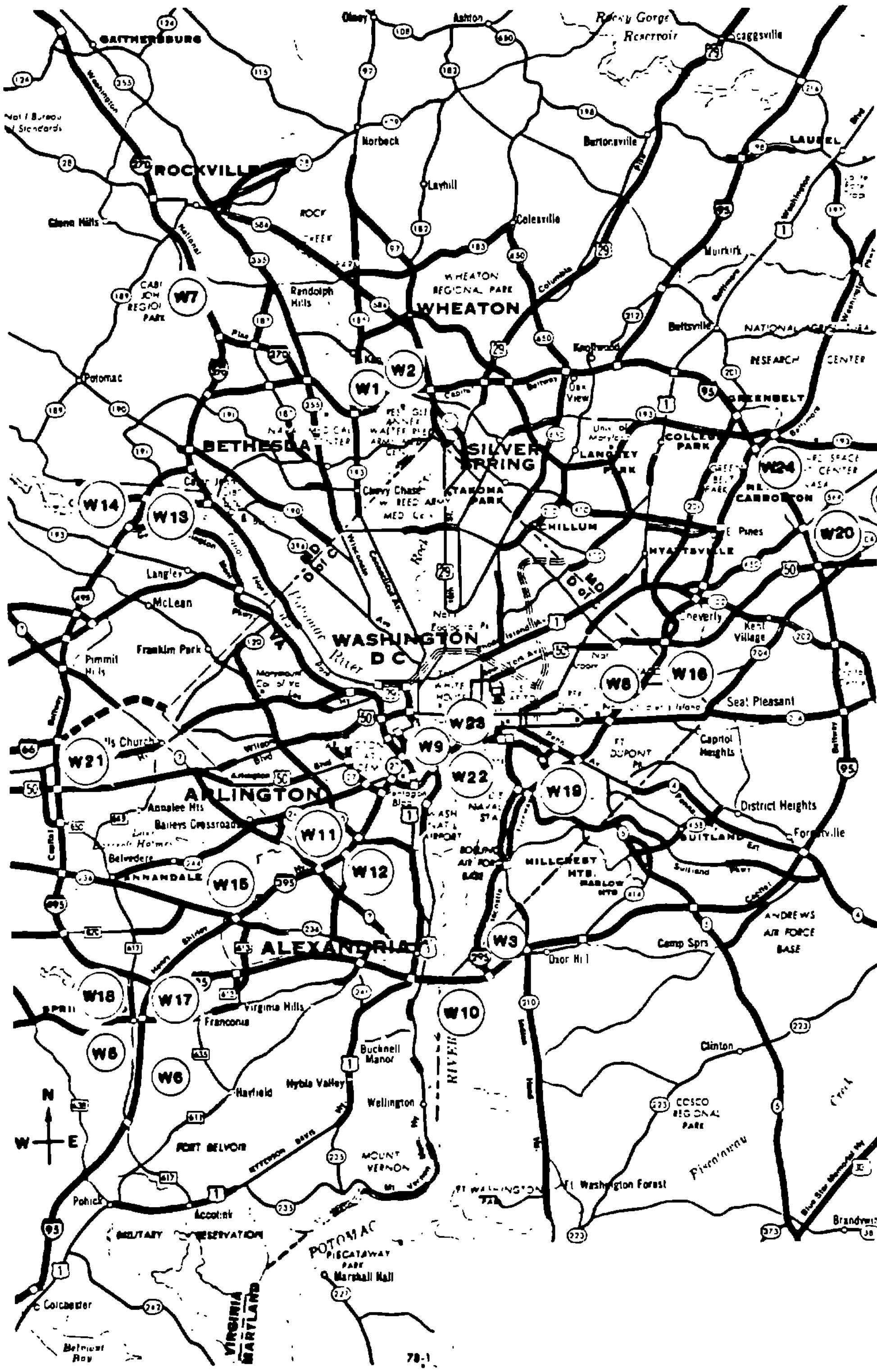


Figure 5. Location of Candidate Sites in the Washington D.C. Area

Figure 6. Location of Candidate Sites in the Los Angeles Area

Table 4. Listing of Candidate Sites

Note: Site numbers are cross-referenced to Figures 4 and 5. A "W" prefix indicates a site in Washington. An "L" indicates Los Angeles. An * indicates that the site was actually filmed.

Site Number	Location	Site Type
*W1	I-495 WB in Montgomery County at Mormon Temple (West of Georgia Avenue)	Horizontal curve
*W2	I-495 WB in Montgomery County west of Md. 97 (Georgia Avenue)	Lane drop
W3	I-95 SB in Prince George's County at Woodrow Wilson Bridge	Lane drop
W4	U.S. Route 50 in Prince George's County at Md. 197	Ramp merge
*W5	I-95 SB in Fairfax County, Virginia at Rt. 617 (Backlick Rd.) on-ramp	Ramp merge
W6	I-95 NB in Fairfax County, Virginia at 642 (Lorton Road) on-ramp	Ramp merge
W7	I-270 SB in Montgomery County at Montrose Road	Ramp merge plus one-sided weave
W8	I-295 NB in Washington, DC at Benning Road	Ramp merge (left side) plus reduced shoulder width
*W9	I-395 SB in Arlington, Virginia at 14th Street Bridge	Ramp merge and weaving section (one-sided)
W10	I-95 NB in Alexandria, Virginia at Woodrow Wilson Bridge	Reduced width section
W11	I-395 SB in Alexandria, Virginia between Quaker Lane and King Street	Reduced lane and shoulder width section
W12	I-395 NB in Alexandria, Virginia between Quaker Lane and Glebe Road	Reduced lane and shoulder width plus weaving section (one-sided)
W13	I-495 NB in Montgomery and Fairfax Counties at Cabin John Bridge	Reduced shoulder width and upgrade
W14	I-495 SB in Fairfax County between Cabin John Bridge and George Washington Parkway	Reduced shoulder width and upgrade section

Table 4. Listing of Candidate Sites (Continued)

Site Number	Location	Site Type
*W15	I-395 SB in Alexandria, Virginia between Holmes Run and Rt. 236 (Duke St.)	Vertical grade (4 percent)
W16	U.S. Route 50 in Prince George's County at Kenilworth Avenue	Weaving section
W17	I-95 NB in Fairfax County, Virginia between Rt. 644 (Old Keene Mill Road) and I-495 (Capital Beltway)	Weaving section (two-sided)
W18	I-95 SB in Fairfax County, Virginia between I-495 (Capital Beltway) and Rt. 644 (Old Keene Mill Road)	Weaving section (one-sided)
**W19	I-295 NB and SB in Washington, DC between Howard Road and 11th Street Bridge	Weaving section (one-sided) (both directions)
W20	U.S. Route 50 in Prince George's County between Md. 704 (Palmer Hwy.) and I-95 (Capital Beltway)	Weaving section (one-sided)
W21	I-495 NB in Fairfax County between U.S. 50 and I-66	Weaving section (two-sided)
W22	I-395 NB in Arlington, Virginia at 14th Street Bridge	Weaving section (two-sided)
W23	I-395 NB (Southwest Freeway) in Washington, DC between 9th Street and S. Capitol St.	Weaving section (two-sided)
*W24	Baltimore Washington Parkway NB at I-95	Weaving section (one-sided)
*L1	Rt. 11 (Pasadena Fwy.) EB at Marmion Way	Horizontal curvature/winding section plus reduced lane and shoulder width
*L2	U.S. 101 (Ventura Freeway) WB at White Oak	Lane drop - 5 lanes to 4 - lane dropped at off-ramp
L3	I-210 (Foothill Freeway) EB at Rosemead Boulevard	Lane drop 5 lanes to 4 lanes
L4	I-405 (San Diego Freeway) NB at Harbor Boulevard	Lane drop - 7 to 5 to 4 lanes

Table 4. Listing of Candidate Sites (Continued)

Site Number	Location	Site Type
L5	I-405 (San Diego Freeway) SB at Mulholland Drive	Lane drop - 5 lanes to 4
L6	I-5 (Santa Ana Fwy.) NB at I-605 (on-ramp NB at Slauson also a problem)	On-ramp merge (fwy to fwy)
L7	I-5 (Santa Ana Freeway) SB at Washington Boulevard	Ramp merge
L8	I-5 (Santa Ana Freeway) NB at Culver Road	On-ramp merge
L9	I-10 (San Bernardino Fwy.) EB at I-605 on-ramp	Ramp merge (fwy to fwy)
L10	Rt. 11 (Harbor Fwy.) NB at I-405 (San Diego Fwy)	Ramp merge (fwy to fwy)
L11	I-405 (San Diego Fwy) SB at Rt. 90	Ramp merge
*L12	I-405 (San Diego Freeway) SB at Santa Monica Boulevard	Ramp merge
*L13	I-405 NB (San Diego Freeway) at Roscoe Blvd.	Ramp merge
*L14	I-10 (Santa Monica Freeway) WB near La Brea Blvd.	Reduced lane width and shoulder usage sections
*L15	I-405 (San Diego Freeway) NB at Santa Monica Blvd.	Reduced lane width and shoulder usage
L16	I-5 (Santa Ana Freeway) SB at Brookhurst	Weaving section
L17	I-10 (San Bernardino Fwy) WB between Garvey Avenue and I-605	Weaving section
L18	I-10 (Santa Monica Fwy) WB between Maple Avenue on-ramp and exits to Rt. 11 (Harbor Fwy.)	Weaving section
L19	I-10 (San Bernardino Fwy.) WB between Atlantic and Long Beach Fwy. (Rt. 7)	On-ramp merge and weaving (one-sided)

Table 4. Listing of Candidate Sites (Continued)

Site Number	Location	Site Type
L20	I-10 (San Bernardino Freeway) EB at end of busway	Left-sided lane drop and weaving section (two-sided)
L21	Rt. 11 (Harbor Fwy.) SB auxiliary lanes between 6th and I-10 (Santa Monica Fwy.)	Weaving section (two-sided). There are actually four two-sided weaves on various auxiliary lanes at this interchange
L22	Rt. 11 (Harbor Freeway) SB between U.S. 101 and 6th Street	Weaving section (1-sided multiple weaves)
*L23	Rt. 11 (Harbor Fwy.) NB between I-10 (Santa Monica Fwy.) and 6th Street	Weaving section
L24	U.S. 101 (Hollywood Fwy.) NB between Vermont and Melrose	Weaving section
L25	U.S. 101 (Santa Ana Fwy.) SB between San Bernardino Fwy. and 1st Street	Weaving section
L26	U.S. 101 (Santa Ana Fwy.) SB between Vignes Street and Mission Road	Weaving section
L27	U.S. 101 (Hollywood Freeway) NB between Highland and Cahuenga Boulevard	Weaving section (two-sided); also on grade
*L28	Rt. 101 (Ventura Fwy.) WB between DeSoto and Canoga	Weaving section
L29	U.S. 101 (Hollywood Freeway) SB between Ventura Freeway and Vineland	Weaving section (could be classified as two-sided)
L30	Rt. 134 (Ventura Fwy.) EB West of Rt. 2 (Glendale Fwy.)	Vertical grade
*L31	I-405 (San Diego Fwy.) NB between Sepulveda and Mulholland	Vertical grade
*L32	U.S. 101 WB between Topanga Canyon Blvd. & Ventura Blvd.	Weaving section (construction site)

peak traffic periods in late fall and through the winter months made any filming during that time impractical. Therefore, the filming was scheduled for the May to June 1983 period, pending the results of the digitizing system evaluation.

Between May 25 and June 17, 1983, a total of 18 freeway sites were filmed, 8 in Washington and 10 in Los Angeles. The following numbers of sites were obtained:

- Weaving sections (7 sites - not all under the preferred traffic conditions).
- Ramp merges (3 sites).
- Reduced width sections (2 sites).
- Upgrades (2 sites).
- Horizontal curves (2 sites).
- Lane drops (2 sites - not all under the preferred traffic conditions).

Filming was conducted primarily in the p.m. peak traffic periods. In some cases, especially in Los Angeles, traffic volumes were heavy enough to require filming in mid-afternoon, to begin filming prior to the onset of congestion. No sites were filmed in the a.m. peak period due to the low sun angles which existed at the times the filming would have to be begun to capture the transition period between uncongested and congested traffic. The selection of the time at which to begin filming was the most difficult part of the scheduling process. An effort was made to start the filming of each site at a time which would have the most likelihood of capturing the transition period between congested and uncongested flow. Traffic flow at each site was carefully studied to choose this start time. Although the desired traffic characteristics were obtained at most of the sites, several of the sites did not break down at the expected time, possibly due to upstream incidents or to normal variations in traffic demand. Filming had to be terminated or redone at two sites due to downstream incidents, which caused traffic to back up into the section being filmed.

Prior to the filming, a set of targets, which would be visible in the film, were set out on the right shoulders of each direction of travel on the freeway sections being filmed. The purpose of the targets was to establish a ground coordinate system in the plane of the roadway which could be used in the digitizing process to calibrate the scale and orientation of each photograph. The targets consisted of 3- to 4-foot squares of dayglow orange plastic material with nylon mesh and were nailed to the pavement the day of or day before the filming. They were reinforced at the corners with nylon strapping tape to minimize the chance of being torn loose where they were nailed to the pavement. Typically, four pair of targets were laid out on each section to be filmed. Only two targets were lost between the time of their placement and the filming of the freeway sections.

The relative position of the targets was established through a ground survey. Longitudinal distances were measured along the plane of the roadway using a steel tape or measuring wheel. These distances were measured twice to verify their accuracy. Lateral distances across the roadway were obtained by either shooting stadia with a theodolite or from measurements taken from the roadway plans. The accuracy of these measurements and the proper calibration of the film in the digitizing process are the primary determinants of the accuracy with which the digitized data sets replicate traffic flow. Each pair of control points were generally located across from one another, except where control point locations would be obstructed from view in the film by tall trees near the highway right-of-way. For some of the tangent sections, it was possible to simplify the survey by using all right angles and locating control points with a right angle prism. The field notes from these surveys were used to establish a ground coordinate system for each site filmed.

DATA REDUCTION

Digitizing System

The system initially envisioned to perform the data reduction was to be designed around a microcomputer, digitizer, and film projector. This concept was maintained throughout the development of the system, but substantial enhancements of this basic concept were needed to produce a working system. Appendix B discusses the various stages of development of the digitizing system.

The final data reduction system consisted of a digitizing tablet and processor, a microcomputer and terminal, a voice synthesizer and a 35 mm full-frame filmstrip projector. The system components are illustrated in Figure 7. A SAGE IV microcomputer with 512 k bytes of memory and an 18 megabyte hard disk was used and UCSD Pascal was employed as the programming language. The microcomputer was operated under a multiuser configuration, enabling two digitizing systems to be operated simultaneously. The second digitizing tablet was needed to reduce the total time required to reduce the data from the films.

A digitizer consists of a digitizing tablet and processor, the function of which is to transmit the X and Y coordinates of any point on the tablet to a computer, when so instructed by the operator. The characteristics of the two digitizing units used in the data reduction process were as follows:

- Calcomp Series 6000, active area 30 in by 40 in (76 cm by 102 cm); resolution to .001 in (.0025 cm), RS232 interface; rear projection; electrostatic principle.
- Calcomp Series 9000, active area 24 in by 24 in (61 cm by 61 cm); resolution to .001 in (.0025 cm); RS232 interface; front projection, electromagnetic principle.

Figure 8 is a photograph of one of the digitizing tablets. The digitizing board is complemented by a microprocessor unit, an RS232 interface, a firmware package, and a 16-button cursor, shown in Figure 9. To digitize a point, the cursor crosshairs are positioned over the point to be digitized and 1 of the 14 eligible buttons is pushed. The eligible buttons are "0-9" and "A-D". The remaining 2 buttons, "#" and "*", are used for special functions. The pushing of a button on the cursor (use the "1" button as an example) with the cursor placed on the digitizing surface returns the following:

1,+00.000,+00.000 followed by a carriage return/line feed.

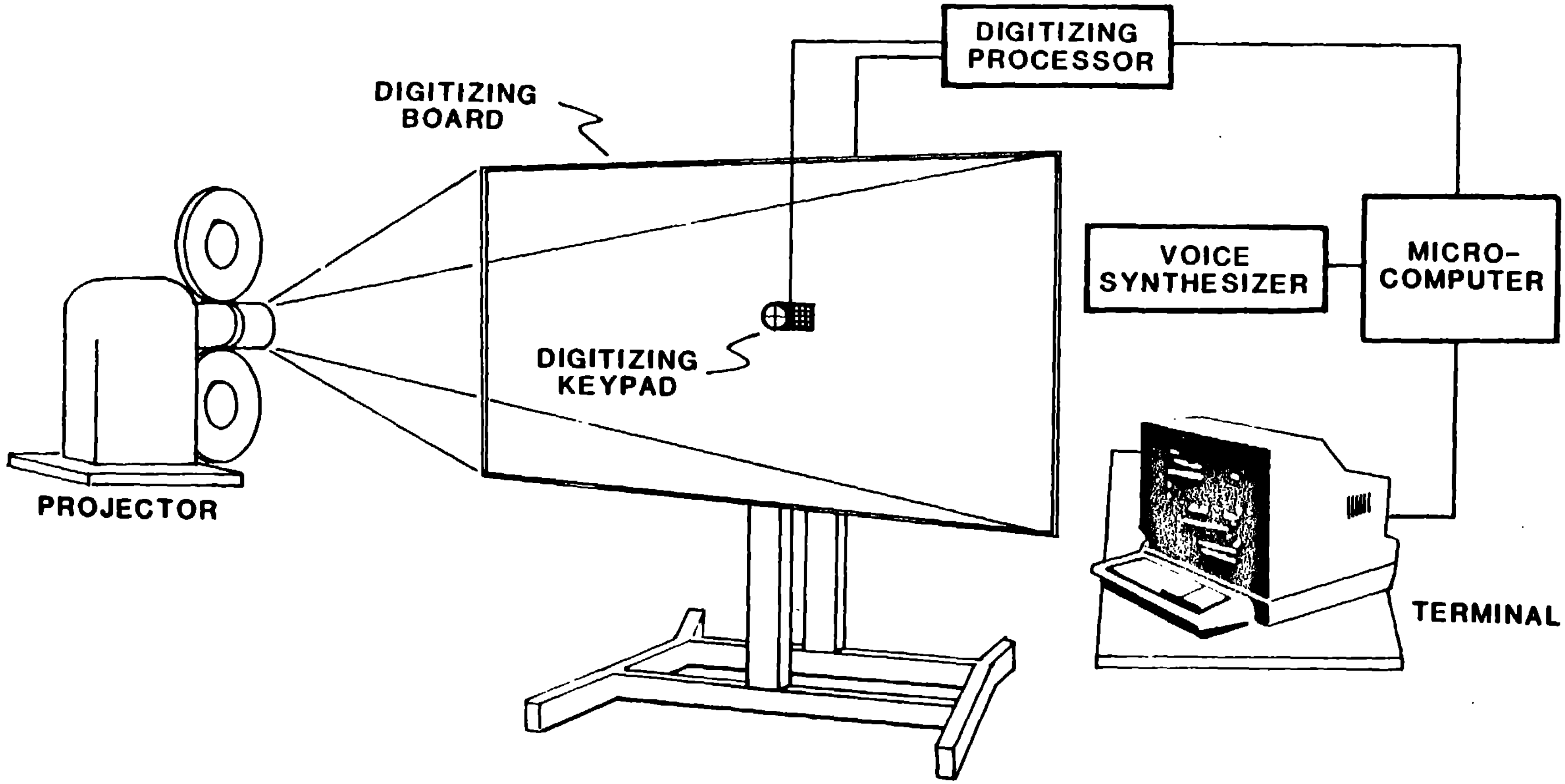


Figure 7. Schematic of Digitizing System Components

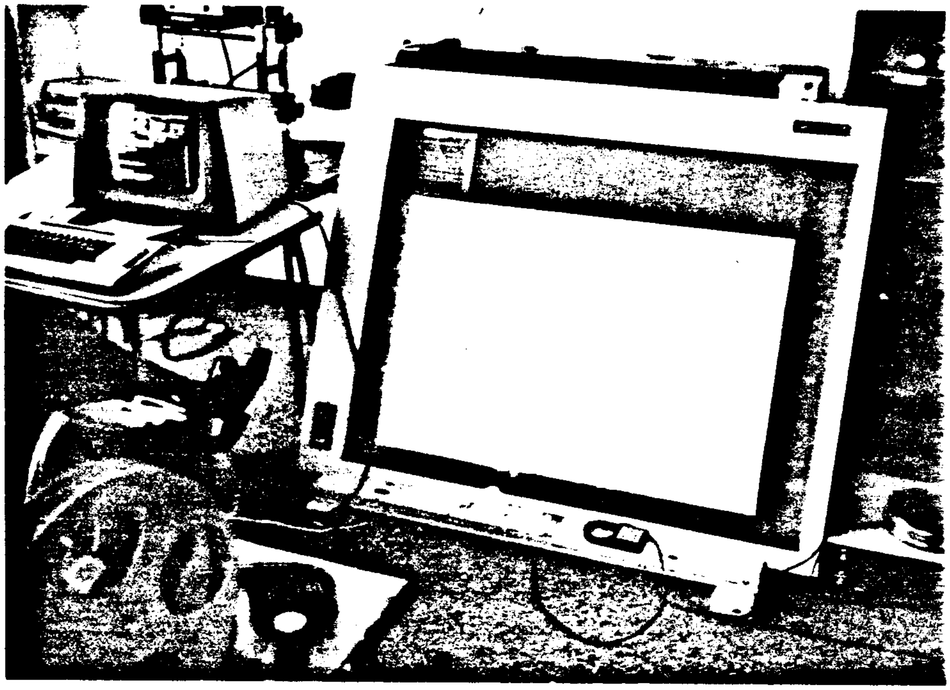


Figure 8. Photograph of Digitizing System Components

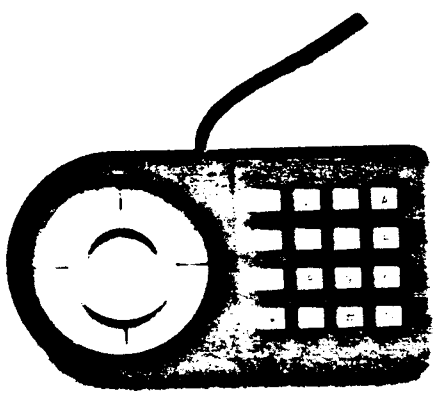


Figure 9. Close-Up View of Digitizing Curser Pad

The x and y coordinates are transmitted, in that order, to the nearest .001 in (.0025 cm). Additional characters of the operator's choosing can be transmitted directly to the current record by pressing the "*" key, followed by the selected characters and another "*". A 63-character menu can be attached to the digitizing surface. Placing the cursor over a particular character on the menu will return that character. A variety of other options, such as rescaling and area computations are available. The operation of the system is fully documented in manuals supplied by the manufacturer.

For the 35 mm projector, it was determined that a filmstrip projector would be adequate for the study, since there was no need to view the film in motion picture fashion. This considerably reduced the cost of the viewing equipment. However, a special filmstrip projector was needed to view the full-frame 35 mm film, since most filmstrip projectors are designed to accommodate half-frame rather than full-frame film. An Apollo Viewlex V-25 projector was chosen for film projection. This system was equipped with a remote control advance, enabling the operator to advance the film while sitting at the digitizing tablet. The projector used a 3-in (76-mm) focal length flat field lens, and was located approximately 6 feet (1.8 m) in front of the digitizing tablet surface. The projector was positioned so that the line passing through the center of the lens was perpendicular to the surface of the digitizing tablet. The rear projection feature of the digitizing tablet was not used, as it was found that a sharper image could be achieved by projecting from the front onto a clean white sheet of paper taped to the digitizing surface. The operator was able to keep from obscuring the projected film image by offsetting his or her head from the projection line. No parallax error was introduced since the cursor crosshairs are essentially flush with the digitizing surface when the cursor pad is placed on the tablet. Five-hundred watt bulbs were used to provide good resolution and color from the projected image. Typical bulb life was 30 hours. Replacing bulbs was one of the major ongoing operational expenses.

The final component of the digitizing system was an Echo GP general purpose speech synthesizer, manufactured by Street Electronics Corporation. The speech synthesizer translates any string of ASCII characters into audible sounds resembling human speech. This device was used to enable the system operator to receive instructions from the computer without having to take his or her eyes off the digitizing tablet. The speech synthesizer was primarily required to pronounce information on vehicle color, type, and lane number. Since many words in the english language are not pronounced phonetically, some of the words used in the software had to be respelled to produce a sound closer to the intended word. For example, the word "VEHICLE" had to be spelled "VEEICKL" to obtain a sound close to the standard pronunciation.

Software Development

The key components of the data reduction process are the algorithms used to compute vehicle position and the method of tracking vehicles through the section. A two-stage process is used to compute vehicle position. First, a photogrammetric technique is used to translate the X-Y coordinates digitized from the projected film image (which is in a perspective view) into the coordinate system of the ground established with the control points (plan view). The specific technique used is termed "projective transformation" and involves the use of four control points and eight simultaneous equations to compute the coefficients of equations which are, in turn, used to compute the X and Y coordinates of the ground plane for any digitized point on the film. This technique has been well described in other publications (Ref. 9 & 10).

The algorithm used to transform film coordinates to ground coordinates was derived from a FORTRAN program written by Bleyl and documented in reference 10. Appendix C contains the article in which that program appeared, and should be referred to for more details on this particular procedure. The validity of the algorithm was checked by digitizing points of known position in the ground plane other than the four control points used in the original calibration.

Figure 10 illustrates the relationship between the plane of the film and the plane of the ground, showing how the digitized position of a vehicle would be translated from one plane to another. The primary rule governing the establishment of the control points is that they lie in the same plane and that the plane follow the vertical alignment of the highway as closely as possible. All vehicles or points digitized will thus take on the coordinates of that plane. If significant changes in vertical alignment occur within a section, separate planes, with separate sets of control points, would be needed to adequately carry out the transformation to ground coordinates. Any points digitized which are not in that plane will introduce a parallax error if the point is not being viewed directly from above. This was particularly important for this study as all highway sections were photographed at an oblique angle.

Other rules governing the use of control points included the need to maintain all of the internal angles of the quadrilateral reasonably close to right angles and to make all sides of the quadrilateral of sufficient length. It was found that the width of the highway did not generally provide sufficient length laterally between control points to enable stability to be achieved in the film-to-ground coordinate transformation. Therefore, a new set of control points was often established on one side of the highway using points outside the highway right-of-way which were also visible in the film (e.g., corners of rooftops) and which were roughly within the plane of the highway.

Figure 11 illustrates a typical control point setup. Points A through H represent the original set of control points surveyed in the field. Four of those points, such as A, C, E, and G might be used to perform the first calibration of the film. Accordingly, these points would be digitized from the first film frame. From this initial calibration, the X-Y coordinates of any point in the same plane defined by ACEG could be established. In the example in Figure 11, two alternate control points (corners of rooftops - points I and J) were found outside the right-of-way at roadway level and their positions were established from ACEG so that they could be used in the film-to-ground coordinate transformations for future frames.

A fifth point (point B, in this example) was always chosen to serve as a checkpoint to ensure that each frame had been properly calibrated. If the coordinates of this point did not fall within an acceptable range, the frame was recalibrated. In addition, it was found that two of the control points should always be located close to the edge of the roadway being studied (e.g., within 10 to 20 feet (3 to 6 meters)), as illustrated by points A and C in Figure 11. The reason for this is that errors in position of points digitized are likely to be greater the further one gets from a control point. The further away from the road edge the control points are, the more likely the lateral positioning of the vehicles will be in error. In the longitudinal dimension, the maximum error is likely to occur midway between control points A and C in Figure 11.

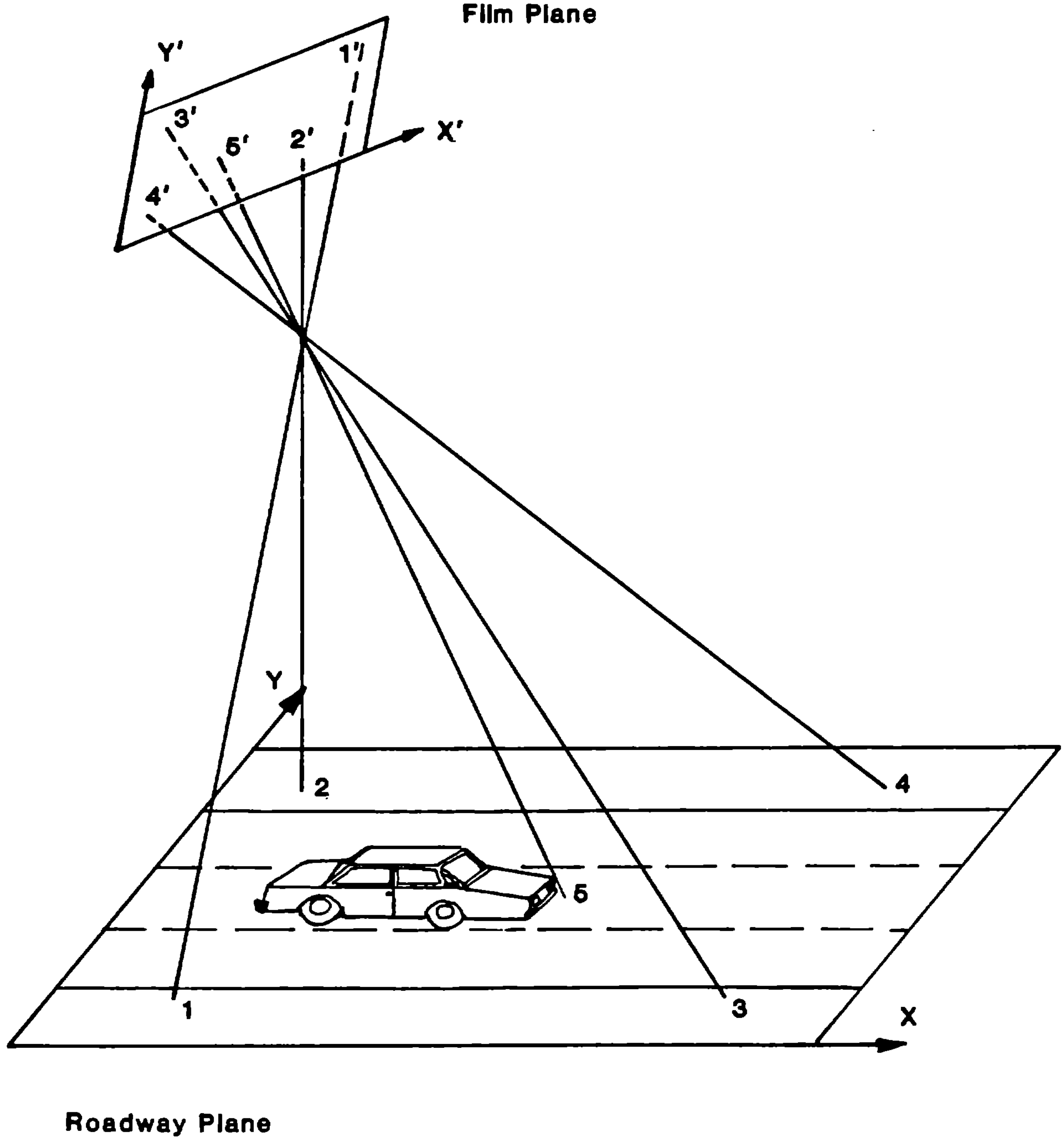


Figure 10. Relationship of Points in Roadway Plane to Points in Film Plane

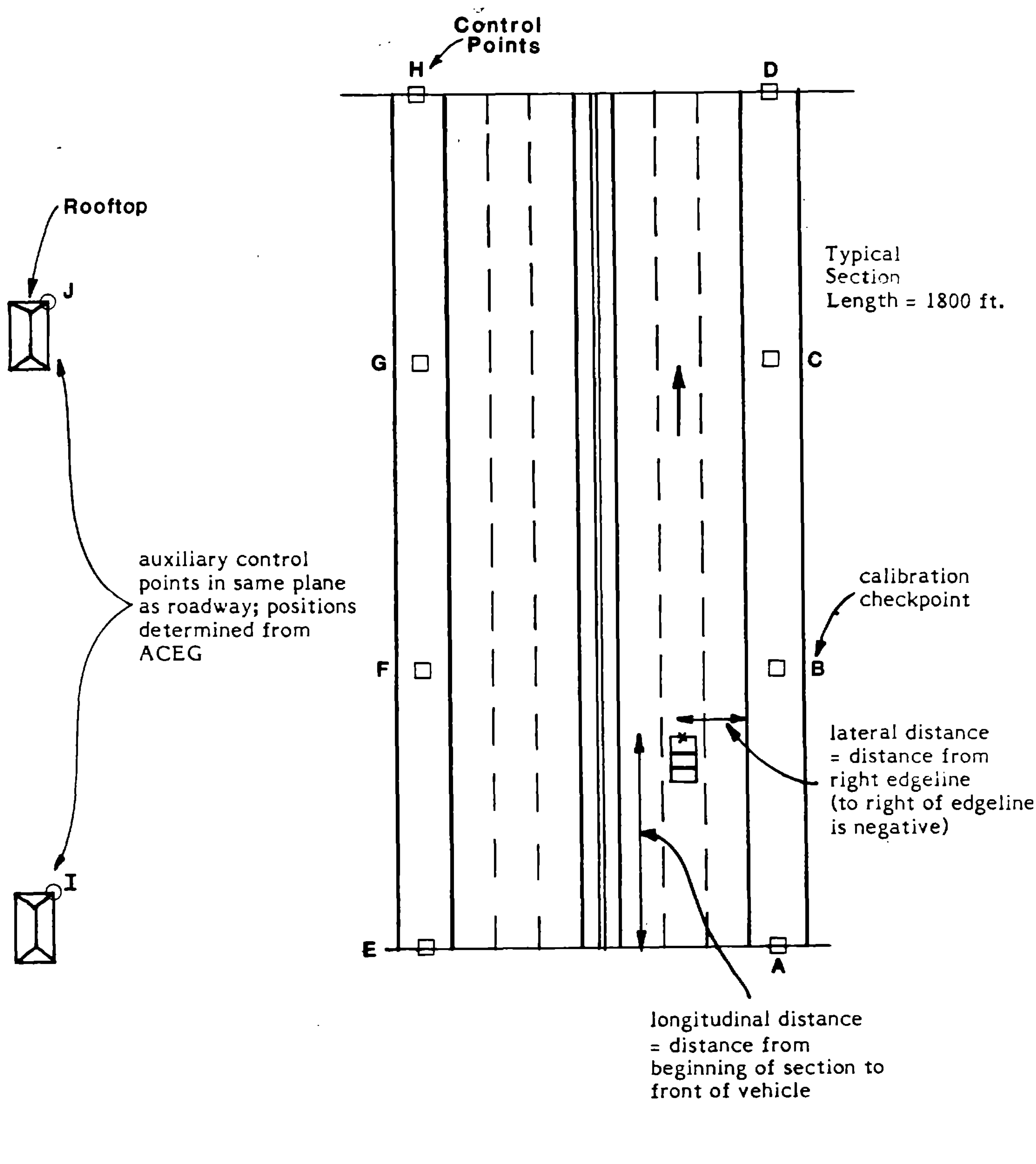


Figure 11. Example Control Points Setup and Vehicle Location Conventions

The second coordinate transformation process involved translating the coordinate system of the ground into the coordinate system of the highway. The highway coordinate system was established to follow the horizontal alignment of the highway. The longitudinal axis was parallel to the highway centerline, coinciding with the right edge of the mainline, and the lateral axis was always perpendicular to the longitudinal axis. The longitudinal coordinates began with zero at the upstream end of the section and ended at the downstream end of the section. The lateral coordinates were measured from a longitudinal baseline, defined to be at the right edge of the mainline. The positive direction was defined as being to the left, and the negative direction was to the right, so that the positions of any vehicles on an off-ramp or on-ramp would take on a negative value. The vehicle location conventions are illustrated in Figure 11.

The mathematics used to translate ground coordinates to highway coordinates were based on standard trigonometric equations used in highway design. More details on the mathematics are provided in Appendix D. Subsections were defined by highway sections with homogeneous geometry. A number of the sections were either entirely tangent or entirely curved throughout, while others required up to three subsections. Appendix I presents the source code for the computer program used on the SAGE IV, written in UCSD Pascal. Appendix I together with Appendix H are contained in a separate volume describing the setup and operation of the digitizing system.

Digitizing Procedures

The digitizing process is illustrated in simplified form in Figure 12. The figure shows the basic iterations involved, but does not show the error checking and correction features, the initial creation of the geometry profile and other more detailed aspects of the process. The operator's manual, contained in Appendix E, describes the digitizing process in more detail. There are some activities which are performed only at the beginning of each film and others which take place once each frame. At the beginning of each film, the ground coordinates of the control points, as obtained in the field surveys, are hard-coded into the computer program. Following compilation, the program is executed and the four control points digitized. Given a satisfactory calibration, the geometry of the highway section is digitized. Each tangent segment requires two digitized points and each horizontal curve segment is fit through three digitized points. A file containing the essential descriptors of the highway geometry is created and stored for use in subsequent frames.

The first frame begins by the operator's digitizing the front and back of all vehicles within the section, beginning at the downstream end. Each vehicle's color, type, and current lane number are entered, proceeding from vehicle to vehicle in an upstream direction, until all vehicles in the first frame have been digitized. All errors are corrected, and the operator ends the digitizing of that frame by entering an exit code after which the vehicles are sorted by longitudinal position and the data written to a file on disk. The digitizing of each subsequent frame of film begins by entering the next frame number to be digitized. The 4 control points are then digitized, and following a computer calibration, a fifth point with known position is used to check the calibration.

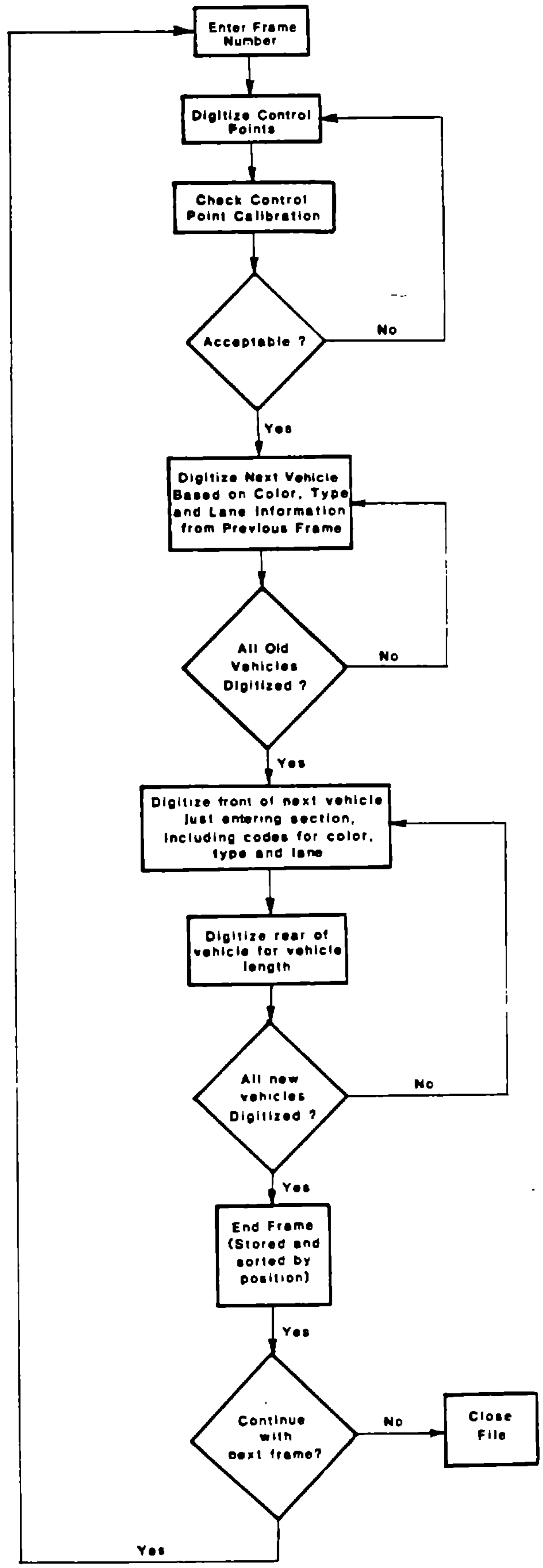


Figure 12. Overview of Digitizing Process

Following a successful calibration, the computer recalls the most downstream vehicle digitized in the previous frame and, through the voice synthesizer, prompts the operator with several items of information: 1) the color of the vehicle, 2) the vehicle type, and 3) the number of the lane in which the vehicle was positioned in the previous frame. Based on this information, the operator finds the vehicle matching that description, beginning the search at the downstream end of the section. The cross-hairs of the digitizer's cursor pad are placed over the center of the front bumper of the vehicle, and the key corresponding to the current lane number of that vehicle is depressed. The depression of the key on the cursor pad transmits the X-Y coordinates of that point on the projected film image along with the lane number to the computer. A vehicle may have changed lanes since the last frame, so that the lane number may have also changed. The computer then performs the film-to-ground and ground-to-highway coordinate transformations and performs a series of checks to screen out possible errors made by the operator (particularly digitizing the wrong vehicle). Provided the computer finds no errors in the operator's digitizing of that vehicle, a new record is created in the vehicle file. The new record includes the frame number, a unique ID for that vehicle, the vehicle's lateral and longitudinal position, and other data such as the vehicle's color, type and length. The computer then prompts the operator with the next upstream vehicle, which the operator then locates in the current frame, just as was done with the first vehicle. The digitizing proceeds in the upstream direction until all of the vehicles which appeared in the previous frame are digitized in the current frame. Vehicles which are entering the section for the first time are then digitized. The vehicle color and type are entered along with the lane number, using the digitizer's cursor pad. Vehicle length is also obtained by digitizing the rear of the vehicle the first time it enters the section.

The accuracy of the longitudinal and lateral position is dependent on a multitude of factors. The most important control on errors is in the placement of the control points and the accuracy of the ground measurements taken. Ideal control point configurations are not always possible. As the points being digitized become farther from either of the control point pairs, the higher the error is likely to be. Points digitized close to a control point will be subject primarily only to errors by the operator in placing the cross-hairs of the cursor over the true position of the vehicle. These errors are typically 2 feet (.6 m) or less. Errors arising from control point calibration are typically greater in the longitudinal dimension than the lateral dimension since the distance from a control point is likely to be greater in the longitudinal than the lateral dimension. The overall positional error is estimated to be within plus or minus 5 feet (1.5 m) in the longitudinal direction and plus or minus 3 feet (0.9 m) in the lateral direction.

The prompting of the operator by the computer is done primarily through a general purpose speech synthesizer. The vehicle color, type, and lane number of the next vehicle to digitize is given audibly, enabling the operator to continually keep his or her eyes on the projected film image, rather than having to look back and forth between a CRT screen and the digitizing surface. When an error or special situation is encountered, a message is sent to the operator through the speech synthesizer to look at the CRT screen, where additional information is displayed. The speech synthesizer not only saves substantial amounts of time in the digitizing process, but also reduces both operator fatigue and the probability of error.

Personnel

Temporary personnel were employed to serve as operators of the digitizing system. Most of the employees were students at local colleges and universities. Each operator was given a training session of approximately 4 hours, and was carefully observed during the initial stages of operation until the quality of their data was assured of being up to expected standards.

Originally, there was substantial concern that the tedious aspects of the digitizing process would quickly create operator fatigue, enabling digitizing to proceed only for relatively short periods before a break was needed. However, it was found that the digitizing was considerably less fatiguing than expected, and that many of the operators could work a full 8-hour day with only the normal breaks. This can be partially attributed to the voice synthesizer, which eliminated having to continually refocus one's eyes between the film image and CRT screen.

The two digitizing tablets were used simultaneously in the same room and run from the same computer. Operations were not noticeably slowed when both systems were in use. However, the operators were required to wear earphones from the voice synthesizers to avoid confusing the message from each other's systems. Each digitizing tablet was used approximately 60 hours per week to further accelerate the schedule. Even at this rate, the digitizing of the 14 films took approximate 18 months, averaging approximately 2 months per film.

The digitizing rate varied with the quality of the film. Sections with asphalt pavement tended to be more difficult to digitize because of the greater difficulty in seeing dark-colored vehicles on the dark pavement. Better contrast was achieved on concrete pavements, especially those which had been heavily travelled and had both dark and light tones. Digitizing vehicles which had been previously digitized could be accomplished at a rate of approximately 5 seconds per vehicle. New vehicles just entering the section could normally be digitized in 20 seconds, including the color, type, and length information. Entering the control points at the beginning of each frame could be done in approximately 30 seconds. Thus, the time to digitize one frame would depend primarily on the number of vehicles within each frame which, in turn, is dependent on the section length, number of lanes, and traffic density. The time to digitize one frame of film would ordinarily take between 4 and 12 minutes, depending on these factors and assuming minimal need for error correction. Error correction is handled through an error correction menu on the CRT screen, which enables the operator to modify an entry, restart the frame at any point, delete an entry, and other options. The number of errors and time to correct an error is dependent on a number of factors, primarily film quality and operator proficiency.

3. DESCRIPTION OF DATA SETS

Chapter 3 provides the description and documentation of the freeway traffic data sets created as a result of the filming and digitizing process. The following topics are discussed:

- Format of the data files.
- Overview of the data sets available.
- Guidelines and precautions for analysis of data.

FORMAT OF DATA FILES

Figure 13 shows the format of the microcomputer data file created as a result of the digitizing process. The section shown is from an upgrade section with five 11-foot lanes, filmed in Los Angeles. The distance of each vehicle from the beginning of the section is shown in field 6, and the lateral position is shown in field 7. If vehicles are traveling in the center of the lane, the value in field 7 should be approximately equal to 11 times the lane number minus 5 to 6 feet (half a lane). Speeds are shown in field 5. Records with a zero speed represent vehicles which had only been digitized once at this point in the file and therefore could not have developed a speed history. As indicated, the file is organized by frame number, with vehicles ordered sequentially from the downstream to upstream end.

For each film there are approximately 3,600 frames to be digitized (1 hour at one frame per second). The number of vehicles within the section may range between 25 and 130, depending on the section and traffic characteristics, but will typically be in the 50 to 60 vehicle range. Thus, the average size of a data set might be nearly 200,000 records, but certain data sets may be half that size while others may be twice that size.

Following the creation of the microcomputer data files, an editing of those files was conducted. During the course of a film, several types of errors might have occurred which could not be corrected using the computer software. The most common of these types of errors was the entry of an apparent vehicle into the data set in one frame which was found not to be a vehicle but a speck or a shadow in a subsequent frame. In other cases the wrong vehicle type code might have been assigned to a vehicle in the frame in which the vehicle entered the section. These errors were corrected through the screen editor on the SAGE IV.

The data files were assembled in stages, beginning with the individual microcomputer files. One microcomputer file might consist of between 5 and 30 frames of data. These files were concatenated in the process of being telecommunicated to a mainframe computer. A software communications package was used to control the transmission of the data through a 1200 baud modem. The typical data set was composed of 120 to 400 individual files of approximately 25,000 bytes each. The data were sent via telephone line to a mainframe computer (IBM 370) at the National Institutes of Health, Bethesda, Maryland, and concatenated into larger

FIELD NUMBERS

1	2	3	4	5	6	7	8	9
53	125	1	14	59	234	50	3	5
53	121	1	17	46	199	7	7	1
53	126	1	15	48	146	6	6	1
53	127	1	18	46	106	19	6	2
53	128	4	19	0	28	8	1	1
54	82	1	12	48	1248	6	3	1
54	86	1	13	47	1240	25	6	3
54	92	1	18	57	1234	36	4	4
54	93	1	16	52	1165	48	2	5
54	94	1	14	52	1150	30	2	3
54	95	4	13	55	1111	49	9	5
54	91	1	17	46	1074	26	7	3
54	90	1	12	46	1055	4	1	1
54	97	1	16	55	1035	38	8	4
54	96	1	20	48	964	27	2	3
54	98	1	14	52	946	15	3	2
54	99	1	15	52	941	48	2	5
54	101	4	19	52	900	16	9	2
54	105	1	15	61	870	36	8	4
54	100	1	20	52	847	16	2	2
54	103	1	12	52	846	5	7	1
54	104	1	19	55	843	50	2	5
54	102	1	18	48	790	26	2	3
54	106	1	19	55	782	49	7	5
54	108	4	22	52	683	26	4	3
54	111	1	13	59	677	49	2	5
54	107	1	19	47	667	16	2	2
54	110	1	19	50	609	24	4	3
54	115	1	16	59	589	39	2	4
54	109	1	13	44	587	16	2	2
54	113	1	15	50	540	28	3	3
54	114	4	16	52	509	5	9	1
54	112	1	15	46	492	16	3	2
54	116	1	17	50	444	5	4	1
54	118	1	12	55	431	48	7	5
54	119	1	16	48	347	4	1	1
54	124	1	16	55	335	36	2	4
54	125	1	14	58	319	49	3	5
54	120	1	11	48	316	27	7	3

KEY TO FIELD NUMBERS

1 – FRAME NUMBER

2 – VEHICLE ID

3 – VEHICLE TYPE CODE

4 – VEHICLE LENGTH (FEET)

5 – SPEED (MPH)

6 – DISTANCE FROM BEGINNING OF SECTION TO FRONT OF VEHICLE

7 – DISTANCE FROM RIGHT EDGELINE TO MIDDLE FRONT OF VEHICLE

8 – VEHICLE COLOR CODE

9 – LANE NUMBER (RIGHT LANE=LANE 1)

Figure 13. Sample Record Format of Digitized Data File

files which could still be managed by the mainframe's editor. Any remaining editing was done on the mainframe, and the mainframe files (10 to 30 files for each data set) were concatenated into a single sequential data file on 9 track 1600 bpi labeled magnetic tape. In addition to the vehicle data file, a file containing data base documentation and the geometric information, coded in INTRAS format, was also created for each data set. The geometry data file and vehicle data file are contained on a single tape for each data set. Appendix F discusses the format of the geometry and vehicle data files. The geometric data are coded using the conventions of the INTRAS freeway simulation model.

The validity of the data is dependent primarily upon the validity of the calibration of each frame using the control points. Since eight pair of control points were generally available at each site, it was possible to use several of the points other than the four used in the calibration itself to check the calibration. Although no ground-based data were collected at the same time as the film data, careful calibration of the film frames insures that the data adequately represent traffic flow, within the general tolerances indicated earlier. Because the vehicle positions are not perfectly precise, there will be some degree of jerkiness associated with vehicle movements, especially if viewed in the unsmoothed 1 second increments. The vehicle movements could be smoothed, if so desired, to eliminate some of the jerkiness of movement. Studying movements over longer time increments than 1 second will proportionately reduce this effect as well.

OVERVIEW OF AVAILABLE DATA SETS

Table 4 in chapter 2 already described the location and type of freeway sections filmed. Table 5 lists the sections for which data sets were created. A particular emphasis was placed on creating ramp merge and weaving data sets since these are the more critical bottleneck types, and since there is still a significant lack of knowledge about microscopic traffic flow in such sections. The estimates of level of service and number of records are approximate, since this contract did not provide for any analysis of the data. For ramp merge, weaving, and lane drop sections, it was desired to cover the transition period from uncongested to congested flow. Although this was achieved for a number of sites, the levels of service indicate that traffic flow for some of the sites never attained the congested flow state. For curve, reduced width, and upgrade sites, level of service D was targeted for and generally achieved. A sketch and documentation of each data set is presented in Appendix G.

GUIDELINES AND PRECAUTIONS FOR ANALYSIS OF DATA

The data sets described in the previous section can potentially provide a wealth of information on microscopic traffic flow through freeway bottleneck sections. Virtually any measure of traffic performance can be derived from the data sets, including measures such as lane change frequencies, lane change gap acceptance characteristics, and car-following characteristics, on which relatively little research has been conducted.

Table 5. Data Sets Available

Site Type and Location	Approximate Level of Service Range[1]	Section Length	No. Lanes[2]	Approximate No. Records	Comment
Horizontal Curve					
I-495 WB west of Georgia Ave., Mont. Co. MD	C-D	1983'	3	140,000	Radius of curve approx.
Lane Drop					
U.S. 101 WB at White Oak, Van Nuys, CA	D	1830'	4/1	200,000	Lane dropped at off-ramp
Ramp Merge					
I-95 SB at Backlick Rd., Fairfax, VA	D-E	1641'	3/1	180,000	
I-405 NB at Roscoe Blvd., Van Nuys, CA	D	1788'	4/1	200,000	
I-405 SB at Santa Monica Blvd., Los Angeles, CA	E	1616'	4/1	290,000	
Reduced Width					
I-10 WB near La Brea Blvd., Los Angeles, CA	C-D	1258	5	120,000	5 11-foot lanes and narrow left shoulder
Weaving					
Baltimore Washington Pkwy. NB at I-95, Prince Georges Co., MD	B-E	1606	2/1	100,000	Cloverleaf interchange
I-395 SB at 14th Street Bridge, Washington, D.C.	D-E	3230	2/2-3	400,000	Two-sided, multiple weaving section
I-295 SB between 11th St. Bridge & Howard Rd.	D-E	2122	2/1	180,000	
I-295 NB between Howard Rd. & 11th St. Bridge	C	1700'	2/1	100,000	
Rt. 11 (Harbor Fwy.) NB between I-10 and 6th St. Los Angeles, CA	E	1831'	3/2	350,000	
U.S. 101 WB between Topanga Canyon Blvd. & Ventura Blvd.	C-D	1258'	3/1	90,000	Construction site with narrow lanes
Upgrades					
I-395 SB at Duke St., Alexandria, VA	D-E	1991'	3	180,000	
I-405 NB at Mulholland Dr., Los Angeles, CA	D-E	1341'	5	140,000	

One foot = .305 m

1 Estimated based on observation of traffic, not on analysis of data.
2 Number to left of slash indicates mainline lanes; number to right indicates auxiliary lanes

However, there are some important precautions to keep in mind when analyzing any of the data sets. Earlier in the report, the point was made that each freeway bottleneck site has its own unique characteristics of traffic flow or geometry which distinguish it from other sites. It should be remembered that conclusions based on the analysis of one site are not necessarily valid for other sites of the same type. There are many factors which can affect traffic flow which these data bases do not quantify. Examples of such factors include: variations in driving habits in different regions of the country, highway features upstream or downstream from the selected site (e.g., a major interchange downstream of the site which influences the lane distribution and lane changing characteristics within the site), pavement surface quality, perceived level of speed enforcement, etc. There may be a tendency to want to apply many of the findings derived from these data sets universally to all other situations of the same type. Before general conclusions are made, the researcher should thoroughly consider the factors which may have influenced traffic flow within the site and whether these should be considered in applying the data to a particular simulation model validation, geometric design problem or other engineering application.

There are several other precautions which should be noted in the analysis of the data sets:

- Because the measurements are not exact, the movement of vehicles will tend to take on a jerky motion, fluctuating between being higher and lower than the true speed of the vehicle. Applying a smoothing algorithm or taking measurements over a longer period than 1 second will reduce this effect. Acceleration and deceleration characteristics should be computed over at least several seconds to avoid being heavily influenced by the measurement errors inherent in the digitizing process.

- At some sites, vehicles were difficult to see in the films under certain conditions. Occasionally, vehicles would be obscured by trucks, and there was no way to determine exactly where the vehicle was until it came into view again. In these cases, the vehicle position was estimated by the operator, and corrections to the position would be made once the vehicle was in view again. If the operator's estimate was off, the vehicle would be accelerated or decelerated, within the limits of normal vehicle operation, until the digitized vehicle position caught up with where the vehicle actually was. The limits used for acceleration and deceleration were 8 mi/h (12.8 km/h) per second and 10 mi/h (16 km/h) per second, respectively. Similar problems could occur where vehicles disappeared into shadows or blended in with the pavement color so that they were difficult to see in the film. Although it is not believed that these problems were frequent, they could explain any abnormal behavior of individual vehicles over short time increments which is detected in the data analysis.

- The computer algorithm used in the digitizing assigned ID numbers to vehicles sequentially in the order in which they were entered in the films. As stated previously, certain vehicles were entered which later turned out not to be vehicles, when later frames were viewed. As a result, there are some ID numbers which are missing from the data sets, and it cannot be assumed that there are vehicles representing all ID numbers between the first and last ID numbers in the film. In addition, the ID numbers do not always start with "1," as the first few frames of film may not have been used in the final data set. The geometry files indicate the starting and ending frame numbers as well as the first and last vehicle ID numbers.

- In general, the operator's designation of lane number should be used to positively identify the vehicle's lane. The only time the digitized lateral position should be needed is for identifying the time of beginning and completion of a lane change. Measurement errors in lateral placement could, at times, cause a vehicle not travelling in the center of a lane to erroneously take on a lateral position which would fall into an adjacent lane. For example, a vehicle whose center was 15 feet (4.5 m) from the right edgeline (lane 2) could, with a 4-foot (1.2-m) lateral position error, be computed as being 11 feet (3.4 m) from the edgeline (lane 1). The operator's designation of lane will provide better data on the true lane of the vehicle.

- For most sites having on or off-ramps, ramp vehicles were added or deleted at the point where the ramp actually merged or diverged from the mainline. For some sites, the ramp vehicles were added early or deleted late, because some vehicles were crossing over the gore area prior to the merge point or after the diverge point. Where the vehicles are added early or deleted late, the lateral placement values no longer correspond to the lane numbers. For example, a vehicle in the middle of the ramp lane might have a lateral placement value of minus 12, rather than minus 6, the gore area having caused a 6-foot (1.8-m) displacement of the vehicle. The longitudinal position may also have a slight (but probably not significant) error, since the longitudinal distance is measured along the right edgeline.

- On curves, the actual distance traversed by a vehicle will vary depending on its distance from the right edgeline. On a left hand curve, the left lane vehicles will actually have travelled a shorter distance than the right lane vehicles. Again, the length of the site is measured along the right edgeline. These differences are not likely to be too important, but the researcher should be aware that they exist.

There are other precautions which pertain to the analysis of each individual data set. These precautions are highlighted in the individual data set documentation in Appendix G. Questions on other aspects of the data sets should be referred to the Federal Highway Administration.

HOW TO REQUEST A COPY OF A DATA SET

Each data set is available on 9-track magnetic tape from the FHWA Office of Research, HSR-10, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, Virginia 22101. Persons interested in obtaining copies of one or more data sets should write to FHWA at this location or call (703) 285-2091. This report provides the documentation necessary to analyze the data sets.

APPENDIX A

RESEARCH QUESTIONS TO BE ADDRESSED BY DATA SETS

The performance of the urban portions of the interstate highway system constructed over the last 20 years is greatly reduced, especially during the peak hours, by the occurrence of bottlenecks (or limited capacity sections). These bottlenecks are caused by:

1. On ramp merging traffic.
2. Weaving sections.
3. Grades and "rollercoaster sections."
4. Lane drops.
5. Freeway to Freeway connectors.
   a. Merging on receiving freeway.
   b. Queue backup onto feeding freeways.
6. Tunnels/overpasses/bridges.
7. Curves.
8. Off-ramp backups.
9. Construction zones.

Note: A rollercoaster section is defined as a series of grade sign changes occurring in a short longitudinal section of freeway.

Due to energy, environmental, and funding considerations, alleviation of these bottleneck conditions by major construction appears unlikely. Thus, it is imperative to improve the efficiency of existing facilties by measures other than additional construction. Examples of such measures include:

1. Reducing lane widths and using shoulders to increase the number of lanes.
2. Ramp control strategies.
3. Mainline freeway control strategies.
4. Diversion systems such as IMIS (Integrated Motorist Information System being installed on Long Island, NY).
5. Lane occupancy control strategies.
6. Reversible lanes.
7. Restriping and use of signs and markings.
8. Minor geometric changes.

Of course, not all of these measures will be applicable to all of the bottleneck conditions. For instance, lane occupancy control would not be helpful in most grade or rollercoaster situations. Before implementing any of these measures, it would be well to test them in advance for particular situations by computer simulation. In order for the simulation activity to be credible, it must be ascertained that the bottleneck situations described above are properly modelled, which can only be done by comparing model outputs to field data collected at specific sites. As a corollary, the data should also be able to give insight into various interactions involved in freeway traffic.

The following areas require collection of new data or assimilation of existing data or identification of existing analyses.

A. Reduced lane widths and use of shoulders.

The geometric standards of urban freeways have been set by the American Association of State Highway and Transportation Officials (AASHTO) in publications such as A Policy on Geometric Design of Urban Highways and Arterial Streets (1973).

In some bottleneck locations, however, where the addition of a 12-foot lane was not feasible, a treatment consisting of reducing lane width and using a portion of 1 or both shoulders has been tried. Studies have shown that the capacity of the affected sections is increased without an undue safety hazard. What is needed, now, is a more detailed traffic analysis involving processing of basic traffic data in order to more fully understand the behavior of traffic in reduced lane width sections. The following questions for various lane width situations should be addressed:

1. What's the effect on car following of vehicles in lanes of less than 12-foot width, specifically with respect to headway distribution?

2. What are the effects on speed/headway distributions?

3. What is the effect on lane changing frequencies?

4. What is the distribution of traffic over all lanes in sections involving shoulder lanes?

5. What is the effect of disabled cars in sections where shoulders have been reduced in width such that there is insufficient room to park the car on the shoulder?

B. Ramp Merges

The following questions should be addressed to analyze vehicle interactions involved in the merging process:

1. What are gap/risk acceptance distributions?

2. How do vehicles force their way into the traffic stream when adequate gaps are not available?

3. How long will drivers wait before forcing their way into the main stream?

4. What percentage of drivers in the mainstream "cooperate" to allow a vehicle to merge in front of them?

5. What is the mainline lane distribution of vehicles as a function of longitudinal distance upsteam of the merge area?

6. What are the merge characteristics for 2-lane entrance ramps where 1 of the lanes is eventually dropped, specifically with respect to lane distribution and gap/risk accpetances?

7. What is the longitudinal distribution of merges from the acceleration lane as a function of the longitudinal distance of the merging vehicle downstream from the gore area?

8. What is the effect of acceleration lane length?

C. Weaving areas (here restricted to simple weaves, both 1- and 2-sided as defined in Chapter 7 of the 1965 Highway Capacity Manual).

The following questions should be addressed to analyze vehicle interactions in weaving areas:

1. One-sided weaves:

   (a) What are the gap/risk acceptance distributions?

   (b) How do entering and exiting vehicles force their way into their respective target lanes? How do these vehicles cooperate with each other?

   (c) What percentage of through vehicles in the mainstream "cooperate" to allow a vehicle to merge in front of them.

   (d) What is the mainline lane distribution of through vehicles as a function of longitudinal distance upstream of the merge area?

   (e) What is the longitudinal distribution of merges in the weaving area both for the entering and exiting vehicles as a function of the longitudinal distance from the upstream gore area?

   (f) What is the effect of length of the merging area?

   (g) What is the effect of the number of lanes involved in the weaving process?

2. Two-sided weaves:

   (a) In 2-sided weaves consisting of an on-ramp on 1 side of the freeway followed by an off ramp on the other side some distance downstream, what is the probability distribution of vehicles, weaving from the on-ramp to the off ramp, being in a given lane as a function of longitudinal distance downstream from the gore area? What are the gap/risk acceptance distributions in merging behavior from the on-ramp as compared with an isolated ramp merge situation?

(b) In 2-sided weaves consisting of the merge and diverge of two freeways, what is the probability distribution of vehicles across the conflicting streams of traffic being in a given lane as a function of longitudinal distance downstream from the merge gore area? How do drivers involved in the weaving process cooperate with each other? How do drivers involved in the weaving process cooperate with non-weaving drivers?

D. Grades and "rollercoaster sections."

The following questions shall be addressed in order to analyze vehicle interactions as affected by 2, 3, 4, and 5 percent grades and "rollercoaster sections."

1. What are the effects on following distances?

2. What are the effects on lane changing/merging situations?

3. What are the effects on vehicle speeds?

E. Horizontal Curves.

The following questions shall be addressed in order to analyze vehicle interactions as affected by curves on urban freeways between two and five degrees of curvature.

1. What are the effects of curves on following behavior?

2. What are the effects of curves on lane changing and merging behavior?

F. Lane Drops.

The following questions shall be addressed in order to analyze vehicle intersections as affected by lane drops.

1. What is the distribution of vehicles leaving the lane to be dropped as a function of the longitudinal distance upstream of the lane drop?

2. What are the gap/risk acceptance distributions of vehicles merging out of the dropped lane as a function of longitudinal distance upstream of the lane drop?

APPENDIX B
RESULTS OF THE PILOT STUDY

OVERVIEW

The pilot study was specifically designed to test the filming and data reduction procedures and to demonstrate the ability of the procedures to produce the required data in an acceptable format. The filming procedures employed time-lapse aerial photography using both 35 mm and 16 mm cameras and included experiments with two types of fixed-using aircraft and a helicopter.

The data reduction procedures involved the digitizing of vehicle positions from the films and a series of computer algorithms to transform the raw data into the time-based lateral and longitudinal positions of vehicles on the freeway section being studied. A description of these procedures and evaluation of the entire process is discussed in the remaining sections.

The initial pilot studies were conducted in the summer of 1982. Filming was conducted in July, followed by initial software development and testing. Two follow-up filming studies were conducted in the fall of 1982 to resolve remaining questions on filming procedures. Further development of the digitizing system took place in the winter of 1982/83.

INITIAL PROCEDURES AND SYSTEM DEVELOPMENT

Pilot Study Filming Sites

Two sites were selected for the initial filming in the pilot study, both of them freeway bottlenecks in the Northern Virginia portion of the Washington metropolitan area. These sites are illustrated in Figures 14 and 15 and described below:

1. I-395 southbound between Holmes Run and Duke Street in the p.m. peak period. This is an upgrade section of approximately 4 percent and approximately 2,000 feet (609 m) long.

2. I-95 southbound between I-495 (Capital Beltway) and Virginia Route 644 (Old Keene Mill Road), also a 2,000-foot (609 m) section. This is a section with heavy weaving movements.

Site 2 was considered to be a "worst case" site since lane changing movement was expected to pose the most significant problems for tracking vehicles through a site. There is a great amount of lane changing and weaving activity at this site, and it appeared that if vehicle trajectories could be developed here, they could also be developed for virtually any other freeway bottleneck location. At this site, the major congestion was actually on the ramps from I-495, with less, although significant congestion on the mainline.

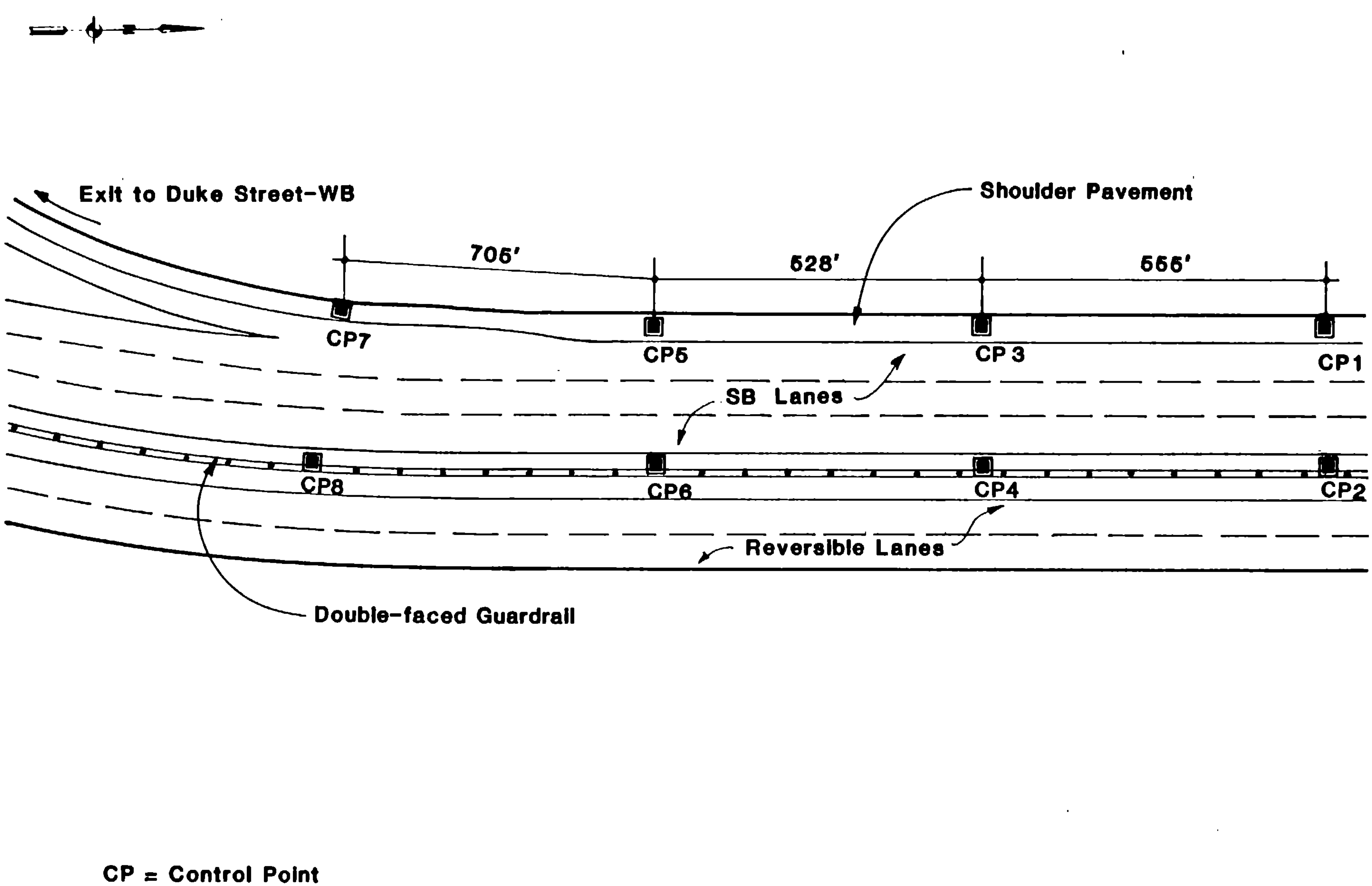


Figure 14. Plan View of Site on I-395 Between Holmes Run and Duke Street

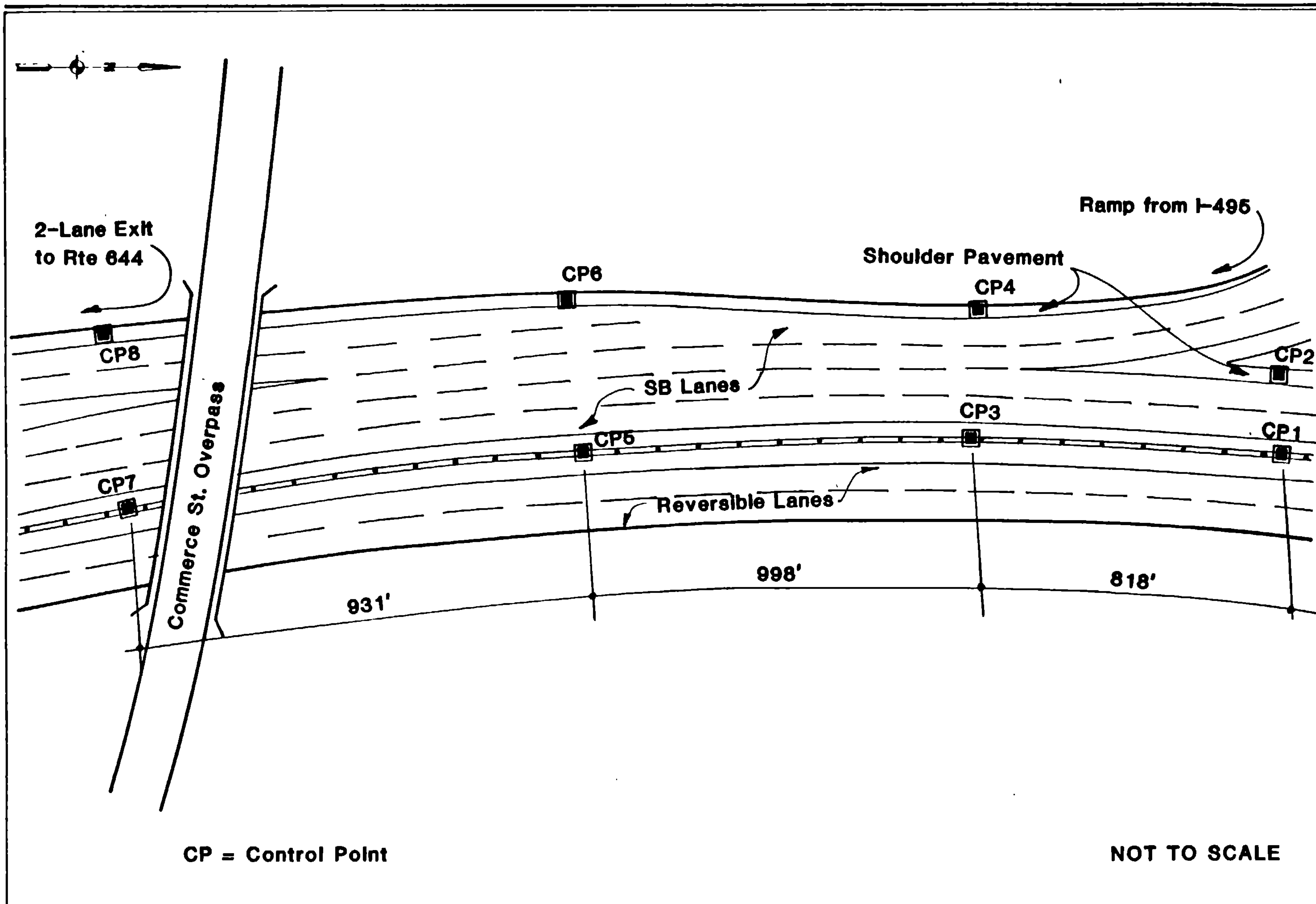


Figure 15. Plan View of Site on I-95 Between I-495 and Rte. 644

Site 1 was essentially a "pipeline" section, although it contains an off-ramp part way up the grade. It was felt important to include a significant grade in the pilot study since this was an additional dimension which must be accounted for in the transformation of vehicle positions to the highway coordinate system. It is expected that the data reduction process for Site 1 would be somewhat easier than for Site 2 due to the lower frequency of lane changing.

Aerial Photography

Camera Equipment and Film

The aerial photography was performed by Photoscience, Inc., of Gaithersburg, Maryland. For the pilot study both 35 mm and 16 mm film were tested. This enabled a tradeoff to be made between the cost of the film and the quality of the photography. Using the larger format film, while more expensive to produce, could offer considerable economies in the data reduction stage.

The camera equipment is described below:

- 35 mm camera - Flight Research model 207
  28-volt system with 10 frames/sec. capability in pulse mode
  shutter speed 1/500th s
  35 mm industrial grade Nikkor lens with auto exposure control
  1,000 ft film magazine
  data slate with digital counter (to record location and frame number)

- 16 mm camera - Canon Scoopic 16 MS
  12-volt system
  Intervalometer modified to enable filming in pulse mode shutter speed 1/225th s

The 16 mm camera was rented for the several days required and did not have a data chamber. Although this made the data reduction process with the 16 mm film more difficult, it did permit a good evaluation of the resolution provided by the film, which was the primary objective of using both film formats. The vehicle digitizing system and computer algorithms were developed and tested using the 35 mm film.

The choice of films was important in maintaining the highest quality possible in the final product. It was determined that a color film was necessary to enable the digitizing system operator to distinguish individual vehicles on the freeway more easily. Two basic film processes are available: 1) using a negative original, copied to a positive, 2) a color reversal film in which the original is developed in a color reversal process and becomes the film used in the data reduction.

There are several advantages of the color negative film. These include:

- Unlimited high quality copies can be made. This provides insurance against the loss, breakage, or destruction of the film, and copies can be distributed to multiple researchers. Copies of color reversal films can be made through a two-step (negative-positive) process, but the quality is considerably inferior.

- The color negative film selected, Eastman 5247, has a higher resolution than available color reversal film (65 lines per mm as opposed to 42 lines per mm). However, following the pilot study filming, it was found that color reversal film of the same resolution is now available.

- The color negative film has more tolerance in exposure settings.

For the above reasons, the color negative film was selected for the pilot study filming.

Ground Control Requirements

The film produced from the aerial photography presents a perspective view of the freeway section being analyzed. Consequently, the lateral and longitudinal dimensions of the freeway are of varying scale, depending on how the section is positioned in each frame, the angle from which the film was taken, and the altitude of the plane. Therefore, to calibrate ground coordinates from the film coordinates and to correct for the perspective view presented by the film, known points on the ground must be established and be visible in each film frame digitized. This can be done by either setting out known points physically near the roadway which are visible from the air (existing features of the highway, such as guardrail termination points and changes in pavement color, could also be used) or by using known points on the State grid system which were also visible in the film.

For the purposes of the pilot study, it was decided to physically lay out known control points on the shoulder of the freeway section as it was not usually possible to locate known points on the State grid system in the film. Four pairs of control points, one point of each pair on each shoulder, were established in a survey, and targets visible from the air were placed on the control points. The approximate location of the points for the pilot tests was shown in Figures 14 and 15. The distances measured were along the plane of the ground, rather than on the horizontal plane so that the longitudinal highway distance would not have to be corrected for grade, so long as the plane of the highway did not significantly vary from the plane of the ground on which the points were set. Techniques for transforming the film coordinates to ground coordinates are discussed in the data reduction section.

Filming Procedures

A Cessna 206 was the aircraft used in the initial pilot study filming. Figure 16 shows the 35 mm camera equipment mounted in the aircraft. The camera mount was placed at an angle out the left rear door of the aircraft. The same mount was used for both the 16 mm and 35 mm cameras. Table 6 indicates the sequence of filming. As indicated, alternative section lengths were covered with the 35 mm film to test the

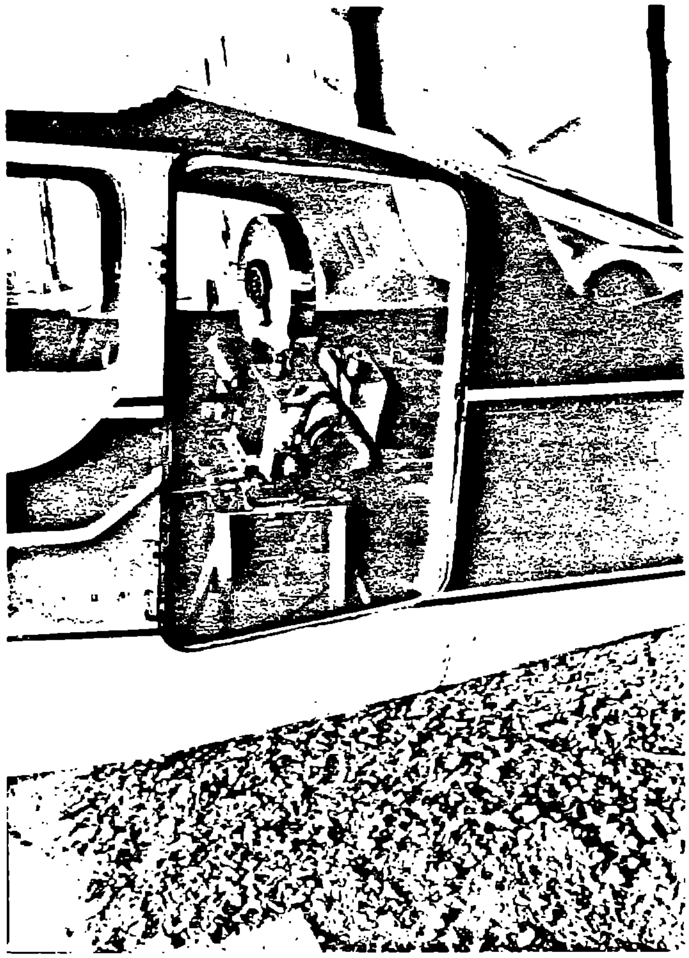


Figure 16.35 mm. Camera Mounted in Aircraft

Table 6. Filming Sequences for the Pilot Study

Camera	Start Time	Filming Time	Site Filmed*	Approx. Section Length	Altitude
16 mm	3:35:30	3 min.	Site 1	1 mile	5,000 ft.
16 mm	3:42:05	3 min.	Site 2	1 mile	5,000 ft.
16 mm	3:47:55	3 min.	Site 2	3/4 mile	4,000 ft.
16 mm	3:51:29	3 min.	Site 2	3/4 mile	4,000 ft.
16 mm	3:59:14	3 min.	Site 2	1/2 mile	2,500 ft.
16 mm	4:02:30	3 min.	Site 2	1/2 mile	2,500 ft.
35 mm	4:22:00	5 min.	Site 1	1 mile	5,000 ft.
35 mm	4:27:47	3 min.	Site 1	1 mile	5,000 ft.
35 mm	4:34:15	3 min.	Site 2	1 mile	5,000 ft.
35 mm	4:38:04	5 min.	Site 2	1 mile	5,000 ft.
35 mm	4:47:05	10 min.	Site 2	3/4 mile	4,000 ft.
35 mm	5:01:00	8 min.	Site 2	1/2 mile	2,500 ft.
35 mm	5:11:00	5 min.	Site 1	1/2 mile	2,500 ft.
35 mm	5:19:15	3:30 min.	Site 1	3/4 mile	4,000 ft.
35 mm	5:25:00	5 min.	Site 1	3/4 mile	4,000 ft.

* Site 1: I-395 SB between Holmes Run and Duke Street

* Site 2: I-95 SB between I-495 and Route 644

range in resolution achieved. Differing the lengths of sections filmed were accomplished by varying the altitude of flight. The 16 mm film was shot, the camera removed from the mount and replaced with the 35 mm camera. Both the 16 mm and 35 mm film was shot at one frame per second.

The aircraft circled around the center of the freeway section in approximately a ½-mile radius, counterclockwise. The pilot was required to continually bank the aircraft and compensate for wind velocity. Winds were light on the day of filming. The camera operator had the responsibility of keeping the camera focused on the center of the section, trying not to allow any part of the freeway section being filmed to slip outside any of the film frames. This proved to be a very tedious and difficult task.

The pilot was also required to stay in constant communication with the control tower at National Airport, since the freeway sections being filmed were only 4 to 5 airline miles from the airport and were thus in a heavy air traffic area. The weather on the day of filming was clear and warm with light and variable winds. The exact start and stop time for each film sequence was recorded to verify the accuracy of the intervalometers.

Aside from the pilot and photographer, a third person was required in the aircraft to monitor the times for each filming sequence, to take detailed notes in a log book, and to assist the photographer in changing cameras. Figure 17 shows a sample frame from a test of the 35 mm camera over I-270 in Montgomery County, Maryland.

Data Reduction

As mentioned previously, the end product of the data collection and reduction process was to be a data file containing the time-based highway coordinates of vehicles in the freeway bottleneck sections, from which can be computed the detailed measures of traffic performance necessary to study vehicle interactions and to calibrate and validate microscopic freeway simulation models. The development of the data format is discussed in the body of this report.

The general process used to reduce the data from the films was to digitize the x-y coordinates of vehicles from the film into a microcomputer and then perform the necessary transformations to produce the final highway coordinates of each vehicle as it passes through the section under study. The digitizing system components, the initial operation of the system and the computer algorithms are discussed in the next three sections.

Digitizing System Components

The initial digitizing system consisted of three basic components: the digitizer, the projection equipment and the microcomputer equipment. Figure 18 is a photograph of the system components.

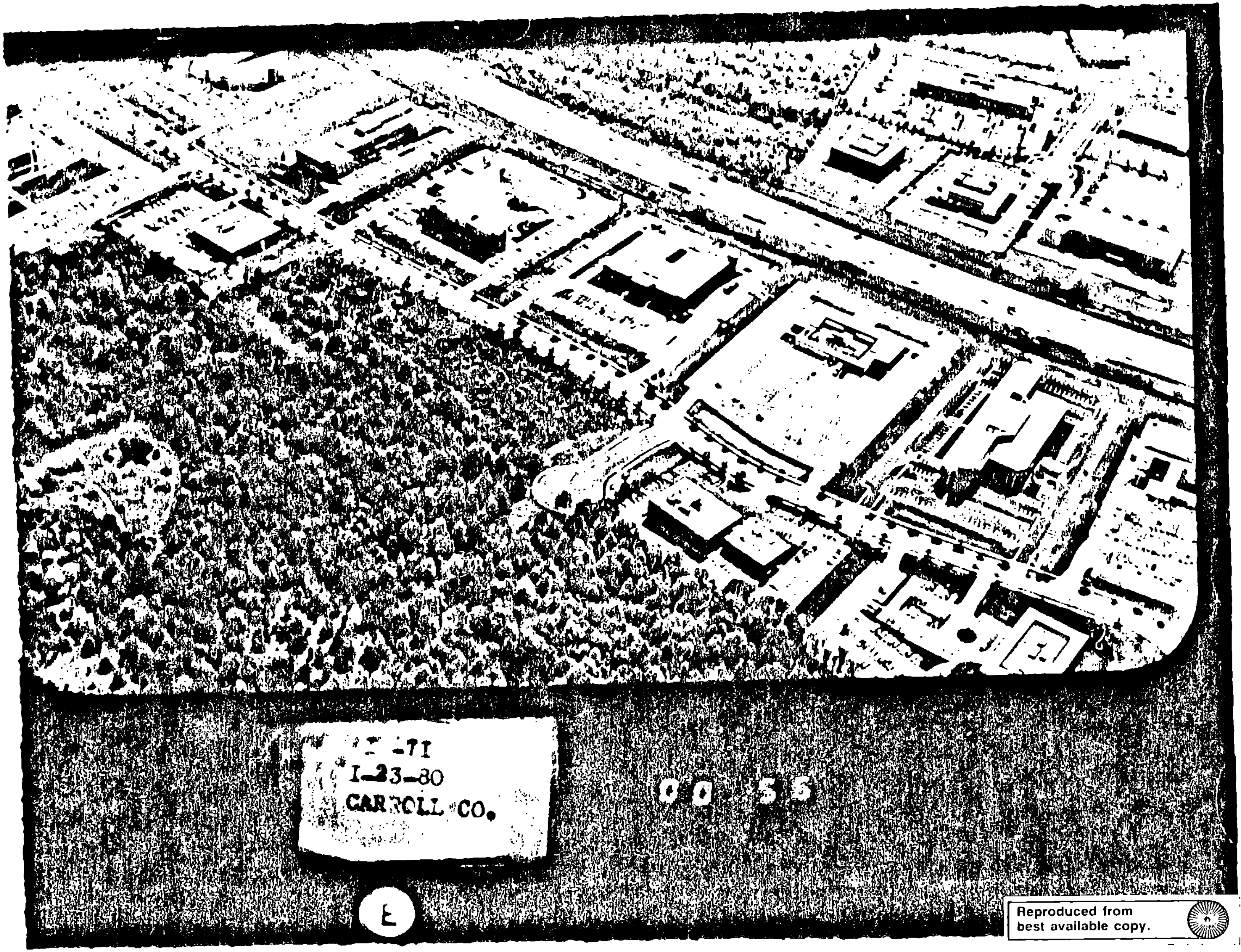


Figure 17. Sample 35 mm. Film Frame (I-270 in Montgomery County)

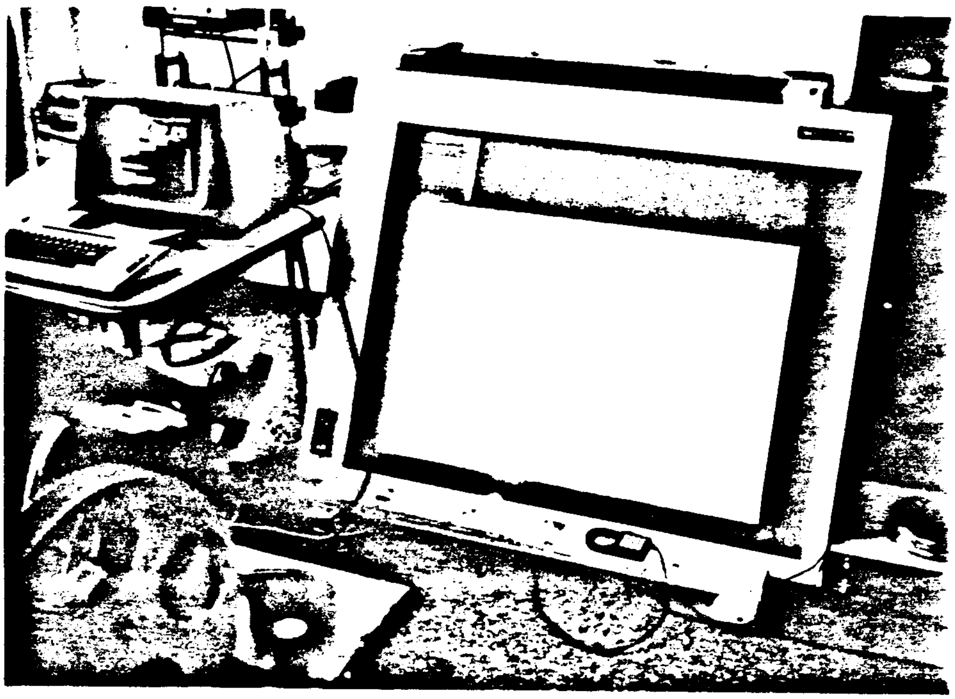


Figure 18. Photograph of Digitizing System Components

Digitizer - A number of digitizers were investigated to identify the most appropriate one for the needs of this study. Of the several types and makes available, a Calcomp Series 6000 rear projection digitizer was selected. The active digitizing area is 30 in by 40 in, and virtually any projection unit can be used, giving substantial flexibility to the system. The digitizing surface can also be used for front projection or for digitizing directly from photographs, plans or diagrams laid on the surface of the board. When projected from the rear, an image is captured on the front surface of the digitizer (i.e., the side of the board from which the operator is to be digitizing), thus eliminating any parallax.

The digitizing board is complemented by a microprocessor unit, an RS232 interface, a firmware package and a 16-button cursor. To digitize a point, the cursor crosshairs are positioned over the point to be digitized and one of the 14 eligible buttons is pushed. The eligible buttons are "0-9" and "A-D." The remaining two buttons, "#" and "*", are used for special functions. The pushing of a button on the cursor (use the "1" button for an example) with the cursor placed on the digitizing surface returns the following:

1,+00.000,+00.000 followed by a carriage return/line feed.

The x and y coordinates are transmitted, in that order, to the nearest .001 in. Additional characters of the operator's choosing can be transmitted directly to the current record by pressing "*", followed by the selected characters and another "*". A 63-character menu can be attached to the digitizing surface, and placing the cursor over a particular character on the menu will return that character. A variety of other options, such as rescaling and area computations are available. The operation of the system is fully documented in manuals supplied by the manufacturer.

Projection Equipment - Both 16 mm and 35 mm single-frame advance projectors were required for the study. The 16 mm projector was obtained from FHWA and can be advanced manually. For the 35 mm projector, it was determined that a standard filmstrip projector would be adequate for the study, since there was no need to view the film in motion picture fashion. High-wattage bulbs were used to provide the best possible resolution and color from the projected image.

Initially, the projector was placed in the rear of the digitizer, and the image projected from that point. Front projection was also tried, and it was found that projecting from the front onto a pure white paper screen placed on the digitizing surface produced the optimum image. It is still valuable, however, to have the flexibility of rear-projection for other possible uses. The projection angle had to be as nearly perpendicular to the digitizing plane as possible to ensure accurate focussing of all parts of the image.

Microcomputer System - A Molecular brand multiuser microcomputer system was employed to accept the raw output from the digitizer and perform the various computations, to provide the operator with the necessary feedback and to store the data (both raw and transformed) on disk. The development system utilized one video monitor, located beside the operator, one 64 k byte processing unit and a Winchester-type hard disk system with 16 megabytes of storage. The system is an in-house system at Comsis Corporation, the subcontractor developing software for the project. The system provided a great deal of flexibility in interaction with the operator and the digitizer. The microcomputer was linked directly to the digitizer electronics unit with standard cables and connectors. The terminal and digitizer were located in a separate room from the computer, enabling the room to be darkened for best viewing.

- <u>Software Development</u> - The body of the report presents an overview of the digitizing process. Three primary software components were required to allow the operator to match vehicles from frame to frame and to make the necessary data manipulations to create data files in the desired format. The following three routines, with the necessary subroutines and auxiliary features were developed:

- Vehicle Matching and Raw Coordinate Digitizing Routine - this routine leads the operator through the digitizing of vehicles on a frame of film and enables him to match vehicles with those of the preceding frame using vehicle type, color, and lane placement information.

- Film-To-Ground Coordinate Transformation Routine - this routine transforms the coordinates of the film (which appear in a perspective view from the point at which the photograph was taken) to the actual ground coordinates on the plane of the highway. A FORTRAN program written by Bleyl (Ref. 10), was used as the basis of the program. It uses four control points of known location on the highway, solves for eight coefficients in eight simultaneous equations, and recomputes the correct ground coordinates in any part of the plane defined by the control points.

- Ground-To-Highway Coordinate Transformation Routine - this routine uses trigonometric functions to transform highway geometry and vehicle positions from the ground Cartesian coordinate system into the highway coordinate system to be used in the final data files (i.e. longitudinal and lateral distance along the alignment of the roadway, using the right edgeline as the reference).

The goal during the pilot study was to develop each of the algorithms to the point where its capability to perform its specified function could be verified. It was not necessary, nor did time allow the full integration of software which was to be used over the long term. However, it was possible to integrate the programs into one contiguous routine but without all the error-checking and data storage functions which would eventually be necessary. Also, additional work needed to be done to allow the program to accommodate a wider range of geometric conditions. The ground-to-highway coordinate transformation routine was originally designed for site 2, and further modifications were required to enable the digitizing of other sites. All programming was done in UCSD PASCAL.

<u>Operation of the System</u>

The digitizing process is described step-by-step in Table 7, assuming that the operator is beginning with a completely new film. In overview, the operator digitizes vehicles from the downstream end of the section to the upstream end, in systematic order. The characteristics of vehicles (ID, lane, type, and color) from the previous

Table 7. Steps in Digtizing Process

Step 1 - System Initialization

Substep 1.1 - Turn systems on and activate computer programs.

Substep 1.2 - Enter ID and ground x-y coordinates of control points.

Substep 1.3 - Designate limits of the section.

Step 2 - Digitize first frame.

Substep 2.1 - Digitize 4 control points by control point ID.

Substep 2.2 - Digitize highway geometrics (two points on tangent, three points on curves).

Substep 2.3 - Push "*" followed by vehicle color and type codes followed by another "*".

Substep 2.4 - Digitize designated corner of the vehicle. Computer will generate ID. Push button corresponding to the lane the vehicle is in. (Lane 1 = right most lane, auxiliary lane included).

Substep 2.5 - Place cursor on opposite end of vehicle (same side) and digitize, pushing "7" to designate opposite end of vehicle is being digitized.

Substep 2.6 - Repeat steps 2.3 through 2.5 for each vehicle, proceeding from downstream to upstream end of section.

Substep 2.7 - Indicate all vehicles in frame digitized and advance projector.

Step 3 - Digitize successive frames.

Substep 3.1 - Digitize 4 control points by control point ID.

Substep 3.2 - Look at video monitor, displaying vehicle ID, lane, type and color. Match vehicle number 1 on monitor with the same vehicle in frame 2 and digitize, pushing button corresponding to lane number. If vehicle is now out of section, place cursor over vehicle and push the "0" button.

Substep 3.3 - Repeat steps 2.3 through 2.5 for all vehicles entering section for first time.

Substep 3.4 - Repeat step 3.2 and 3.3 for all vehicles in each successive frame.

Step 4 - Designate end of digitizing and turn systems off.

frame are displayed on the video screen, in the order that the vehicles were digitized. Figure 19 shows a sample of the information displayed on the video monitor, indicating the vehicle type, color, and lane of vehicle from the previous frame, the position of the vehicle in the succeeding frame and its speed since the last frame. The "S" indicates the vehicle's distance from the beginning of the section and the "d" indicates the distance from the right edge of pavement. The "d" can be divided by lane width to be translated into fractional lanes from the edge of pavement, if desired. The program leads the operator through the list, prompting the operator to match each vehicle with one in the current frame. The operator positions the digitizer's cursor crosshairs over the left front corner (or other predetermined spot) on the vehicle and presses the button corresponding to the vehicle's current lane number. This number and the x-y coordinates are then transmitted to the computer memory along with the vehicle ID, type, length, and color. The coordinates are then transformed to highway coordinates, the transformed data are stored, and the necessary fields brought back to the monitor for the next frame.

INITIAL PILOT STUDY RESULTS AND EVALUATION

This section presents an evaluation of the initial techniques employed in the pilot study and discusses the feasibility of the procedures, or modifications thereof, to produce the data required. With the modifications suggested, the aerial photographic and digitization approach to reducing traffic flow data from film was found to be feasible. Discussed below is an evaluation of each procedural component.

Filming Procedures and Film Quality

The camera equipment and film worked well throughout the course of the pilot study. The basic technique using a fixed-wing aircraft circling above the roadway was found to be feasible. However, there were several deficiencies in the combination of film format and aircraft type used in the pilot study.

It should first be pointed out that the 16 mm film did not produce images of the necessary resolution to permit the digitizing of vehicles on the lengths of freeway necessary. As far as could be determined, the deficiency was due strictly to the limitations of that film format and not due to any problems in the way that the photography was done. The half-frame 35 mm film did prove to yield the necessary resolution, within certain limitations.

One of the limitations of the half-frame 35 mm film, when used with the circling method of aerial photography, involved the rectangular dimensions of the film image, a sample of which was shown previously in Figure 17. The vertical dimension of the film frame, including the space reserved for the data slate and frame counter, was approximately three-quarters of the horizontal dimension. However, the actual vertical dimension of the image without the data slate was little more than one-half of the horizontal dimension. Since the photography must continuously include a fixed section of highway in the filming, the critical dimension of the film was the shorter dimension. Using the circling photography technique, the longer dimension of the film could not be fully taken advantage of. Possible solutions to this problem included

```
NEW VEHICLE  41 ID=    41
ENTER *color type*lane  OR *999*0 TO EXIT
WHT  CAR         50019.864 49961.236
LANE 1    S=       36.04    D=       10.34

NEW VEHICLE  42 ID=    42
ENTER *color type*lane  OR *999*0 TO EXIT

ENTER *num*Option OR 0 TO EXIT

Options:
  1=RESTART AT VEHICLE num
  2=DISPLAY 10 VEHICLES STARTING AT VEHICLE num
  3=REDIGITIZE VEHICLE num

FRAME 364 COMPLETED

        41 VEHICLES ENTERED
         0 VEHICLES EXITED
        41 VEHICLES IN SECTION

ENTER *frame number*time

frame number=999 TO TERMINATE, time=SECONDS SINCE LAST FRAME

ENTER CONTROL POINT NO. (0 TERMINATES INPUT)
CP  1 FILM X-Y  23.573 23.105
CP  2 FILM X-Y  24.162 22.965
CP  3 FILM X-Y  17.800 16.003
CP  4 FILM X-Y  18.741 15.663

ARE THE ABOVE VALUES OK ? (0=YES, 1=NO)

FILM TO GROUND CALIBRATION IN PROGRESS

NEXT VEHICLE  (1) IS A WHT  CAR IN LANE 3  ID=1

Options:
  0=VEHICLE HAS EXITED SECTION
1-6=LANE NUMBER OF VEHICLE
  7=ENTER A NEW VEHICLE
  8=SKIP THIS VEHICLE TEMPORARILY
  9=ADDITIONAL OPTIONS

NEXT VEHICLE  (2) IS A BLU  CAR IN LANE 4  ID=2

         50021.825 49194.377  13 MPH
LANE 1   S=     803.48   D=       9.83

NEXT VEHICLE  (3) IS A BLK  CAR IN LANE 3  ID=3
```

Figure 19. Sample Information Provided to Operator on CRT

modifying the camera to change the position of the data slate, utilizing a hovering helicopter to enable the continuous alignment of the longer film dimension with the freeway section under study or using a full-frame 35 mm camera.

A second problem encountered with the use of the light plane in the aerial photography involved the difficulty of keeping the camera focussed on the same section of freeway from frame to frame. Both the pilot and photographer bear the responsibility of this. The pilot must keep the plane within a reasonably concentric circle around the midpoint of the freeway section and at the same time keep the plane banked at an angle within certain limits of tolerance. He must thus compensate for wind velocity and try not to let the aircraft drift too far from the desired circle or the desired altitude. The most difficult part of this task is in holding a sufficiently tight circle on the downwind side. The photographer must compensate for the instability of the aircraft by rotating the camera on the mount. The presence of air turbulence produces a bouncing effect, making it more difficult for the photographer to keep the camera focussed continually on the section being filmed. The photographer must plan for this by photographing a section longer than is actually necessary.

Additional problems encountered entailed the effect of tall trees on the shoulder side of the section, particularly the site 1 section. First, at the lower altitudes, the trees obscured part of one lane from view when the aircraft was on the shoulder side of the section. This could only be remedied by flying at substantially higher altitudes and/or holding a much tighter radius of flight, both of which pose more significant problems in the holding of the frame on the designated freeway section.

The trees also introduced some shadows onto the section, but vehicles could still usually be identified. Both sections of highway filmed had asphalt paving, on which the dark-colored cars lacked contrast. A lighter pavement color would be expected to yield better contrast with most vehicle colors. Overall, however, the vehicle types and colors were identifiable.

The initial targets used for control points were black-and-white "iron cross" plastic targets. These were either nailed to the shoulder pavement or taped onto the top of the dual faced guardrail in the median. The black and white targets could be seen to varying degrees. There was little difficulty in identifying the 3-foot (.9 m) targets on the dual-faced guardrail, but the 2-foot (.6 m) targets were difficult to see in the film. Surprisingly, a 4-foot (1.2 m) square target placed in the gore area as a further test could not be seen significantly better than the 3-foot (.9 m) target. In all cases, only the white portion of the target was visible and the black quadrants could not be identified. An analysis of the colors which appeared brightest on the film (red, orange, bright blue) indicated that a colored target would improve visibility on the color film being used. A target of at least 3-foot (.9 m) square should be used and should be composed of more rugged materials than used in the initial pilot study.

Digitizing System and Process

The hardware components assembled for the digitizing process were found to be ideally suited to the task. The digitizer was highly reliable and flexible, and was adaptable to certain conditions not originally foreseen (e.g., the higher resolution in projecting from the front rather than the rear). The microcomputer system and projector also functioned well.

The primary challenge in developing the digitizing process was developing the software to derive vehicular coordinates based on the coordinate system of the highway, and to enable the operator to match vehicles from frame to frame as efficiently as possible. Although the software could not be completely developed by the completion of the pilot study, it was developed to the point where assurance could be given that the operator could match vehicles and that the correct highway coordinates were being ascertained. The initial algorithms included the recording of vehicle type and color, but the vehicle length component was not originally included.

Tests of the digitizing procedures were made in several ways. Approximately 2 minutes (120 frames) of 35 mm film were digitized from site 2 over a section length of approximately 900 feet (274 m). In addition, each component of the digitizing process was tested, as described below.

Film-to-Ground Coordinate Transformation

This was tested by first digitizing four control points, on which the calibration was performed. One or more intermediate control points, whose ground x-y coordinates were known, were then digitized, and the error between the predicted and known locations of these intermediate points was determined. The maximum error occurs near the midpoint between the two control point pairs, with errors becoming less as one approaches the control points at either end. The longitudinal error was found to be quite sensitive to even small operator errors in digitizing the control points.

Repeated digitizing of selected points in site 1 indicated that the standard deviation of the errors in the lateral direction was approximately 3 feet (.9 m). In the longitudinal direction, the standard deviation was approximately 5 feet (1.5 m). The absolute error in the longitudinal direction tended to be higher than in the lateral direction because of the greater length involved. For each 1-foot (.3 m) error in the longitudinal direction, there will be a 0.68 mi/h (1.094 km/h) error in the measurement of speed between successive frames.

The error in the film-to-ground coordinate transformation can be attributed to several factors: limitations of the operator in placing the cursor cross-hairs precisely over the center of the control point; distortions introduced by the camera or projector lenses; and failure of the control points to lie exactly in the same plane. A significant change in vertical alignment within a section would require two or more separate transformations with coordinates that correspond to the separate planes.

One of the most important discoveries concerning the use of the control points was the need to spread the control points in the lateral direction as well as in the longitudinal direction. In the pilot study, the control points were placed on the right shoulder and median, involving a lateral separation of only 50 to 60 feet (3 to 4 lanes plus shoulder). When the control points are this close, a small error in digitizing a control point (especially a lateral error) can produce a major distortion in the perspective grid. It was later found that placing control point pairs on the right shoulder of opposing traffic directions produced much better stabilization in the control point calibrations, since the lateral separations were usually 100 feet (30.5 m) or more.

Ground-to-Highway Coordinate Transformation

This routine worked remarkably well, as long as the correct film-to-ground transformation had been accurate. The geometry was incorporated by digitizing appropriate points along the right edgeline of the mainline lanes, which was used as the baseline for lateral placement of the vehicles. Everything digitized thereafter would be recorded as the distance from the operator-defined beginning of the section and as the distance from the right edgeline. Distances to the left of the edgeline were considered positive; distances to the left were considered negative. This lateral distance can also be divided by the lane width to put it in the form of fractional lanes. To test the error contribution of the ground-to-highway coordinate routine, three vehicles on the same film frame were digitized several times, redigitizing the roadway geometry each time. In addition, multiple frames were digitized using a one-time digitization of the geometry from the first frame. From these exercises it was concluded that the highway geometry could be digitized in the first frame only and did not have to be redigitized each frame.

Vehicle Matching Routine

Given an acceptable level of film resolution (which was obtained with half-frame 35 mm film at the lower altitudes of flight), the vehicle matching routine worked very well. The vehicle type, color, and lane characteristics were sufficient to identify virtually every vehicle, even those undertaking rapid lane-changing. The primary concern with the vehicle matching process is with the time required to digitize given quantities of vehicles. There are several time components that affect the overall time to digitize a frame or series of frames, as discussed below:

- Time to digitize control points - this is done at the beginning of each frame and requires approximately 30 seconds total, including a calibration check with a fifth control point. However, if the initial calibration is not within a sufficient error tolerance, a recalibration must be done taking additional time.

- Time to digitize a vehicle the first time it enters the section - this involves specifying vehicle color and type and digitizing both the front and rear of the vehicle. This requires approximately 20 seconds per vehicle. For a ½-mile (.8045 m) section, with vehicles travelling at an average of 30 mi/h (48.27 km/h) under congested flow, a vehicle would be digitized 60 times, so that the initial color, type, and length digitizing would have to be done only one time out of 60. With higher speeds or shorter section lengths, this proportion would be higher, resulting in a higher average digitizing time per vehicle.

- Time to digitize a vehicle each successive time it is in the frame - this involves simply locating the cursor over the appropriate corner of the vehicle being matched and pressing the button corresponding to the lane number. In this case, the average time per vehicle is approximately 5 seconds.

- Time to store data from each frame and advance film - 30 seconds.

ADDITIONAL FILMING EXPERIMENTS

Having demonstrated the basic feasibility of the digitizing process, additional aerial filming was done to resolve the remaining questions on film format, aircraft, and photographic procedures.

A brief experiment was conducted using a hovering helicopter and 35 mm half-frame format. This configuration was also found to be impractical. Although 1 hour of film could conceivably be obtained with this method, ideal conditions of wind velocity and direction would be needed at every site to avoid overheating of the helicopter engine. These highly restrictive requirements, the cost of helicopter rental and the inability to find commercial helicopter companies willing to fly under such conditions all contributed to the elimination of this method from further consideration. If it were possible to film safely and economically from a helicopter, that would be preferable to the circling technique used with a fixed wing aircraft, as accuracy in the digitizing process is easier to achieve when the section is being continuously filmed from approximately the same point. However, an alternative to the helicopter and the small fixed wing aircraft had to be sought.

The final experiment involved the use of a Heli Porter STOL (Short Take-Off and Landing) aircraft with a full-frame 35 mm film format. This aircraft proved to be considerably more stable as a filming platform than the Cessna and was able to hold a tighter radius around the site. Combined with the larger film format, this configuration proved to meet all of the filming requirements and was therefore adopted as the method to be used. Enough test film was shot in October 1982 to allow further development of the data reduction process. Although 70 mm film was considered in this experiment, the cost of the film and of projection equipment was substantially higher than 35 mm film, and only 40 minutes of continuous 70 mm filming could be obtained with the available film magazine size.

APPENDIX C

ARTICLE ON FILM-TO-GROUND COORDINATE TRANSFORMATION BY BLEYL

Traffic Analysis of Time-Lapse Photographs Without Employing a Perspective Grid

by Robert L. Bleyl

For 40 years traffic engineers have been using time-lapse photography in making traffic studies. In analyzing the time-lapse frames, a perspective grid onto which the photographs are projected has usually been used. From a number of recently published articles, it is apparent that the perspective grid method of analysis is still being widely used.

This method of analyzing time-lapse photographs has a number of weaknesses: the grid is not easy to establish; in the field, numerous control points must first be laid out on the roadway, filmed, and then used in drawing a complete perspective grid on the projection surface. If the camera or projector is moved, a new grid may be needed. Analysis of the film is slow because it is necessary to position each frame so that the perspective grid is exactly aligned with known points in the photograph. In reading the position of a vehicle (usually one of the tires), visual interpretation is required; visual scaling is complicated by the non-linearity of the perspective grid scale.

A few years ago, Huber and Tracy[1] employed a superior method of determining the longitudinal and lateral position of vehicles observed in time-lapse photographs. They used a numerical routine that calculated the longitudinal and lateral position of the vehicle on the roadway from the *rectangular* coordinates of the vehicle in the film image. Instead of the extensive markings needed to establish the perspective grid, only four reference points were needed. Registration of the film image with the registration points was accomplished numerically rather than physically, as is required with the perspective grid. If the camera were moved between frames, such as might occur when filming from a moving vehicle, it would be a simple process to determine the new relationship between the roadway plane and the film plane. There are a number of devices on the market to facilitate the process of reading rectangular film coordinates. Because of the nature of the numerical relationship between two oblique planes, it is recommended that the conversion from film coordinates to roadway coordinates be accomplished using a computer.

The purpose of this paper is to present the details of this method in a form ready for practical application. A FORTRAN IV computer program subroutine for making the transformation from the rectangular film coordinate system to a rectangular roadway coordinate system is presented. A review of the theory behind the method and instructions on using the subroutine follow:

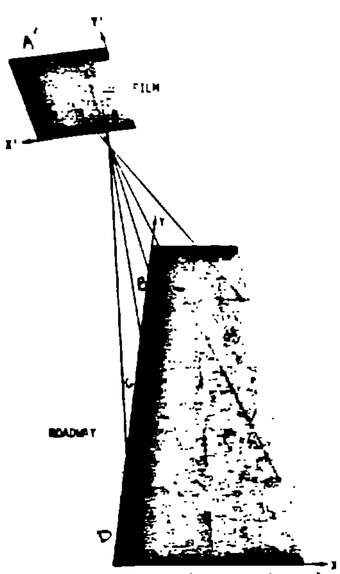


Figure 1: Diagram showing the relationship between points in the roadway plane and the film plane.

Consider the relationship between a roadway plane and a film plane, as shown in Figure 1. Each point, A through E, on the roadway plane has a corresponding point, A' through E', on the film plane. Each point in the roadway plane can be defined by the lateral and longitudinal roadway coordinates XR and YR: in the film plane, the corresponding points can be defined by the rectangular film coordinates XF and YF. The numerical relationship between the two planes is:[2]

$$XR = \frac{C_1 + C_2XF + C_3YF}{C_4XF + C_5YF + 1.0}$$

$$YR = \frac{C_6 + C_7XF + C_8YF}{C_4XF + C_5YF + 1.0}$$

where

- XR, YR = X and Y coordinates of any point in the roadway plane,
- XF, YF = X and Y coordinates of the same point in the film plane,
- $C_1 \ldots C_8$ = Coefficients that remain constant as long as the oblique relationship between the two planes does not change.

In order to establish the specific relationship between the two planes, the coordinates of four reference points in the roadway plane and the coordinates of the associated points in the film plane must be known. No three points

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Bleyl was associated with the Bureau of Highway Traffic at Yale and Penn State Universities when the computer program presented in this paper was developed and refined.

may lie on the same straight line.

Solution of the above equations for each of the four reference points will yield eight equations in eight unknowns. The eight simultaneous equations can be solved easily using an electronic digital computer to determine the eight unknown coefficients. Once the eight coefficients have been calculated, the roadway coordinates (XR, YR) of any other point can be calculated by solving the above equations using the corresponding film coordinates (XF, YF).

As long as the camera (film plane) remains fixed relative to the roadway plane, the same coefficients can be used on successive frames. Should the camera or projector be jarred or moved, the film coordinates of the four reference points can easily be reread and the eight coefficients quickly recalculated.

In processing successive frames photographed from the same position, it is not necessary to physically register each photograph at exactly the same point on the rectangular grid. The necessary positioning can be accomplished numerically by reading the location of one reference point in each frame and transposing the coordinates of additional points in that frame to the proper position for analysis.

A computer program subroutine for accomplishing the conversion of coordinates from the film plane to the roadway plane is shown in Figure 2. The subroutine contains only 66 statements and occupies less than 750 words of computer storage.

In using this subroutine, the eight coefficients must first be calculated. This calibration is accomplished by supplying the film and roadway coordinates of four reference points. A FORTRAN statement of the following form is included in the main program to accomplish this task:

CALL CALIBR (XR, YR, XF, YF)

where

XR, YR = Real arrays of four elements each (standard word length) containing the X and Y coordinates of the four roadway reference points,

XF, YF = Real arrays of four elements each (standard word length) containing the X and Y coordinates of the four corresponding film reference points.

A FORTRAN statement of the following form is subsequently employed in the main program to convert the X and Y coordinates of any point on the film image to the corresponding X and Y coordinates on the roadway:

CALL COORD (X, Y)

where

X, Y = Real variables of standard length. Prior to this statement, X and Y contain the coordinates of a point on the film plane. Following this statement, X and Y contain the corresponding coordinates of the point on the plane of the roadway.

```
      SUBROUTINE CALIBR(XR, YR, XF, YF)
C
C     ESTABLISHES RELATIONSHIP BETWEEN TWO RECTANGULAR
C       COORDINATE SYSTEMS IN DIFFERENT PLANES
C
      DIMENSION  A(8,8), B(8)
      DIMENSION  XR(4), YR(4), XF(4), YF(4)
C
C     SET UP 8 BY 8 MATRIX A AND 1 BY 8 MATRIX B
      DO 10 I=1,4
      A(I,1) = 1.0
      A(I,2) = XF(I)
      A(I,3) = YF(I)
      A(I,4) = -XF(I) * XR(I)
      A(I,5) = -YF(I) * XR(I)
      A(I,6) = 0.0
      A(I,7) = 0.0
      A(I,8) = 0.0
      B(I) = XR(I)
   10 CONTINUE
      DO 20 I=5,8
      J = I-4
      A(I,1) = 0.0
      A(I,2) = 0.0
      A(I,3) = 0.0
      A(I,4) = -XF(J) * YR(J)
      A(I,5) = -YF(J) * YR(J)
      A(I,6) = 1.0
      A(I,7) = XF(J)
      A(I,8) = YF(J)
      B(I) = YR(J)
   20 CONTINUE
C
C     SOLVE EIGHT SIMULTANEOUS EQUATIONS   AX=B
      DO 120 I=1,8
   30 F = A(I,I)
      IF(F .NE. 0.0) GO TO 80
C       COEFFICIENT = 0.0   FIND ALTERNATE
      J = I
   40 J = J+1
      IF(J .GT. 8)  GO TO 60
      IF(A(J,I) .EQ. 0.0)  GO TO 40
C       ALTERNATE FOUND   SWITCH ROWS
      DO 50 L=1,8
      TEMP = A(I,L)
      A(I,L) = A(J,L)
      A(J,L) = TEMP
   50 CONTINUE
      TEMP = B(I)
      B(I) = B(J)
      B(J) = TEMP
      GO TO 30
C       NO ALTERNATE CAN BE FOUND
   60 WRITE(6,70)
   70 FORMAT('1 MATRIX HAS NO SOLUTION')
      STOP
C       DIVIDE ROW TO GET UNITY COEFFICIENT
   80 DO 90 J=1,8
      A(I,J) = A(I,J) / F
   90 CONTINUE
      B(I) = B(I) / F
C       ZERO REMAINDER OF COLUMN
      DO 110 J=1,8
      IF(J .EQ. I)  GO TO 110
      F = A(J,I)
      IF(F .EQ. 0.0)  GO TO 110
      DO 100 K=1,8
      A(J,K) = A(J,K) - F*A(I,K)
  100 CONTINUE
      B(J) = B(J) - F*B(I)
  110 CONTINUE
  120 CONTINUE
C       SOLUTION OF 8 SIMULTANEOUS EQUATIONS COMPLETED
      RETURN
C
C     CALCULATE ROADWAY COORDINATES GIVEN FILM COORDINATES
      ENTRY  COORD(X, Y)
      XX = (B(1) + B(2)*X + B(3)*Y) / (B(4)*X + B(5)*Y + 1.0)
      Y  = (B(6) + B(7)*X + B(8)*Y) / (B(4)*X + B(5)*Y + 1.0)
      X = XX
      RETURN
      END
```

Figure 2: FORTRAN subroutine to convert film coordinates to roadway coordinates.

This statement can be used any number of times as long as the relationship between the two planes remains fixed.

If the time-lapse photographs are being made from a moving position, such as from an airplane, or if the relationship between the roadway plane and the film plane should change, the eight coefficients must be recalculated for each new position by the CALL CALIBR (XR, YR, XF, YF) statement.

This procedure assumes that all

roadway reference and observation points are located in the plane of the pavement surface. The point of contact between a tire and the pavement would be used in analyzing the time-lapse photographs. Unless the filming takes place from a position off the roadway, it may be difficult to get an accurate reading on this contact point. When filming must be done from a point near or over the roadway, another target might be used in locating the position of vehicles. Huber and Tracy made their observations at night using vehicle headlights for their target.[1] Reference points for the vehicle headlight plane could be established by placing reference targets on poles or posts at the appropriate elevation above the roadway plane (2.25 ft for passenger cars; 3.25 ft for trucks and buses).

The method presented in this paper for analyzing time-lapse photographs has many advantages over the perspective grid method. It is hoped that the computer program subroutine described herein will enable users of time-lapse photography to analyze their films more efficiently, more rapidly, and more accurately than was possible in the past.

References

1. Huber, M. J., and Tracy, J. L. *Effects of Illumination on Operating Characteristics of Freeways*, Report 60, National Cooperative Highway Research Program, Highway Research Board, Washington, D.C., 1968, Appendix B.
2. Hallert, B., *Photogrammetry, Basic Principles and General Survey*, McGraw-Hill, New York, 1960.

APPENDIX D.
EQUATIONS USED FOR GROUND-TO-HIGHWAY COORDINATE TRANSPORTATION

METHOD to CALCULATE "S" and "d" for VEHICLES in a CURVE SUBSECTION

Given:

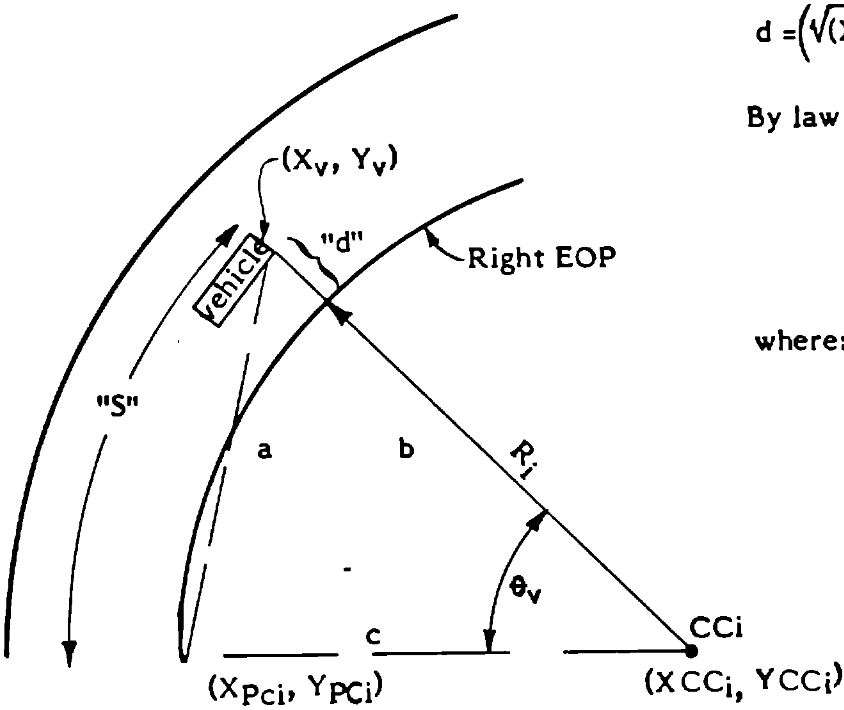
CC_i = Center of curve, subsection i, with known ground coordinates (X_{cci}, Y_{cci})

R_i = Radius of curve, subsection i, to right EOP

PC_i = Beginning of curve, subsection i, with known ground coordinates (X_{pci}, Y_{pci})

(X_v, Y_v) = Vehicle ground coordinates

"RIGHT-HAND" CURVE



$$d = \left(\sqrt{(X_v - XCC_i)^2 + (Y_v - YCC_i)^2}\right) - R_i$$

By law of cosines:

$$\cos\theta_v = \frac{b^2 + c^2 - a^2}{2bc}$$

where:

$$a = \sqrt{(X_v - XPC_i)^2 + (Y_v - YPC_i)^2}$$

$$b = R_i + d$$

$$c = R_i$$

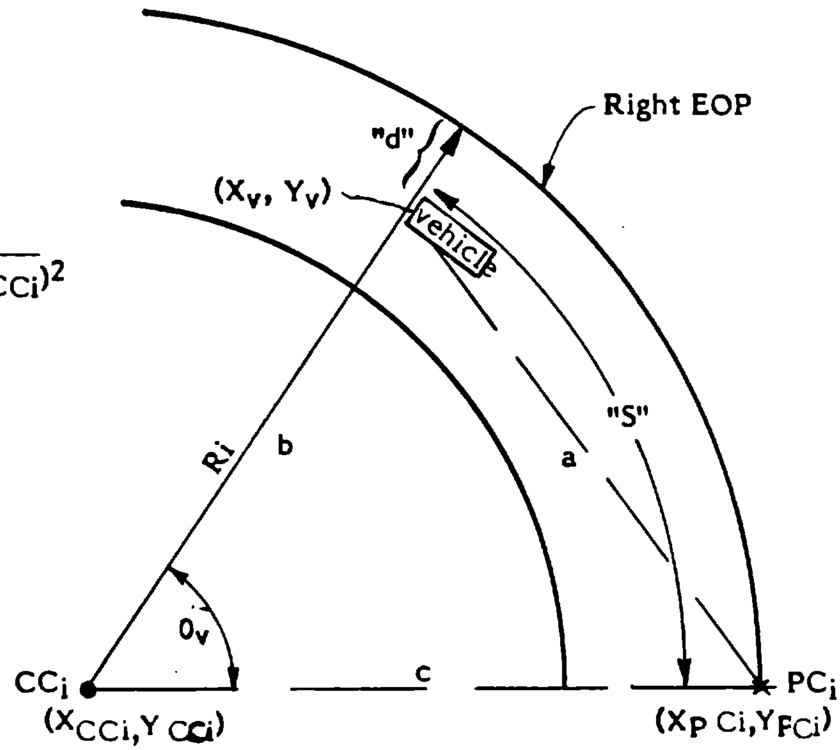
Solve for: (in degrees) $\theta_v = \text{Cos}^{-1}\left[\dfrac{(R_i + d)^2 + R_i^2 - [(X_v - X_{PC_i})^2 + (Y_v - Y_{PC_i})^2]}{2(R_i + d)(R_i)}\right]$

then

$S = (R_i + d)\ \theta_v$ (where θ_v is in radians)

"LEFT-HAND" CURVE

$d = R_i - \sqrt{(X_v - X_{CCi})^2 + (Y_v - Y_{CCi})^2}$



By law of Cosines:

$$\cos \theta_v = \frac{b^2 + c^2 - a^2}{2bc}$$

where

$$a = \sqrt{(X_v - X_{PCi})^2 + (Y_v - Y_{PCi})^2}$$
$$b = R_i - d$$
$$c = R_i$$

Solve for: (in degrees $\theta_v = \cos^{-1}\left[\frac{(R_i - d)^2 + R_i^2 - \left[(X_v - X_{PCi})^2 + (Y_v - Y_{PCi})^2\right]}{2(R_i - d)(R_i)}\right]$

then: $S = (R_i - d)\,\theta_v$ (where θ_v is in radians)

METHOD to CALCULATE "S" and "d" for VEHICLES in a TANGENT SUBSECTION

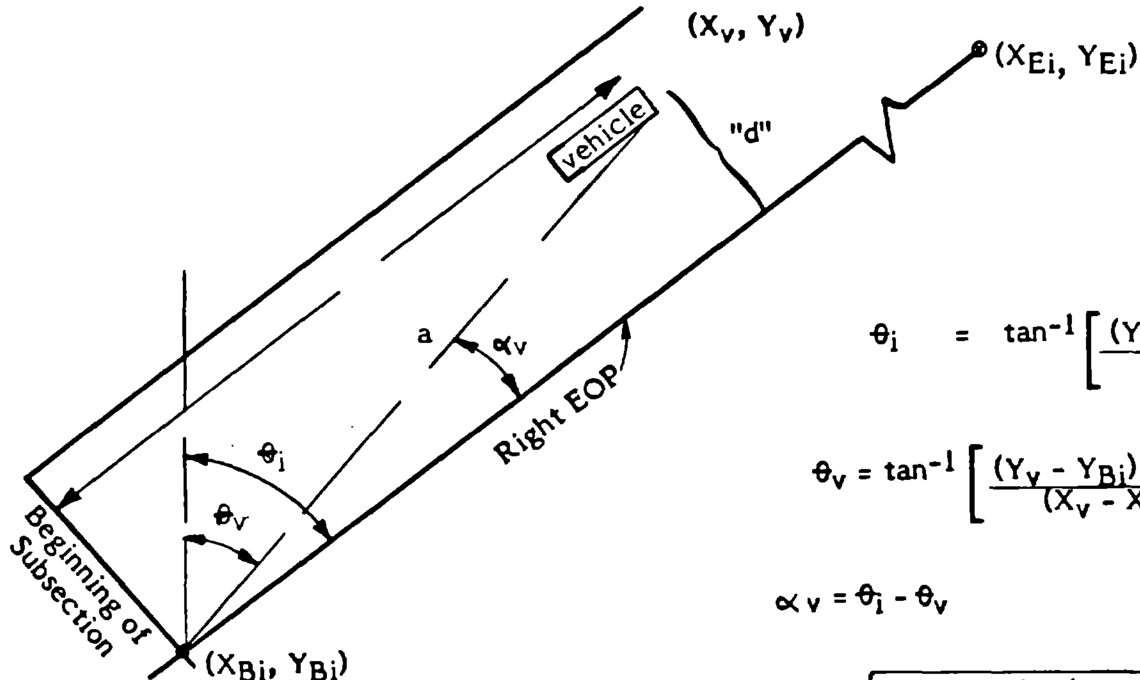
Given:

(X_{Bi}, Y_{Bi}) = Ground coordinates of beginning of Subsection i, at Right EOP.

(X_{Ei}, Y_{Ei}) = Ground coordinates of End of Subsection i, at Right EOP.

0_i = Bearing of tangent (can be calculated)

(X_v, Y_v) = Vehicle ground coordinates



$$\theta_i = \tan^{-1}\left[\frac{(Y_{Ei} - Y_{Bi})}{(X_{Ei} - X_{Bi})}\right]$$

$$\theta_v = \tan^{-1}\left[\frac{(Y_v - Y_{Bi})}{(X_v - X_{Bi})}\right]$$

$$\alpha_v = \theta_i - \theta_v$$

Let $a = \sqrt{(X_v - X_{Bi})^2 + (Y_v - Y_{Bi})^2}$

then: $d = a(\sin \alpha_v)$

and $s = a(\cos \alpha_v)$

APPENDIX E

MANUAL FOR OPERATORS OF THE JHK & ASSOCIATES DIGITIZING SYSTEM

INTRODUCTION

This manual describes how to use the aerial photography digitizing system developed by JHK & Associates and the Comsis Corporation for the FHWA research study entitled "Freeway Data Collection for Studying Vehicle Interactions." This introduction will present a brief background on the system, followed by a description of how it operates.

The purpose of the Freeway Data Collection Study is to provide a set of data bases suitable for the study of how traffic flows through different types of freeway sections. Hopefully, this information will help highway designers in their job of designing freeway improvements and new freeway systems. In this study, we are tracing the movements of vehicles in very detailed fashion as they move through a section of freeway. To do this, we have taken pictures of rush-hour traffic from an airplane at a rate of once each second for a period of a little over 1 hour. We have done this for about 18 different locations in the Washington, DC area and the Los Angeles area.

We will be projecting these films, one frame at a time, onto an electronic device called a "digitizer." The digitizer is used to "digitize" the positions of vehicles going in a certain direction. This means that it plots the position of each vehicle in a form which can be used by a computer. One of the important parts of the digitizer is a keypad which you will be holding in your hand. This keypad has a set of crosshairs which you will use to line up with vehicles projected on the film and a set of buttons which you will push at the appropriate time. Your pushing a button on the keypad will send information over to the computer, which is connected by a cable to the digitizer. Another device, called a voice synthesizer, will give you instructions on what vehicles to be looking for in the film. The voice synthesizer simply takes information from the computer and talks to you about it rather than your having to read it. The operation of the system will become clearer if we take a step-by-step look at how it works.

The digitizing system uses a microcomputer to oversee the operation of the system. This particular computer is a Sage IV microcomputer, and you can give it instructions from either the typewriter-like keyboard or from the keypad on the digitizer. All the Sage IV really does is keep track of all the vehicles that you digitize, perform a lot of calculations and give you instructions on what to do next.

Listed below are steps you should follow, beginning with turning the system on. Where you see something in quotation marks type in what is between the quotation marks, but not the quotation marks themselves.

1. To turn system ON

   - turn the terminals ON
   - turn the SAGE ON
   - turn the digitizer ON for system 1 or 2 (depending on which one you want to use)

   - turn the voice synthesizer ON for system 1 or 2
   - turn the projector fan ON and then the projector lamp for system 1 or 2

2. From the main (no. 1) terminal Press RETURN and wait to see " "

3. Type in "IH MUBOOT" and press RETURN. The system will respond with "TYPES TO START SYSTEM." Type in "S" without a RETURN at terminal no. 1 or 2. The system will respond with the following display:

   FROM PREVIOUS RUN:
   FILE NAME: BKL18.DAT DRIVE = DRIVE_A:
   LAST FRAME: 146

   SELECT ONE OF THE FOLLOWING OPTIONS:

   0) VERIFY THE HARD DISK ===== HAVE YOU VERIFIED THE HARD DISK TODAY?

   1) CONTINUE A PREVIOUS RUN
   2) START A NEW RUN
   3) OPTION 1 USING SAVED GEOMETRY
   4) OPTION 2 USING SAVED GEOMETRY

   5) CONVERT DATA FILE TO TEXT FILE
   6) COPY DATA FILES TO FLOPPY DISK
   7) ACCESS FILES DIRECTORY

   8) ACCESS SYSTEM UTILITIES
   9) EXIT TO P_SYSTEM OPERATING SYSTEM

   ENTER ONE OF THE ABOVE OPTIONS...

4. At this point, select option 3 by typing in a "3".

5. The system will then show you some information from the previous run (name of last file and number of last frame). It will ask whether you want to use previous run information. You almost always will want to use the previous information. We will let you know about any exceptions. At this point enter "Y" and a return.

6. Next, the system will ask you the name of the new file. This will always be three letters (such as BKL), followed by a number (always one higher than the last file) followed by a "DAT". For example, if the previous file was named BKL18.DAT, the new file would be BKL19.DAT. The system will then show you which disk drive it plans to send the file to (such as DRIVE_A:). You should respond with a "Y" and a RETURN.

7. Next, the system will ask you the name of the highway geometry file. We will give you what to put in here, as it will change with each film. Enter the file name and a RETURN. The type "Y" to accept the information as OK.

8. Once you have completed step 7, the system will say the following:

   KEYBOARD INPUT COMPLETE. ALL INPUT NOW FROM CURSOR PAD
   ENTER *FRAME NUMBER*TIME
   FRAME NUMBER=9999 TO TERMINATE, TIME=SECONDS SINCE LAST FRAME

   From now on, you will do everything from the digitizer's keypad. At this point, push "*", the frame number (at the bottom of the picture), another "*" and a "1". It will then ask you if it is OK. If it is, enter a "0" for yes.

9. Next, the system will ask you to enter the control points (usually 4). These are locations on the film that the system will use in computing the position of vehicles. We will show you where these points are for each film. Put the cursor's crosshairs over each point and press the number corresponding to the point. After you have put in the last control point, enter "0". This terminates the input, and the system will respond by asking you for a calibration checkpoint. Put the crosshairs over the calibration checkpoint, and push any number (but not a letter). The system will give you X and Y coordinates of that point. If these are within the bounds that we give you, enter a "0" in response. If they are not within the bounds, this is an indication that you made a mistake. In this case, enter a "1" for NO, reenter one or more of the control points you may have entered wrong, and repeat the checkpoint process.

10. After this, you will hear the voice synthesizer tell you several things about the first vehicle you are to digitize in that frame. The first vehicle should always be near the end of the section where the vehicles leave. The system will tell you the color and type of vehicle and which lane it was in in the previous frame. Lanes are numbered from right to left, with on-ramps, off-ramps, and auxiliary lanes numbered 8 or 9. When you find the right vehicle, put the crosshairs over the middle front of the vehicle and push the button representing the lane number the vehicle is <u>now</u> in (not the lane it was in the last frame - sometimes they will have changed lanes). See the notes on "Things to Remember" for some important guidance on how to do the digitizing.

11. Once you have digitized the first vehicle, the system will tell you the next vehicle and so on until all the vehicles which were in the last frame have been digitized.

12. Once you have done all the vehicles, the system will say "NEXT," which tells you to digitize any new vehicles that have entered the section for the first time. Now you should push buttons in the following order:

    * COLOR, TYPE*LANE

The system will respond by saying "ENTER BACK." At this time, put the crosshairs over the back end of the vehicle and press any number. The system will then ask for the next vehicle until all the new vehicles are done. It is important that you not digitize vehicles before they have entered the section. The vehicle can be digitized after its front has crossed the boundary line. Do not forget to check for new vehicles on any on-ramps in the section. You may also need to delete cars that leave the section on an exit ramp.

The vehicle colors and types are labeled on the cursor pad. The colors are labeled as follows:

1) (WHT) = white
2) (BLK) = black
3) (RED) = red
4) (BLU) - blue
5) (GRN) = green
6) (YEL) = yellow
7) (BRN) = brown
8) (GRY) - gray
9) (2TN) = two-tone (any combination of two colors)

In choosing a color for the vehicles, you don't need to worry about picking exactly the right color. Just pick one that will help you to identify the vehicle in later frames.

Vehicle types are as follows:

1) (CAR) = passenger car
2) (VAN) = van or pickup truck
3) (TLR) = car, van or pickup truck with trailer
4) (SUT) = single unit truck
5) (TTR) = tractor trailer truck
6) (BUS) = bus

The most common vehicle types you will have are cars, single unit trucks, and tractor trailer trucks. Single unit trucks are any trucks without a trailer. Sometimes they are hard to tell apart from cars, but usually they look wider or longer than cars, and they would cast longer shadows than cars. In most films, it may not be easy to distinguish vans and pickup trucks. If you are not sure, just call the vehicle a car. It is important to identify trucks, however.

13. Once you have completed a frame, enter *9999*0. This will put you into another menu on the CRT which is used to correct errors, just in case you want to fix something before you end a frame (more about how to do that later). Entering a "0" at this point will give you a message that the frame is completed, and the system will ask you for a new frame number. If you enter an *9999*0 at this point, the system will abort the run. This means it will throw out the data from the frame you are in, save data from the previous frames, close out the file, and put you back in the main menu (see #3). You shouldn't need to do this very often.

14. Correcting errors: Occasionally you may make a mistake, and need to go back and redo one or more vehicles you have digitized. The error correction menu is used to do this. You can get to this menu in one of two ways:

- If you have not finished digitizing the old vehicles (vehicles present in last frame) enter a "0".
- If you have finished digitizing the old vehicles, enter "*9999*0".

The menu will give you the following choices:

1) LIST 10 VEHICLES
2) RESTART AT VEHICLE N
3) REDIGITIZE VEHICLE N
4) DELETE VEHICLE N
5) CHANGE COLOR OF VEHICLE N
6) TURN OFF THE SPEED CHECK
7) RESTART THIS FRAME

These options are described below. For all options, enter an: "*", followed by the vehicle identification number, followed by another "*", followed by the option number (1 to 7). A vehicle must have already been digitized in the current frame in order for this to work. It will not work on a vehicle which has not yet been digitized. Options 1, 3, 4, 5, and 6 will return you to the error correction menu. If you are not finished digitizing all the old vehicles yet, entering a "0" at this point will put you back at the next vehicle to digitize.

1) <u>LIST 10 VEHICLES:</u> If you enter "*ID*1" (where ID is the identification number of the vehicle you are interested in - it is labeled "NV" on the screen), the system will list information on ten vehicles, starting with the one you indicated with the ID number. To return to the error correction menu, enter any number. This option is normally used to identify vehicles for which you may want to correct errors.

2) <u>RESTART AT VEHICLE N:</u> If you enter "*ID*2", the system will allow you to redo a series of vehicles, starting with the one you specified by the ID number. You may restart with any vehicle that has already been digitized. This option would normally be used when you find out you have digitized the wrong vehicle or have made some other mistake.

3) <u>REDIGITIZE VEHICLE N:</u> If you enter "*ID*3", the system will allow you to redigitize only one vehicle. It will prompt you with the color, type, and lane, as usual, but will send you back to the error correction menu after you have digitized the vehicle. You would only use this option if you wanted to redo a single vehicle which was digitized wrong earlier in the frame. You will use RESTART AT VEHICLE N much more often.

4) <u>DELETE VEHICLE N:</u> If you enter "*ID*4", the system will delete the vehicle from the frame. The vehicle would not appear in any subsequent frames. You would use this option primarily to delete vehicles that were exiting on an exit ramp somewhere in the middle of the section. You may

occasionally need to use it to delete a vehicle which is actually nonexistent (e.g., it may have looked like a vehicle at first, but turned out to be a spot on the film).

5) CHANGE COLOR OF VEHICLE N: If you enter "*ID*5", the system will permit you to change the color of the vehicle you identified. The system will tell you audibly to "enter new color for vehicle N." At this point press the number corresponding to the new color. The system will use the new color for that vehicle from then on and will return you to the error correction menu. It is not important that you have exactly the right color, so don't feel that you need to use this option very often, if ever. Just make sure you give the vehicle a color which will help you to keep track of it.

6) TURN OFF THE SPEED CHECK: On very rare occasions you may get caught in a situation where a vehicle is not even close to being in the right place, and you can't digitize the vehicle anywhere without getting a speed error. This option is available as a last resort to let you get around the problem vehicle and, if necessary, to delete it. Do not use this option without first consulting a supervisor, as it indicates that there are other problems also.

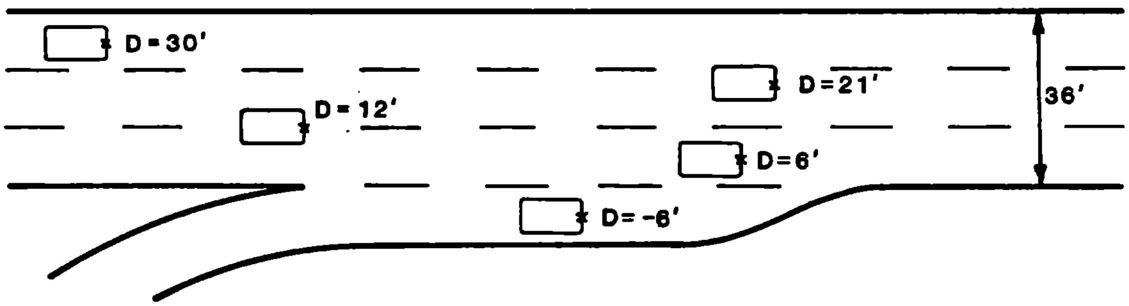
7) RESTART THIS FRAME: This option is available in case you need to start a frame completely over. Usually what happens is you forgot to advance the film, even though you may have entered in the right frame number. If you get speed errors on every vehicle, this is probably what has happened. To restart the frame enter "*ID*7". The ID may be of any vehicle already digitized (note: you must digitize at least the first vehicle, to use this option). The system will then ask you if you really do want to restart the frame. If you do, enter "0" for yes, and the system will ask you for the frame number again, and you may start all over.

THINGS TO REMEMBER

1) The proper positioning of vehicles in a lane is extremely important. The position in the lane is given by the value of "D". Vehicles centered in lanes 1, 2, or 3 and 8 should have D values in the following range (when middle front of vehicle is digitized):

lane 1: 3 to 9
lane 2: 15 to 21
lane 3: 27 to 33
lane 8: -3 to -9

You should be able to tell about what the D value should be by seeing where the vehicle is positioned relative to the lane lines. Here are some examples:



You may need to shift where you put the crosshairs left or right from the front middle of the vehicle to adjust for this.

2) Missed vehicles - it is possible that you may occasionally miss a vehicle at the beginning of the section. Add it as soon as you see that it is, in fact, a vehicle.

3) Vehicles not actually there - sometimes there might be vehicles you thought were there in an early frame, but later on you found out it was only a speck or shadow. Delete these when you discover that they are not there, and be sure to list the error along with the vehicle ID and frame number on the pad of paper provided.

4) A speed error usually means that you digitized the wrong vehicle. It can also mean you digitized the right vehicle in the wrong position, either in this frame or the last frame. If you suspect that you made the mistake in the previous frame, digitize points in front of or behind the vehicle in the current frame in small increments until the speed error no longer occurs.

5) There is a question on what to do when you cannot see a vehicle because it is hidden behind a truck, lost in a shadow or blends in with the pavement. If you cannot locate a vehicle for any of the above reasons, you need to estimate about where that vehicle is. The easiest way is to just try digitizing about where you think it is until you no longer get a speed error. However, it is also important that the speed you get is about the same as the speed of other vehicles in the same lane. If you don't check this, that vehicle could inadvertently overrun other vehicles in that lane. When you are adding new vehicles, it is important that you carefully examine the road for all possible new vehicles, including those

that tend to blend into the pavement. If you think there might be a vehicle there but are not sure, it is better to add it anyway and delete it in a later frame if it turns out not to be a vehicle.

6) THE "LANE CHANGE" MESSAGE. Whenever you change the lane of a vehicle (from lane 1 in the previous frame to lane 2 in the current frame, for example), the system will tell you audibly that you made a lane change. The main reason the system tells you this is to help you catch any errors you made in pressing the lane number. For example, it is sometimes easy to be digitizing rapidly along and hit a 2 for a car that was actually in lane 1 in the last frame and is still in lane 1. In other words, you just pushed the wrong button. If the system did not give you the "lane change" message, you probably would never have known you made this mistake, and if it was not a legitimate lane change, you can go back and redo the vehicle with the right lane number using the RESTART or REDIGITIZE options.

APPENDIX F
FORMAT OF THE GEOMETRY AND VEHICLE DATA FILES

This appendix provides general documentation for a set of data bases developed for FHWA consisting of traffic movements on selected freeway sites in the Washington, DC and Los Angeles, California metropolitan areas. These data sets consist of a record of the lateral and longitudinal positions of vehicles each second over a 1-hour period under a range of traffic conditions. The data sets are intended to be used for the study of microscopic vehicle movements, and include a variety of geometric configurations: weaving sections, ramp merges, vertical grades, horizontal curves, lane drops, and reduced width sections.

Each data set is contained in two files, on a 9-track magnetic tape. The geometric data comprise the first file, followed by the vehicle file. The geometric data are coded according to the conventions of the simulation model INTRAS, but exclude the traffic inputs, which can be derived through the analysis of the vehicle data. The data formats for the geometry files, taken from the INTRAS users manual, are presented at the end of this appendix. Those items from the INTRAS documentation which are included in the geometry files are designated with an asterisk.

The format for the vehicle data as well as comments on the use of the data are provided below:

- Frame record: (Card type 21)
  - col. 1-4 - time interval between frames in thousanths of a second
  - col. 6-9 - start frame number
  - col. 11-14 - end frame number
  - col. 16-20 - first vehicle ID
  - col. 22-26 - last vehicle ID

- Queue length record: (Card type 22)
  - col. 1-3 - node nos. identifying beginning of link
  - col. 4-6 - node nos. identifying end of link
  - col. 8-10 - number of vehicles in queue upstream of beginning of section at time zero
  - col. 11-13 - number of vehicles in queue at time = 5 minutes
  - col. 14-16 - number of vehicles in queue at time = 10 minutes
  - continue each 5 minutes up to 60 minutes

- Vehicle records

1. Cols. 1-4 - Film frame number. The frame numbers do not generally start with one. The frames are numbered sequentially from the beginning of the file to the end.

2. Cols. 6-9 - Vehicle identification number. Each vehicle is assigned an identification number which is unique for that vehicle. ID's generally increase with time into the film, but they are not necessarily sequential in any given frame, since vehicles are frequently passed by other vehicles.

There may be some ID's missing, as some "supposed" vehicles were digitized and later deleted when they were found not to be vehicles (they may have been specks on the film instead).

3. Col. 11 - Vehicle type (1 = passenger car, 2 = pickup truck or van, 3 = no. 1 or 2 with trailer, 4 = single unit truck, 5 = tractor-trailer truck, 6 = bus). Category 2 was used primarily as an additional factor to assist those reducing the data in distinguishing among vehicles. Types 2 and 3 would normally be included in the passenger car category. Categories 2, 3, and 6 were used only rarely. Single unit trucks could not be identified by the number of axles or tires because of the small scale and the aerial view. The method for identifying single unit trucks was not perfect, as it was sometimes difficult to distinguish the smaller single unit trucks from the longer passenger cars in the aerial view. Recreational vehicles may have been classified as single unit trucks or cars, depending on their size. They were classified as trucks primarily by virtue of their size, as they appeared from the air, but could occasionally be mistaken for passenger cars or vice-versa. Motorcycles could not be seen in the film.

4. Cols. 13-14 - Vehicle length - Length of vehicle in feet, typically within plus or minus 3 feet (0.9 m).

5. Cols. 16-17 - Vehicle speed since last frame (mi/h). Speed was computed from the difference in the vehicle's longitudinal position between frames at 1-second intervals. The actual speed should be computed using the specified frame interval (card 21). In the first frame in which a vehicle enters a section, the speed could not be computed and is listed as 0. Limits were used on frame-to-frame speed changes to assist the operator in digitizing: 8 mi/h (12.8 km/h) on acceleration and 10 mi/h (16 km/h) on deceleration. These limits may have been reached when vehicles were difficult to see (e.g., hidden in shadows, behind trucks, or color blended in with pavement).

6. Col. 19-22 - Distance from beginning of section to front of vehicle, in feet. This distance is typically accurate within 3 to 5 feet (0.9 to 1.5 m), depending on the length of the section, angle of photography, location within the section and other factors. Because this distance is not exact, vehicle movements may appear to be slightly "jerky," when taken in 1-second increments. Movements taken over longer time periods will appear to be smoother. Therefore, caution should be exercised when looking at acceleration and deceleration characteristics over 1-second increments. Vehicles entering from ramps are added at the point where the ramp actually joins the mainline. Vehicles exiting to off-ramps are included up to or slightly beyond the point where the ramp and mainline diverge.

7. Col 23-25 - Distance from right edge of mainline to middle front of vehicle, in feet. The left front corner was used in several of the films. For vehicles to the right of the mainline, these values would be negative. These distances are typically accurate within 3 feet (0.9 m). For 12-foot lanes, a value between 0 and 12 should correspond to lane 1, 12-24 to lane 2, -12-0 to lane 8, etc. The primary use of this value would be for lane change times and lateral velocity, The lane number entered by the operator (col. 30) offers a more positive identification of the lane.

8. Col. 27 - Vehicle color - a number representing the manually assigned color of a vehicle. Its only use would be to assist in locating a specific vehicle in a review of the original film itself.

9. Col. 30 - Manually assigned lane number. This is the lane number assigned the vehicle by the operator each time the vehicle was digitized. It is recommended that this number be used as a positive identification of all origin and destination lanes, as the lateral distance (col. 23 to 25) could occasionally fall outside the correct lane, particularly at entry or exit ramps.

The format for the geometry file is indicated below. The file consists of selected data records and fields from the INTRAS format specifications, from the INTRAS User's Manual, June, 1977. Items designated with an "*" are included in the geometry files.

Network Name Card - Type 01

Cols.	Description
*1-60	Alphanumeric description of network, data, etc.
63-66	Maximum length of initialization (network priming) period, in seconds.
68	Flag (=0, ≠0) if full time (is note, is) to continue to maximum length even though equilibrium is reached.
69	Flag (=0, ≠0) if simulation (is not, is) to proceed if equilibrium (input-output) is not achieved during fill time.
72	Flag (=0, ≠0) if statistics are to be (cumulative, subinterval specific).
73-74	Hrs. Simulation Min.starting time Sec.on 24-hour clock
*79,80	= 01, card type.

Link Geometry Cards - Type 02

Data for exit links must not be specified on this card type, nor on any other link specific card type.

Cols.	Description
*1-3	Node at upstream end of link. For entry LINKS this number 40-42must be (≥ 700, ≥ 800) for (freeway, non-freeway) entries. Corresponding numbers in the 700 and 800 series may not be used (i.e., if 703 is used as the upstream node of freeway entry, then 803 may not be used elsewhere in the network).
*4-6 43-44	Node at downstream end of link.

Cols.	Description
*8-11	Link length (feet). For urban links this distance is measured 47-50from stop line to stop line. Maximum length of freeway links is 9,800 ft. The limit for ramp and surface links is 3,265 ft. Not an input for entry links; a default value of 9,825 will be used for freeway entries, 3,275 for surface entries.
*12	Link type, as follows: 51 0 (blank) or 1 = Urban links (all non-freeway links which do not connect directly to freeway links). 2 = Ramps (all non-freeway links which do connect directly to freeway links). 3 = Freeway links.
*13-14	Mean desired free-flow speed (mph). The mean speed of 52-53traffic under low enough density conditions such that speeds are freely chosen. (Speed limit was used for geometry file.)
*15 54	Number of through lanes (maximum 5). This figure does not include turn pockets for urban links or auxiliary lanes for freeway links. Maximum number of lanes for ramps is 2. Maximum number of lanes for surface links = 5 - number of turn pockets. (Freeway entry links cannot have auxiliary lanes.)
*16-18	Grade, in $\pm$ percent. 55-57
*19-21	Node at downstream end of link receiving left turning traffic 56-60from this link. Leave blank if link being defined (in columns 1-6) is an on-ramp.
*22-24	Node at downstream end of link receiving through traffic 61-63from this link.
*25-27 64-66	Node at downstream end of link receiving right turning traffic from this link. Leave blank if link being defined (in columns 1-6) is an on-ramp. For entry ramps, only a through receiving (freeway) link may be specified. For exit ramps, two movements, at most, may be specified, 1 of which must be through. More complex turn movements from an exit ramp require the placement of a dummy node such that the downstream portion of the ramp may be specified plus at most, 1 other right or left turn movement to a ramp link.

Cols.	Description
	Network exit links are implicitly specified by setting the node numbers at the downstream end of links receiving the exiting traffic (≥ 700, ≥ 800) for (freeway, non-freeway) exits. As specified in the column 1-3 description, corresponding numbers in the 700 and 800 series may not be used. An off-ramp may may not be an implied exit link.
*29-30 68-69	Location on this freeway link at which drivers begin to react to an upcoming exit or location where early warning sign becomes visible to the motorist; expressed as percent of link length measured from upstream node. One hundred percent is not an allowable value. Signs located at the downstream extremity of a freeway link should be coded as positioned 0 percent on the succeeding link.
*31-33 70-72	Node locating off-ramp, freeway junction referred to by early warning sign of columns 29-30.
*79,80	= 02, Card Type.

Link Name Cards - Type 03

Cols.	Description
*1-3	Node at upstream end of link
*4-6	Node at downstream end of link
*7-24	Alphanumeric Link Name
*25-48 49-72	Same as Cols. 1-24 for another link
*79,80	= 03, Card Type

Freeway Link Operation Cards - Type 04

Cols.	Description
*1-3 40-42	Node at upstream end of freeway link (≥ 700 for freeway entry link).
*4-6 43-45	Node at downstream end of freeway link.
*9-12 48-51	Radius of curvature, feet (0 or blank denotes a straight link).
*13 52	Auxiliary Lane Code for First Auxiliary Lane (Freeway entry links cannot have auxiliary lanes). = 0 or blank: No auxiliary lane = 1: Right hand acceleration lane

Cols.	Description
	= 2: Right hand deceleration lane = 3: Right hand full auxiliary lane (Lane length = Link Length) = 4: Left hand acceleration lane = 5: Left hand deceleration lane = 6: Left hand full auxiliary lane (Lane Length = Link Length)
*14-18 53-57	Lane length (feet) for first auxiliary lane. An acceleration lane extends for the specified distance from the upstream node. A deceleration lane extends for the specified distance from the downstream node. This field need not be specified for code = 3 or 6. To facilitate the internal logic of SIFT, it is important to correctly categorize the type of auxiliary lane. A deceleration lane is defined as a lane which is not fed directly by a lane in an upstream freeway or ramp length. An acceleration lane is defined as a lane which does not feed directly a lane in a downstream freeway or ramp link. Its length should also be less than the link length. Only lanes which connect directly with lanes in both upstream and downstream links may be categorized as full auxiliaries.
*19-24 58-63	Same as Cols. 13-18 (52-57) for second auxiliary lane.
*27 66	Identification of lane entered in through receiving link by vehicles in lane 1 of this link. If through movement is an exit link, code a "1" in Col. 27. Lanes are identified as follows:

Lane	ID
Second Auxiliary Left Lane	7
First Auxiliary Left Lane	6
Lane 5	5
Lane 4	4
Lane 3	3
Lane 2	2
Lane 1 (Right-most through lane)	1
First Auxiliary Right Lane	8
Second Auxiliary Right Lane	9

Cols.	Description
29-30	Specification of lanes separated by physical barriers which prevent weaving. Insert the lane ID of the right hand lane of each such pair. Thus, two such conditions may be specified for each link.
*31-32 70-71	Superelevation (percentage).

Cols.	Description
*33 72	Pavement code: 1 - dry concrete; 2 - wet concrete; 3 - dry asphalt; 4 - wet asphalt Note: default is dry concrete.
36-39 75-78	Distance from upstream node of link for freeway data station (0 is no station), feet.
40-78	Same as Cols. 1-39 for another freeway link.
79,80	= 04, Card Type.

Ramp Link Operation Cards - Type 05

Cols.	Description
*1-3 40-42	Node at upstream end of ramp link.
*4-6 43-45	Node at downstream end of ramp link.
7 46	"Type" of downstream intersection. Used as index of TLNK array to select appropriate distribution about mean queue discharge headway (default = 1).
8,9 47,48	Mean queue discharge headway in tenths of a second (i.e., 24 = 2.4 seconds). (This field is ignored for on ramps.)
*12 51	Identification of lane entered is through receiving link by vehicles in lane 1 of this link. If through movement is an exit link, code a "1" in Col. 27. Lanes are identified as follows:

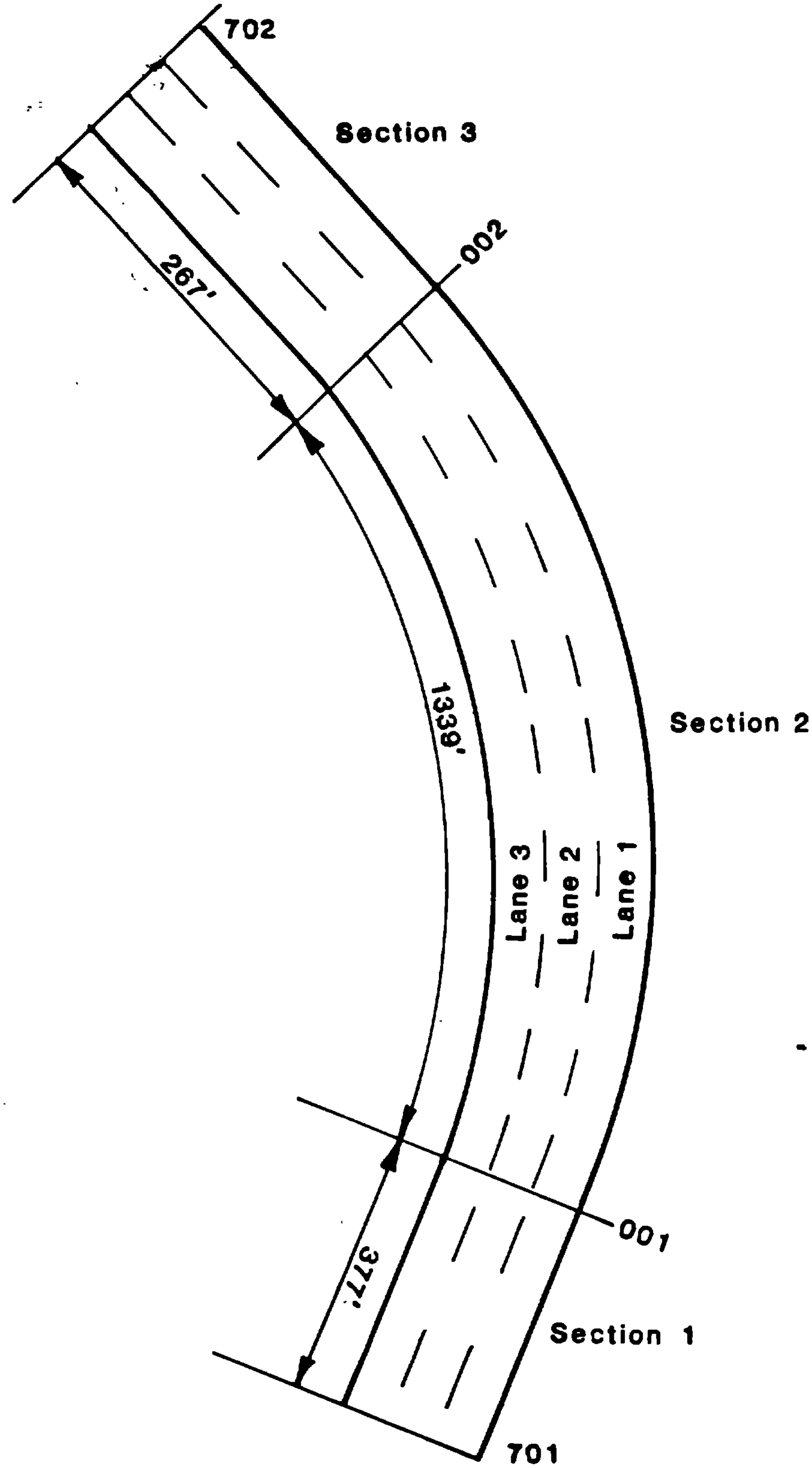
Lane	ID
Second Auxiliary Left Lane	7
First Auxiliary Left Lane	6
Lane 5	5
Lane 4	4
Lane 3	3
Lane 2	2
Lane 1 (Right-most through lane)	1
First Auxiliary Right Lane	8
Second Auxiliary Right Lane	9

Cols.	Description
*15-18 54-57	Radius of curvature (ft). 0 or blank for straight link. (May not be specified after first subinterval.)
*19-20 58-59	Superelevation (%). (May not be specified after first subinterval.)
*21 80	Pavement code: 801 - dry concrete; 2 - wet concrete; 3 - dry asphalt; 4 - wet asphalt. Note: Default is dry concrete. (May not be specified after first subinterval.)
*40-60	Same as for Cols. 1-21 for another ramp link.
*79,80	= 05, Card Type.

APPENDIX G
SKETCHES AND DOCUMENTATION OF INDIVIDUAL DATA SETS

I-495 Westbound, West of Georgia Ave. in Montgomery County, Maryland

This site is a horizontal curve on I-495 (Capital Beltway) westbound, approximately 0.5 mile west of Georgia Avenue in Montgomery County, Maryland (near Washington, D.C.). The site included a curve of approximately 5 degrees (1,100-foot radius) with short tangent sectoins on either end. There was no queues during the filming period, and levels of service were in the C to D range.



Site type = Horizontal Curve

Total length = 1983'

Lane width = 12'

Grade: -3%

Curve radius - 1100'

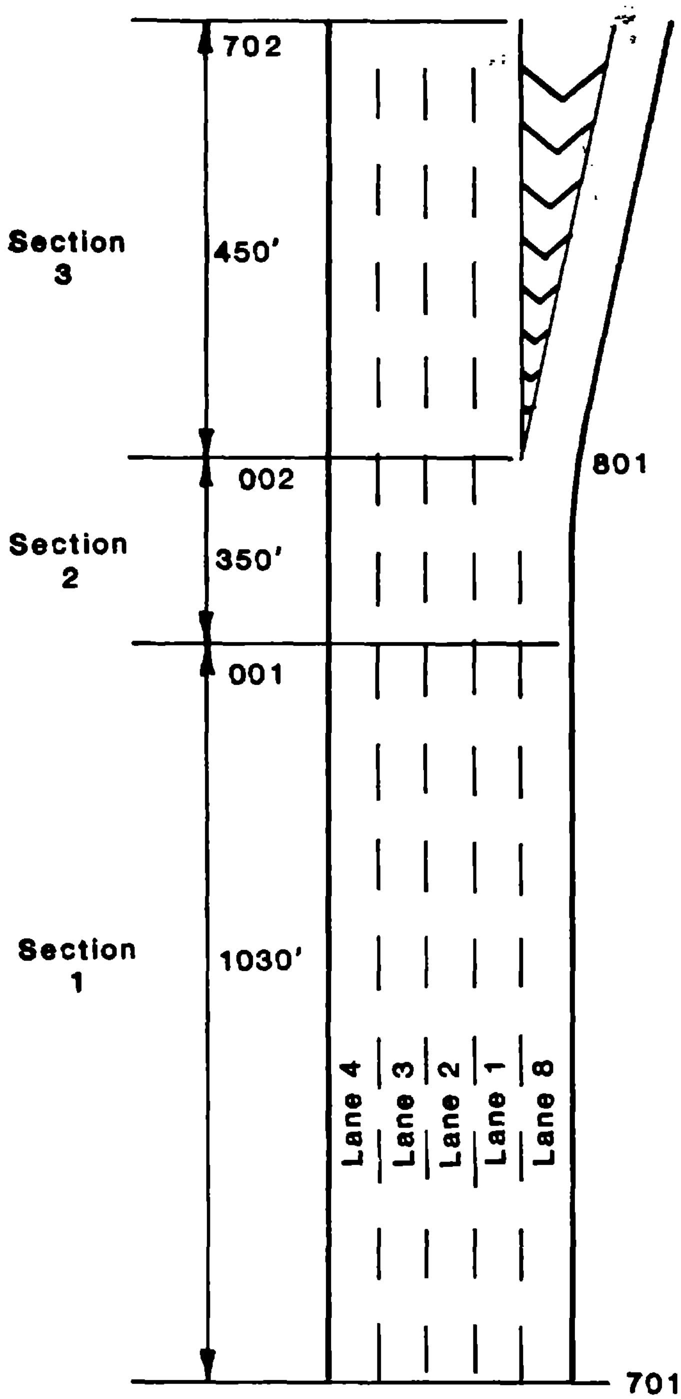
Superelevation on curve = .07

Shoulders = 10' Right
= 4' Left

Figure 20. I-495 Westbound, West of Georgia Ave. (Horizontal Curve)

U.S. 101 (Ventura Freeway) Westbound at White Oak
Van Nuys, California

This site is a lane drop approaching the White Oak exit on U.S. 101 (Ventura Freeway) westbound in Van Nuys, California. The lane is dropped at the exit ramp, in a transition from a five-lane to a four-lane section. The section is 1,830 feet (557.5 m) long, overall, with the upstream end of the site approximately 1,400 feet (425.9 m) from the gore area. There was no queuing within the section during the course of the filming, and speeds were generally 45 mi/h (72.5 km/h) or higher. Operation was in the level of service C to D range. It is estimated that 300 to 400 vehicles merged from lane 8 (off-ramp approach) to lane 1 during the course of the film (based on observation and not on actual processing of the data). It should be recognized that much of the lane changing in response to the lane drop takes place well in advance of the portion of the site filmed. This data set contains data on only that part closest to and including the lane drop itself.



Site type: Lane Drop

Total length = 1830'

Tangent

Lane width = 12'

Grade: Section 1 = +1.2%
Section 2 = +2.6%
Section 3 = +2.6%

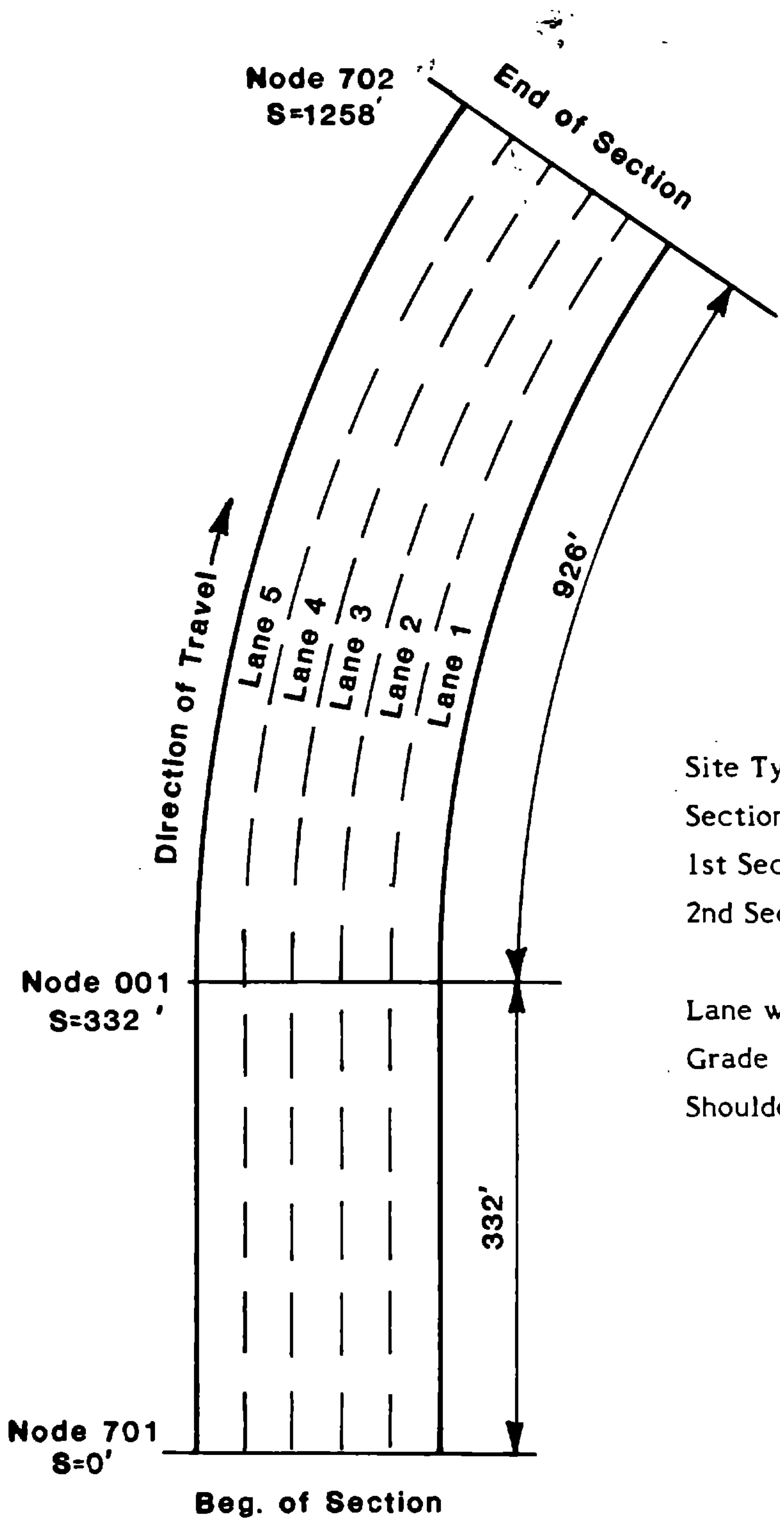
Cross-slope = .02

Shoulders = 8' Right
= 8' Left

Figure 21. U.S. 101 (Ventura Freeway) Westbound at White Oak

I-10 (Santa Monica Freeway) Westbound near LaBrea Ave., Los Angeles

This site is a reduced width section on I-10 (Santa Monica Freeway) westbound between Washington Boulevard and LaBrea Ave. The site is partly tangent and partly curved, with a total length of 1,258 feet (383.2 m). The section had been widened from four to five lanes by reducing lane width to 11 feet (3.3 m) and using most of the left shoulder as a travel lane. Levels of service during the filming were estimated to be in the D range. No traffic disturbances occurred during the filming period.



Site Type: Reduced width section

Section length: 1258'

1st Section tangent, 332'

2nd Section curve, radius = 5000'

superelevation = .02

Lane width = 11'

Grade = +0.2%

Shoulders = 10' right

2' left

NOT TO SCALE

Figure 22. I-10 (Santa Monica Freeway) Westbound near LaBrea Ave., Los Angeles

I-95 Southbound at Backlick Road (Route 617) in Fairfax County, Virginia

This site is a single-lane ramp merge onto a 3-lane mainline. The section is 1,641 feet (499.9 m) long with an 800-foot (243.7 m) acceleration lane. Traffic ranged from an approximate level of service C to E, but essentially no queues extended upstream of the start of the section.

A tractor-trailer truck was parked well off on the right shoulder for the first third of the film, but did not have any apparent affect on traffic. However, a tow truck did pull around the tractor-trailer and may have interfered with flow between approximately frames 500 and 600. Also, approximately 5 minutes before the end of the film, an accident occurred upstream, causing a lighter than usual flow within the section.

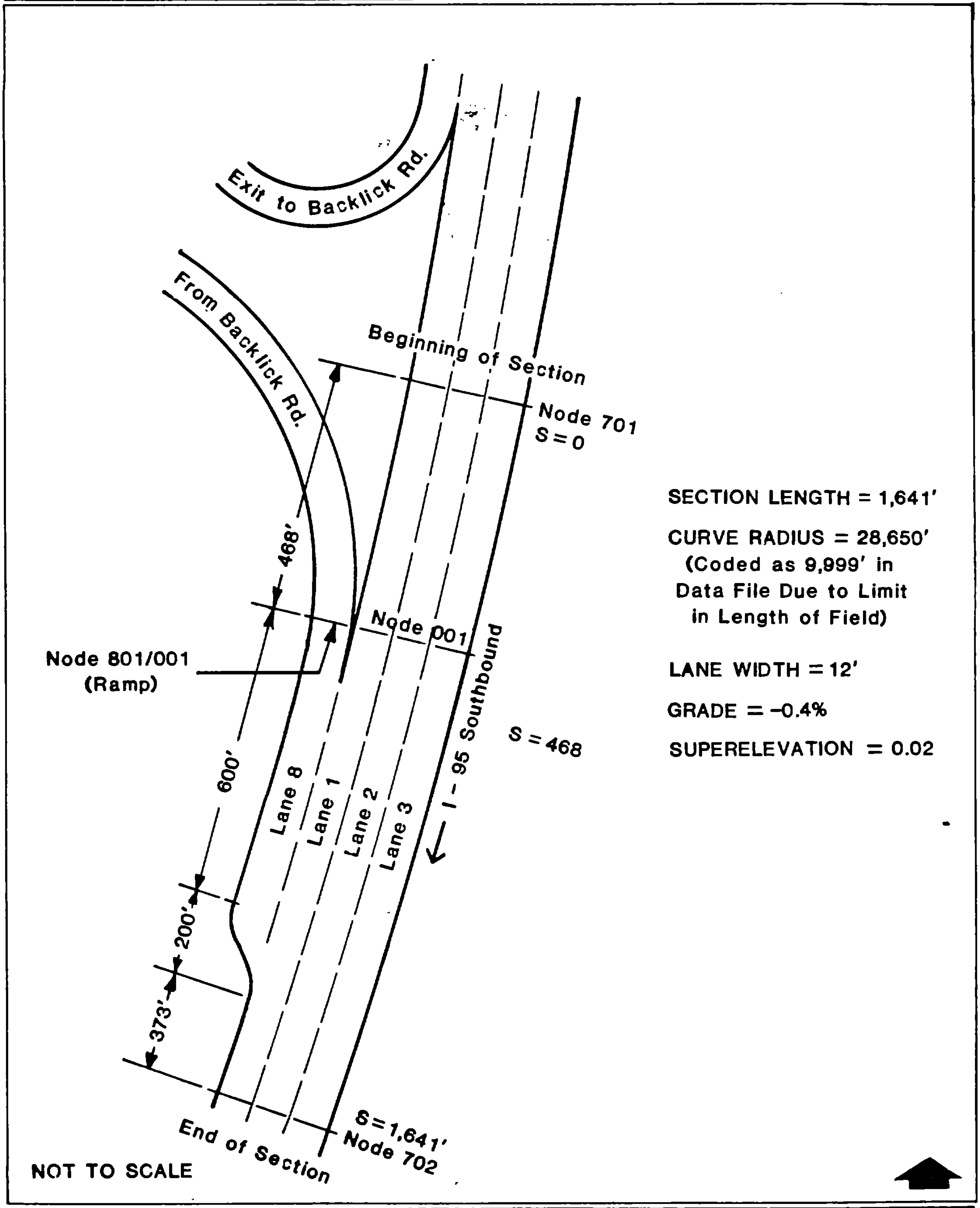


Figure 23. I - 95 Southbound at Backlick Rd. (Route 617) in Fairfax County, Virginia - Ramp Merge

I-405 Northbound at Roscoe Boulevard in Van Nuys, California (Los Angeles Area)

This site is a ramp merge, 1,788 feet (544.7 m) long with four mainline lanes and one ramp lane. The ramp was metered and a queue of approximately 10 to 15 vehicles in each of two queuing lanes gradually built up over the course of the filming. The flow rate appeared to be relatively constant throughout the period. The level of service was generally in the C to D range.

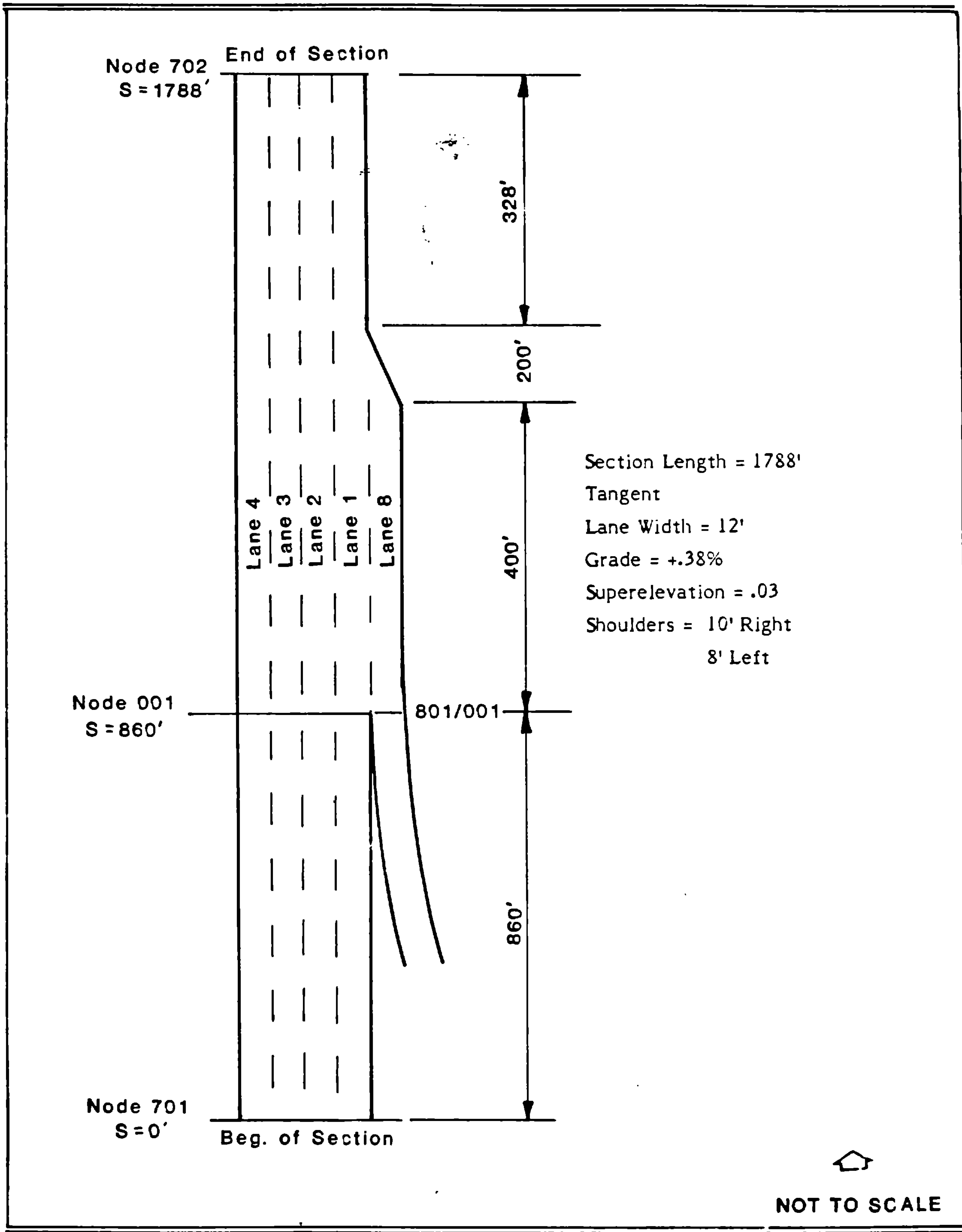


Figure 24. I-405 Northbound at Roscoe Blvd. in Van Nuys, California

I-405 Southbound at Santa Monica Boulevard, Los Angeles

This site is a ramp merge onto I-405 southbound from Santa Monica Boulevard in Los Angeles. It is a four-lane section, plus the ramp, 1,616 feet (492.3 m) long on a short 3 percent downgrade. Traffic was free-flow for the first several minutes of the film, after which a surge in ramp volume caused flow to break down in the rightmost lanes. Flow continued in that state for the remainder of the period. There was a significant differential in the speeds between the right and left lanes. This may have been partially caused by a high traffic demand in the right mainline lanes due to a major freeway interchange located a short distance downstream of the site, at which many of the vehicles were preparing to exit. No incidents affected flow in the section. Queuing began to extend outside the section approximately 30 minutes into the film as a result of the ramp merging activity.

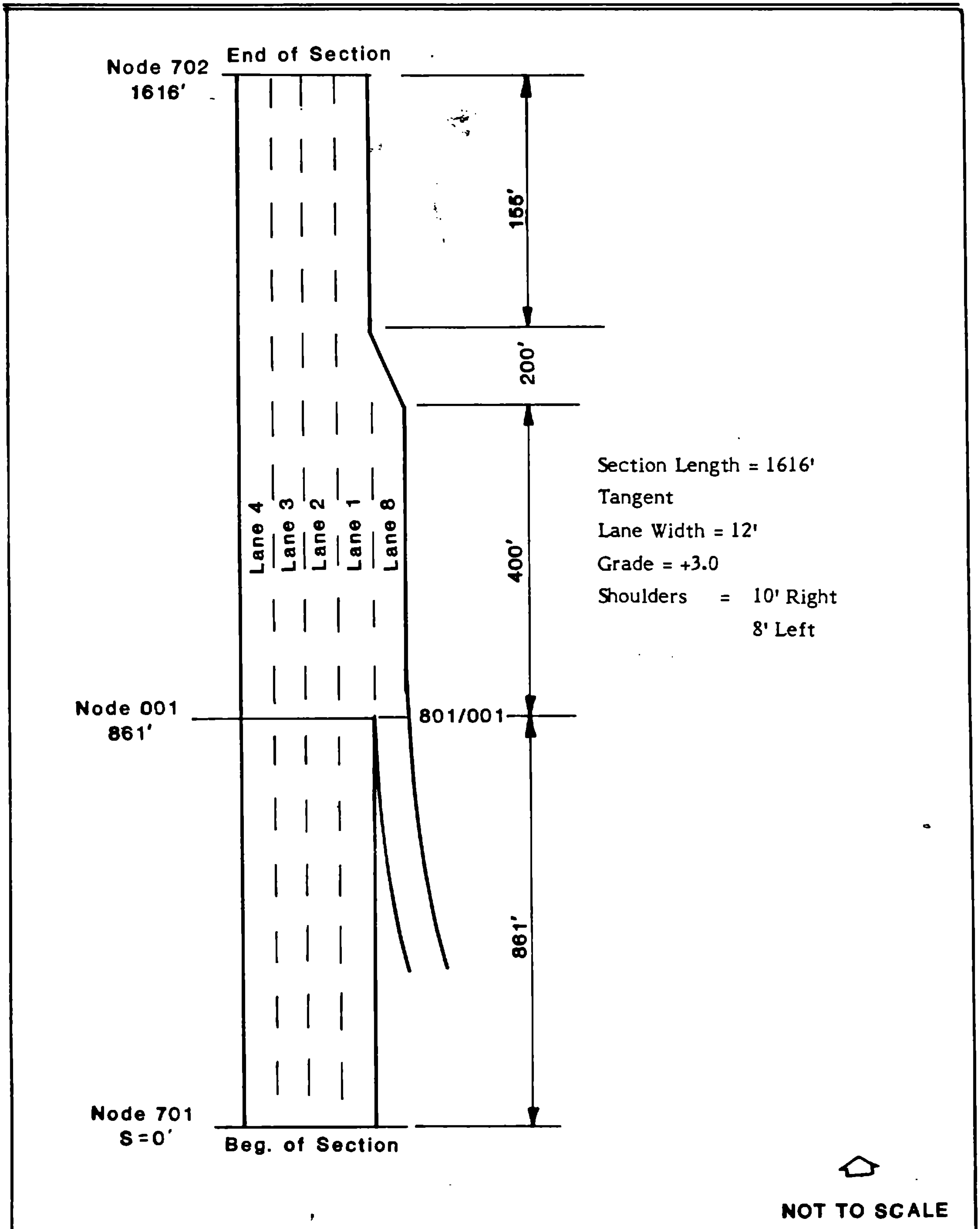
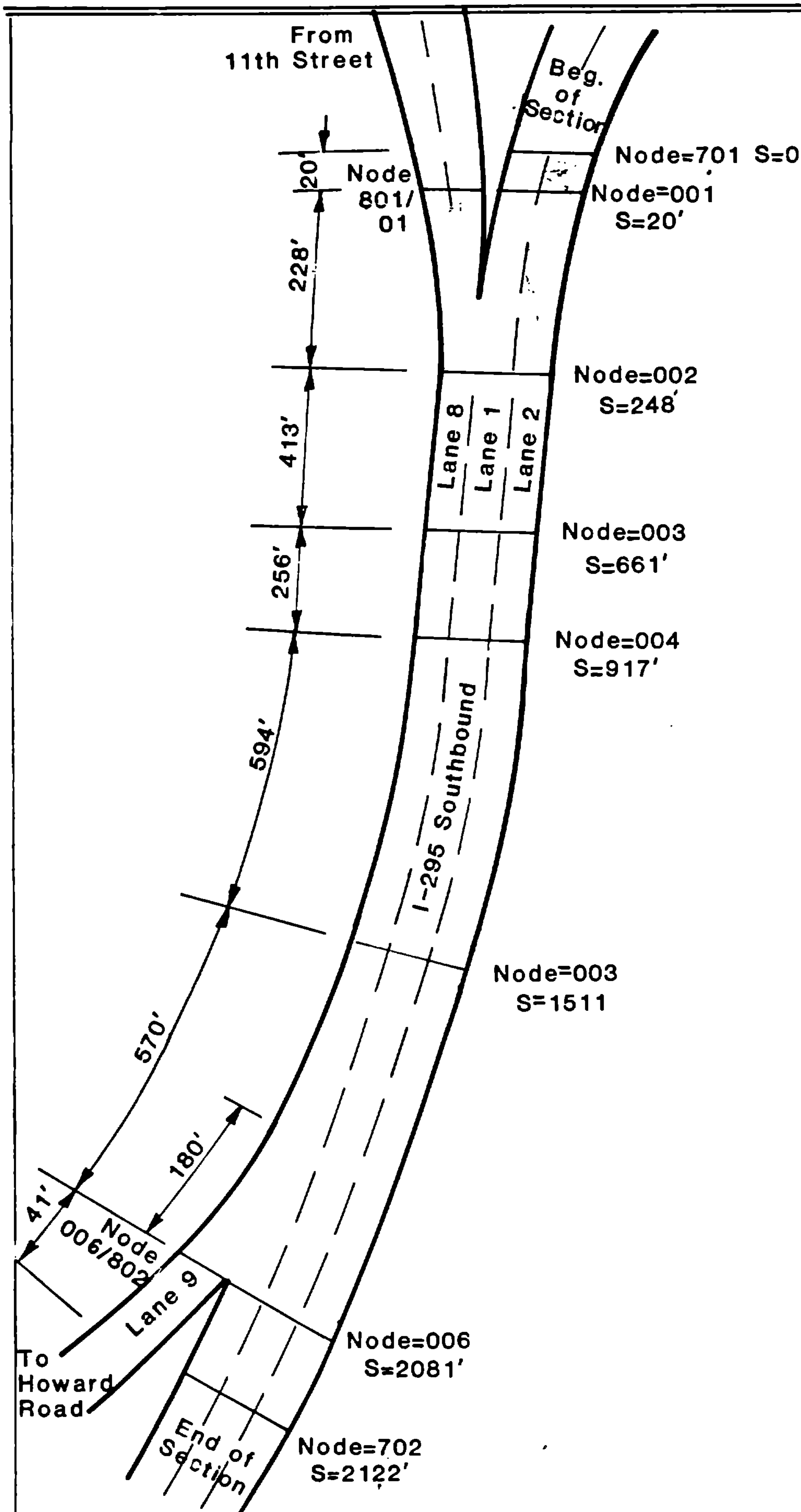


Figure 25. I-405 Southbound at Santa Monica Blvd. in Los Angeles, California

Anacostia Freeway (I-295) Southbound
Between 11th Street and Howard Road
Washington, D.C.

This site is weaving section created by the adding of an exclusive right side on-ramp followed by an off-ramp approximately 2,000 feet (609.3 m) downstream. Vehicles exiting from the mainline to Howard Road are required to completely cross this high-volume lane added at the on-ramp. The on-ramp narrows from two lanes to one lane as it approaches the merge with the mainline. The merging of these two lanes to one, along with the very heavy demand on the ramp could have been partially responsible for the relatively slow on-ramp speeds that will be noticed in the data. In addition, there were occasionally vehicles which actually did not merge on the ramp within the lane lines but merged into mainline traffic upstream of the designated merge point by cutting across the gore area. All on-ramp vehicles were coded as being in lane 8 at least the first time they entered the section, whether or not they prematurely merged with the mainline. On-ramp vehicles were digitized prior to the point of tangency with the mainline, and because of this, the lateral distance values will be a lower (more negative) value than usual when vehicles first enter the section.

Levels of service during the filming appeared to be relatively constant, with an estimated D or E level for weaving traffic for most of the period and a B to D level for mainline nonweaving traffic. The filming period began with on-ramp traffic already somewhat congested, and short but continuously moving queues were noted on the on-ramp throughout the period.



Node 701-001, 001-002
Radius = 1910' Left
Superelevation = .04
Grade = -2.5%

Node 002-003
Tangent
Grade = -2.5%

Node 003-004
Tangent
Grade = +.95%

Node 004-005
Radius = 1637' Right
Superelevation = .045
Grade = +.95%

Node 005-006
Radius = 1637' Right
Superelevation = .045
Grade = +2.5%

Node 006-702
Radius = 1637' Right
Superelevation = .045
Grade = +2.5%

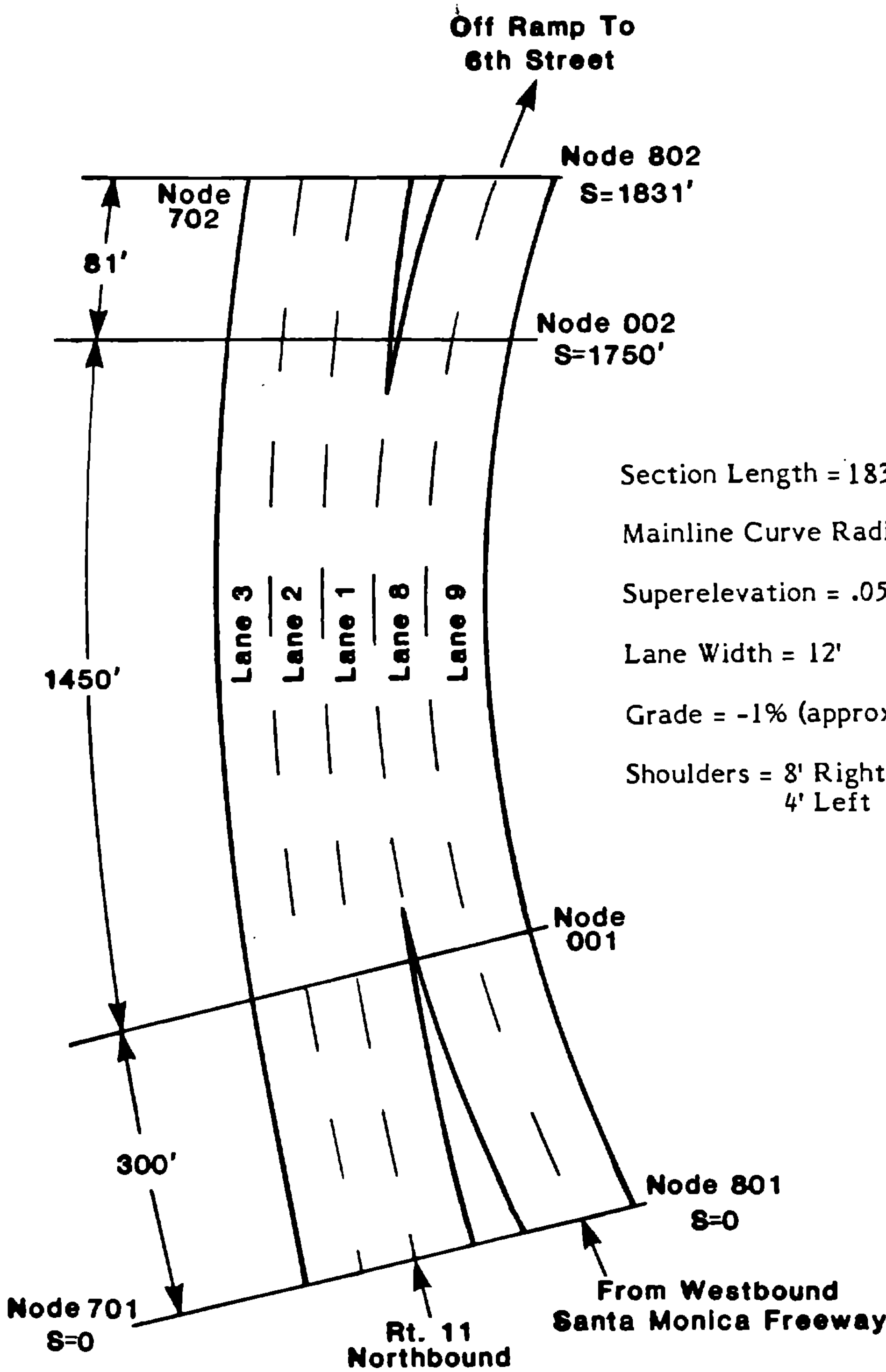
Lanes are 12' wide

Figure 26. I-295 (Anacostia Freeway) Southbound Between 11th Street and Howard Road, Washington, D.C.

Route 11 (Harbor Freeway) Northbound between I-10 (Santa Monica Freeway) and 6th Street, Los Angeles, California

This site is a weaving section on the Harbor Freeway northbound between the Santa Monica Freeway on-ramp and the 6th Street off-ramp near downtown Los Angeles. There are three lanes on the mainline merging with two ramp lanes from the Santa Monica Freeway, as shown in the diagram. Approximately 15 minutes into the film there was an incident just downstream of the site which created severe congestion within the site. This was cleared approximately 30 minutes into the film at which time traffic flow returned to normal. Later in the film, traffic again became heavily congested, but this is believed to be a result of the weaving section itself. The user of this data tape may want to selectively eliminate portions of the film during which downstream congestion influenced flow within the site. The best way to locate the usable sections is to find those sections of the data in which speeds were higher at the downstream end of the site than they were in the middle of the site. Levels of service were in the D to F range for the duration of the film. There was significant queuing on both the mainline and on-ramp for most of the filming period.

In most of the films, the ramp vehicles are not added until they reach the point at which the ramp and mainline actually join. In this film, vehicles were added somewhat earlier because, in the heavy merging and slow speeds, vehicles sometimes crossed the gore area to either merge with the mainline from the ramp or to exit on the ramp from the mainline. Also, vehicles on the off-ramp were not exited from the frame until the very end of the section, rather than where the mainline and ramp begin to diverge. The only effect this has on the data is that the field indicating the lateral placement of the vehicles will contain values which do not correspond to the lanes. Since lateral placement is measured from the right edgeline, vehicles on the on-ramp upstream of the merge area or on the off-ramp downstream of the diverge area will have lateral placement values more negative than would normally be expected. Normally, lane 8 would contain vehicles with a lateral distance from the right edgeline of 0 to -12 feet (3.65 m). In this case, however, the lateral distance values for ramp vehicles at the beginning and end of the site will be more negative than usual, since the vehicles are farther to the right of the edgeline.



Section Length = 1831'

Mainline Curve Radius = 2900' Right

Superelevation = .05 (approx.)

Lane Width = 12'

Grade = -1% (approx.)

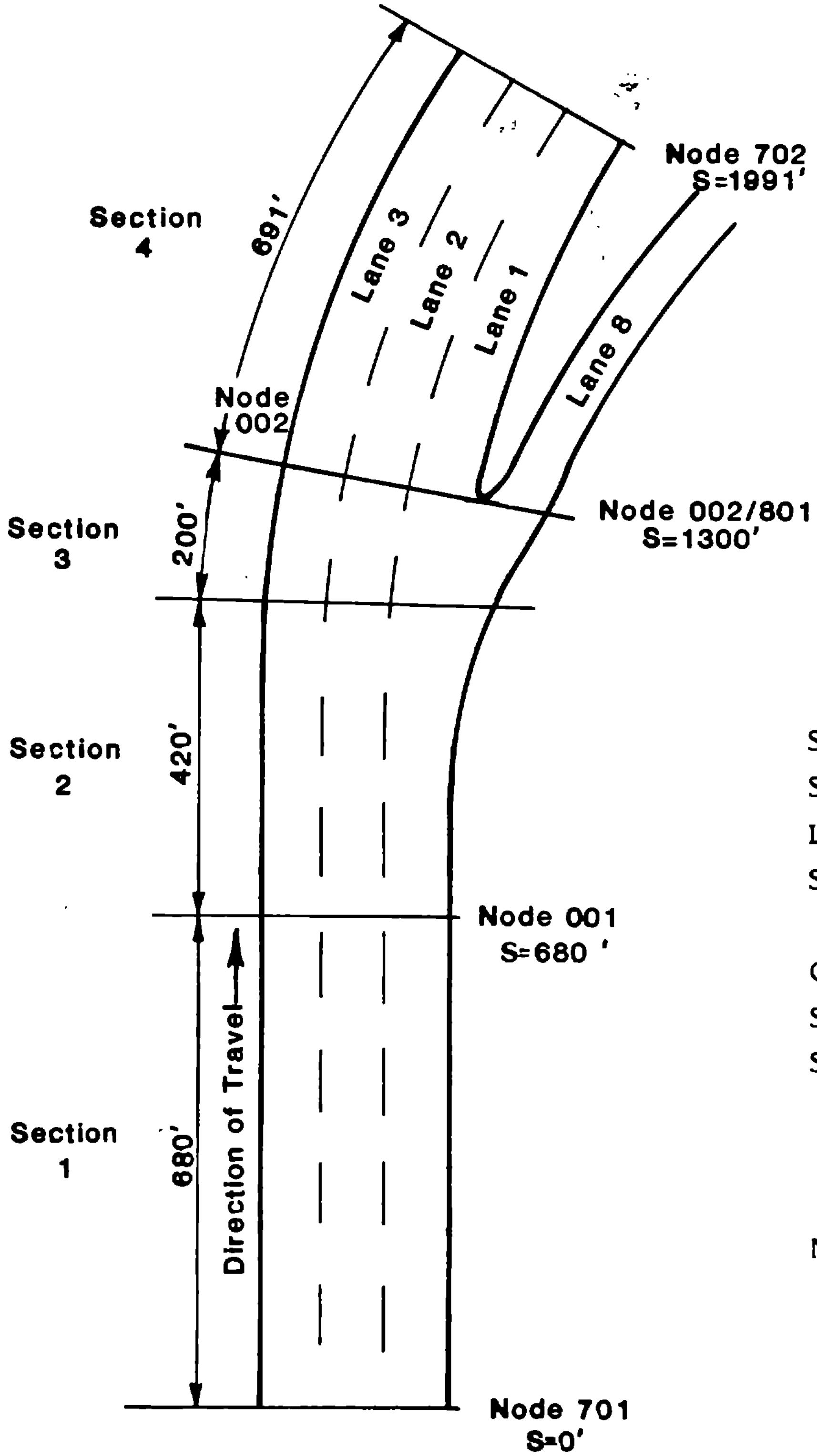
Shoulders = 8' Right
4' Left

NOT TO SCALE

Figure 27. Rt. 11. (Harbor Freeway) Northbound Between Santa Monica Freeway and 6th Street, Los Angeles

I-395 (Shirley Highway) Southbound at Duke St. in Alexandria, Virginia

This site is a 4.2 percent upgrade section 1,991 feet (606.5 m) long. Just prior to the section is a vertical curve, transitioning the freeway from an approximate 3 percent downgrade to the upgrade section studied. Thus, speeds at the entry point to the upgrade section were probably not affected significantly by the grade itself. The beginning of the vertical curve was approximately 1,000 feet (304.6 m) upstream of the beginning of the study section. The vertical curve flattened out to approximately 2 percent just downstream of the study section. A cloverleaf interchange was located approximately 1,000 feet (304.6 m) downstream of the site. The interchange was not believed to have affected traffic flow within the study section, but lane changing activity within the section in anticipation of the interchange could have had some effect. Levels of service were estimated to be within the D to E range. Other than certain vehicles moving slowly up the grade, there were no traffic disturbances during the filming period.



Site Type: Upgrade

Section length: 1991'

Lane width: 12'

Shoulders: 10' Right
4' Left

Grade: =+4.2% all sections

Section 1 = Tangent

Sections 2, 3, 4 = Curve
Radius = 6000'
Superelevation = .02

Note: Roadway transitions from 3% downgrade 1000' upstream of section

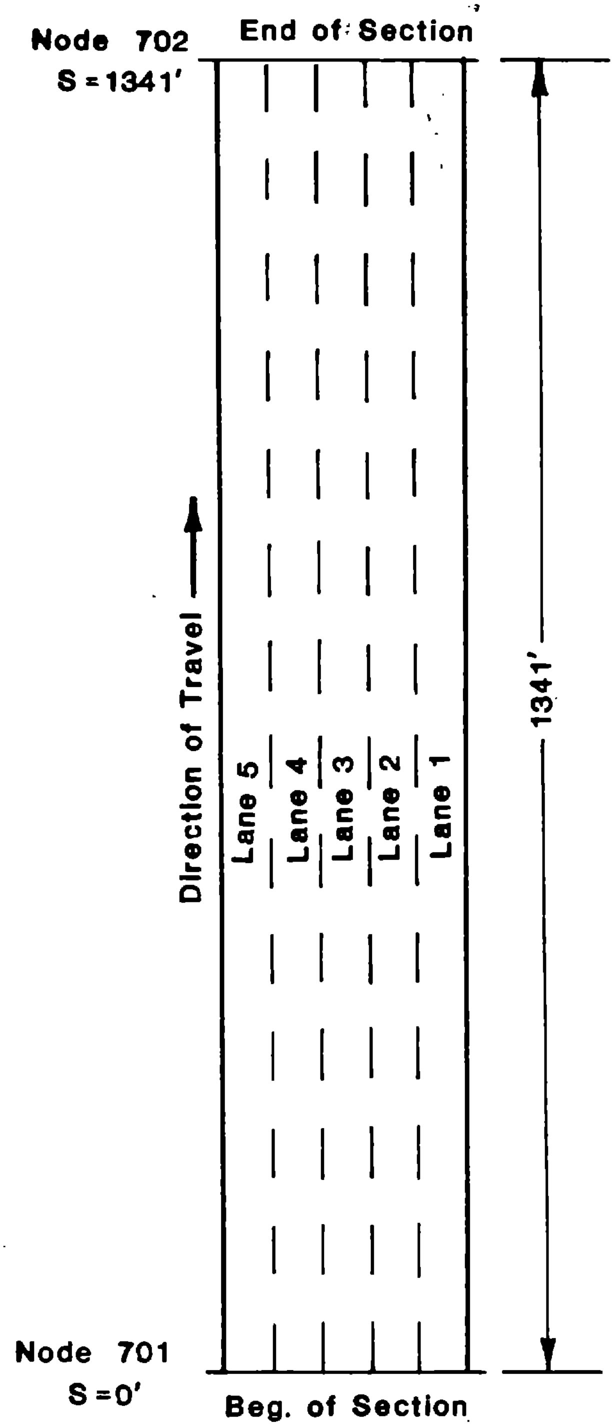
NOT TO SCALE

Figure 28. I-395 (Shirley Highway) Southbound at Route 236 (Duke St.) in Alexandria, Virginia

I-405 Northbound at Mulholland Drive, Los Angeles

This site is an upgrade, 1341 feet (408.5 m) long. The section is approximately one-half mile from the top of a 2.5-mile (4.02 km) long grade. The level of service was in the C to E range. The site consists of a tangent section with five 11-foot (3.3 m) lanes and a narrow left shoulder.

Several traffic disturbances occurred during the filming. Approximately 22 minutes into the film there was a vehicle stalled in the right lane just downstream of the section. The vehicle was moved off onto the right shoulder 2 minutes later. Approximately 38 minutes into the film a truck traveling very slowly passed through the section and stopped on the shoulder approximately 1,000 feet (304.6 m) downstream of the section. There appeared to be some congestion developing in the left lanes as a partial result of these events, possibly caused by lane changing to avoid these problems.



Site Type: Upgrade

Section length = 1341'

Tangent

Lane Width = 11'

Grade = +3.0%

Cross-slope = .02

Shoulders = 10' Right
4' Left

Note: Section is near top of an approximate 2.5 mile grade

NOT TO SCALE

Figure 29. I-405 Northbound at Mulholland Drive

Baltimore-Washington Parkway Northbound at I-95 (Capital Beltway) in Prince Georges County, Maryland

This site is a cloverleaf-type weaving section, 1,606 feet (489.2 m) long with a 695-foot (211.8 m) weaving section. Traffic ranged from an approximate level of service B to C at the beginning of the filming level of service E in the last 10 minutes of the film, during which there were short queus on the mainline and ramp.

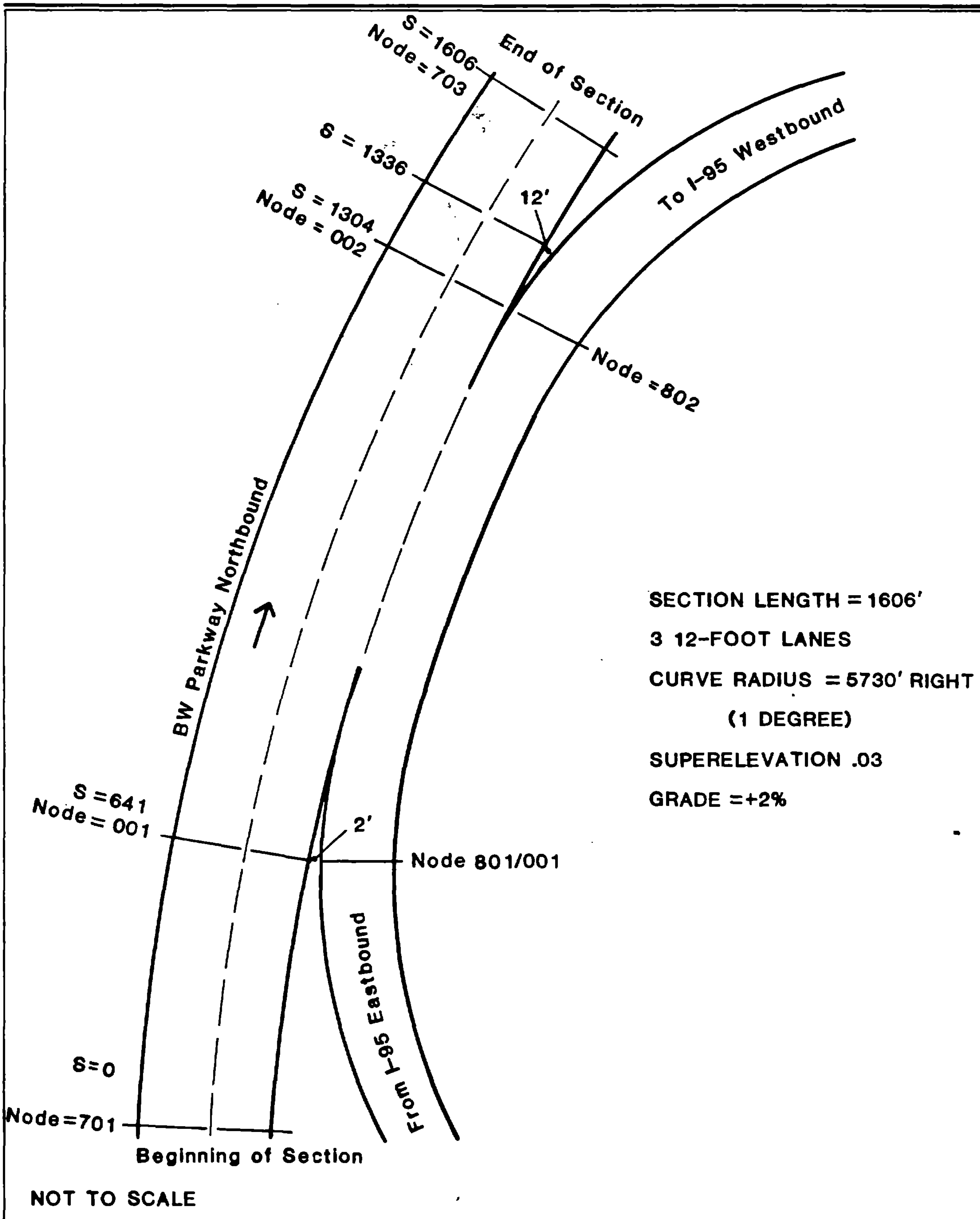
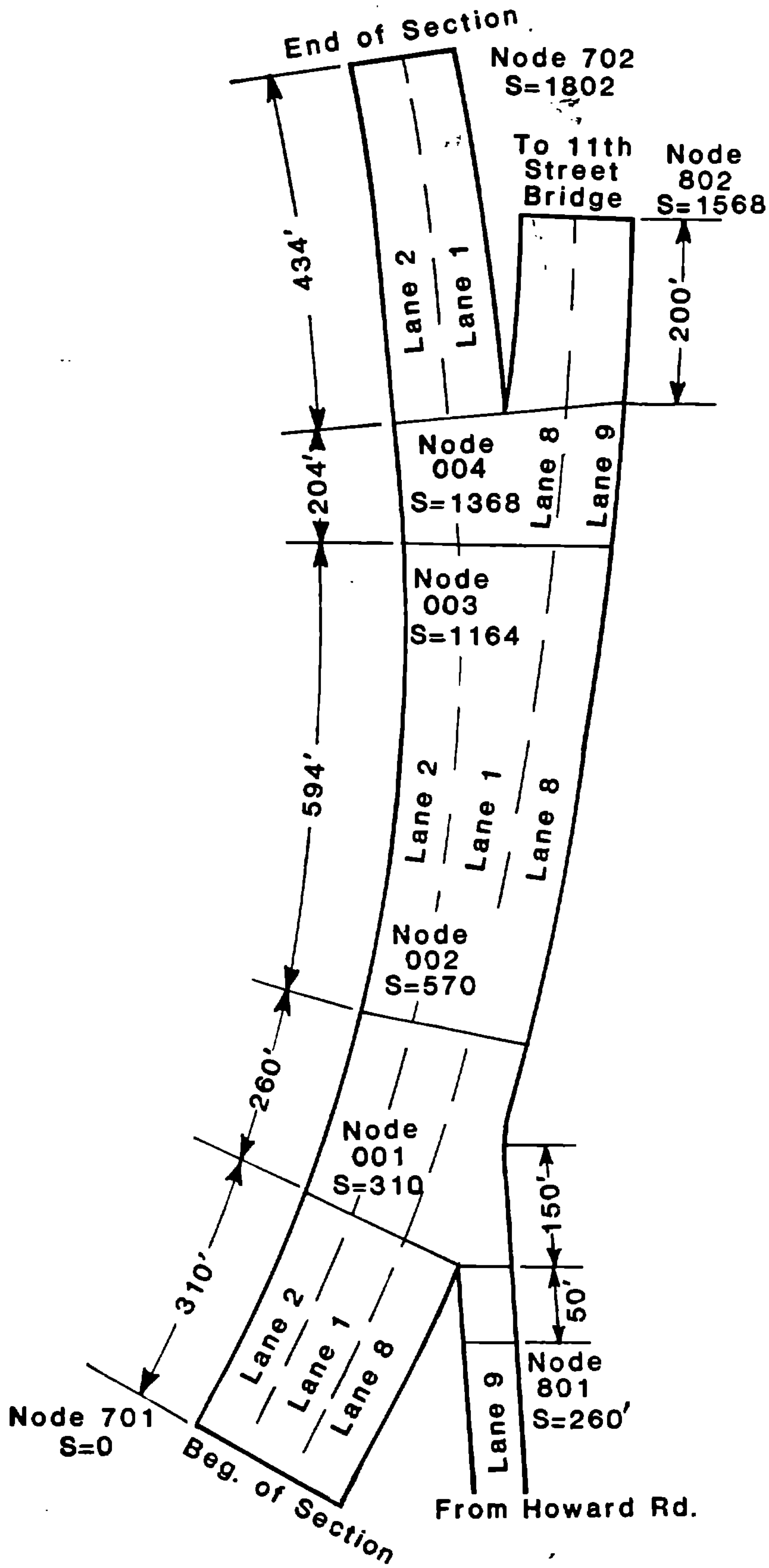


Figure 30. Baltimore-Washington Parkway Northbound at I-95 (Capitol Beltway)

I-295 Northbound Between Howard Road and 11th Street Bridge, Washington, DC

This is a weaving site, 1802 feet (550 m) long. The weaving area itself is approximately 1058 feet (322 m) long. The level of service is estimated to have been in the C range. One of the aspects of this site which is different from the other weaving sites is that there is no on-ramp acceleration lane. Consequently, there were occasionally vehicles stopped on the on-ramp waiting for gaps in traffic. Vehicles on the on-ramp were digitized at least 100 feet (30 m) upstream of the point at which the on-ramp merged with the mainline so that vehicle movement in anticipation of the merge could be captured. It should be remembered that the lateral distance values of any vehicles on the ramp prior to the merge point do not correspond to the lane number (i.e. the lateral distances are more negative than the lane number would indicate). There is a special marking of a solid white line between lanes 1 and 2 of the mainline, probably with the intent to limit lane changing. This did not particularly appear to affect traffic behavior, however. There were no incidents or other traffic disturbances during the course of the filming.

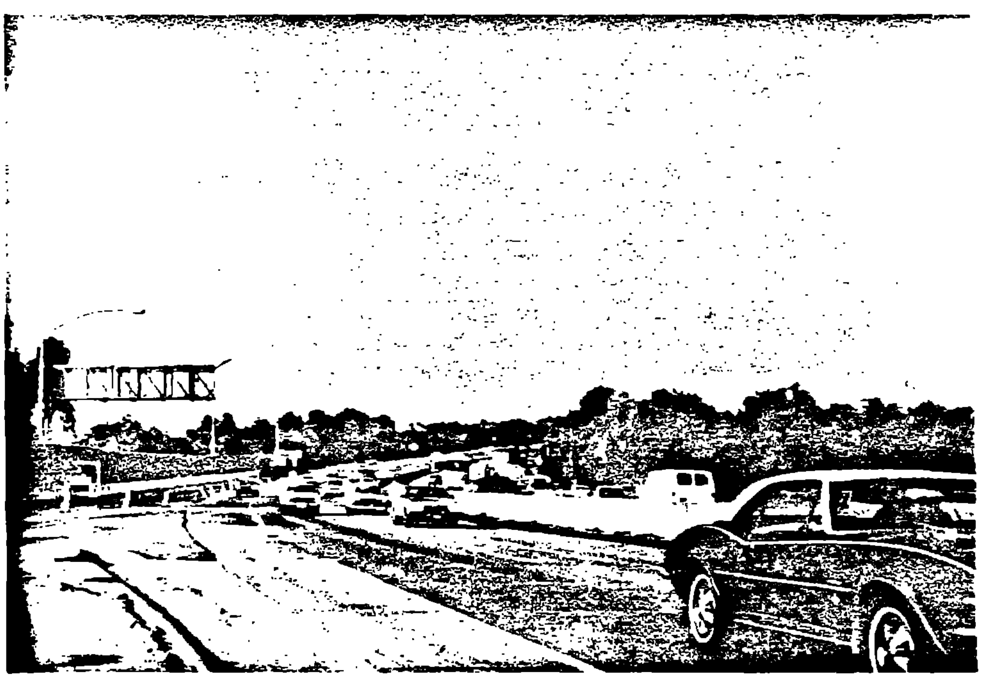


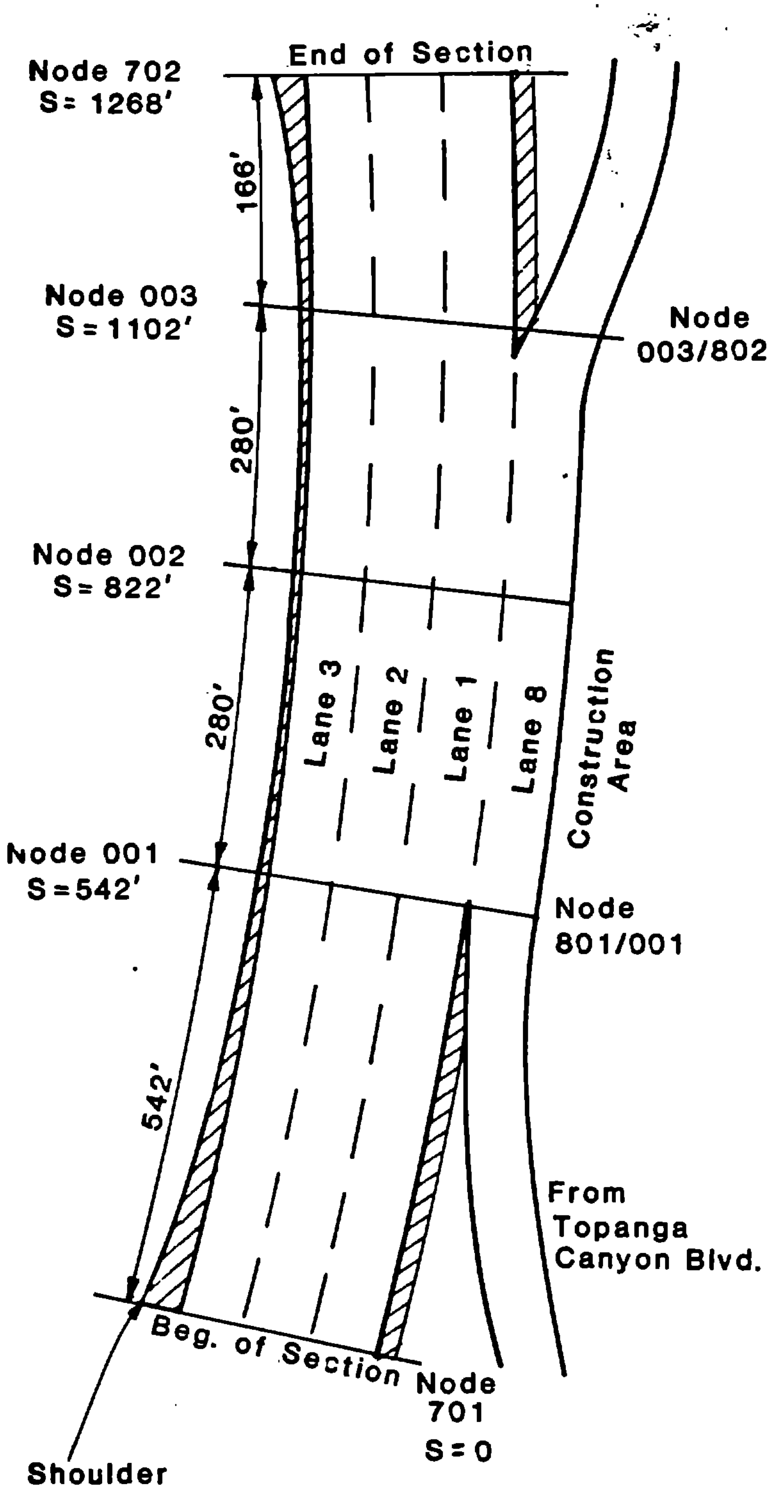
Site Type: Weaving
Lane width = 12
Shoulders = 8' Left
10' Right
Node 701-001, 001-002
Radius = 1637' Left
Superelevation = .045
Grade = -2.5%
Node 002-003
Radius = 1637' Left
Superelevation = .045
Grade = -.95%
Node 801-001
Tangent
Node 003-004
Tangent
Grade = -.95%
Node 004-702, 004-002
Tangent
Grade = +2.5%

Figure 31. I-295 (Anacostia Freeway) Northbound Between Howard Road and 11th Street Bridge, Washington, D.C.

U.S. 101 (Ventura Freeway) Westbound between Topanga Canyon Blvd. and Ventura Blvd.

This is a weaving site in a construction zone, 1268 feet (387 m) long. The weaving section itself is approximately 560 feet (171 m) long. It was felt that the response of traffic to the narrow lanes and shoulders created by the construction activity would be of interest, and the site was therefore chosen for data reduction. The construction involved the addition of a weaving lane to a section which previously had been an on-ramp followed by an off-ramp without acceleration or deceleration lanes. To accomplish the construction, the roadway was restriped to use the left shoulder as part of the left travel lane, as shown in the figure. The area to the right of the auxiliary lane had been excavated and was still several feet below the highway surface at the time of the filming. Folding barricades were used to delineate the point of pavement dropoff. A ground-level photograph of the site is shown below. In the middle of the construction section the lane widths were 11 feet (3.4 m) for the mainline lanes and 10 feet (3.1 m) for the auxiliary lane. The level of service was in the C-D range. There were no incidents or other traffic disturbances during the course of the filming period.





Site type: Weaving and reduced lane width due to construction

Total length = 1268'

Node 701-001
- Radius = 1910' Left
- Superelevation = .06
- Grade = -3%
- Shoulders = 8' Left
- = 10' Right

Lane width = 12

Node 001-002
- Radius = 2860' Left
- Superelevation = .06
- Grade = -3%
- Shoulders = 2' Left
- = 0' Right
- Lane width = 11' for 1, 2 & 3
- 10' for 8

Node 002-003
- Radius = 2860' Left
- Superelevation = .06
- Grade = +1%
- Shoulders = 2' Left
- 0' Right
- Lane width = 11' for 1, 2, 3
- 10' for 8'

Node 003-702
- Tangent
- Grade = +1%
- Shoulders = 8' Left
- 10' Right
- Lane width = 12'

NOT TO SCALE

Figure 32. U.S. 101 (Ventura Freeway) Westbound between Topanga Canyon Blvd. and Ventura Blvd.

I-395 (Southwest Freeway) Southbound at the 14th Street Bridge in Washington, DC

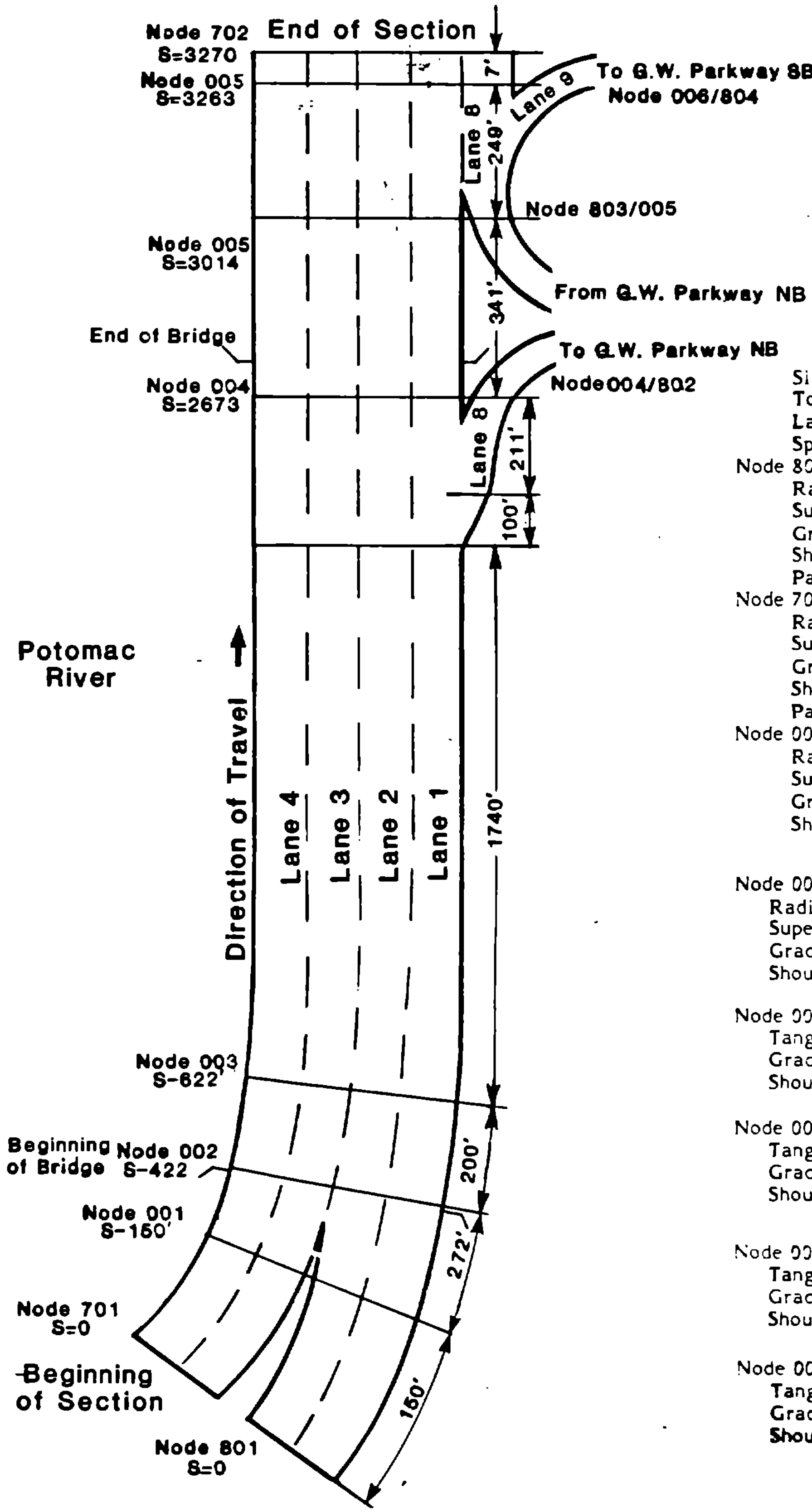
This site is a multiple weaving section, 3270 feet (997 m) long, on I-395 crossing the Potomac River between Washington, DC and Arlington, Virginia. It was over 1000 feet (305 m) longer than the next longest site, which presented more difficulty in the data reduction stage than was experienced in the other films. First, due to the smaller scale of the photographs, the digitized postions of the vehicles are slightly less accurate than in the other films. Thus, the vehicular movements may appear to be jerkier when this data set is analyzed. It is also more likely that some vehicles may have been missed because of their small size and their blending in with the pavement. It is not believed that there were many instances of this, however. In addition, the photographer was required to maintain a smaller margin of overlap on either end of the site, to allow the aircraft to fly at the lowest possible altitude to optimize film resolution. Because of this, portions of the freeway section were "cut off" in the filming, preventing vehicle movements from being digitized. This occurred primarily at the upstream end of the section when the aircraft was flying parallel to the roadway on the west side of the bridge.

Although there was relatively little weaving and merging activity in the sections cut off in the film, it was felt that it would be useful to create two versions of this data set, one which contained a raw, unedited version of the data and another for which the unknown vehicle positions were, in essence, simulated to provide an estimate of vehicle postions for the cut off portions. Therefore, a computer program was written to compute the estimated positions of each vehicle which was not able to be digitized where it actually entered the section. The vehicle positions were reconstructed assuming that each vehicle had maintained a constant speed up until the point where it was first digitized and that the vehicle had been in the same lane since the beginning of the section. Although this is obviously not a perfectly accurate assumption, it is sufficient to compute vehicle positions to be used in some of the macroscopic measures, such as traffic density. The portions cut off should not be used in an analysis of vehicle trajectories or microscopic interactions with other vehicles. A third file on the data tape (in addition to the geometry and vehicle data files) contains information on which frames were cut off. This data file provides a listing of the longitudinal distance of the most upstream vehicle for which the position actually digitized. Information on the most upstream vehicle is only given for frames which were cut off and for which at least one vehicle position was simulated. This file should be used to screen out the simulated portions of the data set from any microscopic analysis performed. The format of the data file is as follows:

- columns 2-5 = frame number
- columns 8-11 = ID of most upstream vehicle not simulated. All vehicles upstream of this point can be considered to be simulated
- columns 14-17 = distance from beginning of section of vehicle identified in columns 8-11.

The level of service during the filming was in the D-E range. There was a short queue extending upstream from the site in lanes 3 and 4 at the beginning of the period. This queue built up to approximately one mile (1.6 km) in length within the next 20 minutes and remained that long for the duration of the filming period. The source of the congestion was the high traffic demand upstream of lanes 3 and 4, which was forced to merge into two lanes just upstream of the site. There was very little queuing on the approach to lanes 1 and 2.

The speed limit for this section, which emerges from a heavily built up area of the downtown, was 40 mph (64 kph), partially accounting for the relatively low speeds across the bridge. Thus, the analyst should be cautioned to not completely attribute speeds within the section to the weaving activity alone. Also affecting speeds may have been the pavement surface, which contained a number of patched and pothole areas. There was a heavy weaving movement from lanes 3 and 4 across to the exit ramps to the George Washington Parkway. There were no incidents or other traffic disturbances during the course of the filming.



Site type: Two-sided weave
Total length = 3270'
Lane width = 12'
Speed limit = 40 mph

Node 801-001
- Radius = 955' Left
- Superelevation = .07
- Grade = +3%
- Shoulders = 10' Right
- Paved gore left

Node 701-001
- Radius = 880' Left
- Superelevation = .07
- Grade = +3%
- Shoulders = 6' Left
- Paved gore right

Node 001-002
- Radius = 955' Left
- Superelevation = .07
- Grade = = +3%
- Shoulders = 10' Right, 6' Left

Node 002-003
- Radius = 955' Left
- Superelevation = .06
- Grade = 0%
- Shoulders = 2' Right, = 2' Left

Node 003-004
- Tangent
- Grade = 0%
- Shoulders = 2' Right, = 2' Left

Node 004-005
- Tangent
- Grade = -1%
- Shoulders = 4' Left, = 4' Right

Node 005-006
- Tangent
- Grade = -1%
- Shoulders = 4' Left, = 2' Right

Node 006-702
- Tangent
- Grade = -1%
- Shoulders = 4' Left, 10' Right

NOT TO SCALE

Figure 33. I-395 Southbound at 14th Street Bridge in Washington,D.C.

REFERENCES

1. Federal Highway Adminstration (FHWA), National Highway Inventory and Performance Summary, Wash., D.C., FHWA, Dec. 1977, pp. I-5 and I-6.

2. "Highway Capacity Manual," HRB Special Report 87, Wash., D.C., HRB, 1965.

3. Roess, R., et al., Freeway Capacity Procedures, Brooklyn NY, Polytechnic Institute of New York, (For FHWA), 1979.

4. Huber, M.J. and D.L. Gerlough, "Traffic Flow Theory - A Monograph," TRR Special Report 165, Wash., D.C., TRB, 1981.

5. Transportation Research Board, "The Application of Traffic Simulation Models," TRR Special Report 194, Wash., D.C., TRB, 1981.

6. Wicks, D.A. and E.R. Lieberman, Development and Testing of INTRAS, A Microscopic Freeway Simulation Model, Huntington Station, NY, KLD Associates, 1980, 4 vols. (FHWA-RD-80-106 to 109)

7. Charles, S.E., et al., Exit Ramp Effects on Freeway System Operations and Control, Wash., D.C., ITE (UCLA), (For FHWA), 1971.

8. Raudseps, J.G., Automatic Extradition of Highway Traffic Data Form Aerial Photographs, Cambridge, MA, Transportation Systems Center, Apr. 1975. (DOT-TSC-FHWA-75-1)

9. Garner, J.B. and L.J. Mountain, "Traffic Data Collection - An Alternative Method?" Traffic Engineering & Control, V.19:10, Oct. 1978, pp. 451-454.

10. Bleyl, R.L., "Traffic Analysis of Time-Lapse Photographs Without Employing a Perspective Grid," Traffic Engineering, V.42:11, Aug. 1972, pp. 29-31.

BIBLIOGRAPHY

1. Ahmed, M.S. and A.R. Cook, "Analysis of Freeway Traffic Time Series Data by Using Box-Jenkins Techniques," Transportation Research Record 722 (TRR), Wash., D.C., Transportation Research Board (TRB), 1979, pp. 1-9.

2. Baehker, R., et al., "Toward a Laboratory Instrument for Motion Analysis," Computer Graphics, V. 15:3, Aug. 1981, pp. 191-197.

3. Bleyl, R.L., "Traffic Analysis of Time-Lapse Photographs Without Employing a Persepective Grid," Traffic Engineering, V. 42:11, Aug. 1972, pp. 29-31.

4. Bochner, R.J. and W.J. Fognimi, "Future Trends in Automative Design and Their Effects on Highway Geometric Design Standards," Interim paper from ITE Committee 5B-3, published in WDCSITE Newsletter, Winter 1982.

5. Courage, K.G., et al., "Operating Parameters for Main-Line Sensors in Freeway Surveillance Systems," TRR 601, Wash., D.C., TRB, 1976, pp. 19-28.

6. Courage, K.G., et al., "Some Electronic Measurement of Macroscopic Traffic Characteristics on a Multilane Freeway," HRR 279, Wash., D.C., Highway Research Board (HRB), 1969, pp. 160-161.

7. Charles, S.E., et al., Exit Ramp Effects on Freeway System Operation and Control, Berkeley, CA, Institute of Transportation and Traffic Engineering (ITTE), for Wash., D.C., Federal Highway Administration (FHWA), 1971.

8. Cook, A.R., and D.E. Cleveland, "Detection of Freeway Capacity - Reducing Incidents by Traffic - Stream Measurements," TRR 495, Wash., D.C., TRB, 1974, pp. 1-11.

9. Cornette, D., Operational Characteristics of Lane Drops, Lexington, KY, Division of Research - Kentucky Dept. of Highways, 1972.

10. Cyra, D.J., "Traffic Data Collection Through Aerial Photography," HRR 375, Wash., D.C., HRB, 1971, pp. 28-39.

11. Drew, D.R., et al., "Gap Acceptance in the Freeway Merging Process," HRR 208, Wash., D.C., HRB, 1967, pp. 1-36.

12. Drew, D.R., "Microscopic Models of Traffic Flow, Traffic Engineering, V.36:8, May 1966, pp. 51-53.

13. Dudek, C.L., et al., "Incident Detection on Urban Freeways," TRR 495, Wash., D.C., TRB, 1974, pp. 12-24.

14. Everall, P.F., Urban Freeway Surveillance and Control: The State of the Art, Wash., D.C., FHWA, 1972.

15. Gafarian, A.V., et al., "An Experimental Validation of Various Methods for Optaining Relationships Between Traffic Flow, Concentration and Speed on Multilane Highways," HRR 349, Wash., D.C., HRB, 1971, pp. 13-30.

16. Gafarian, A.V., et al., Characteristics of Multilane Traffic Flow From Aerial Data, Los Angeles, CA, Univ. of Southern California, 1976. (DOT-TST-76T-2).

17. Gafarian, A.V., et al., "Some Properties of Freeway Density as a Continuous -Time Stochastic Process," TRR 667, Wash., D.C., TRB, 1978, pp. 79-83.

18. Garner, J.B. and L.J. Mountain, "Traffic Data Collection - An Alternative Method?" Traffic Engineering & Control, V.19:10, Oct. 1978, pp. 451-454.

19. Goldblatt, R.B., "Investigation of the Effects of Location of Freeway Traffic Sensors on Incident Detection," TRR 773, Wash., D.C., TRB, 1980, pp. 24-31.

20. Goodwin, D.N., "Freeway Lane Drops," National Cooperative Highway Research Program Report 175 (NCHRP), Wash., D.C., TRB, 1976.

21. Heath, W., "Inexpensive Aerial Photography for Highway Engineering and Traffic Studies," TRRL SR 632, Crowthorne, England, Transport and Road Research Laboratory (TRRL), 1980.

22. "Highway Capacity Manual," HRB Special Report 87, Wash., D.C., HRB, 1965.

23. Houpt, P.K., et al., Traffic Surveillance Data Processing in Urban Freeway Corridors Using Kalman Filter Techniques, Cambridge, MA, Massachusetts Institute of Technology, 1978. (DOT-TSC-RSPA-78-18).

24. Huber, M.J. and D.L. Gerlough, "Traffic Flow Theory - A Monograph," TRR Special Report 165, Wash., D.C., TRB, 1975.

25. Johnson, R.T., and L. Newman, "East Los Angeles Interchange Operation Study," HRR 244, Wash., D.C., HRB, 1968, pp. 27-46.

26. Kell, J.H., "Interim Materials on Highway Capacity," TRB Circular 212, Wash., D.C., TRB, 1980.

27. Kittleson, W.K. and P.J. Tarnoff, "Development of Efficient Procedure for Recreating and Analyzing Traffic Flow Patterns on Urban Freeways, " TRR 682, Wash., D.C., TRB, 1978, pp. 68-75.

28. Levin, M., "Freeway Lane-Changing Process: A Microscopic Approach," TRR 596, Wash., D.C., TRB, 1976, pp. 30-32.

29. Lindley, J.A., and S.C. Tignor, "Getaway Flow Rates for Freeway Incident and Geometric Bottleneck," Public Roads, V.43:1, 1979, pp. 1-7.

30. Linger, E.M., et al., "Effect of Trucks, Buses, and Recreational Vehicles on Freeway Capacity and Service Volume," TRR 699, Wash., D.C., TRB, 1979, pp. 17-26.

31. May, A.D., et al., Development and Evaluation of Incident Detection Algorithms for Electronic Detector Systems on Freeways, Berkeley, CA, ITTE, 1974. (DOT-TST-75-94).

32. May, A.D., et al., Optimal Design and Operation of Freeway Incident Detection-Service Systems, Berkeley, CA, ITTE, 1975. (DOT-TST-75-92).

33. McCasland, W.R., Use of Freeway Shoulders to Increase Capacity, College Station, TX, Texas Transportation Institute, 1978.

34. McDermott, J.M., et al., Chicago Area Expressway Surveillance and Control: Final Report, Oak Park, IL, Illinois Department of Transportation, 1979. (FHWA-IL-ES-27).

35. Mika, H.S., et al., "Dual Mode Behavior of Freeway Traffic," HRR 279, Wash., D.C., HRB, 1969, pp. 1-12.

36. Mountain, L.J. and J.B. Garner, "Traffic Data Acquisition from Small-Format Photography," TRR 795, Wash., D.C., TRB, 1981, pp. 21-23.

37. Pahl, J. "The Effect of Discrete Time Measurement on Speed Data, HRR 349, Wash., D.C., HRB, 1971, pp. 1-12.

38. Pahl, J., "Gap-Acceptance Characteristics in Freeway Traffic Flow, HRR 409, Wash., D.C., HRB, 1972, pp. 57-63.

39. Pahl, J., "Lane-Change Frequencies in Freeway Traffic Flow," HRR 409, Wash., D.C., HRB, 1972, pp. 17-25.

40. Payne, H.J., et al., Development and Testing of Incident Detection Algorithms, Santa Monica, CA, Technology Service Corp., 1974, 4 vols. (FHWA-RD-76-19 to 22).

41. "Photography From Lightplanes and Helicopters," Kodak Publication No. M-5, Rochester, NY, Eastman Kodak Co., 1971.

42. Pignataro L.J., et al., "Weaving Areas - Design and Analysis," NCHRP Report 159, Wash., D.C., TRB, 1975.

43. Raudseps, J.G., Automatic Extraction of Highway Traffic Data From Aerial Photographs, Cambridge, MA, Transportation Systems Center, Apr. 1975. (DOT-TSC-FHWA-75-1).

44. Roess, R., et al., Freeway Capacity Procedures, Brooklyn, NY, Polytechnic Institute of New York (for FHWA), 1979.

45. Seguin, E.L., et al., Urban Freeway Truck Characteristics, State College, PA, Institute for Research, (for FHWA), 1982.

46. St. John, A.D. and D.R. Korbett, "Grade Effects on Traffic Flow Stability and Capacity," NCHRP Report 195, Wash., D.C., TRB, 1978.

47. Tarnoff, P.J. and W.K. Kittleson, "Derivation of Freeway Speed Profiles From Point Surveillance Data," TRR 682, Wash., D.C., TRB, 1978, pp. 66-68.

48. Tolle, J.E., "Vehicular Headway Distributions: Testing and Results," TRR 567, Wash., D.C., TRB, 1976, pp. 56-64.

49. Transportation and Traffic Engineering Handbook, 3rd. ed., Wash., D.C., Institute of Transportation Engineers, 1976, pp. 16-37.

50. Transportation Research Board, "The Application of Traffic Simulation Models," TRR Special Report 194, Wash., D.C., TRB, 1981.

51. Uren, J. and J.B. Garner, "Integrated System for Urban Traffic Data Collection," TRR 699, Wash., D.C. TRB, 1979, pp. 41-49.

52. Wang, J.J., et al., Improving the Safety and Traffic Operations of Freeway Lane Drops, San Francisco, CA, JHK & Associates (for FHWA), 1977.

53. Wattleworth, J.A., et al., "Operational Effects of Some Entrance Ramp Geometrics on Freeway Merging," HRR 208, Wash., D.C., HRB, 1967, pp. 79-114.

54. Weinberg, M.I. and K.J. Tharp, "Application of Vehicle Operating Characteristics to Geometric Design and Traffic Conditions, NCHRP Report 68, Wash., D.C., HRB, 1969.

55. Wicks, D.A. and E.B. Lieberman, Development and Testing of INTRAS, A Microscopic Freeway Simulation Model, Huntington Station, NY, KLD Associates, 1980, 4 vols. (FHWA-RD-80-106 to 109).

56. Wicks, D. and J. Cohen, Scot Model Calibration and Validation, Data Acquisition and Reduction, Huntington Station, NY, KLD Associates, 1974.

57. Worrall, R.D. et al., "Lane Changing on a Multilane Highway," HRR 279, Wash., D.C., HRB, 1969, pp. 160-161.

58. Ybarra W.A. and A.D. May, Bay Area Freeway Operations Study, Berkely, CA, ITTE, 1968.