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EVALUATION OF RAMP METERING STRATEGIES AT LOCAL ON-RAMPS AND FREEWAY-TO-FREEWAY INTERCHANGES USING COMPUTER SIMULATION MODELLING APPROACH

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Abdul-Rahman Ibrahim Hamad

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Major professor

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EVALUATION OF RAMP METERING STRATEGIES AT LOCAL ON-RAMPS

AND FREEWAY-TO-FREEWAY INTERCHANGES USING

COMPUTER SIMULATION MODELLING APPROACH

By

Abdul-Rahman Ibrahim Hamad

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ABSTRACT

EVALUATION OF RAMP METERING STRATEGIES AT LOCAL ON-RAMPS AND FREEWAY-TO-FREEWAY INTERCHANGES USING COMPUTER SIMULATION MODELLING APPROACH

By

Abdul-Rahman Ibrahim Hamad

Ramp metering is a strategy of freeway operations designed to improve the flow of freeway traffic by controlling the rate at which additional vehicles are allowed into the traffic stream. The primary goal of ramp metering is the efficient use of the highway system.

Many large urban centers have installed freeway ramp metering systems to help reduce the congestion on their urban freeways (e.g., Detroit, Los Angeles, Chicago, and Houston). The problem is that these systems do not show the expected benefits when there are freeway-to-freeway interchanges in the urban freeway system. This is because these interchanges are not metered and the large volumes travelling between the freeways tend to interrupt the smooth flow that is supposed to be achieved from the ramp metering strategy.

This study utilized the Integrated Traffic Simulation (INTRAS) model, which is a microscopic freeway simulation model, to define the optimal strategy for metering flow onto the freeway and to evaluate the benefits of such strategy. The evaluation was conducted on the portion of the Ford Freeway (I-94) within the Detroit city limits.

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Abdul-Rahman Ibrahim Hamad

Field data including volume, speed, vehicle mix, and volume/capacity ratio were used to calibrate and validate the INTRAS model.

The results of the study indicated that significant benefits, in terms of reduced delay and increased speed on the freeway, can be achieved by introducing ramp metering to both local on-ramps and freeway-to-freeway interchanges.

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All praise and thanks are due to Allah, Lord of the Universe, for His merciful divine direction throughout my study.

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CHAPTER 1

INTRODUCTION AND STATEMENT OF PROBLEM

1.1 INTRODUCTION

Urban freeways are expected to move large volumes of traffic throughout the day, but particularly so during the peak traffic volume periods which may occur two or more times a day at some sites. Urban freeways usually operate satisfactorily during the early years after they have been opened to public traffic. Often, though, in the later stages of their design life, the operation of urban freeways, especially in freeway and ramp merging areas, deteriorate to such an extent that they become highly congested, unstable, and ineffective in moving high volumes of traffic at the very time the demand is heaviest and the need the greatest.

Ramp metering is a strategy of freeway operations designed to improve the flow of freeway traffic by controlling the rate at which additional vehicles are allowed into the traffic stream. The primary goal of ramp metering is the efficient use of the highway system.

The freeway on-ramp is the interconnecting roadway between the freeway and the adjoining highway or street that provides vehicle access to the freeway. Freeway ramp control systems are used to control the flow of vehicles onto the freeway and, thereby, maintain freeway operations at an acceptable service level.

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Ramp control systems can be implemented on individual on-ramps or on a sequence of on-ramps. Different types of systems have been used since the early 1960s, including:

1. ramp closure,
2. pre-timed or fixed-time control,
3. gap-acceptance control, and
4. traffic responsive or real-time control.

The most rudimentary ramp control system is a ramp closure. For this type of control, vehicle access to the freeway for a given on-ramp is prohibited during the peak periods. This type of control is used where a downstream one-way constriction, called a bottleneck, adversely restricts the free movement and flow of traffic because the traffic demand exceeds the available freeway capacity. By eliminating the additional on-ramp flow via a ramp closure, the traffic obstruction at the bottleneck may be prevented. Ramp closure is considered by many traffic engineers to be the least desirable type of control.

Pre-timed ramp control systems utilize one or two traffic signals located on the ramp upstream of the beginning of the acceleration lane. For many applications the traffic signal rests in red until a ramp vehicle arrives at the traffic signal, at which time it is turned green to allow vehicle passage. The traffic signal remains green until the vehicle is detected by an inductive loop, called a check-out sensor, which is located just downstream of the traffic signal. When the check-out sensor detects a vehicle the traffic signal is turned yellow for a short period of time until it again displays red. If a subsequent vehicle is waiting at the traffic signal, it is detained for a pre-timed interval to allow separation between ramp vehicle releases. In this way pre-timed ramp control limits or meters vehicle access to the freeway. At some locations, instead of single vehicle metering, two or more vehicles are permitted access to the freeway when the traffic signal is turned green.

In gap-acceptance ramp control, the release of ramp vehicles from the ramp-side traffic signal is coordinated so that both acceptable gaps on the freeway and ramp vehicles arrive at the merge area at the same time. An acceptable freeway gap is an opening in the right lane freeway traffic that exceeds a predefined time separation below which ramp drivers are not able or willing to make a merge. Drew (1967) defines an acceptable gap as "one equal to or larger than the critical gap," where the critical gap is "that gap for which an equal percentage of ramp traffic will accept a smaller gap as will reject a larger one."

The gap-acceptance type of ramp control differs from the pre-timed control in that with pre-timed control the release of ramp vehicle is not coordinated in any way with the acceptable freeway gaps. For gap-acceptance control two freeway inductive sensors are used by a mini-computer to determine the size of the freeway gap and the speed at which the gap is traveling towards the merge area. The actual release time of the ramp vehicles is computed so that both the acceptable gap and the ramp vehicle arrive at the merge area simultaneously. Gap-acceptance control systems also employ a maximum waiting time from the moment a ramp vehicle activates the check-in sensor. If the computer does not find an acceptable gap within that time

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time period, the vehicle is released from the traffic signal in the same way as in pre-timed ramp control.

In real-time ramp control systems, traffic is monitored along a section of the freeway for the purpose of adapting the ramp metering rate or flow in accordance with the existing freeway traffic conditions. With a traffic responsive system, when the freeway flow is approaching downstream capacity, the flow from the ramp is reduced to prevent a breakdown in the freeway flow. A traffic responsive system also permits an increase in the ramp flow whenever the freeway flow decreases. Typically, the monitoring of freeway traffic conditions is a function of either a volume or an occupancy measure. For either measure, the ramp traffic flow is based upon maintaining the total demand to a value equal to or less than the downstream capacity in order to maintain a given service level.

1.2 PROBLEM STATEMENT

Many large urban centers have installed freeway ramp metering systems to help reduce the congestion on their urban freeways (e.g., Detroit, Los Angeles, Chicago, and Houston). The problem is that these systems do not show the expected benefits when there are freeway-to-freeway interchanges in the urban freeway system. This is the case in the City of Detroit.

In Detroit there are three major freeway-to-freeway interchanges along the Ford Freeway. The interchange ramps are not metered, and the large volumes travelling between the freeways tend to interrupt the smooth flow that is supposed to be achieved by the ramp metering strategy. The interchanges are about one mile apart, which means that

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the weaving areas between the interchanges are very limited and many traffic conflicts are expected to occur. In addition, the Lodge Freeway interchange, which is located in the middle, has a left-hand on-ramp and off-ramp interchange beside the regular right-hand ramps.

Field data collected along the Ford Freeway showed large differences in the average speed of traffic between the parts of the freeway around the interchange areas and the parts that are outside those areas when the ramps were metered. For example, the average speed at the Van Dyke on-ramp, which is located outside the interchange areas, increased after ramp metering by about 15% (53 to 61) during the morning peak hour, while the average speed at the Linwood on-ramp, inside the interchange areas, did not show any improvement.

The research discussed here was addressed to an examination of the ramp metering operation of the Surveillance Control and Driver Information (SCANDI) system in Detroit. The objectives were to determine the effects of ramp metering on the Ford Freeway and adjacent surface streets (that is defining the queue lengths behind the metering signal and their spill-back onto the surface streets), and to evaluate new strategies that can be used to increase the benefits of the system. Of special concern was an evaluation of the strategy of metering part or all of the three major freeway-to-freeway interchanges along the Ford Freeway (I-94) within the Detroit city limits. The three freeways that intersect with the Ford Freeway are the Jeffries (I-96), the Lodge (US-10), and the Chrysler (I-75).

One of the most important tools used to evaluate potential large-scale changes in traffic systems is simulation modelling. If a traffic system is represented on a computer by means of a simulation model, it is possible to predict the effects of traffic control and traffic management strategies on the system's operational performance. The use of simulation allows the testing of metering strategies other than the one in operation to determine if those strategies can be more effective than the one now in use.

For this dissertation the Integrated Traffic Simulation (INTRAS) model (Wicks and Lieberman, 1977) was used to evaluate the ramp metering system in Detroit.

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CHAPTER 2

LITERATURE REVIEW

There are several areas that need to be discussed before presenting the research itself. These include: control strategies for freeway operations, characteristics of ramp metering, and the reasons behind using simulation computer models instead of empirical approaches.

2.1 CONTROL STRATEGIES FOR FREEWAY OPERATIONS

Travel demand continues to increase, especially on urban freeways, which causes the congestion on those facilities to increase. Past studies (e.g., Wattleworth, et al. 1967, and Newman, et al. 1970) have demonstrated that this increase in congestion can be slowed by exercising some type of traffic control strategy.

Limiting access to a highway usually results in improved operations and safety for many motorists at a cost to a few motorists. This is part of the reasoning behind building limited access highways. Typically, the more limited the access, the better the level of service offered to the user. Therefore, the operation of roads that are already access limited, such as freeways and expressways, can be further improved by further regulating the access points. This is called ramp control, and has been the topic of many studies in the past t

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past twenty-five years (e.g., Wattleworth, et al. 1967, Gervais 1964, and Newman, et al. 1970). This review chronicles the major developments in ramp control strategies.

Ramp closures were investigated prior to ramp metering, because of their relative simplicity. The reasoning behind ramp closure was that, if higher volumes of traffic could leave the center-city by freeway in a given period of time, there would be a less of backlog of traffic in the central business area in the evening peak periods. Closing selected on-ramps would reduce the volume and density on the freeway, thereby increasing speed, as well as eliminating traffic conflicts at merge areas. Many cities experimented with on-ramp closures, with favorable results [e.g., Houston (Pinnel, et al. 1965), and Detroit (Gervais, 1964)].

In the mid 1960s, ramp metering began to replace ramp closures as a means to control freeway volumes. The first meters (May, 1964) were fixed-time meters, releasing cars at constant intervals. Many early experiments with metering (Gervais, 1964) employed a policeman with a clock controlling the rate of access of vehicles from ramps. The policemen were eventually replaced by signals and new metering strategies were employed. Demand-capacity metering and gap-acceptance metering were two of the new strategies (both were discussed earlier in the introduction). Both relied on loop detectors to gather information on the freeway flow.

The major drawback of gap-acceptance metering is that gaps are not stable, and may disappear after they are identified. Munjal, et al. (1973) compared fixed-time and gap-acceptance metering on the Long Island Expressway in New York City in 1969. They found that while gap-acceptance metering is only slightly more accurate than fixed-time metering in finding acceptable gaps, that when the gaps are found, the merge is much smoother. It was also suggested that prohibiting lane changing into the outside lane between detector location and ramp location would cut the gap-acceptance failure rate roughly in half.

Another way of approaching the gap instability problem was the use of a pacer system. Tignor (1975) tested such systems in Boston in 1970. Typically, the system consisted of a band of lights which represent a gap in freeway traffic. The band travels along a guardrail type signal, changing length and speed as does the gap. The pacer system consisted of a series of green lights similar to conventional traffic lights which flashed on ahead of the driver to lead him into the gap. The system used seven sets of loop detectors in the right lane of the freeway to detect gaps. Public response to the system was good.

2.2 RAMP METERING SYSTEMS

Chicago, Detroit, and Los Angeles each have a centralized traffic control center from which they receive data from television and electronic sensors, provide incident detection and motorist aid services, and control ramp metering. In addition, other cities use computers to optimize a series of metered ramps along a freeway corridor in order to minimize the travel time on the corridor.

Five case studies, the Lodge Freeway in Detroit, Michigan, the Gulf Freeway in Houston, Texas, the Dan Ryan Expressway in Chicago, Illinois, the Harbor and Hollywood Freeways in Los Angeles, Cali

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California, and the Inland and Helix Freeways in San Diego, California, are presented in the following sections.

2.2.1 Detroit

The John C. Lodge Freeway surveillance project in Detroit had as one of its objectives the development of a traffic control system, including ramp metering. Two experiments were carried out in the early 1960s concerning ramp closure (Gervais, 1964). The first tested the effectiveness of "don't enter" signs above a ramp on the Lodge Freeway. This study showed that while motorists read these signs, they did not always obey them. For the second experiment, conducted in 1963, nine entrance ramps on a three mile study section were closed, either individually or in various groups, during varying times, although always during peak flows. Data on the effect of this experiment were collected through TV surveillance, roadway sensors, and license plate surveys.

Although no specific conclusions were made regarding which ramps should be closed or for how long, it was determined that an effective choice of ramp closures will improve freeway flow. During ramp closure times, the freeway volume and average speed increased, as did, surprisingly, lane changes. The latter may suggest a more fluid state of flow. The number and severity of traffic stoppages dropped. Flow on the surface streets was not analyzed as thoroughly, but no change in the level of service was observed.

Public response to the experiment was largely favorable, although when no barriers or police enforcement was present at a closed ramp, the violation rate was about 30-35%. After all the ramps were reope

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reopened, surface street volumes remained higher than before the study, suggesting that many drivers learned from the experience.

Wattleworth, et al. (1967) studied the effect of ramp metering on traffic flow when the first ramp meters were installed on the Lodge Freeway in July, 1967. An inventory of the freeway and surface street system and capacities was taken. Traffic was counted to determine intersection capacities, and loop detectors were installed on some ramps to determine demand. For other ramps, volumes were inventoried by manual counting or aerial photography. Sonic detectors were used to measure freeway volume. These data collectors provide information for a freeway input-output study. In addition, some origin-destination surveying was done via questionnaires.

Eight ramps were metered: one with a pre-programmed signal cycle (i.e., based on fixed-time control strategy); And the others with gap-sensitive cycles (i.e., based on gap-acceptance control strategy). In addition, the surface street intersection signal network was revised.

Since data were collected for only a few days after the meters were installed, the results were not significant. Travel time (both total and average) dropped on the freeway (about 200 vehicle-hours saving was estimated), and on the surface streets as well, although the latter is likely a result of the improved signalization network. Average speed on the freeway increased by about 15 mph during the busiest hours.

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2.2.2 Houston

The first studies of ramp control on the Gulf Freeway in Houston were done in 1964 (Pinnell, et al., 1965). These studies indicated that by controlling the inbound entrance ramps during the morning peak period, the inbound level of service could be significantly improved and the total travel time greatly reduced. As a result of this research, five ramps were controlled; four by closure and one by manual metering by policemen.

Pinnell, et al., conducted a second study during the first three months of 1965. In this study, nine ramps were controlled along a 5.3 mile study section. Three ramps were closed, five were manually metered, and one was metered by a conventional overhead traffic signal on the service drive. The initial control period was two weeks, and in that time total daily vehicle-hours in the study area dropped from 1244 to 873 on the freeway and frontage road vehicle-hours increased only from 190 to 201. On the manually metered ramps, the stationed officer decided whether to release one or several cars at a time; it was concluded that single vehicle releases are preferable. Public response to this study was very favorable, with 65% of the respondents in favor of continuing the ramp controls.

Between March, 1966 and July, 1967 several gap-acceptance ramp meters were installed along the Gulf Freeway. Buhr, et al. (1969) concluded that gap-acceptance metering was generally more desirable than demand-capacity metering, ramp geometry and traffic flow permitting. Gap-acceptance meters require a computer controller to interpret signals from loop detectors and operate the meters accordingly.

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The controllers for the first ramp meters were analog computers. In July, 1967, a digital computer was first used on the Gulf Freeway (Buhr, et al., 1969). It was hypothesized that digital computers would be ideal for optimizing a system of ramps, but would be too expensive to control a single ramp.

2.2.3 Chicago

The Chicago area expressway surveillance project included a ramp metering study on the northbound Dan Ryan Expressway with the objective of gaining better knowledge of the relative effects of various geometric design features on ramp control strategies.

"An interplay between the expressway and the frontage street resulted in the generation of exceedingly high entrance ramp demands at the points where the expressway curves away from the frontage street. Congestion was triggered by high volumes force-merging with a near-capacity expressway, while the frontage street, through its discontinuity, was directly involved in sustaining the cause of congestion and delaying the local recovery from congested operation" (Fonda, 1969).

A ramp control strategy was introduced to the expressway in the form of fixed-time "one-vehicle-at-a-time metering utilizing manually operated portable equipment" (Fonda, 1969). The control strategy was implemented on four successive entrance ramps with the objective of adjusting the merge demands to a level that could be accommodated.

The results of the study were that the congestion was not eliminated, but the extent and duration were significantly reduced. "The severity of congestion was reduced such that individual motorist save

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saved up to five minutes in traversing the 3.6-mile study section. A daily average of 627 vehicle-hours of expressway travel time was saved during control, while the peak-period vehicle-miles of expressway travel increased by 5 percent." (Fonda, 1969).

The increase of delay surface streets around the controlled section was negligible, but the waiting time for vehicle in queue to enter the expressway, through the metered ramps, reached 7 minutes as a maximum. Even with long waiting time the "compliance with the one-vehicle-at-a-time scheme averaged 90 percent." (Fonda, 1969).

2.2.4 Los Angeles

The California Department of Transportation has the responsibility of handling the operations, operational analysis (appraisal and interpretation of traffic flows), and planning of operational improvements. By 1969, three ramp metering systems were in use (Newman, et al. 1970 and Russell, 1969).

The most documented of these is the Harbor Freeway project. This project, conducted on a 5-mile section of the southbound lanes of the Harbor Freeway in September, 1968, evaluated the effectiveness of ramp control strategy. Speed, volume, travel time, and density were measured before and after ramp control was implemented in the form of one ramp closure and five metered ramps. Three of the ramps released single cars at set intervals, the other two released platoons of vehicles. Aerial photography was used to take an inventory of the layout and demand on the freeway. Density contour maps were used to identify trouble spots. Origin-destination surveys were used to identify alternative routes and decide which ramps to meter or close.

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Demand-capacity analyses were also used to ensure that the controlled ramp volumes would not push freeway volumes above capacity.

As a result of these studies it was decided to give preferential treatment to buses, allowing them to bypass the meters and make left turns where other traffic could not. Freeway speeds increased from 20 to 40 mph. Daily savings were approximately 1000 vehicle hours on the freeway, with a resultant loss of only 130 vehicle hours on the ramps and surface streets. Newman, et al. (1970) concluded that the success of this project is due in part to unusual strategies: preferential treatment to buses, timing of surface intersection signals to allow frontage road queues to cross intersections, and two-abreast release of vehicles at one ramp.

The Hollywood Freeway project consisted of one metered ramp and one ramp which is closed by barricades during the peak period. The metered ramp is operated by a pretimed signal. Travel time savings were about 450 vehicle hours per day, consisting of 500 hours saving for freeway users upstream of the bottleneck less 50 hours for loss to diverted or delayed ramp traffic, (Russell, 1969).

2.2.5 San Diego

In 1969 a study was conducted on a 3.2 mile section of the Inland Freeway in Chula Vista. In that study four ramps were controlled, "Peak-hour input from these four ramps was reduced by 580 vehicles, and input to the mainline upstream of the control section was increased by 540 vehicles. Speed on the freeway increased from 26 mph to 43 mph for the higher volume. Traffic on parallel streets increased 225 vehicles." (Russell, 1969).

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In San Diego there are several freeway-to-freeway interchanges that are being controlled by ramp metering. Those are part of a central control strategy that involve more than 75 local and freeway-to-freeway ramps in San Diego (Wherry 1987). According to Wherry, the central control strategy does not take in account the fact that the ramp is coming from a local street or a freeway. Instead the ramps are categorized in regard of the volumes using each ramp, and the number of lanes on each ramp is also dependent on the volumes on each ramp. Those categories are: one lane for ramps with volumes less than 600 vph, one or two lanes for ramps with 600-1000 vph, two lanes (one of them is a high occupancy vehicle (HOV) lane) for ramps with 1000-2000 vph, and for ramps with volumes over 2000 vph there are three lanes (one of them is an HOV lane). In the last two categories the majority of the ramps are freeway-to-freeway ramps but there are also some local ramps.

One example of a freeway-to-freeway ramp metered location is the Route 94 Freeway connector to the westbound Helix Freeway. This ramp has 2 lanes for single occupancy vehicles (SOV) and one HOV lane. The control strategy on the ramp is fixed-time in which 2 vehicles per green per lane are allowed to enter the freeway, which means that 6 vehicles-at-a-time can enter the Helix Freeway. This ramp has been controlled in this way since 1978. The success of this strategy resulted it being used on other freeway-to-freeway locations in San Diego.

According to Wherry (1987), the average volumes on the ramps during the morning peak-period are 1600 vph on the SOV lanes and 525 vph on the HOV lane, and the average maximum delays are 5 minutes and

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45 seconds, respectively. The violation rate for running the red signal is about 15 percent, and the violators in HOV lanes were about 6 percent of the total vehicles on the ramp. The public reaction to the strategy of controlling the freeway-to-freeway ramps can be described as fair (Wherry, 1987). This noted by the low percentage of violations on these ramps and from the long queues on the ramps, where the drivers are willing to wait 5 minutes to get onto the other freeway instead of diverting to other routes.

Table 1 summarizes some of the features and results of the ramp control systems, or the case studies, that were included in the literature review above.

2.3 COMPUTER SIMULATION MODELS

"Simulation is essentially a working analogy. It involves the construction of a working model presenting similarity of properties or relationships to the real problem under study. Simulation is a technique which permits the study of a complex traffic system in the laboratory rather in the field. In a more general sense, simulation may be defined as a dynamic representation of some parts of the real world achieved by building a computer model and moving it through time." (Buhr, et al., 1968).

Simulation consists of using an analog or digital computer to trace time paths. "An analog computer is one in which computation is performed by varying the state of some physical element in which the variables are continuous." (Gerlough, 1964). "A digital simulation

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TABLE 1. SUMMARY OF RAMP CONTROL CASES

		SECTION	No. OF	RESULTS		
		LENGTH	RAMPS	V	Veh. Hours	
FREEWAY	CITY	mi		mph	Freeway	Local
HARBOR	Los Angeles	5	6	+20	-1000	+130
HOLLYWOOD	Los Angeles	-	2	-	- 500	+ 50
Chula Vista	San Diego	3.2	4	+16	-	-
GULF	Houston	6	9	+16	- 360	+ 23
LODGE	Detroit	3.2	8	+15	- 200	-
Dan Ryan	Chicago	3.6	4	-	- 627	-

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is characterized by the use of a digital computer. Whereas the analog computer must handle all elements of the simulation simultaneously (in parallel), the digital computer handles elements of the simulation one after another (in series)." (Gerlough, 1964).

The simulation of any system normally requires the following steps:

1. Definition of the problem that need to be solved.
2. Formulation of a model, or choosing a model that fits the needs of the problem.
3. Preparation of the computer "program" which will implement the model.
4. Conducting experimental runs of the simulated system or in other words calibrating and validating the model to define the parameter values to be used.
5. Interpretation of results.

The model is a statement of the problem with only important features of the system under study included. "Characteristics of a system should be stated by mathematical equations when possible. If data are not known or a suitable mathematical statement is not possible, the behavior of the system is described in words. There may be parts of the system which involve random or stochastic variables. These are treated by what are known as Monte Carlo techniques." (Gerlough, 1964).

The traffic flow in any given network with a specific set of rules of conduct and controls can be simulated using the previous procedures. Then, the effect of any change in the network variables, like the control devices, can be observed if a random sample of the traffic

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traffic flow is introduced into the network. The preparation of these random samples can be done by empirical data only or a combination of empirical data and some theoretical assumptions (Gerlough 1964).

The formulation of a model for freeway traffic flow must include a description of system behavior in terms of rules of the road and provide methods for the implementation of these rules within a computer. Gerlough (1964) defined one possible set of rules for a four-lane divided freeway in a section without interchanges as the following:

1. Each vehicle proceeds in either the right or left lane at its desired speed or the maximum allowable speed until it encounters another vehicle in the same lane.
2. The encountering vehicle, if it is in the right lane, examines the lane to its left. If the encounterring vehicle is in the left lane, it examines the lane to its right. A lane change is made if it is safe to do so. If it is not safe to change lanes the encounterring vehicle decreases its speed to that of the encountered vehicle.
3. During each time increment, all vehicles in the left hand look for opportunities to move to the right.
4. During each time increment, all vehicles traveling at speed less than their desired speed look for opportunities to increase their speeds.

The simulation approach is far more appealing and practical than a strictly empirical approach for the following reasons (Goldblatt, et al, 1984):

1. It is less costly, by far.

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2. Results are obtained in a fraction of the time required for a field experiment.
3. The data generated by simulation include many MOEs that cannot, practically, be obtained empirically.
4. Disruption of traffic operations is completely avoided.
5. Many designs requires significant physical changes to the facility, such changes cannot be implemented for experimental purposes.
6. Analysis addressing the operational impact of projected traffic demand patterns or of new facilities must be conducted by simulation or equivalent tool.

Furthermore, these models produce information which allows the designer to focus his/her thinking, to identify the weaknesses in his/her concepts or designs, and therefore to provide the basis for identifying the optimal form of his/her candidate approach.

Computers have been used to simulate freeway traffic flow for more than thirty years. In this time, the models have changed dramatically.

According to the Federal Highway Administration (FHWA), "the first actual documented simulation was performed in 1955 on an analog computer" (Ross and Gibson, 1977).

Since the late 1960s computer use has become more widespread in ramp control strategies. Several simulation models have been developed to model ramp metering. The object of this is to eliminate the cost of implementing and evaluating different metering strategies in the field.

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Levy, et al. (1961) developed a digital simulation model which duplicated traffic flow on a 17,000 foot section of a freeway, including two on-ramps and two off-ramps. This model was derived from statistical analysis of traffic data collected from several freeways. The analyses performed included development of a volume-speed relationship, and investigation of traffic lane distribution, gap acceptance levels, and behavior of exiting vehicles. This model was primarily used to determine the effects of different interchange configurations and spacing.

By 1964, the Highway Research Board (HRB) recognized published work on different types of traffic simulation, including freeway, intersection, network, and tunnel simulations. Most of this work, however, dealt with simulation theories and techniques, not actual models. Levy's model was lauded in the HRB report as one which "may advance techniques to the point of usefulness for design purposes." (Gerlough, 1964). In that report also some guidelines were given regarding the important elements of any simulation model. Those elements are:

1. Statement of the behavior of each of the components and inputs of the system. This also include the probability distribution of any random phenomena.
2. Selection of the measures of effectiveness by which the performance of the system will be judged.
3. Statement of any particular assumption or simplifications of the model which may be necessary to permit the adaptation of the model to a particular computer.

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At this point, the digital computer was determined to be superior to the analog computer for the purpose of traffic simulation, due to its adaptability and ability to handle more diverse input data.

Buhr, et al. (1968) at the Texas Transportation Institute (TTI) developed a microscopic model to analyze the effects of the different types of ramp metering. This model was similar to Levy's in that it simulated only a short section of freeway with up to six ramps. The logic was based on more recent studies of gap acceptance done by the TTI and was designed to replicate the results of fixed-time, demand-capacity, and gap-acceptance metering, as well as no metering.

The simulation logic for stepping vehicles through the system, in Buhr model, was divided into "three classifications: (a) flow logic for unimpeded vehicles, (b) car-following logic for platooned vehicles, and (c) maneuvering logic for vehicles executing maneuvers involving more than a single stream of traffic." (Buhr, et el., 1968).

Sinha and Dawson (1970) developed a microscopic model based on traffic behavior equations listed in the 1965 Highway Capacity Manual. Different freeway traffic situations can be simulated, using this model, by merely inputing the descriptive geometric characteristics and traffic data including speed distributions, total traffic volume, and the percentage of commercial vehicles in the stream.

The Sinha and Dawson model had the capacity for simultaneous, dynamic analysis of traffic flow on 5 freeway lanes, 4 on-ramps, and 6 off-ramps. The ramps may be located on the right-hand or left-hand side of the freeway. The program logic for the processing of vehicles in the system was divided into five parts. Separate routines were prepared for the processing of vehicles on through lanes, on-ramps,

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acceleration lanes, deceleration lanes, and off-ramps. This model was "validated at both microscopic and macroscopic levels. Several different macroscopic comparisons were made between simulated phenomena and data collected on sections of the Eisenhower Expressway in Chicago and a Long Island parkway, and data reported in the 1965 Highway Capacity Manual. The comparisons were consisted and reasonable." (Sinha and Dawson, 1970).

In 1977 the FHWA prepared a review of network simulation models. Nineteen models were discussed in three classes: single road, single intersection, and network. Ten models were considered obsolete, six models were considered suitable for current computer use, and the simulation portions of three signal optimization models (i.e., TRANSYT, SIGOP II, and CORQ1C) were examined. The report (Ross and Gibson, 1977) discussed the operating principles and unique features of each model, as well as the validity and usefulness of the output. The computer language, type of machine needed, core requirements, and execution speed were listed, if known, for each model.

During 1970-80 the range of work utilizing traffic flow simulation increased. Studies by Sakashita, et al. (1971) and Posner (1976) included determination of optimal motorist-aid strategies and the economic impacts of high-occupancy-vehicle lanes. The evolution of the simulation model continued as well, with models such as INTRAS and FREFLO capable of modelling larger freeway segments and incorporating accident and accident response simulation. Previous measures of effectiveness such as travel time and delay time were joined by new measures such as fuel consumption and pollutant emission (Payne, 1979).

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There are many traffic simulation models available, and table 2 summarizes the features of those models which simulate freeway traffic.

2.4 SUMMARY

The literature review reveals that the use of ramp metering as a control strategy for urban freeways is widely used. Different ramp metering strategies are used, but the the fixed-time metering strategy is considered most reliable and simplest to implement.

The strategy of metering a freeway-to-freeway interchange ramp is also discussed in the literature review, the technique has been used in San Diego successfully.

Nothing was found that addressed simulation of freeway-to-freeway control strategies in conjunction with the usual control strategies at local on-ramps by means of computer models. Gordon (1972) developed some ideas, but they were theoretical and based upon developing mathematical equations to calculate the delay and queue at the on-ramp of the interchange.

The use of traffic simulation models, as a reliable approach, to evaluate the effectiveness of ramp metering operations is also documented in the literature review.

TABLE

MODEL

INTRAS

FREFLO

FRECON

FREQ

CORQ

CORCON

TRAFLO

Parts

TABLE 2. SUMMARY OF FREEWAY SIMULATION MODELS

MODEL	MODEL TYPE	MODEL PURPOSE	TRAFFIC FLOWS
INTRAS	stochastic microscopic	incident detection and evaluation of control strategies	vehicle-specific time-stepping simulation.
FREFLO	deterministic macroscopic	simulate freeway 1-direction	conservation equation dynamic speed density
FRECON	macroscopic	simulate freeway 1-direction	modified from FREFLO
FREQ	macroscopic	simulate freeway and evaluate priority lanes.	H.C.M. (speed-volume curve)
CORQ	macroscopic	queueing in freeway corridor.	step-function travel time.
CORCON	macroscopic	queueing in freeway corridor.	step-function travel time.
TRAFLO	microscopic	all networks	FREFLO

parts of this table were taken from Aerde, et al. (1987).

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2.5 OBJECTIVES OF THE STUDY

The objective of this dissertation is to develop operational guidelines to measure the efficiency of flow on the freeway through different ramp metering strategies, including the metering of freeway-to-freeway interchange ramps.

The study conducted in this dissertation utilizes the INTRAS model, which is a microscopic freeway simulation model, to determine the optimal strategy for metering flow onto the freeway, and to evaluate the effect of the different types of strategies that can be implemented.

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CHAPTER 3

THE INTRAS MODEL

3.1 GENERAL

From the beginning of this study it was apparent that computer modeling would be required since the number of variables required to be analyzed precluded a hand calculation approach. The problem that remained was finding a software package that could perform the desired analyses. INTRAS was selected to meet this need because of its features and capabilities which were summarized in table 2 in chapter 2, and are discussed in more details in this chapter.

Released in 1980 by the FHWA (Wicks and Andrews, 1980), INTRAS is an acronym for Integrated Traffic Simulation. INTRAS has a number of features that make it suitable for the system analysis required in this research.

INTRAS allows for an unprecedented level of detail in the modelling of an urban freeway system. It is a vehicle-specific time-stepping simulation designed to represent traffic and traffic control strategies in a freeway and surrounding surface street environment.

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3.2 PROGRAM PURPOSE AND CAPABILITIES

INTRAS has been developed for use in studying freeway incident detection and control strategies. It is based on knowledge of freeway operations and surveillance systems and incorporates detailed traffic simulation logic developed and validated for this purpose, (Wicks and Lieberman, 1977).

To allow simulation of freeway control policies, including ramp metering and diversion, the capability of modelling the off-freeway environment (i.e., the ramps and the surface streets that service the ramps) is included in INTRAS.

3.3 NETWORK IDEALIZATION AND MODELLING CONCEPTS

The representation of a "real world" traffic system in the terminology of INTRAS is the most important task a user faces. The simulation results cannot reflect the actual traffic system unless it is accurately represented to the model. The model's concept of the real network is built upon the data supplied (i.e., measurements of various network features and characteristics). A familiarity with definitions of these features is, therefore, required for the user to successfully utilize INTRAS.

3.3.1 Network Representation

The geometric representation of a roadway system for the INTRAS model is comprised of links (one-directional roadway segments) and nodes (intersections or geometric discontinuities). The logical division of a road system into links may correspond to the natural segmentation caused by cross streets or ramp junctions. Figures 1 and

2 represent a typical roadway system and its network representation, respectively. If analysis of a natural segment indicates different characteristics on one portion than on another, it may be desirable to further subdivide the segment. For example, if it is observed that on the upstream portion of a segment, traffic always travels at a slower speed than on the downstream, the actual segment may be represented in the model inputs by two links with differing free-flow speeds. A change in grade is also sufficient reason for segmentation.

Implementation of this type of characteristic would be accomplished by the insertion of an additional node. For example, link (8,9) in Figure 2 might be partitioned into two links, (8,15) and (15,9), by the insertion of an intervening node 15.

To permit appropriate logical treatment for roadway sections of diverse characteristics, and to realize some computer storage economy, three link types are defined for INTRAS.

A "surface" link is defined as a non-freeway roadway segment servicing one direction of traffic. The nodes at each end represent at-grade intersections. Each surface link extends from the upstream stopline to the downstream stopline.

Vehicles traversing an INTRAS surface link are moved at constant time intervals. The method properly replicates (Peat, et al. 1973) the dynamics of traffic on urban networks. A "freeway" link is defined as a one-way roadway segment, of a controlled-access highway, and is characterized by generally constant geometric characteristics (grade, curvature, number of through lanes). The extremities of a freeway link correspond to either ramp junctions or significant geometric changes.

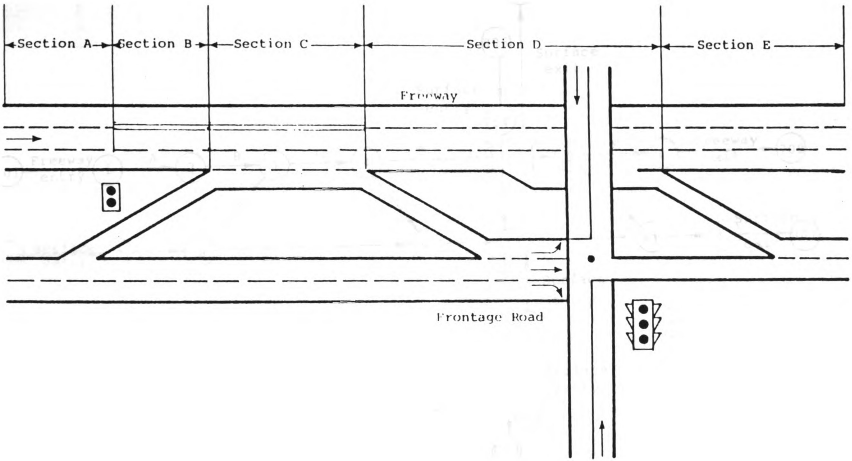

Figure 1. Sample Physical Freeway-Frontage Road Network

Source: Wicks and Andrews (1980)

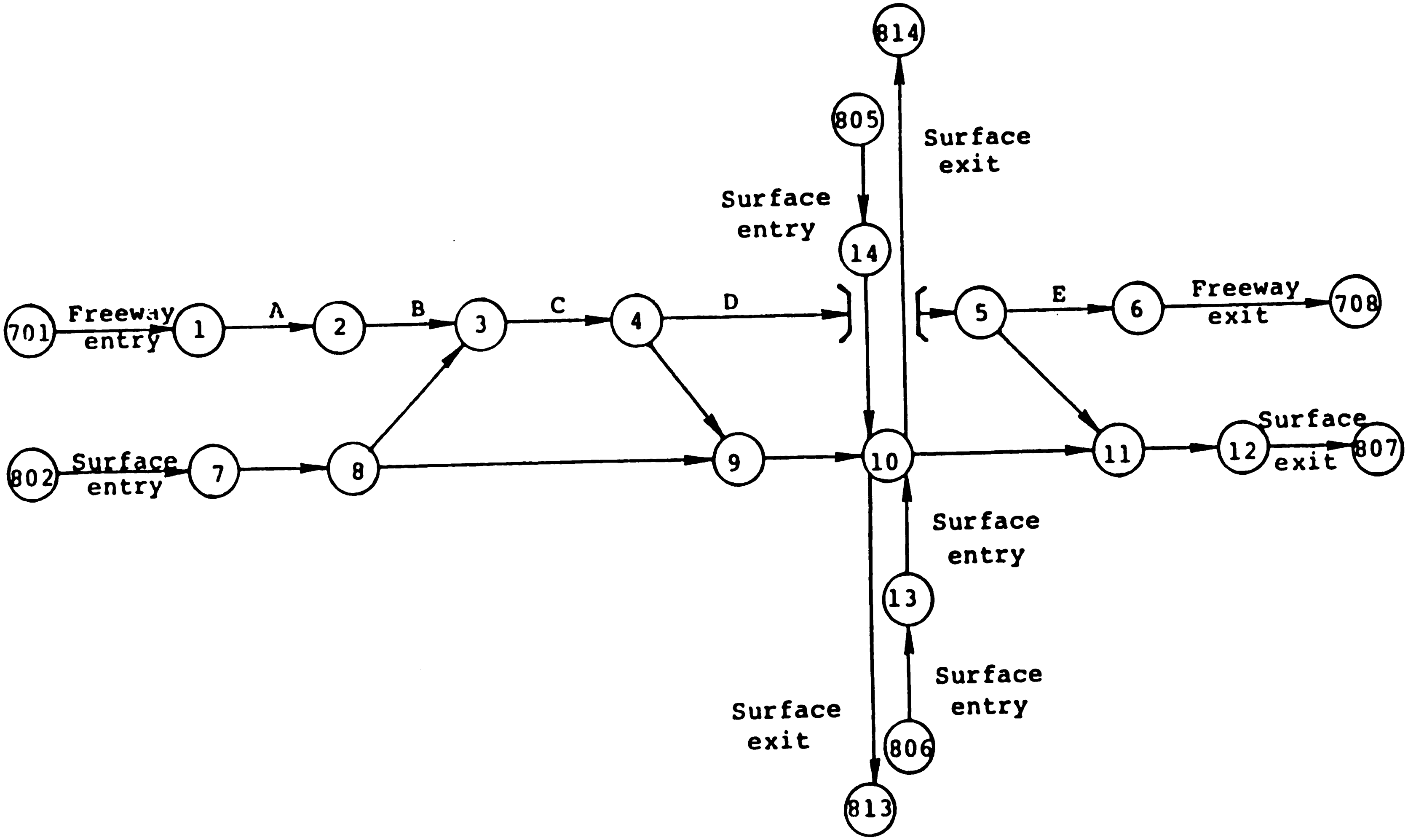

Figure 2. Representation of Sample Network

Source: Wicks and Andrews (1990)

Each freeway link may contain up to five through lanes and two auxiliary lanes.

Each auxiliary lane may be described as:

a. acceleration- A lane which extends from the upstream extremity of a freeway link to some mid-link position

b. deceleration- A lane which extends from a mid-link position to the downstream extremity of a freeway link

c. full- A lane which extends for the full length of a freeway link with at last one end connecting to an on or off-ramp

Auxiliary lanes may occur on either the left or right-hand side of the roadway. Typical freeway links are illustrated in Figure 3.

Vehicles traversing freeway links move in accordance with the logic of car following, lane-changing and vehicle generation component models developed for INTRAS (Wicks and Lieberman, 1977).

A "ramp" link is defined as a one-way non-freeway roadway segment which connects directly to a freeway link. Ramps may be one or two lanes in width. Ramp links are further characterized as either on or off-ramps indicating the end of the link which connects to the freeway. The same logic is applied to move vehicles on ramp links as on surface links.

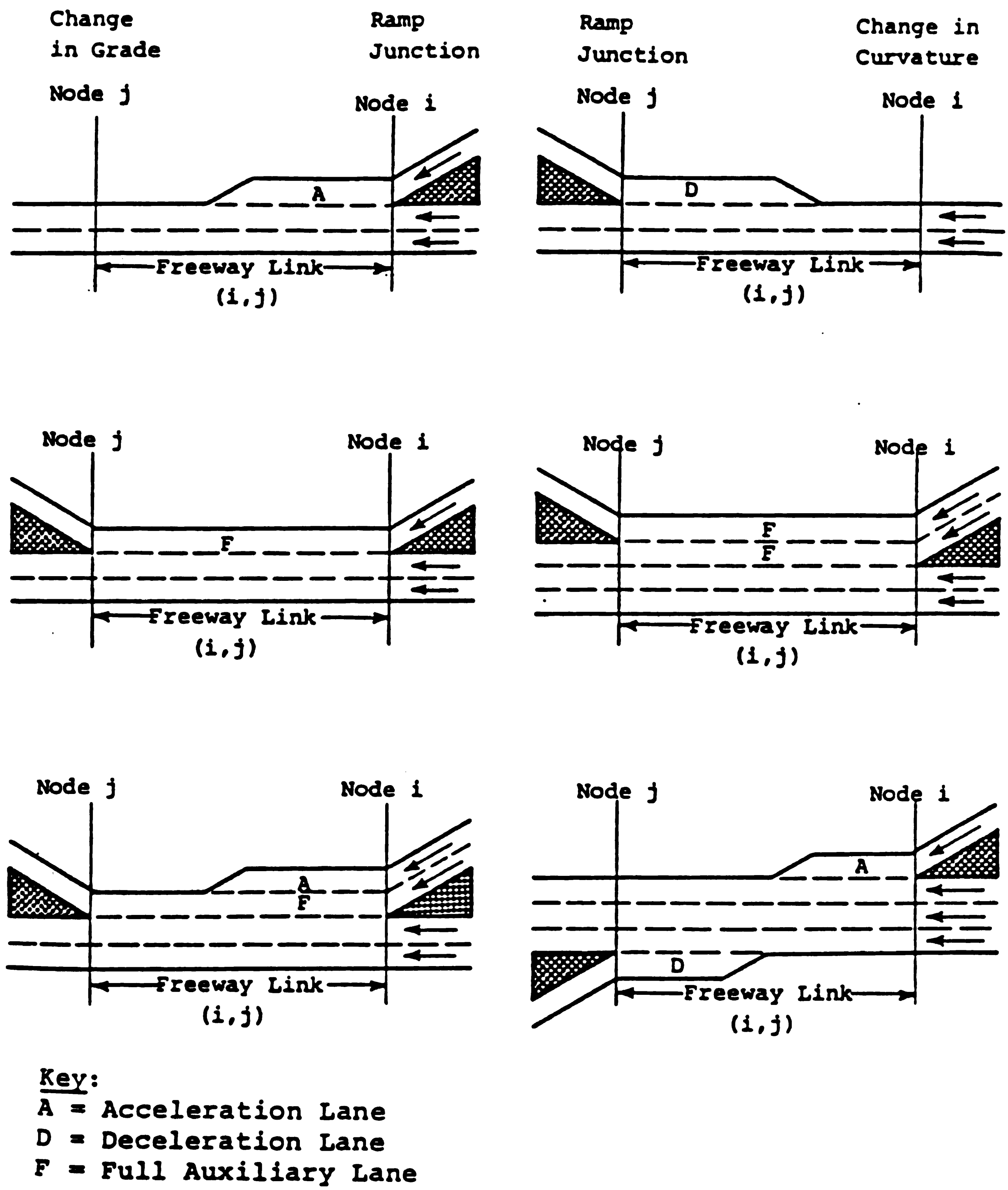

Figure 3. Typical Freeway Link Configuration

Source: Wicks and Andrews (1980)

Because the simulated network is just a portion of some real world traffic system, special links have been devised to handle conditions at the network extremities. These links serve to process vehicles in to and out of the simulated study network.

Links handling incoming traffic are called entry links. The INTRAS model allows both freeway and surface entry links. They are coded on input cards and processed the same way as interior freeway and surface links but are subject to a few additional requirements. For freeway entries, auxiliary lanes may not be specified, nor pockets on surface entries. It is not necessary for these links to exactly replicate geometry of their real world counterparts. What is important is that the incoming volumes, distributions of vehicle types, and incoming lane distribution (for freeway entries) be accurately specified. The performance of vehicles on these special purpose links are not included in the network totals of the output reports.

Traffic leaving the network is said to move on to exit links. These links are never coded on input cards and therefore not included in link data arrays or processed explicitly. The notion of exit links only exists in connection with traffic movements. If an interior link specifies a node on the periphery as a destination for some traffic movement (i.e., left-turn, thru or right-turn), then an exit link is implied and traffic may leave the network by it.

Nodes on the periphery of the network (i.e., upstream nodes of entries and downstream nodes of exits) are identified to INTRAS by node numbers greater than 699. Values from 700 to 799 are reserved for freeway peripheral nodes, while those from 800 to 899 represent nodes associated with surface entries and exits.

3.3.2 Geometric Features

To model a roadway system in sufficient detail to replicate "real world" traffic statistics, it is necessary to accommodate those geometric features which significantly affect traffic performance. These features included in the INTRAS design are:

Intersections - Each intersection is identified by a unique node number. Links are identified by the ordered pair of node numbers which identify their upstream and downstream extremities. There may be up to four links approaching, and four links departing, at a given intersection (node).

Vehicles on each approach link to an intersection may have up to three destinations (receiving links) upon passing through that intersection. Each of these receiving links is entered by performing the associated traffic maneuvers: left turn, through movement or right turn. Left turners seek gaps in opposing traffic; right turners slow before turning, etc.

Freeway-Freeway and Freeway-Ramp Interconnections - The lane alignment of freeway links and on-ramp links with the next downstream freeway link is defined by two input specifications. First, the number and type (through, auxiliary) of lanes which comprise each link is specified. Second, the lane in the downstream link which receives traffic from the right-most through lane of the upstream link must be identified.

Freeway links are logically connected to downstream off-ramps by specifying the number of ramp lanes, and whether it is a right-hand or left-hand off-ramp. The outside lanes on the designated side of the freeway are then internally assigned as connecting to the off-ramp.

Grade Specification - INTRAS has been designed to accept link-specific grade as input. Thus, it is proper to define a continuous section of roadway (containing a significant change in gradient, usually 1%) as two contiguous links, with a node defined at the point where the grade changes.

Curvature - A change in horizontal curvature is sufficient reason to segment a roadway section into two links. Two methods of limiting vehicle performance on horizontal curves are available in the INTRAS design. First, a lowered value of desired free-flow speed may be defined for an affected link. Although easy to apply, this method presumes some pre-analysis on the part of the user.

Second, radius of curvature, super elevation and pavement condition may be defined. An internal table is referenced to determine friction coefficient from pavement condition. The basic equation for vehicle operation on a curve is then used to generate an upper bound for desired free-flow speed.

$$V = \sqrt{15R(e+f)}$$

where, e = rate of roadway superelevation, foot per foot

f = friction coefficient for given pavement condition

R = radius of curve in feet

V = vehicle speed, miles per hour

The simulation model applies the minimum of the input free-flow speed, and the curvature dictated upper bound, to traffic on the subject link.

Lane Separation - The typical freeway often contains sections changing where lane changes are physically prohibited by virtue of barrier curbs or traffic islands. These restrictions are designed to segregate through traffic from weaving traffic, or, to guide vehicles around some obstruction (bridge abutments, etc.). INTRAS is designed to accept physical barriers of this nature on a link-specific basis.

3.3.3 Traffic Flow Patterns

Examination of the flow of traffic through a "real" traffic system is necessary to set up traffic flow patterns through a network. Turning movements (as percentages or counts) must be defined by the user in the model input. Lane channelization and early warning signs provide the model with information needed to guide vehicles into the proper lanes to negotiate these prescribed maneuvers.

The early warning sign capability of INTRAS allows the user to define the point on the roadway at which drivers begin to react to an upcoming off-ramp. As simulated vehicles pass an early warning sign, they are assigned to either turn or remain on the freeway at the indicated off-ramp. Their desired lane thereafter reflects this downstream movement. If an early warning sign is not specified for a particular off-ramp, then vehicles do not exhibit lane preferences (due to the off-ramp) until they enter the freeway link which connects directly to the ramp.

3.3.4 Signal and Sign Control

Each intersection in a simulated study network requires a control policy to establish the right-of-way for approaching vehicles. INTRAS has the ability to simulate both fixed-time signal control and sign control. Provision has been made for the modular inclusion and referencing of the specially coded subroutines to model traffic responsive signal control. Ramp metering and freeway traffic diversion procedures (described in later sections) utilize this provision.

Fixed-Time Signal Control - Intersections of an INTRAS simulated network may be controlled by fixed time signals of up to six control intervals each. During each interval, one of the following standard signal configurations is applied to control each of the approach links:

Amber

Green

Red

Red with Green Right Arrow

Red with Green Left Arrow

Red with Right Turn after Stop

No Turn - Green Through Arrow

Red with Left and Right Green Arrows

No Left Turn -Green Through and Right

The duration of each control interval is user-specified. In this research the network no surface street intersections were modelled due to time and data limitations.

Sign Control - Each intersection not controlled by a fixed-time signal is controlled by either stop or yield signs. The user must specify which approaches face such signs. For the common situation, where no control of any kind is present, the INTRAS user needs to specify yield signs for one approach direction to indicate the minor street.

3.3.5 Traffic Descriptive Features

Each driver-vehicle pair in a traffic stream behaves as an individual entity having different motivations and standards of performance. This quality is modelled in INTRAS to achieve the proper stochastic variation in individual vehicle performance. To accomplish this, the INTRAS design provides for five vehicle types, each possessing its own family of vehicle characteristics (length, speed acceleration profile, etc.). These characteristics may be revised as an option, so that the particular vehicle types chosen for the basic INTRAS model do not constitute a limitation on the user. The vehicle-types chosen for the basic INTRAS model are:

Low Performance Passenger Car

Intercity Buses

Single Unit Trucks

Trailer Truck Combinations

Variations within vehicle types are attributed to differences in driver performance. Decile distributions of these characteristics (variation about mean free-flow speed, queue discharge headway, etc.) are implemented in the INTRAS model.

3.3.6 Freeway Traffic Responsive Control

Vehicles entering the freeway via on-ramps may be subjected to a variety of control techniques. In parallel to, or independent of on-ramp control, diversion of freeway vehicles to a parallel service facility may be simulated. In this dissertation the diversion option was not used because there are no continuous service roads parallel to the Ford Freeway where this study was conducted.

On-Ramp Controls: Four methods of on-ramp control can be implemented in the INTRAS model. A typical geometric configuration of a metered on-ramp site is shown in Figure 4.

1. Clock Time metering: To simulate clock-time control of on-ramp, one fixed metering rate (vehicles per minute) is specified at each such node. A countdown clock is assigned to each associated on-ramp and the signal is set to "green"

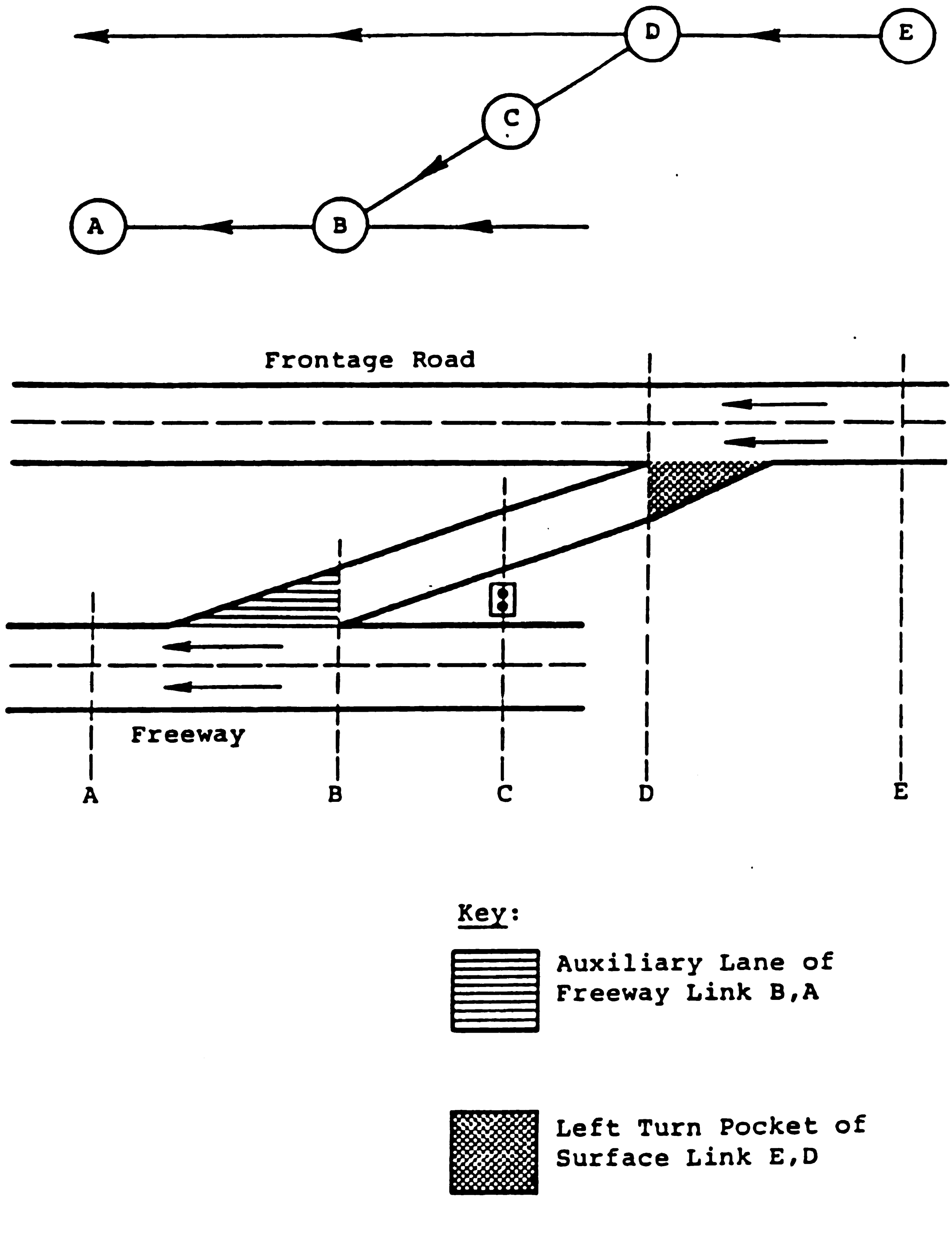

Figure 4. Typical Metered Ramp Geometry

Source: Wicks and Andrews (19[illegible]) each time the clock returns to zero. The signal is maintained at "green" until a vehicle is discharged, and is then set to "red".

2. Demand-Capacity ramp metering: In this ramp metering strategy, vehicle headway on the ramp is set at a rate dependent on the available capacity of the freeway. The level of available capacity is established by comparing the number of vehicles on the link with a given capacity value set by the user.
3. Speed control ramp metering: For this control option, a vehicle is released if the speed on the freeway is above a user-specified threshold value.
4. Gap acceptance merge control: Under this ramp control option, a vehicle is released when an acceptable gap exists on the freeway receiving link. The acceptable gap is specified as a minimum required headway between two vehicles on the freeway link.

3.4 SIMULATION AND PROGRAMING METHOD

The INTRAS simulation model employs a time stepping procedure for moving discrete vehicles through the simulated traffic network. Each time step all vehicles in the network are processed in accordance with their desired speeds and destinations inhibited by the immediate traffic and control environment. A description of the various traffic and network characteristics modelled by INTRAS was presented in Section 3.3., and more discussion about the different parts of INTRAS simulation logic is presented in section 3.6.

3.5 ASSUMPTIONS AND LIMITATIONS

Certain restrictions on network geometry and parameter values were required before the programming of INTRAS could begin. Reasonable values for these restrictions were chosen by considering the mission of the program and then determining limitations which could not reasonably be considered to interfere with the expected applications. These design limitations are the subject of this section.

The geometry of the simulated network is restricted as to link lengths, maximum allowable lanes on each link, and number of approaches to each node. These restrictions are identified in Table 3. Similar in nature to the geometric restrictions is the limitation on signal control intervals. A maximum of six such intervals are permitted for signal controlled intersections.

In the calibration of INTRAS (Wicks and Lieberman, 1977) assumptions were made as to the degree of detail required to accurately represent the dynamic characteristics of freeway traffic. A maximum of five vehicle types were defined. The first two types are allowed to exhibit different acceleration characteristics in the freeway and non-freeway environments. Five grade categories are provided. The first of these categories is assumed to represent a negative gradient, and so, no limitation on desired speed (due to grade) is designed for this category.

TABLE 3. INTRAS Geometric Limits

Definition		Limitation
Number of through freeway lanes per link		≤ 5
Number of auxiliary freeway lanes per link		≤ 2
Number of ramp lanes per link		≤ 2
Number of surface lanes per link (including pockets)		≤ 5
Number of right turn pockets per surface link		≤ 1
Number of left turn pockets per surface link		≤ 1
Length of freeway links		≤ 9800 feet
Length of surface and ramp links		≤ 3265 feet
Number of approaches to surface intersection	(node)	≤ 4 surface links
	or	≤ 3 surface links and 1 ramp link
Number of approaches to freeway intersection	(node)	≤ 1 freeway link
	or	≤ 1 ramp link

3.6 SIMULATION DEVELOPMENT

3.6.1 The Car Following Model

A fail-safe car-following model is the process of determining a vehicle's speed and position given that its leader has a speed and position that has already been calculated for the current time scan. Generally, the output of the model is the acceleration of the following vehicle. A fail-safe model has two elements. First, there is the car-following model which calculates the follower's behavior based on some prescribed desired speed. Secondly, there is an overriding collision prevention model which is based on the following vehicle being able to avoid a collision when the leader undergoes its most extreme deceleration pattern.

The algorithm used in INTRAS for the car-following model is called "The PITT Algorithm". The primary car-following relationship in the algorithm is that a following vehicle will attempt to maintain a space headway that is calculated by the following equation:

$$\text{Space headway} = L + kv + 10 \quad \text{feet.}$$

Where, L is the length of the leading vehicle, v is the speed of the leader, and k is a calibration parameter which is a function of driver type. The full car-following formula and its derivation can be found in Wicks and Lieberman (1977).

An initial operational test was applied to this car-following model through simulating the car-following behavior in a single lane. Platoons of two vehicles and five vehicles were run down the lane at a constant speed. An artificial velocity disturbance was applied to the leading vehicle, and the behavior of the followers was examined. Figures 5 and 6 show the behavior of five-vehicle platoon traveling at 60 feet/second, with either a one-second or three-seconds scanning interval. The velocity of the leader was varied by applying an acceleration of -6 feet/second/second for 6 seconds, a zero acceleration for 3 seconds and an acceleration of 6 feet/second/second for 6 seconds. The figures illustrate the velocity response of the third and fifth vehicles in the platoon. The results of the test are excellent, as can be seen in the figures, with the following vehicles demonstrating good oscillatory behavior, while remaining fundamentally stable. The behavior at the longer scanning interval was reasonably consistent. Overall, under the simple operational test, the PITT model consistently showed satisfactory behavior, Wicks and Lieberman (1977).

3.6.2 Lane Changing Process

The development of the lane changing component in INTRAS was given a great deal of attention since it is an essential requirement that the model satisfactorily perform lane changing and merging at high volumes. It is also essential that the lane changing component of INTRAS be fully integrated with its the car-following component.

Figure 7 shows the lane changing process in INTRAS. Where "a vehicle wishing to change to another lane, vehicle 3, looks at the gap available in that lane and carries out the following checks:

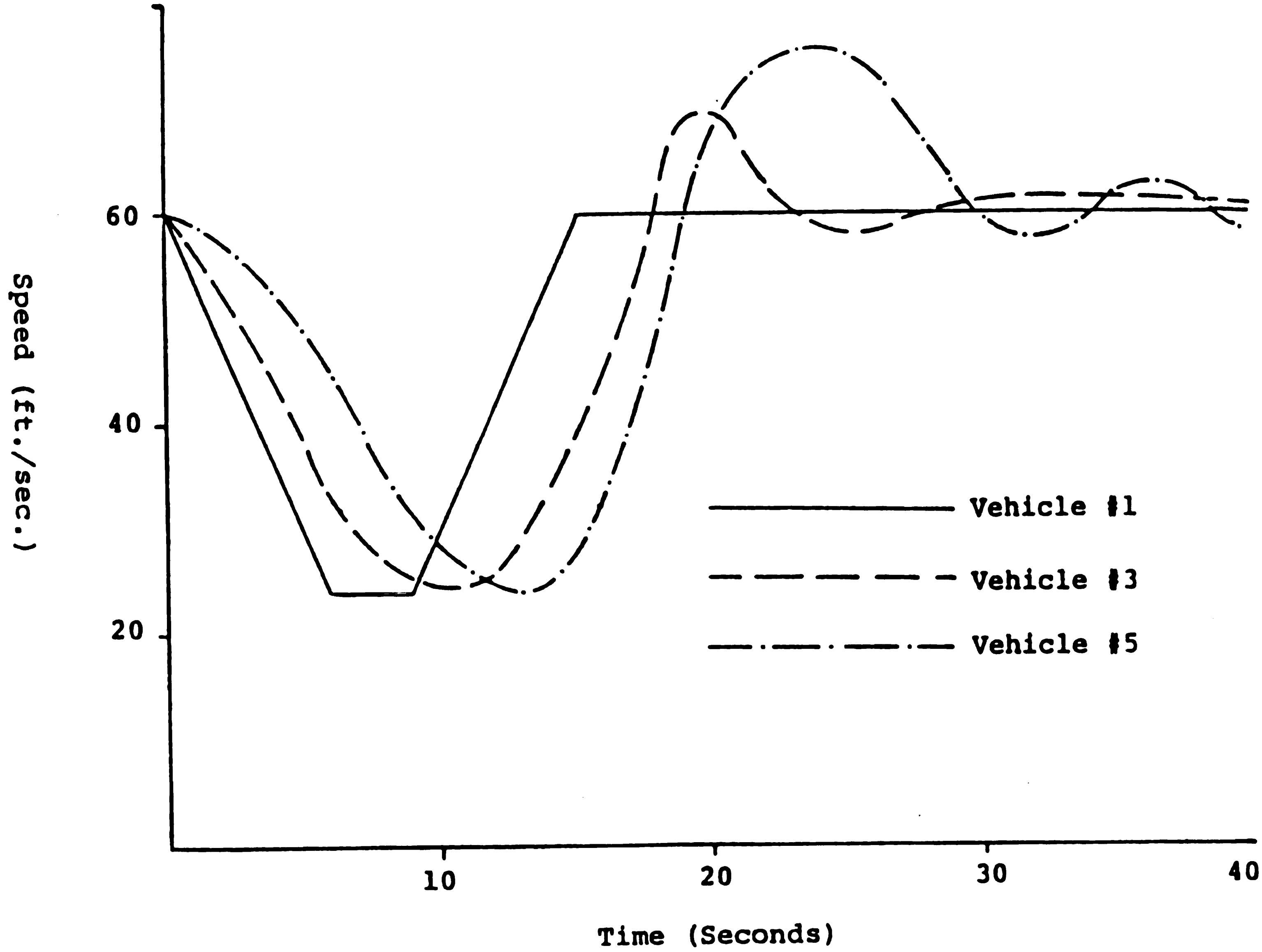

Figure 5. Platoon Behavior: PITT Algorithm-One Second Interval

Source: Wicks and Lieberman (1977)

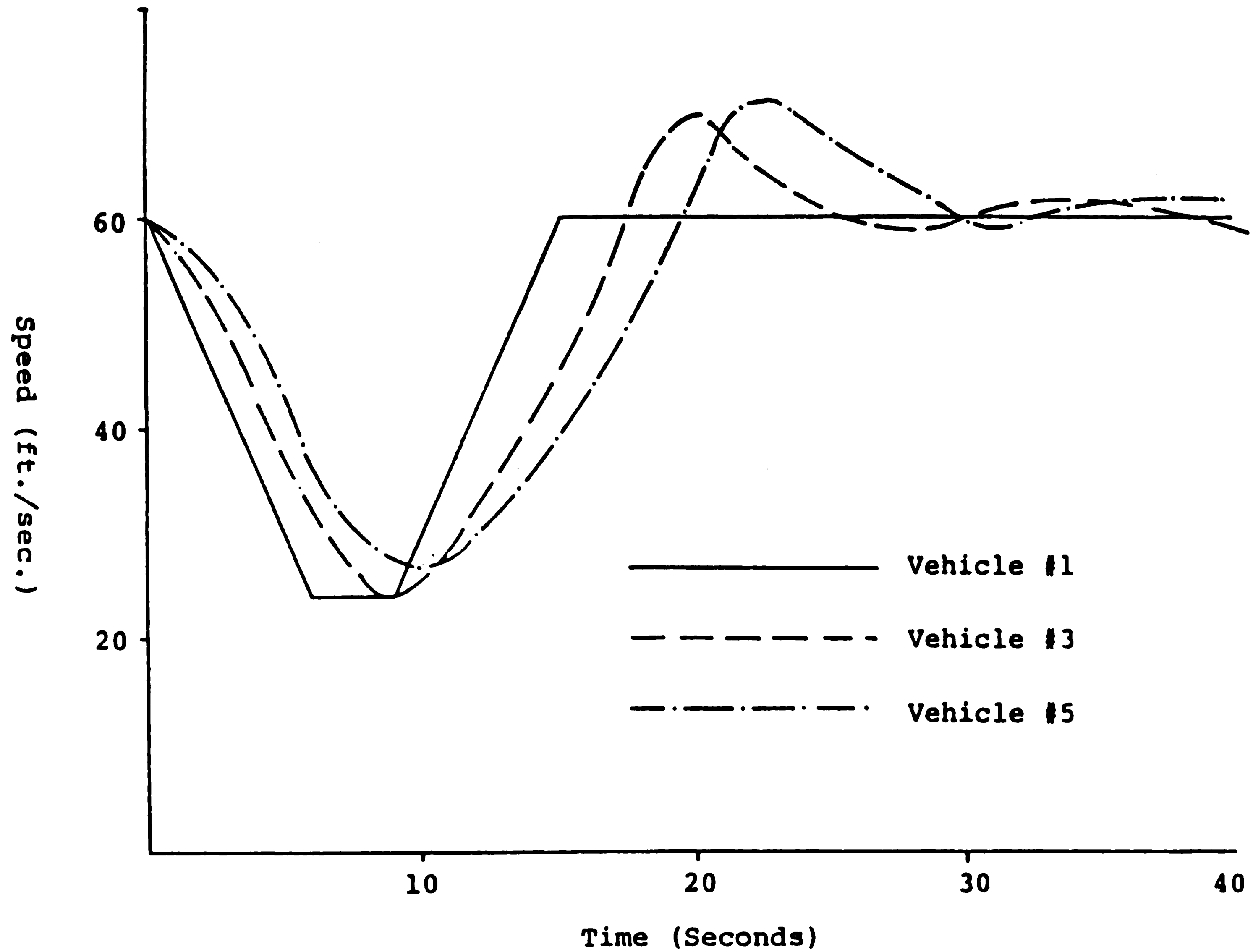

Figure 6. Platoon Behavior: PITT Algorithm-Three Second Interval

Source: Wicks and Lieberman (1977)

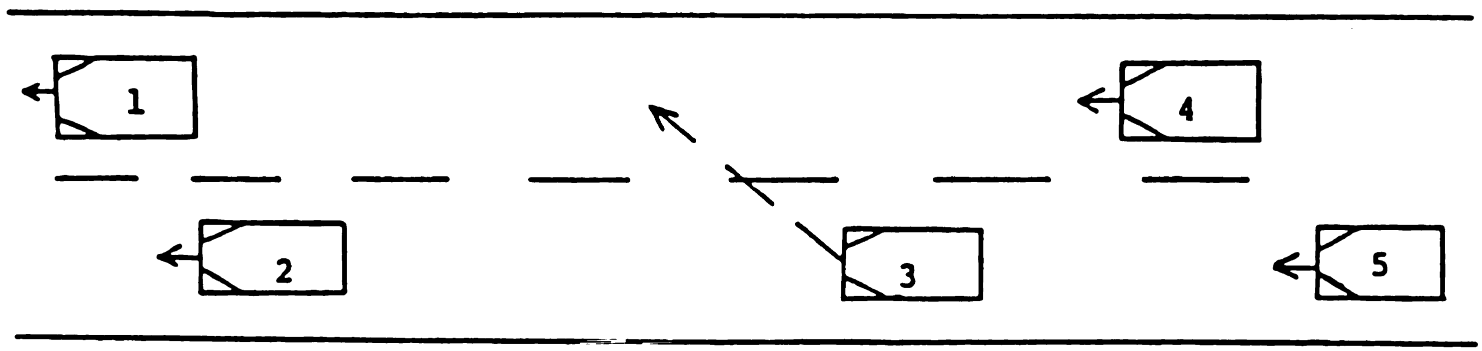

Figure 7. The Lane Changing Vehicles

Source: Wicks and Lieberman (1977)

1. Does the lead headway to the gap leader, vehicle 1, satisfy the car-following rules?
2. Does the lag headway to the gap follower, vehicle 4, satisfy the car-following rules?

If the answer to both is yes, then the vehicle can move to the new lane." (Wicks and Lieberman, 1977).

The default value, in INTRAS, of the acceptable gap in the target lane is 3.1 seconds, and it is applied deterministically. This default value was used in this research after several sensitivity runs with different values for the acceptable gap showed that 3.1 is the best value to be applied in this situation.

For a full review of the lane changing process in INTRAS see Wicks and Lieberman (1977).

3.6.3 Vehicle Generation

The Vehicle generation in INTRAS takes place on an entry link (i.e., a dummy link) which feeds the first link of the freeway or the first link of the surface road. The vehicles are generated using a negative exponential gap distribution. The vehicle characteristics are randomly generated (i.e., driver type, vehicle type, desired lane, and desired speed), Wicks and Lieberman (1977).

The headway between the generated vehicles is "checked through the car-following equation and ,if too short, is adjusted upward to the minimum safe following position. The speed and position of the new vehicle are thus determined. Vehicles are generated such that each lane of the dummy link always has at least two vehicles in it unless an excess of vehicles has already been generated. In this way, each generated vehicle has time to respond to the car-following rules and be operating normally by the time it enters the simulated freeway." (Wicks and Lieberman, 1977).

For more details on the vehicle generation logic of INTRAS see Wicks and Lieberman (1977).

CHAPTER 4

METHODOLOGY

4.1 IMPLEMENTATION OF INTRAS

Since the INTRAS model has not been released for public use yet, a copy of it was obtained directly from FHWA for the study.

The FHWA copy of the model was written for IBM mainframe, and the first step in the implementation was to convert the model so it could be run on the MDOT Burroughs mainframe. The conversion process was a lengthy one since the Burroughs has an old Fortran compiler version, and its random access memory (RAM) is too small to handle all the subroutines and large arrays of the model.

These limitations of the Burroughs mainframe led to many changes in the source code of the model. The major changes were the elimination of the fuel consumption and the plotting subroutines from the model, and the reduction in sizes of many storage arrays.

Since the INTRAS simulation model requires a lot of input data with many variables involved, the second step in the implementation process was to break those variables into two categories: control variables, and fixed parameters.

Control variable: The primary goal of this dissertation was to improve the freeway traffic operation by optimizing the metering rate on the on-ramps. This specific scope led to the choosing of only one control variable, which was the timing of the signals, which control the metering rate of the ramps.

INTRAS has the ability to model this metering rate in four different ways, because it has four types of ramp metering control methods: Clock time metering, speed control metering, demand/capacity metering, and gap acceptance merge control.

In this study, the control method that was used to model the control variable was the "Clock Time Metering". That decision was based on the conclusion, from the literature review, that it is the simplest method to implement and the most reliable of the four methods. Also the literature review (Munjal, 1973, Buhr, et al., 1969, and Buhr, et al., 1969) revealed that the other three control methods have high failure rates and are not stable because their implementation depends totally on accurate and continuous operation (which is usually hard to achieve) of implemented detectors in the pavement.

Fixed parameters: The rest of the potential variables (both network variables and model parameters were kept fixed during the study.

4.2 STUDY AREA

The evaluation was conducted on the portion of the Ford Freeway (I-94) within the Detroit city limits. That is, where the ramp meters are installed on that freeway. The study area boundaries are shown in Figure 8.

The Ford Freeway runs about 15 miles inside the City of Detroit, where it has three major freeway-to-freeway interchanges. All the

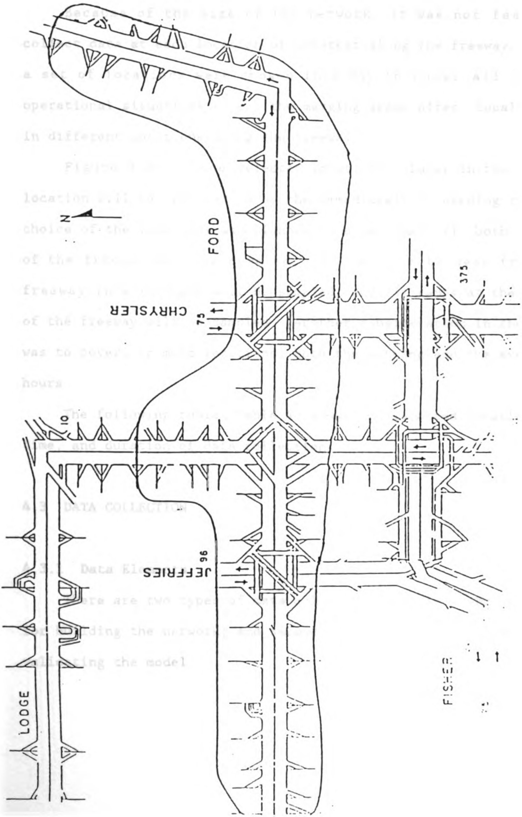

Figure 8. Study Area Boundaries

non-freeway entrance ramps have ramp metering signals to control vehicle entry to the freeway at a rate of one car per green interval.

Because of the size of the network, it was not feasible to collect data at each location of interest along the freeway. Instead, a set of locations were chosen in a way to cover all different operational situations (i.e., the merging areas after local entrances in different locations along the freeway).

Figure 9 shows the selected locations. Later in the study each location will be referred to by the immediately proceeding ramp. The choice of the locations was planned in a way that: (1) both directions of the freeway will be covered, (2) ramps in between freeway-to-freeway interchanges will be sampled, and (3) ramps at the outskirts of the freeway will be sampled. Another consideration in the sampling was to cover, in most locations, both the morning and the evening peak hours.

The following table ,Table 4, shows the selected locations, date, time, and duration of data collection.

4.3 DATA COLLECTION

4.3.1 Data Elements

There are two types of data collected for this study: first, data for building the network; and second, data needed for calibrating and validating the model.

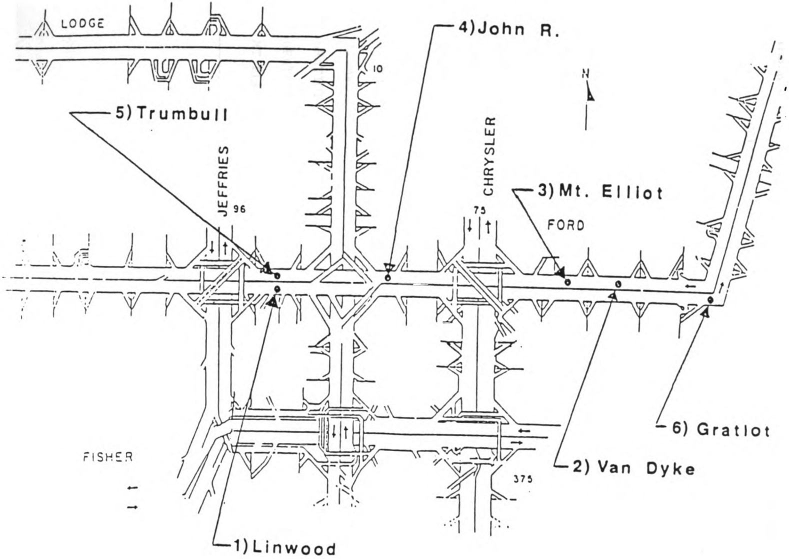

Figure 9. Selected Locations for Sampling

TABLE 4. SELECTED LOCATIONS: DATE, TIME, AND DURATION OF DATA COLLECTION

LOCATION	DIR.	DATE	TIME	DURATION	METER
LINWOOD	EAST	09/03/86	8:00-5:30	10 min/hr	on
LINWOOD	EAST	09/10/86	8:00-5:30	10 min/hr	off
MT.ELLIOT	WEST	09/17/86	9:00-5:30	10 min/hr	on
MT.ELLIOT	WEST	09/18/86	9:00-4:30	10 min/hr	off
VAN DYKE	WEST	09/17/86	8:30-noon	10 min/hr	on
VAN DYKE	WEST	09/18/86	8:30-noon	10 min/hr	off
JOHN R.	WEST	10/15/86	3:30-5:00	15/30 min	on
JOHN R.	WEST	10/16/86	3:30-5:00	15/30 min	off
TRUMBULL	WEST	10/28/86	3:30-5:30	15/30 min	on
TRUMBULL	WEST	10/29/86	3:30-5:30	15/30 min	off
GRATIOT	EAST	11/18/86	3:30-5:00	15/30 min	on
GRATIOT	EAST	11/19/86	3:30-5:00	15/30 min	off
MT.ELLIOT	WEST	04/16/87	7:30-3:00	5/30 min	off

1. Model building data: Table 5 summarizes the geometric and operational data elements needed for running the INTRAS model. The geometric data were taken from the Ford Freeway design plans, and the operational data were collected from the computer outputs of the main frame computer that controls the SCANDI system. These data include: total volume on the freeway, volumes on each lane on the freeway, and volumes on entrance and exit ramps.
2. Field data: These data includes vehicle speeds, vehicle mix, and volumes on both the main freeway and the on-ramp at each sample location. The procedure that was used to collect the field data is discussed in section 4.3.2.

Figure 10 summarizes the data elements needed for this study and their sources.

4.3.2 Field Data Collection Procedures

The collection of data was done in two steps: first, pilot data were collected during the period between April, 1986 and July, 1986. These data were used to check both the ability of the model to operate correctly, and the ability of the students involved in the data collection phase to operate with consistency and accuracy. Second, the final data were collected at the selected sampling locations between August, 1986 and April, 1987.

The dates for collecting the final data were chosen to represent normal traffic operations and volumes for the City of Detroit (i.e., schools are open). Furthermore, the data were collected only during normal weekdays (i.e., Tuesday, Wednesday, and Thursday) to avoid any

TABLE 5. INPUT DATA REQUIRED FOR INTRAS

GEOMETRIC

Links defined by upstream, downstream node numbers.

Link lengths.

Number of lanes.

Turn pockets.

Grade.

TRAFFIC VOLUMES

On all entry links nodes stratified by vehicle type (up to 5 types)

Link-specific turn movements.

TRAFFIC CONTROL SPECIFICATIONS

Stop and yield signs.

Turn restrictions.

Traffic signals.

Traffic control may be fixed-time or traffic-actuated.

Route diversion specifications.

DRIVER'S AND OPERATIONS CHARACTERISTICS

Driver's response mechanisms: free-flow speed, sensitivity, discharge headway.

Link-specific mean speed for free-flowing traffic.

Vehicle-type operational characteristics: acceleration, deceleration.

(1)

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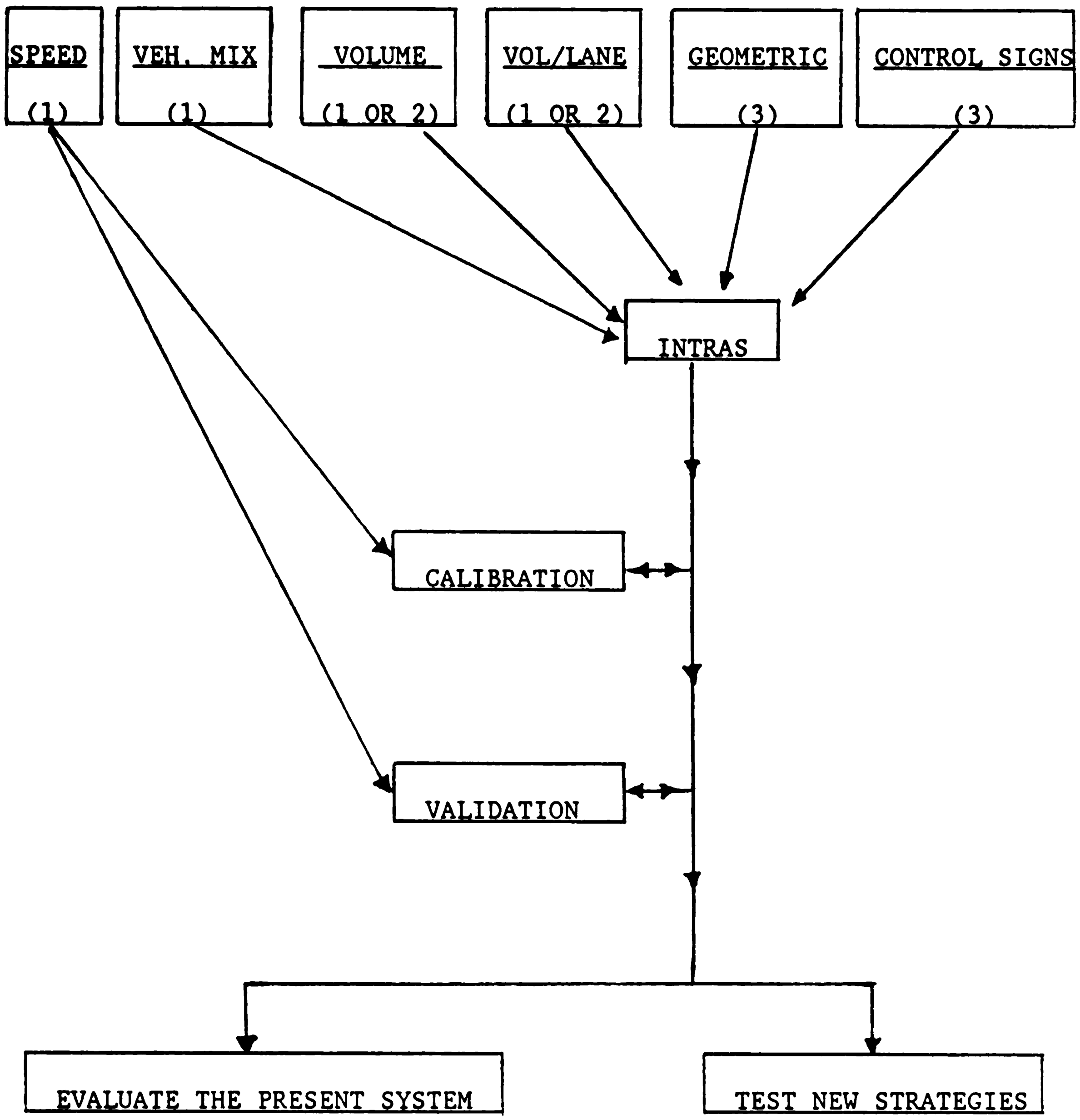

(1) Field data (2) SCANDI computer data (3) Design plans

FIGURE 10. DATA ELEMENTS: SOURCES AND FLOW THROUGH THE STUDY

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abnormal traffic situations due to the start of the week (i.e., Monday), or due to the weekend traffic fluctuation on Friday afternoon hours. Efforts were made to collect the data during dry weather days so the weather condition effect on driver behavior will not affect the evaluation process.

A video camera, that has a built-in timing clock, was used to collect the data. This was done by placing the camera on the bridge that crosses over the freeway following the intended sampling location.

Pavement taping marks were placed at 50 foot intervals on the shoulders of each selected location prior to filming, and used when performing data reduction.

For the locations where both peak hours were to be sampled, the data collection procedure was to film a 10 minute period of each hour for the whole day (i.e., between 8:00 a.m., and 5:30 p.m.). For the location where only the evening peak hour's data was to be collected, the procedure was to film the whole peak hour period (i.e., between 3:00 p.m., and 5:30 p.m.).

Special arrangements were made to collect data needed for the study, since the ramp meters are already installed and in operation. These arrangements were made in coordination with SCANDI operation control engineers, since the ramp meters are controlled from the SCANDI operation room.

These special arrangements consisted of the following:

a. Coordination of a timetable for collecting the data at each location.

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b. The collection of data at each location was done during a period of two consecutive days.

c. On the first day, data were collected with ramp meters in operation (i.e., all ramp meters ON).

d. In the second day, for the same location, the ramp meters were turned off and data were collected in the same manner as the first day (i.e., all ramp meters OFF).

e. The data collection procedure was performed on two days per week at the maximum to avoid any false traffic diversion due to changes of ramp metering status.

Through the SCANDI office, state police operational reports were obtained for same periods of time that filming took place to verify that no incidents occurred which might affect freeway flow.

4.4 DATA REDUCTION

The Mt. Elliot entrance ramp onto the west bound Ford Freeway will be used as an example to illustrate the data reduction procedure used throughout this project. The data used for this example were collected September 18, 1986, between 10:00 a.m. and 10:10 a.m., and are considered to be a representative sample for the one hour period between 10:00 a.m. and 11:00 a.m. The following steps summarize the reduction procedure:

4.4.1 Building the Grid

Using the pavement marks that were placed on the shoulder, a grid consisting of two lines that are 100 feet apart was drawn on the monitor screen that is showing the data, as in Figure 11.

4.4.2 Sample Size

Two procedures were used to reach a decision on the sample size required for the study:

1. Statistical approach:

   The following equation was used to determine the sample size:

$$n = \left[(Z_{\alpha/2})^2 * (S)^2 \right] / d^2$$

where:

n = the sample size;

d = tolerable margin of error of mean value;

S = standard deviation of sample distribution; and

Z = standard normal statistic (table value).

A pre-study was conducted to calculate the values needed for the equation, and the results were found as follows:

d = ± 2.0 mph was found to be a reasonable assumption. This was decided by comparing the estimation of the different persons collecting the data with the speeds of pilot vehicles with known speed appearing on the screen along with the regular traffic.

S = 6.67, this was the average value of the values of standard deviation from different data sets. These values are shown in Table 6.

Z = 1.96, assuming 95% confidence level

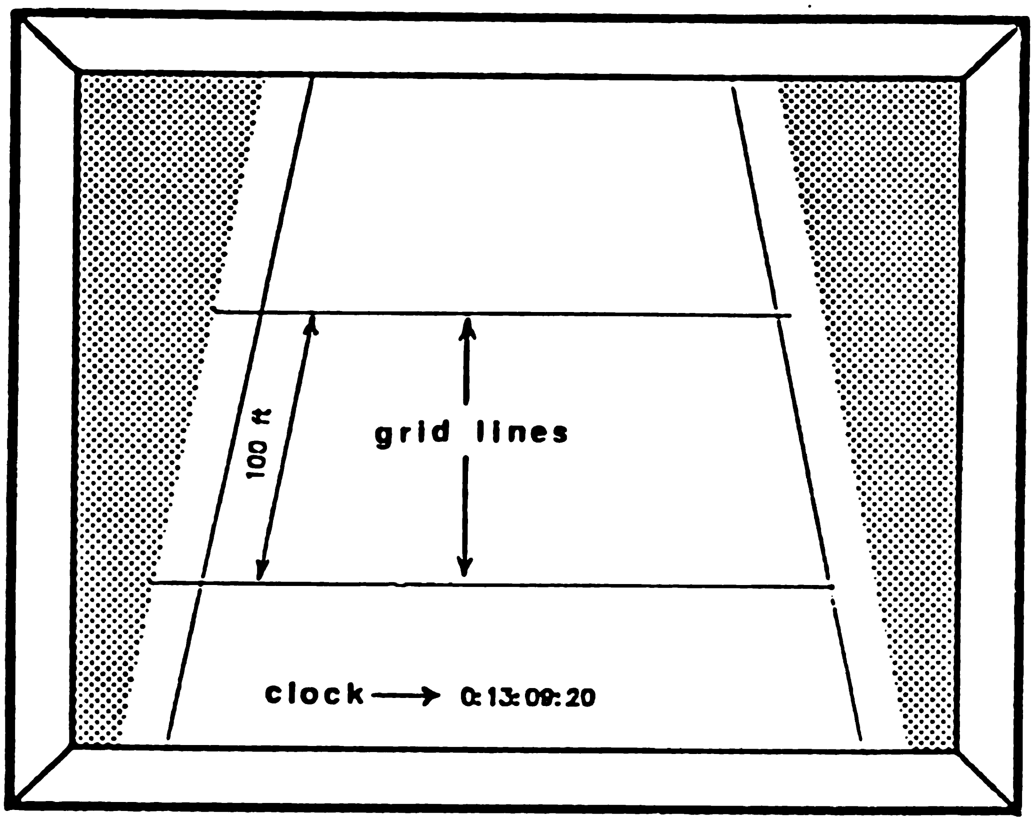

Figure 11. Placement of Grid on the Screen

TABLE 6. CALCULATION OF STANDARD DEVIATION

LOCATION	DATE	TIME	AVE. SPEED	S.D.
LINWOOD	9/3/86	13:00	59.25	7.23
		14:00	58.24	7.34
		16:30	61.33	5.78
		8:00	38.63	9.98
		9:00	49.22	7.40
		10:00	54.85	5.56
		11:00	57.57	7.84
		12:00	54.94	5.45
MT. ELLIOT	9/17/86	8:00	57.80	7.26
		9:00	60.03	6.70
		10:00	63.41	6.03
		11:00	58.78	5.26
		12:00	61.09	9.22
MT. ELLIOT	9/18/86	9:00	35.21	5.50
		10:00	58.91	7.54
		11:00	60.72	6.32
		12:00	58.83	6.09
VAN DYKE	9/17/86	8:30	59.05	7.24
		9:30	60.54	7.94
		10:30	55.06	5.03
		11:30	53.74	6.10
VAN DYKE	9/18/86	8:30	27.58	5.51
		9:30	53.15	6.11
		10:30	61.24	6.76
		11:30	58.17	5.57

ave. S.D. =6.67

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Using the above values in the equation gives $n = 43$ vehicles.

2. Empirical approach:

   a. A sample of volume (i.e., 15 vehicles) was chosen from the collected field data, and the average observed speed was plotted as indicated by point 1 in Figure 12.

   b. A second sample of the same size was selected, and the average speed of those two samples was plotted as point 2.

   c. This procedure was continued until a stable average speed ($S1 = 58.90$) was reached at point 4.

   d. The volume associated with that value (i.e., 60 vehicles) was considered the sample size that will assure stable measures by students estimating the speeds.

As a result of the two approaches, the sample size n for this study was taken as $n = 60$ vehicles per data set.

4.4.3 Data Collection

To achieve balance in collecting the 60 vehicles and to satisfy the assumption of independence for the sample units (i.e., vehicles), an equal number of vehicles was taken from each lane of the freeway (i.e., 20 veh. per lane). The choosing of vehicles in each lane was random. To avoid any bias in the calculated overall average speed of the three lanes of the freeway due to lane volume differences, the average speed of each lane was weighted according to the percentage of volume of that lane to the total volume on the freeway before calculating the overall average speed.

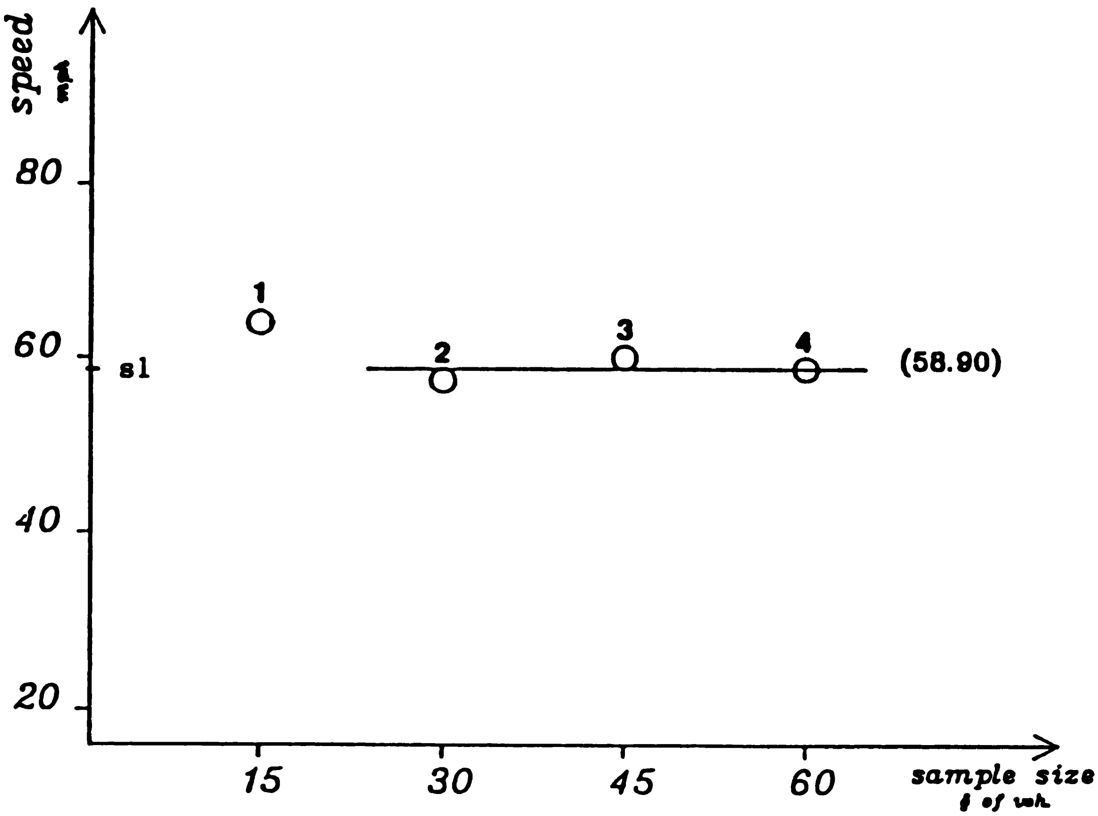


Figure 12. Choosing the Sample Size

The data collected from the screen included: What lane the vehicle was in, time when the vehicle was at the first grid line (start time), time when the vehicle was at the second grid line (stop time), and type of vehicle. The vehicles were categorized in to four types (i.e., low performance passenger cars, high performance passenger cars, single unit trucks, and trailer trucks.) that INTRAS can simulate. The fifth type INTRAS can simulate, which is the intercity buses, is not simulated here because of its low percentage on the network (less than 1%). The difference between a low performance and a high performance passenger car is in the acceleration rate assigned to each type by the model. High performance cars are assumed to have higher acceleration rates (like sport cars). Distinguishing between these two type during screen data reduction was rather difficult, instead an assumed percentage (10%) of high performance cars was used in the model based on direct observation in the field.

Table 7 illustrate the raw data collected for Mt. Elliot location on 9/18/86 between 10:00 and 10:10 a.m.

4.4.4 Calculating the Speeds

a. A special Fortran program was used to read the collected data and to convert it to speed data. Tables 8, and 9 show the Fortran program used for the data reduction, and the output file for the speed data at the Mt. Elliot location.

b. The same procedure was used to calculate the speeds on all the selected locations. Table 10, and Figure 13 were prepared to summarize the results at all locations.

Table 7. Mt. Elliot Observed Data File

TYPE	LANE	START TIME	STOP TIME	TYPE	LANE	START TIME	STOP TIME	TYPE	LANE	START TIME	STOP TIME
2	1	0:02.98	04.09	1	2	12.74	13.74	1	3	25.76	26.87
1	2	14.06	15.16	1	3	24.09	25.09	2	1	7:05.57	06.94
1	3	29.41	30.15	2	1	4:09.53	10.80	1	2	17.25	18.39
1	1	1:05.21	06.43	1	2	16.27	17.32	4	3	34.17	35.21
1	2	22.26	23.43	1	3	39.70	40.70	1	1	8:02.06	03.90
1	3	41.98	43.05	1	1	5:07.19	08.36	1	2	06.74	08.00
2	1	2:02.87	04.07	1	2	29.11	30.45	2	3	41.47	42.57
1	2	21.79	22.92	2	3	40.05	40.99	2	1	9:06.13	07.36
2	3	38.27	39.24	1	1	6:05.01	06.35	1	2	24.35	25.45
2	1	3:07.30	08.64	1	2	13.22	14.52	1	3	56.18	57.21
2	1	0:06.39	07.62	2	2	25.62	26.85	1	3	34.17	35.45
1	2	20.84	21.97	2	3	48.68	49.78	1	1	7:11.91	13.28
1	3	34.28	35.31	1	1	4:06.16	07.10	1	2	31.83	33.03
1	1	1:09.48	10.72	1	2	12.73	13.80	1	3	47.05	48.18
2	2	32.47	33.70	1	3	47.30	48.46	2	1	8:04.30	06.10
1	3	52.90	54.03	1	1	5:12.90	14.03	1	2	29.35	30.59
1	1	2:09.81	11.08	1	2	40.59	41.70	1	3	50.25	51.28
1	2	28.20	29.30	1	3	53.94	55.07	1	1	9:12.90	14.30
1	3	41.48	42.55	1	1	6:09.25	10.49	2	2	30.63	31.72
1	1	3:16.55	17.78	2	2	20.83	22.00	1	3	26.78	27.81

DATE: 09/18/86
TIME: 10:00
LOCATION: MT.ELLIOT

Table 8. Data Reduction Fortran Program

```
*DEBUG
C       SCHOOL ANALYSIS PROGRAM
        PROGRAM LNVI
        INTEGER SL(800),EL(800),K(800),T1(800),T2(800)
        REAL V(600),AVEV(800)
        REAL TOV,GAV,STD,SSD,TOVA,TOVB,TOVC,NUMA,NUMB,NUMC,GAVA,GAVB,GAVC
        CHARACTER*75 NAME

        OPEN(10,FILE='DETROIT')
        OPEN(20,FILE='CASE1', STATUS='NEW')

        READ(10,222)NAME
        WRITE(20,310)NAME
        WRITE(20,400)
        DO 50 I=1,800
          READ(10,555,END=99)K(I),SL(I),EL(I),T1(I),T2(I)
50      CONTINUE

99      I2=I-1

          DO 100 I=1,I2

                IF(T1(I).EQ.0) GOTO 60
                V(I)=(100.0/(T2(I)-T1(I)))*100.0*(3600.0/5280.0)

                WRITE(20,444) I,V(I),K(I)

100       CONTINUE

          I1=I2

          NUMA=0
          NUMB=0
          NUMC=0

 60       DO 70 I=1,I2

                IF(SL(I).EQ.2) THEN
                GOTO 260
                ELSE IF(SL(I).EQ.3) THEN
                GOTO 360
                END IF

                TOVA=TOVA+V(I)
                NUMA=NUMA+1
                GOTO 70

260             TOVB=TOVB+V(I)
                NUMB=NUMB+1
                GOTO 70

360             TOVC=TOVC+V(I)
                NUMC=NUMC+1

 70       CONTINUE

          GAVA=TOVA/NUMA
          GAVB=TOVB/NUMB
          GAVC=TOVC/NUMC

          TOV=TOVA+TOVB+TOVC
          NUM=NUMA+NUMB+NUMC
          GAV=TOV/NUM

          DO 300 I=1,I1
            SSD=SSD+(V(I)-GAV)**2
300       CONTINUE

        STD=SQRT(SSD/(I1-1))

        WRITE(20,999)GAV,STD
        WRITE(20,998)GAVA,GAVB,GAVC

        STOP

222     FORMAT(75A)
310     FORMAT(5X,75A)
400     FORMAT(//)
555     FORMAT(I1,I1,I1,I4,I4)
560     FORMAT(2X,'I=     ',F4.2)
444     FORMAT(2X,'LANE ',I3,12X,'AVE. SPEED=',F6.2,12X,'VEH.TYPE:  ',I1)
999     FORMAT(//,25X,'AVERAGE SPEED=',F5.2,//,25X,'SAMPLE STD.=   ',F6.2)
998     FORMAT(5X,'LANE 1 SPEED=',F5.2,5X,'LANE 2 SPEED=',F5.2,5X,'LANE 3
       *SPEED=',F5.2)
        END
```

Table 9. Mt. Elliot Output Data File

CAR# 1	AVE. SPEED= 61.43	VEH. TYPE: 2
CAR# 2	AVE. SPEED= 61.98	VEH. TYPE: 1
CAR# 3	AVE. SPEED= 61.98	VEH. TYPE: 1
CAR# 4	AVE. SPEED= 55.89	VEH. TYPE: 1
CAR# 5	AVE. SPEED= 58.28	VEH. TYPE: 1
CAR# 6	AVE. SPEED= 63.72	VEH. TYPE: 1
CAR# 7	AVE. SPEED= 56.82	VEH. TYPE: 2
CAR# 8	AVE. SPEED= 60.34	VEH. TYPE: 1
CAR# 9	AVE. SPEED= 70.29	VEH. TYPE: 2
CAR# 10	AVE. SPEED= 50.88	VEH. TYPE: 2
CAR# 11	AVE. SPEED= 68.18	VEH. TYPE: 1
CAR# 12	AVE. SPEED= 68.18	VEH. TYPE: 1
CAR# 13	AVE. SPEED= 53.69	VEH. TYPE: 2
CAR# 14	AVE. SPEED= 64.94	VEH. TYPE: 1
CAR# 15	AVE. SPEED= 68.18	VEH. TYPE: 1
CAR# 16	AVE. SPEED= 58.28	VEH. TYPE: 1
CAR# 17	AVE. SPEED= 50.88	VEH. TYPE: 1
CAR# 18	AVE. SPEED= 72.53	VEH. TYPE: 2
CAR# 19	AVE. SPEED= 50.88	VEH. TYPE: 1
CAR# 20	AVE. SPEED= 52.45	VEH. TYPE: 1
CAR# 21	AVE. SPEED= 61.43	VEH. TYPE: 1
CAR# 22	AVE. SPEED= 49.77	VEH. TYPE: 2
CAR# 23	AVE. SPEED= 59.81	VEH. TYPE: 1
CAR# 24	AVE. SPEED= 65.56	VEH. TYPE: 4
CAR# 25	AVE. SPEED= 37.06	VEH. TYPE: 1
CAR# 26	AVE. SPEED= 54.11	VEH. TYPE: 1
CAR# 27	AVE. SPEED= 61.98	VEH. TYPE: 2
CAR# 28	AVE. SPEED= 55.43	VEH. TYPE: 2
CAR# 29	AVE. SPEED= 61.98	VEH. TYPE: 1
CAR# 30	AVE. SPEED= 66.20	VEH. TYPE: 1
CAR# 31	AVE. SPEED= 55.43	VEH. TYPE: 2
CAR# 32	AVE. SPEED= 60.34	VEH. TYPE: 1
CAR# 33	AVE. SPEED= 66.20	VEH. TYPE: 1
CAR# 34	AVE. SPEED= 54.99	VEH. TYPE: 1
CAR# 35	AVE. SPEED= 55.43	VEH. TYPE: 2
CAR# 36	AVE. SPEED= 60.34	VEH. TYPE: 1
CAR# 37	AVE. SPEED= 53.69	VEH. TYPE: 1
CAR# 38	AVE. SPEED= 61.98	VEH. TYPE: 1
CAR# 39	AVE. SPEED= 63.72	VEH. TYPE: 1
CAR# 40	AVE. SPEED= 55.43	VEH. TYPE: 1
CAR# 41	AVE. SPEED= 55.43	VEH. TYPE: 2
CAR# 42	AVE. SPEED= 61.98	VEH. TYPE: 2
CAR# 43	AVE. SPEED= 72.53	VEH. TYPE: 1
CAR# 44	AVE. SPEED= 63.72	VEH. TYPE: 1
CAR# 45	AVE. SPEED= 58.78	VEH. TYPE: 1
CAR# 46	AVE. SPEED= 60.34	VEH. TYPE: 1
CAR# 47	AVE. SPEED= 61.43	VEH. TYPE: 1
CAR# 48	AVE. SPEED= 60.34	VEH. TYPE: 1
CAR# 49	AVE. SPEED= 54.99	VEH. TYPE: 1
CAR# 50	AVE. SPEED= 58.28	VEH. TYPE: 2
CAR# 51	AVE. SPEED= 53.27	VEH. TYPE: 1
CAR# 52	AVE. SPEED= 49.77	VEH. TYPE: 1
CAR# 53	AVE. SPEED= 56.82	VEH. TYPE: 1
CAR# 54	AVE. SPEED= 60.34	VEH. TYPE: 1
CAR# 55	AVE. SPEED= 37.88	VEH. TYPE: 2
CAR# 56	AVE. SPEED= 54.99	VEH. TYPE: 1
CAR# 57	AVE. SPEED= 66.20	VEH. TYPE: 1
CAR# 58	AVE. SPEED= 48.70	VEH. TYPE: 1
CAR# 59	AVE. SPEED= 61.98	VEH. TYPE: 2
CAR# 60	AVE. SPEED= 66.20	VEH. TYPE: 1

AVERAGE SPEED=58.91

SAMPLE STD. = 6.99

LANE 1 SPEED=53.69 LANE 2 SPEED=59.17 LANE 3 SPEED=63.87

TABLE 10. SUMMARY OF AVERAGE SPEEDS AND VOLUMES

LOCATION	DATE	TIME	VOLUME (VPH) RAMP	FREEWAY*	AVE. SPEED (MPH)**	METER
LINWOOD	9/3/86	8:00	306	5736	38.63	ON
		9:00	240	5166	49.22	ON
		10:00	198	4266	54.85	ON
		11:00	186	4170	57.57	ON
		12:00	252	4236	54.94	ON
		1:00	210	4440	59.25	ON
		2:00	222	4674	58.24	ON
		4:00	120	4812	61.33	ON
LINWOOD	9/10/86	8:00	318	6138	31.05	OFF
		9:00	150	5148	53.20	OFF
		10:00	138	4536	56.18	OFF
		11:00	216	4028	58.19	OFF
		12:00	210	4356	57.39	OFF
		1:00	210	4182	59.50	OFF
		2:00	186	4578	56.39	OFF
		4:00	126	5346	54.80	OFF
VAN DYKE	9/17/86	8:30	413	5478	59.05	ON
		9:30	377	4884	60.54	ON
		10:30	372	3816	55.06	ON
		11:30	468	3690	53.74	ON
VAN DYKE	9/18/86	8:30	---	5394	27.58	OFF
		9:30	432	4782	53.15	OFF
		10:30	432	4068	61.24	OFF
		11:30	456	3703	58.17	OFF
MT. ELLIOT	9/17/86	9:00	408	5370	60.03	ON
		10:00	336	3978	63.41	ON
		11:00	414	3894	58.78	ON
		12:00	414	3960	61.09	ON
		2:00	486	4248	56.99	ON
		3:00	504	5106	56.12	ON
		4:00	606	4440	60.98	ON
MT. ELLIOT	9/18/86	9:00	396	5670	35.21	OFF
		10:00	306	4002	58.91	OFF
		11:00	348	4032	60.72	OFF
		12:00	444	3852	58.83	OFF
		2:00	576	4374	58.23	OFF
		3:00	732	5406	53.02	OFF
		4:00	438	4368	58.81	OFF

TABLE 10 - CONTINUE

JOHN R.	10/15/86	3:30	---	5072	25.30	ON
		4:00	---	4912	25.06	ON
		4:30	---	5036	25.21	ON
JOHN R.	10/16/86	3:30	---	5264	25.62	OFF
		4:00	---	5112	32.53	OFF
		4:30	---	4632	25.51	OFF
TRUMBULL	10/28/86	3:30	547	5509	35.60	ON
		4:30	663	5294	36.38	ON
		5:30	624	5169	40.60	ON
TRUMBULL	10/29/86	3:30	600	5500	38.10	OFF
		4:30	653	5649	38.38	OFF
		5:30	624	5306	37.08	OFF
GRATIOT	11/28/86	3:30	240	6204	58.27	ON
		4:00	290	6236	58.98	ON
		4:30	320	6256	46.95	ON
GRATIOT	11/29/86	3:30	200	6064	63.19	OFF
		4:00	270	6580	62.77	OFF
		4:30	250	6508	58.64	OFF
MT. ELLIOT	4/16/87	7:30	720	6552	37.84	OFF
		8:00	492	6528	39.39	OFF
		8:30	492	6840	48.01	OFF
		9:00	324	5412	63.57	OFF
		9:30	384	4512	65.54	OFF
		10:00	456	4428	63.75	OFF
		10:30	408	4704	64.06	OFF
		11:00	408	4104	64.05	OFF
		11:30	372	3972	66.79	OFF
		12:00	384	4188	64.38	OFF
		1:00	252	4260	66.70	OFF
		1:30	288	4536	66.20	OFF
		2:00	384	4776	63.65	OFF
		2:30	1488	5712	47.36	OFF

* - This is the volume on the freeway after the on-ramp, so it includes the on-ramp volume.

** - This is the observed speed in the merging area. The distance between the ramp gore (i.e., the start of the acceleration lane) and filmed location varies for each sampled location.

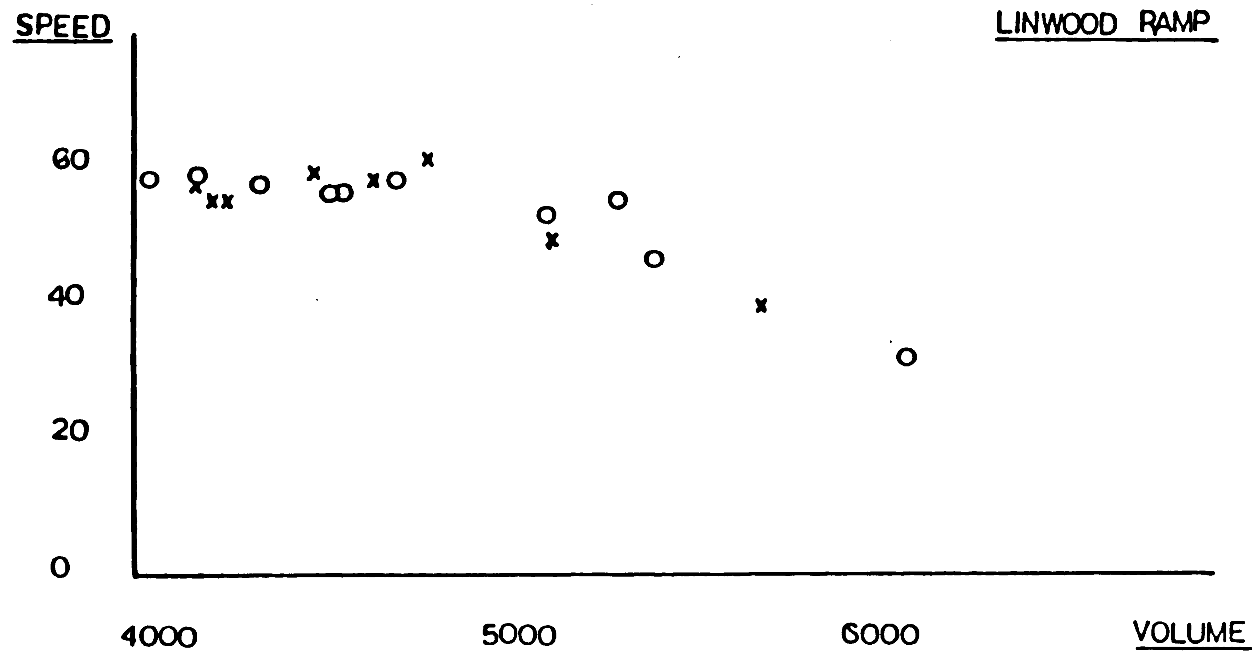


Fig.13-a

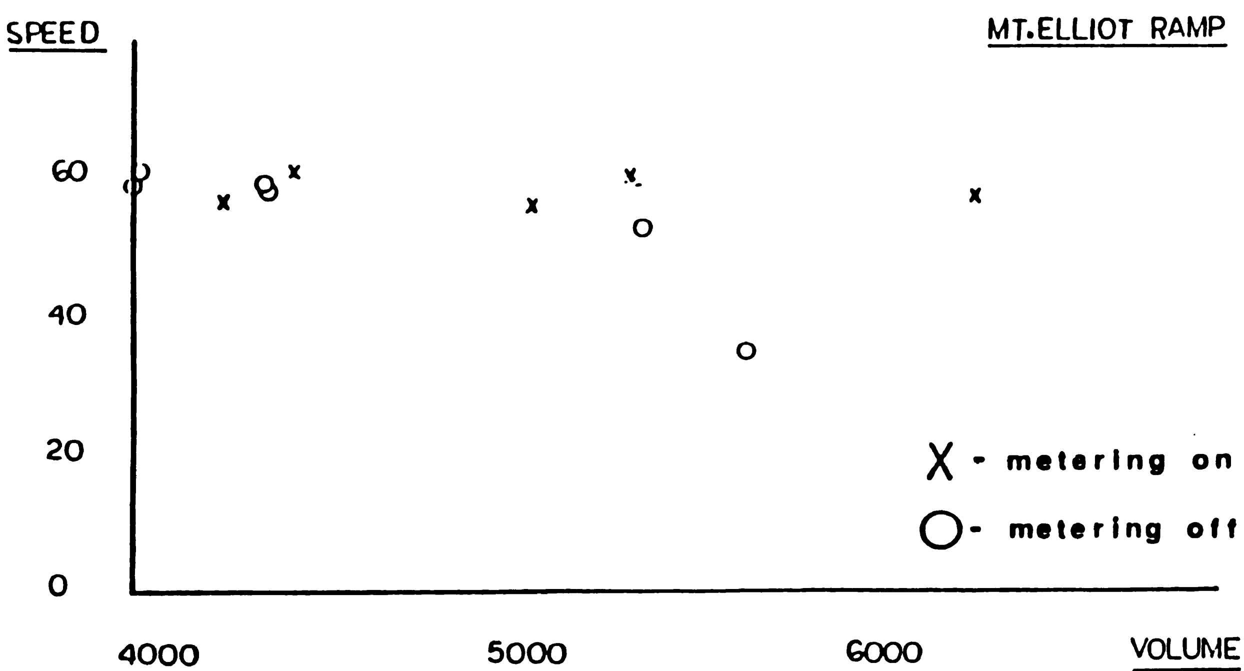


Fig.13-b

Figure 13. Speed-Volume Plots for Sampled Locautions

FIGURE 13. CONTINUE

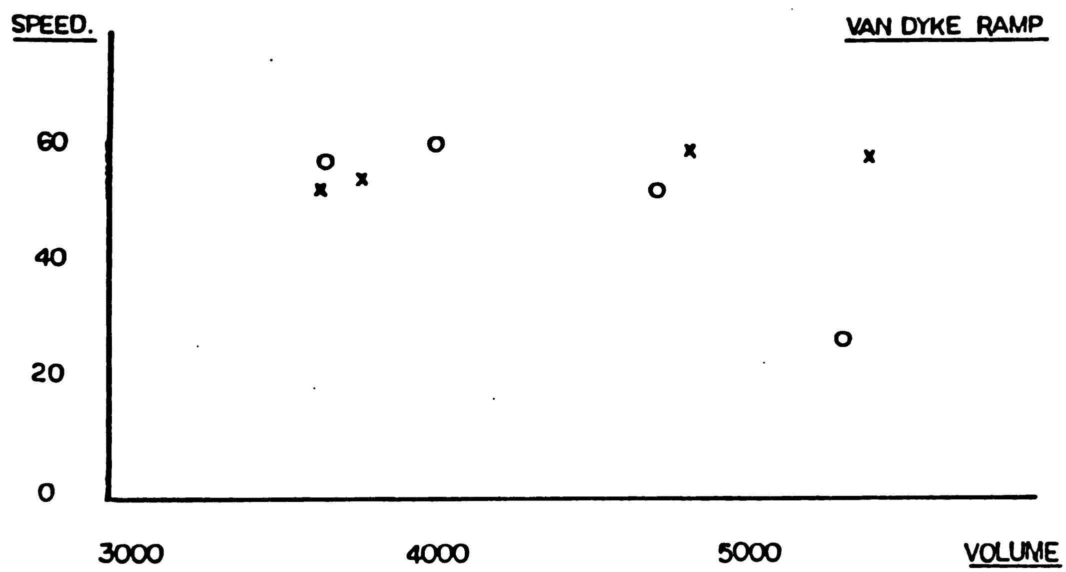


Fig.13-c

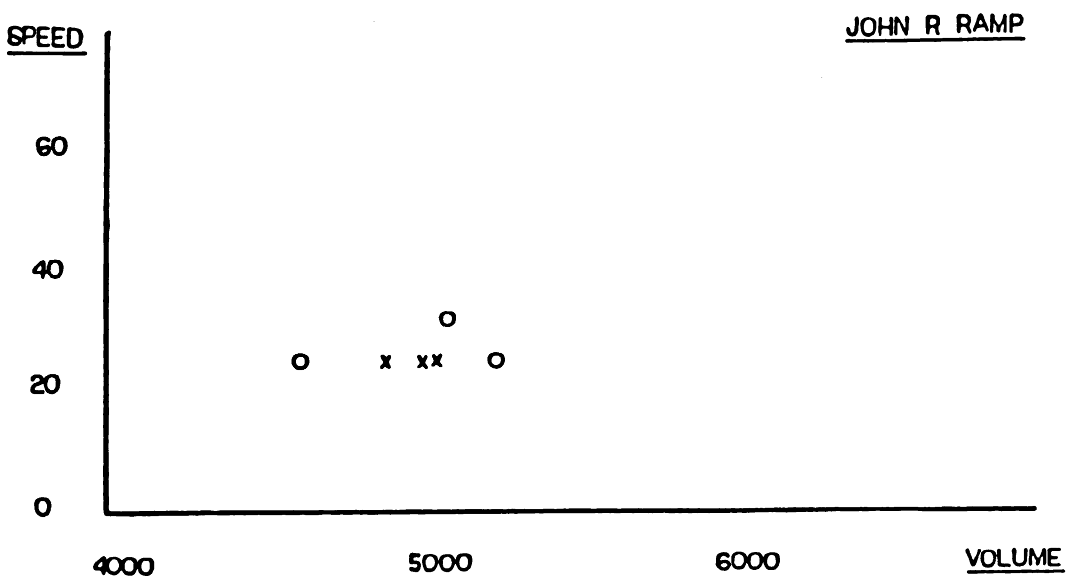


Fig.13-d

FIGURE 13 - CONTINUE

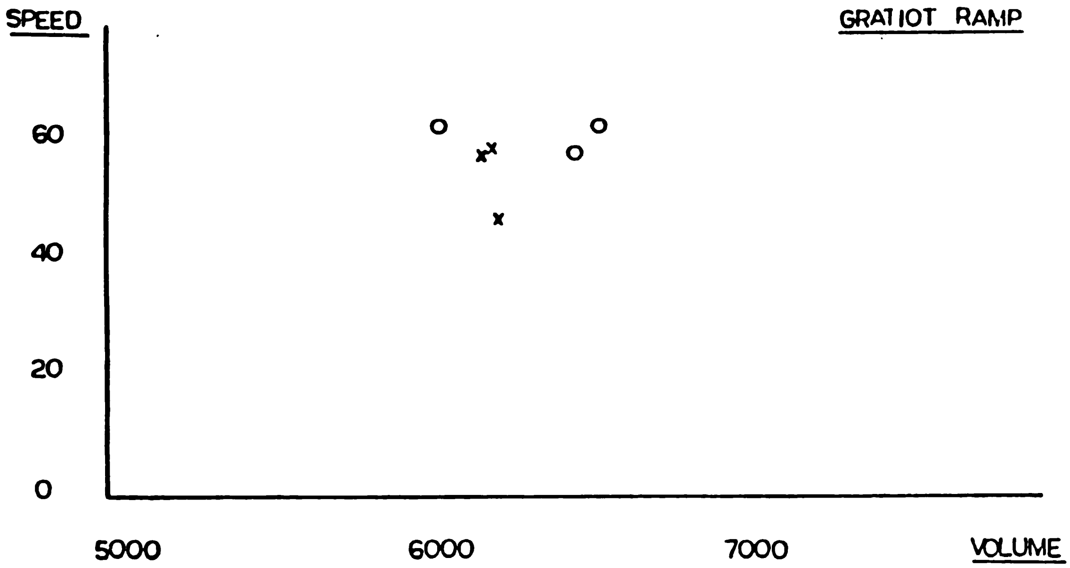


Fig.13-e

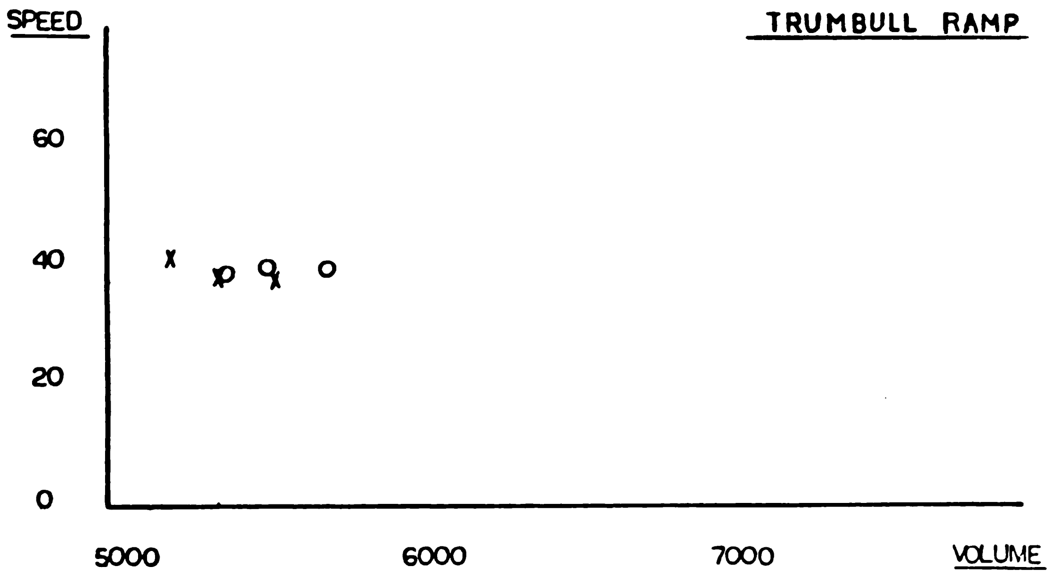


Fig.13-f

CHAPTER 5

CALIBRATION AND VALIDATION

Calibrating any model requires the analyst to make several runs for one set of data (i.e., one time sample at one location), and for each single run a chosen parameter(s) will be given a new value(s) until the difference between the MOE from the model and the observed MOE from the field data becomes statistically insignificant. The MOE that was compared in this study was the average speed.

5.1 THE CALIBRATION DATA

In this study, the model was calibrated using the volume, vehicle mix, and speed data collected at the MT. Elliot location on the westbound Ford Freeway on April 16, 1987.

The sub-network that was used to calibrate the model, Figure 14, contains the stretch of westbound Ford Freeway that starts just upstream of the Mt. Elliot entrance ramp and ends after the merging area that follows the ramp. The merging area is the area of interest in this study, and it is the area where the field data were collected.

Figure 15 shows the volume-speed curve for this data (based on 14 time points). This curve is very similar in shape to the

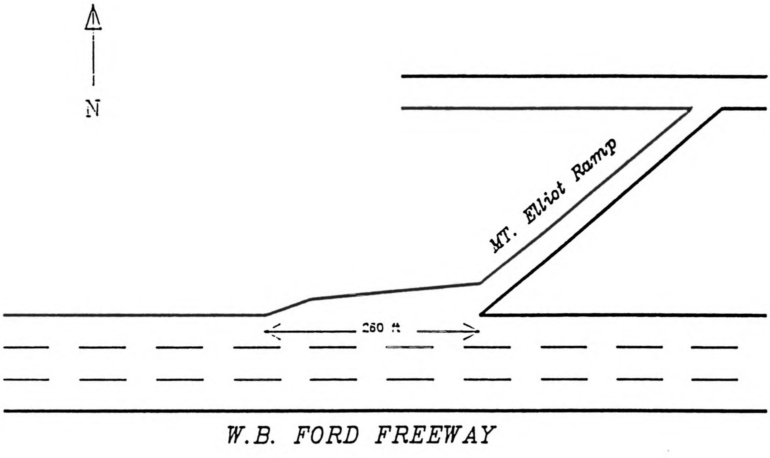


Figure 14. Mt. Elliot Sub-Network

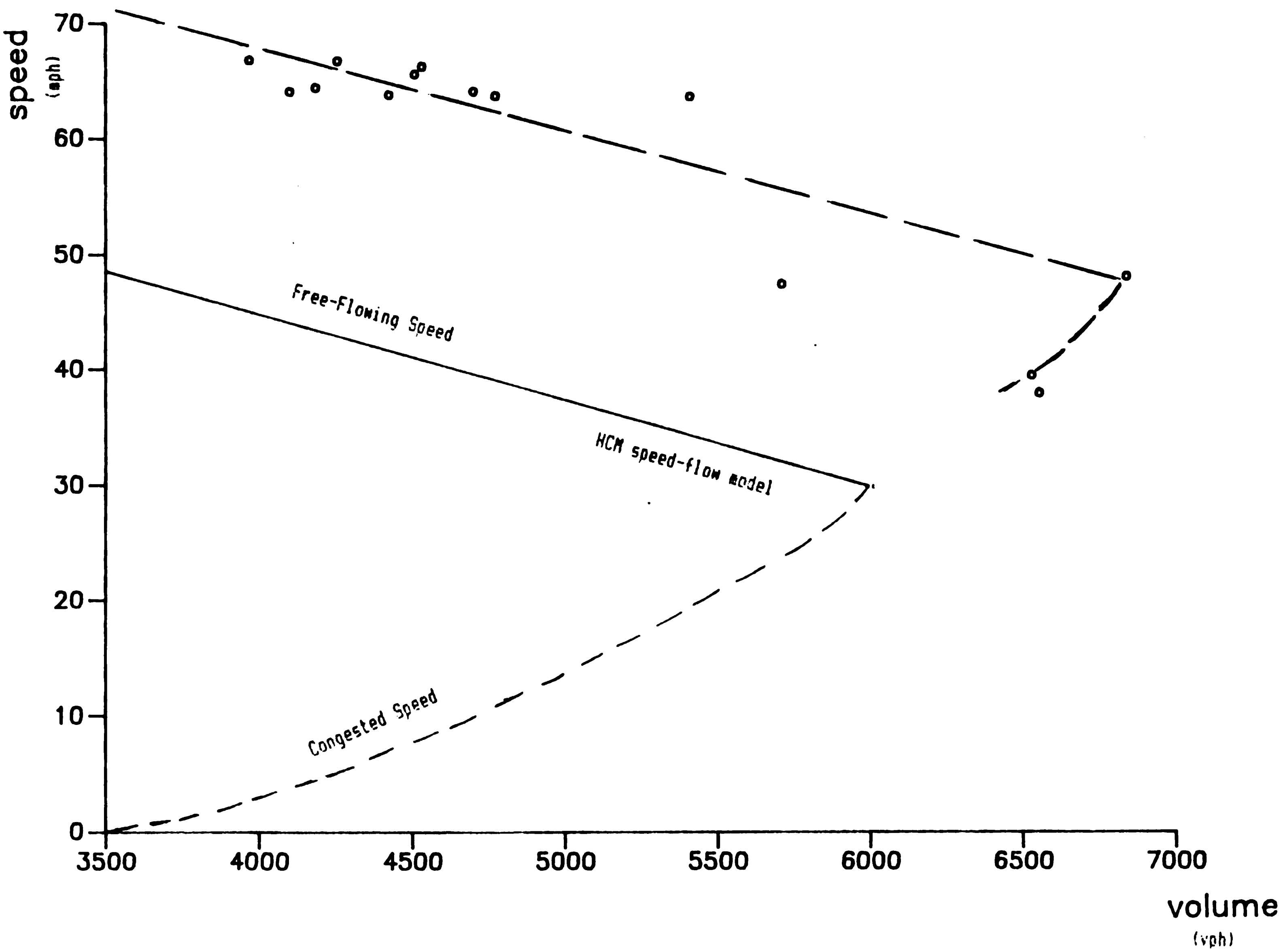


Figure 15. Speed-Volume Curve for Mt. Elliot

classic volume-speed curve in the 1965 Highway Capacity Manual which was superimposed over the same figure. The main differences between the two curves are that in the Detroit data the traffic stream maintains peak speed over a wider range of volumes, and higher peak speeds in Detroit data. This indicated that the data are similar to the general nationwide traffic behavior, but have some special characteristics (specifically driver behavior in Detroit seems to be more aggressive than "average" behavior).

This means that some of the default parameter values for INTRAS (which was calibrated to fit the general traffic behavior) need to be changed so the model can replicate the Detroit data. After coding the sub-network and loading it into the model, the model was run using the observed volume and vehicle mix data.

5.2 CHOOSING THE APPROPRIATE VARIABLES

The first step in calibrating INTRAS was to test the different calibration variables available and choose the appropriate values that will cause the model to simulate the Detroit data with acceptable accuracy. This was done by testing one variable at a time and comparing the effect of each variable on the performance of the model (i.e., the resulting average speed at each time point). Testing the variables was done by changing their embedded values in the model. This process was done externally (i.e., without the need to recompile the model every time a change is made), since INTRAS allows a change of the embedded values of the calibration variables, through special input cards.

Some of the calibration variables were not tested because they deal with the movement of vehicles on the surface links (which was not the main concern here).

The first variable to be tested was the acceptable lag in the target lane which determines if vehicles can change lanes. Different values were applied to that lag and tested. The embedded value for this variable is 3.1 seconds, and 8 new values were tested (using card type 35). These values were 2.5, 2.7, 2.9, 3.3, 3.5, 3.7, 3.9, and 4.1 seconds. A total of 126 computer runs were executed (i.e., 9 for each of the 14 time points), but the response of the model to the new values was not significant over the default value in simulating the observed speeds, so the default value was kept in the model.

Amount of time needed to complete a lane-change maneuver was the second variable to be tested. The embedded value for this variable is 3 seconds. Since the field data indicated an aggressive driver's behavior, the new values tested (using card type 49) were 2 seconds and 1 second. A total of 42 computer runs were executed (i.e., 3 for each time point), but the response of the model to the new values was not significant over the default value in simulating the observed speeds, so the default value was kept in the model.

"As each vehicle enters a link, it is assigned a free-flow speed. This is obtained by multiplying a percentage by the free-flow speed specified for that link. This percentage is obtained from a decile distribution." (Wicks and Andrews, 1980). This decile distribution was the third variable tested (using card type 40). The default assigned percentages (which should always add up to 1000) are:

I	1	2	3	4	5	6	7	8	9	10
% values	75	81	91	94	97	100	107	111	117	127

where I is the driver type index.

INTRAS defines 10 types of drivers on the road ranging from very aggressive driver (type 10) to timid driver (type 1). Since Detroit data are to the aggressive side, five percentage distributions that gave higher percentage values to the more aggressive driver types were tested. The following is an example of one of the distributions tested:

I	1	2	3	4	5	6	7	8	9	10
% values	74	77	86	90	92	103	110	116	122	130

A total of 70 computer runs were executed (i.e., 5 for each time point), but the response of the model to the new values was not significant over the default value in simulating the observed speeds, so the default value was kept in the model.

Card type 40 was also used to test the fourth calibration variable which is the percentage of mean speed by driver type I on freeway links. The default assigned percentages (which should always add up to 1000) are:

I	1	2	3	4	5	6	7	8	9	10
% values	82	91	94	97	99	101	103	106	109	118

As in the case of the last variable, five percentage distributions that gave higher percentage values to the more aggressive driver types were tested. The following is an example of one of the distributions tested:

I	1	2	3	4	5	6	7	8	9	10
% values	78	87	90	93	95	105	107	110	113	122

A total of 70 computer runs were executed (i.e., 5 for each time point), but the response of the model to the new values was not significant over the default value in simulating the observed speeds, so the default value was kept in the model.

The fifth and sixth variables tested variables (i.e., the sensitivity factors and the free-flow speed) were found to be the best variables to cause the model to simulate the Detroit data with acceptable accuracy, and they will be discussed in more detail in the next section.

5.3 THE CAR FOLLOWING MODEL

The main formula in the INTRAS model that was focused on during the calibration is the "car following model", (see section 3.6.1). This model calculates and defines the acceleration of the following car depending on the relative locations and speeds of the two cars (i.e., the leading car and the following car), and type of driver of each car.

This formula also contains an array of car-following parameters that relates to the "driver's sensitivity". The input values for this array can be changed externally by changing the values assigned to type of driver in card 43. The values that can be assigned to the parameters (i.e., sensitivity factor k in the equation in section 3.6.1) through this card range from 0 to 99. The smaller the value of the parameter, the more aggressive the drivers are assumed to be. The default values of the sensitivity factors (SF) are as follows:

I	1	2	3	4	5	6	7	8	9	10
SF	15	14	13	12	11	10	9	8	7	6

Ten sets with ten different values for the sensitivity factors were tested. The first set (S#1) had the default values shown earlier, the second set (S#2) had very low values (i.e., from SF= 9 for I= 1 down to SF= 0 for I= 10), which should reflect a very aggressive behavior, the third set (S#3) had values on the higher side (i.e., from SF= 30 for I= 1 down to SF= 21 for I= 10), and the rest of the sets had intermediate values between those two extremes. Table 11 shows the values that were used in each set.

As stated earlier, the lower the values of the parameters the more aggressive the drivers are assumed to be. So, six of the ten sets were built with values lower than the embedded values to cover all the possible values in the lower side. The remaining three sets were built with values higher than the embedded values to observe the performance of the model on that side (which was not expected to give good results for Detroit data).

The free-flow speed on the freeway links can have any value up to 99 mph, but the maximum speed on the ramp links is 67 mph. The value of the free-flow speed is assigned to each link via card type 02. Since the field data collected in Detroit indicated high speeds during the off-peak hours, the speed values that were tested on the different links of the network were on the high side.

Five different sets of free-flow speed values were tested:

	1	2	3	4	5
Freeway links:	65	70	75	75	80
Ramp links:	50	55	55	65	65
Surface links:	45	45	50	50	55

TABLE 11. SENSITIVITY FACTOR VALUES

Set #	I:	1	2	3	4	5	6	7	8	9	10
S#1		15	14	13	12	11	10	9	8	7	6
S#2		9	8	7	6	5	4	3	2	1	0
S#3		30	29	28	27	26	25	24	23	22	21
S#4		10	9	8	7	6	5	4	3	2	1
S#5		11	10	9	8	7	6	5	4	3	2
S#6		12	11	10	9	8	7	6	5	4	3
S#7		13	12	11	10	9	8	7	6	5	4
S#8		14	13	12	11	10	9	8	7	6	5
S#9		19	18	17	16	15	14	13	12	11	10
S#10		21	20	19	18	17	16	15	14	13	12

The procedure that was used to select the best combination of SF and free-flow values is described in the next section.

5.4 CALIBRATION PROCEDURE

5.4.1 The Computer Runs

50 runs were executed for each time point to cover all the possible combinations of ten sets of SF and five sets of free-flow speeds. Since there are 14 time point in the calibration data, A total of 700 computer runs were executed in the process of selecting the best combination of SF and free-flow speeds.

This was done by using the same sub-network for Mt. Elliot but the hourly volume and the vehicle mix were adjusted for each data point.

Paired comparisons were performed between the observed data and each of the fifty sets, and the combination that gave the smallest average difference was composed of S#5 and speed set 3.

Table 12 shows the results of 140 runs, or ten sets, with the average difference and the standard deviation at the bottom of each column. All the shown sets were executed with speed set 3, but each set has different SF values.

5.4.2 The Significance Level Test

The rest of the calibration procedure will be focused on the set that were found to have the most favorable effect on the results (i.e., S#5, and speed set 3). Figure 16 shows the model speeds of this set and the observed speeds.

TABLE 12. OBSERVED AND MODEL SPEEDS FOR MT. ELLIOT

T.P.	O.S.	S#1	S#2	S#3	S#4	S#5	S#6	S#7	S#8	S#9	S#10
1	37.84	45.7	46.0	40.1	45.8	43.3	44.8	44.3	45.6	45.7	42.6
2	39.39	40.4	35.3	34.7	38.8	43.5	40.0	41.7	40.9	38.6	37.5
3	48.01	41.6	45.5	36.0	47.0	48.0	46.5	45.3	45.2	40.8	37.0
4	63.57	50.1	51.7	40.3	49.3	55.6	56.2	54.0	53.5	36.1	42.3
5	65.54	53.0	50.9	35.3	51.7	54.2	57.0	53.8	53.8	48.5	36.7
6	63.75	52.9	52.7	32.2	53.2	55.7	55.2	54.2	56.7	51.9	35.2
7	64.06	53.8	49.8	33.5	50.8	58.4	57.6	56.4	56.2	47.8	34.2
8	64.05	52.9	53.7	48.7	53.8	60.9	60.5	54.3	59.3	46.3	49.5
9	66.79	57.7	57.0	53.9	55.9	65.0	62.3	59.6	58.0	54.8	54.3
10	64.38	57.0	55.1	49.9	55.3	61.0	60.2	56.7	56.1	54.6	52.5
11	66.70	52.9	54.7	48.5	56.6	59.3	60.9	54.5	55.0	53.2	50.8
12	66.20	56.2	55.2	50.1	55.5	62.8	59.7	58.7	60.2	53.8	51.5
13	63.65	55.3	53.6	37.5	51.9	63.4	62.0	59.9	58.3	52.9	40.5
14	47.36	46.3	46.8	44.6	47.3	51.3	48.9	48.8	48.3	45.7	45.9
Ave. D =		7.53	8.09	16.86	7.74	2.78	3.54	5.65	5.30	10.8	15.06
S.D. =		6.16	6.26	10.67	6.61	5.07	4.38	5.64	5.54	8.56	10.67

T.P.: Time Point, O.S.: Observed Speed,

Ave. D: Average Difference, S.D.: Standard Deviation

Since the sample size is small, the model output speeds were tested against the observed speeds using a paired comparison and a t-test. The pairs were in the form Di = Si - Ci, and the null hypotheses was:

$$Ho : \delta = 0$$

$$\text{and,} \quad H1 : \delta \neq 0$$

where: $\delta = E(Di) = E(Si\text{-}Ci)$.

The main assumption involved is that the paired differences Di's constitute a random sample from a normal population $N(\delta, \sigma)$. All the differences are shown in Table 13.

$$D = \Sigma\, Di/n \qquad \text{and} \qquad Sd = [\Sigma(Di\text{-}D)\ ]/(n\text{-}1)$$

Which gave the following results for this sub-network:

$$D = \pm\ 2.782 \text{ mph} \qquad \text{and} \qquad Sd = 5.072$$

A 95 % confidence interval (CI) for δ is given by the equation:

$$D \pm (t_{\alpha/2} * Sd)/\sqrt{n}$$

Which gives: <u>CI = (-0.13 , +5.69)</u>

Where: $t_{\alpha/2}$ is based on d.f.= 13. The t table gives $t_{\alpha/2} = 2.145$

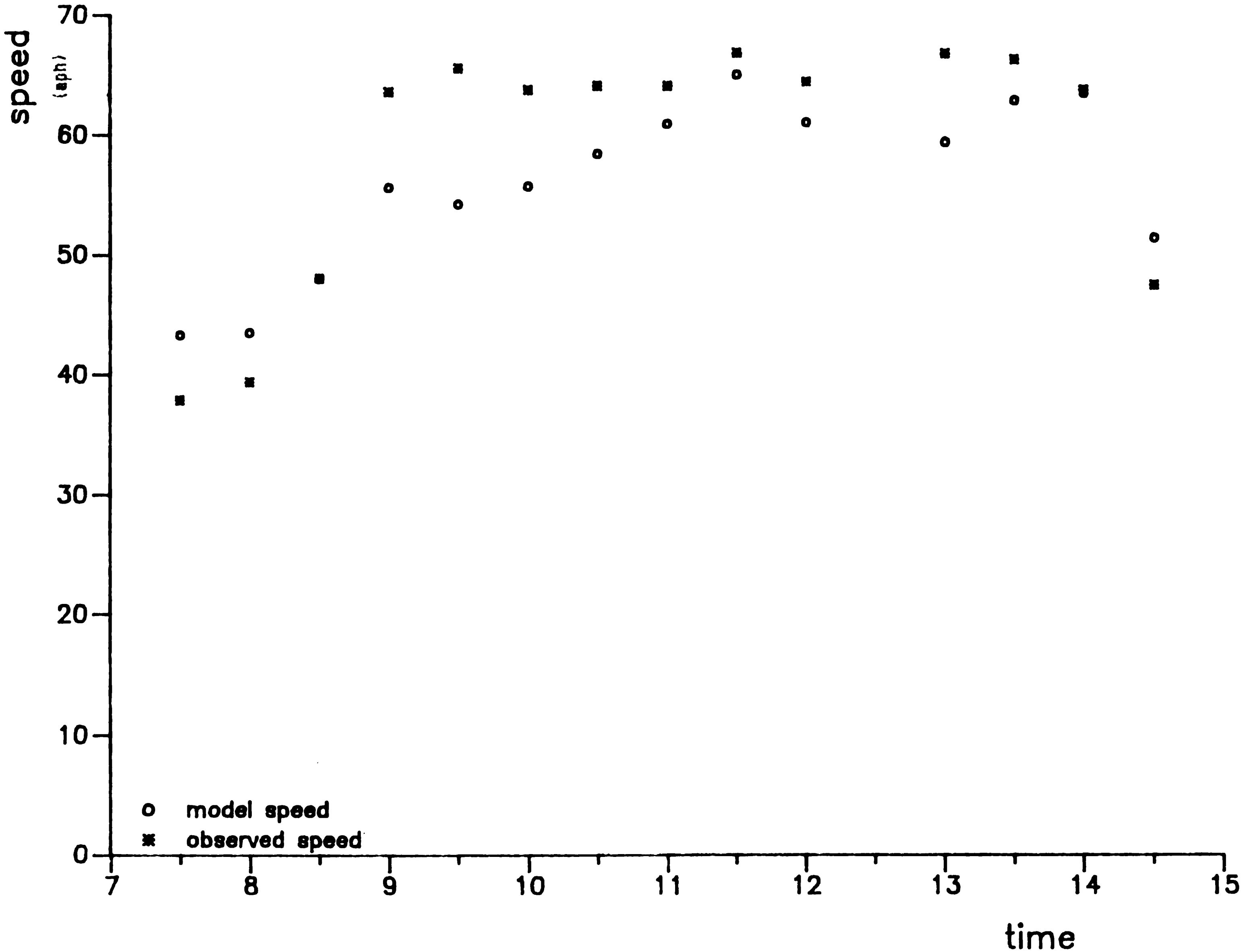


Figure 16. Observed and Model Speeds for Mt. Elliot

TABLE 13. PAIRED COMPARISON OF SELECTED PARAMETERS

TIME	**OBSERVED SPEED** Si - mph	MODEL SPEED(S#5) Ci - mph	DIFFERENCE Di = Si-Ci
7:30	37.84	43.3	-5.46
8:00	39.39	43.5	-4.11
8:30	48.01	48.0	0.01
9:30	63.57	55.6	7.97
9:30	65.54	54.2	11.34
10:00	63.75	55.7	8.05
10:30	64.06	58.4	5.66
11:00	64.05	60.9	3.15
11:30	66.79	65.0	1.79
12:00	64.38	61.0	3.38
1:00	66.70	59.3	7.40
1:30	66.20	62.8	3.40
2:00	63.65	63.4	0.25
2:30	47.36	51.3	-3.94

D = 2.782

Sd = 5.072

A test of Ho : $\delta = 0$ is based on the statistic test:

$$t = D / [Sd/\sqrt{n}] \qquad , \text{d.f.} = n-1$$

That gave: $t = 2.052$ which is smaller than $t_{\alpha/2} = 2.145$

The calibration was considered successful when the null hypotheses passed the t-test, this was when the calculated value of t became insignificant (i.e., smaller than the tabulated t value). And at least half of the individual points passed the CI test, as shown in Figure 17. Which means that the model, with the new parameter values, is ready to be used to replicate the traffic behavior in Detroit with an acceptable margin of error. The calibration process was most effective in a speed range of 48-68 mph.

A sample of the model outputs (i.e., the results of the simulated data at 7:30 a.m.) for the calibration sub-network at Mt. Elliot can be found in appendix B.

5.5 THE VALIDATION

The intent of validation is to run the model (in this case INTRAS) with different data than the data used for calibration, but without changing the final values of the calibrated parameters on card 43. The validation data can be from the same location (i.e., Mt. Elliot), or other locations on the Ford Freeway.

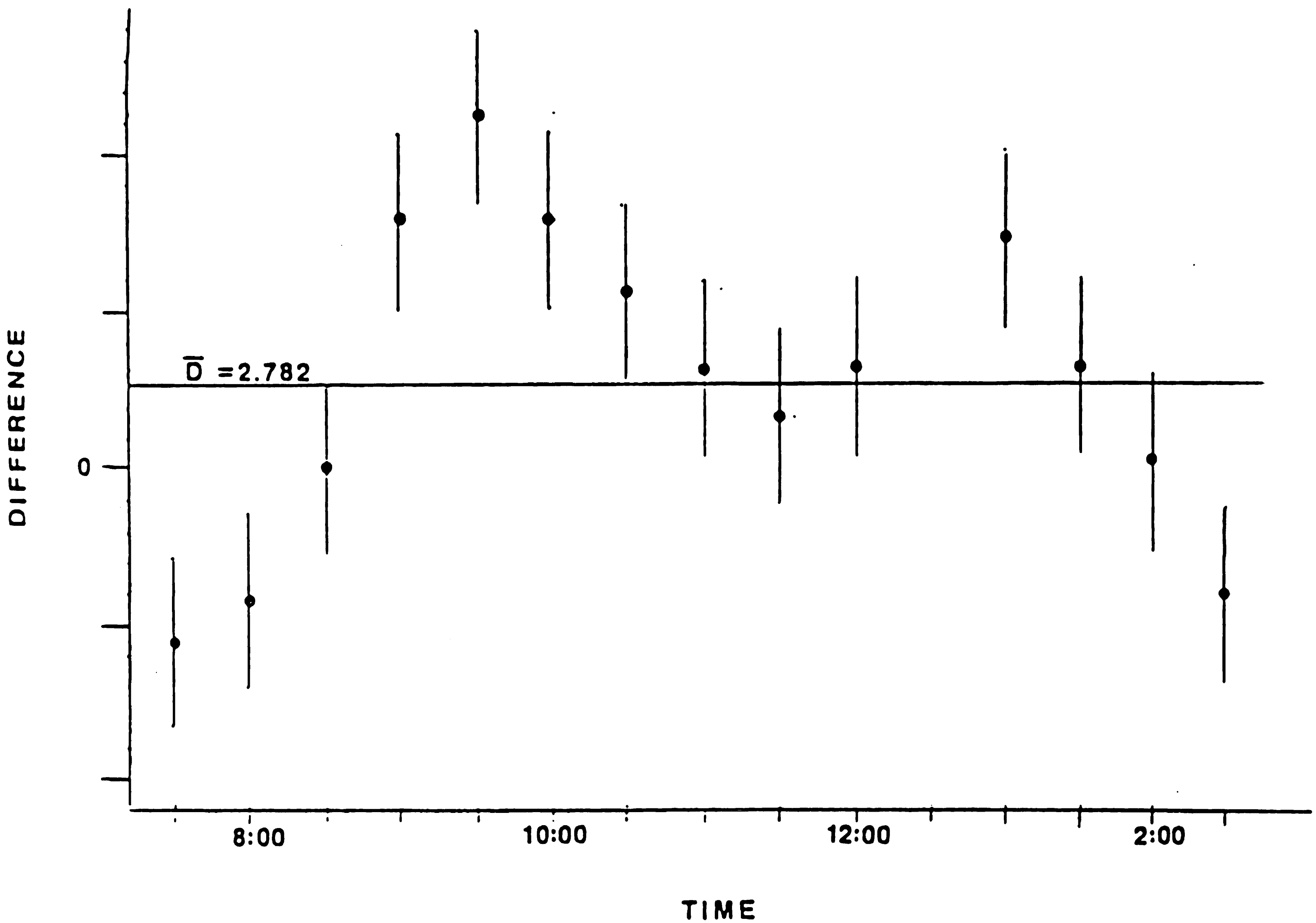


Figure 17. The Confidence Interval Test

The validation of the model consists of five parts as follows:

a. The same location (i.e., Mt. Elliot) but with different data from a different date (i.e., 9/18/86) with the ramp metering off;

b. The same location with different data from a different date (i.e., 9/17/86) with the ramp metering on;

c. A new location (i.e., Gratiot) on the east direction of the Ford Freeway, with ramp metering off;

d. A new location (i.e., Trumbull) on the west direction of the Ford Freeway, with ramp metering off; and

e. A new location (i.e., Van Dyke) on the west direction of the Ford Freeway, with ramp metering on.

Several data points for each of the five parts above were loaded to the model each as a sub-network. The model was run for each sub-network and the results of those runs are shown in Table 14.

The model output speeds in each of the five parts compared very well to the field as can be seen also in Table 14. In almost all cases the difference between the observed speed and the model speed passed the CI test.

The validation process gave good results when the speeds were in the range of 38-64 mph. Which is close to the calibration range.

TABLE 14. THE VALIDATION RESULTS

LOCATION	DATE	TIME	OBSERVED SPEEDS	MODEL SPEEDS	METERS
MT. ELLIOT	9/18/86	9:00	35.21	40.00	OFF
		10:00	58.91	61.90	OFF
		3:00	53.02	53.70	OFF
MT. ELLIOT	9/17/86	9:00	60.03	46.20	ON
		10:00	63.41	64.91	ON
		3:00	56.12	55.90	ON
GRATIOT	11/19/86	3:30	63.19	61.10	OFF
		4:00	62.77	60.20	OFF
		4:30	58.64	57.70	OFF
TRUMBULL	10/29/86	3:30	38.10	39.30	OFF
		4:30	38.38	39.70	OFF
VAN DYKE	9/17/86	8:30	59.05	62.4	ON
		9:30	60.54	64.8	ON

CHAPTER 6

APPLYING THE CONTROL STRATEGIES

Following the calibration and the validation of the model, the model is ready for simulating the whole network under study (i.e., the Ford Freeway inside Detroit city limits) in one run. Therefore, the whole network was coded in two files (i.e., each direction on a file) and made ready to run after solving some problems with the INTRAS user's manual. (see Appendix A for the coded network)

6.1 PROBLEMS WITH INTRAS USER'S MANUAL

The attempt to run the entire one direction network was not easy because some INTRAS features did not operate in the manner described in INTRAS User's Manual, Wicks and Andrews, (1980).

Three major problems in the user's manual were found during this research. First, the model, although it would accept a left-hand off-ramp, did not accept a left-hand on-ramp while the user's manual stated that "auxiliary lanes may occur on either the left or right hand side of the roadway." (Wicks and Andrews, 1980). The on-ramp from southbound Lodge Freeway on to the Ford Freeway is the only left-hand on-ramp and it had to be coded as a right-hand on-ramp to be accepted by the model.

Second, the user's manual gives specification to where the early warning, for exiting vehicles, should be located. "It (means the warning sign) must be positioned downstream of the previous off-ramp and upstream of the freeway link connecting directly to the specific off-ramp." (Wicks and Andrews, 1980). This was found not always accurate, at least not a must, in the sense that the model gave better results when some of the early warning signs where located upstream of the previous off-ramp.

Third, the user's manual has a section titled Size Modification Procedures, this is to help the user change the capacities of model variables in case this is needed. In this project, there was a need to increase the maximum number of nodes, and the steps that were given in the user's manual for making that change was followed (i.e., changing the value of NTOTN in BLOCK DATA INTVAR, and changing the sizes of SIGI array in COMMON /A3/, SIG array in COMMON /A6/, and SNODE array in COMMON /A7/) but the model did not respond accurately. After checking the variable and array lists in the model four more arrays that needed to be changed, were found. Three of those arrays (IORG, IRV, and IREN) are located in COMMON /ONVEH/, and the fourth array (NACT) is located in COMMON /ACT10/.

6.2 EVALUATING THE PRESENT CONTROL STRATEGY

The control method used to run INTRAS is called "Clock Time Metering". To simulate clock-time control of on-ramps, one fixed metering rate (vehicles per minute) is specified at each node. A count down clock is assigned to each associated on-ramp and the signal is set to "green" until a vehicle is discharged, and is then set to "red" (Wicks and Andrews, 1980). The evaluation procedure was conducted on the East Bound Ford Freeway for one peak hour as follows:

6.2.1 The Basic Run

The first run of the network was done with the ramp metering off. It was considered the basis of comparing the do-nothing strategy (ST#1) with the present control strategy and the suggested control strategies. This was done to define the benefits of the ramp metering strategy in terms of the MOEs of concern [i.e., average speed on the freeway, average speed of the whole system (including ramps and surface links), total delay, delay on the ramps and surface links, total vehicle-time, total vehicle-miles, and moving/total time].

6.2.2 Applying the Present Control Strategy

The second run was designed to test the operating plan currently used in this corridor (ST#2). The present metering rate is 15 vehicles per minute (i.e., 1 veh./4 sec). This rate was simulated on each ramp on the east direction of the freeway and the model was run for that direction.

6.2.3 Discussion of Results

The results for the peak hour for both runs are presented in Table 15, where the significant benefits of the control strategy ST#2 can be clearly noticed. The increase of the average speed of the corridor is 8 % , the reduction in total delay is over 17 %, and about

TABLE 15. COMPARING MEASURES OF EFFECTIVENESS FOR ONE PEAK HOUR (NO-METERING VS. PRESENT STRATEGY, ALL NETWORK)

M.O.E.	NO-METERING ST#1	PRESENT METERING STRATEGY- ST#2	Difference	%
Vehicle-miles	73938.41	73852.29	- 86.12	-0.1
Vehicle-minutes	105051.02	97168.53	-7882.49	-7.5
Moving/Total trip time	0.577	0.622	+0.045	+7.8
Travel Time(min)/ Veh-mile	1.42	1.32	-0.10	-7.0
Speed mph	42.23	45.60	+3.37	+8.0
Total Delay (Veh-min)	44399.56	36717.66	-7681.90	-17.3
Delay Time(min)/ veh-mile	0.60	0.50	- 0.10	-16.7

7,900 vehicle-minutes were saved in one hour. This demonstrated clearly the effect of ramp metering in increasing the efficiency of flow on the freeway.

6.3 TESTING NEW STRATEGIES AT LOCAL ON RAMPS

After determining the benefits of the present strategy, other metering strategies were tested to determine the metering rate that will maximize the benefits (i.e., increase the speeds and reduce delays).

6.3.1 Applying the Strategies

The first step was to apply uniform metering rates to all the local on-ramps. The rates that were tested were: 5, 6, 7, and 8 second headway on all ramps.

The first new strategy **ST#3** (5 sec. headway) showed a minimal change in results from the present strategy on the freeway (i.e., **ST#2**) on the freeway and the freeway corridor overall, but the average speed on the ramps and surface links dropped . The second new strategy **ST#4** (6 sec. headway) showed better results on both the freeway and the freeway corridor. The third new strategy **ST#5** (7 sec. headway) showed further improvement of speeds on the freeway but the average speed on the freeway corridor was reduced as a result of the long queues on some of the heavy volume ramps. The fourth new strategy **ST#6** (8 sec. headway) crashed in the computer because the length of some of the ramp queues exceeded the length of those ramps and the simulation was aborted. The results of all runs are shown in Table 16, 17, and 18.

TABLE 16. COMPARING MOEs OF DIFFERENT METERING STRATEGIES AT LOCAL ON-RAMPS ONLY (ALL NETWORK)

Strategy #	Veh-Minute min	Total Delay min	Change in Delay	Speed mph	Change in Speed
ST#1					
No-Metering	105051	44399	0.0%	42.23	0.0%
ST#2					
4 sec. headway	97168	36717	-17.3%	45.60	8.0%
ST#3					
5 sec. headway	97206	37303	-16.0%	45.19	7.0%
ST#4					
6 sec. headway	93524	32921	-25.9%	47.62	12.8%
ST#5					
7 sec. headway	99795	39447	-11.2%	44.99	6.5%
ST#6 8 sec. headway		crashed			
ST#7					
6 sec. on ramps w/volume >400 vph	91958	31782	-28.4%	47.98	13.6%

TABLE 17. COMPARING MOEs OF DIFFERENT METERING STRATEGIES AT LOCAL ON-RAMPS ONLY (FREEWAY ONLY)

Strategy #	Veh-Minute min	Volume veh/ln/hr	Density veh/ln-mile	Speed mph	Change in speed
ST#1					
No-Metering	101410.86	1571	37.2	42.20	0.0%
ST#2					
4 sec. headway	93466.49	1569	34.3	45.70	8.3%
ST#3					
5 sec. headway	92750.24	1555	34.0	45.70	8.3%
ST#4					
6 sec. headway	88798.58	1578	32.6	48.40	14.7%
ST#5					
7 sec. headway	85702.91	1579	31.5	50.20	18.9%
ST#6 8 sec. headway		crashed			
ST#7					
6 sec. on ramps w/volume > 400 vph	87214.52	1562	32.0	48.80	15.6%

TABLE 18. COMPARING MOEs OF DIFFERENT METERING STRATEGIES AT LOCAL ON-RAMPS ONLY (RAMP AND SURFACE LINKS)

Strategy #	Veh-Minute min	Moving/Total Time	Speed mph	Change in Speed
ST#1				
No-Metering	3648.05	0.82	43.00	0.0%
ST#2				
4 sec. headway	3702.04	0.80	42.10	-2.0%
ST#3				
5 sec. headway	4455.93	0.66	34.90	-18.8%
ST#4				
6 sec. headway	4726.18	0.62	32.90	-23.5%
ST#5				
7 sec. headway	14086.00	0.25	13.30	-69.0%
ST#7				
6 sec. on ramps w/volume > 400 vph	4743.78	0.62	32.80	-23.7%

To fine tune the model results, modifications were next made to the best defined strategy (i.e., **ST#4**). By observing the speed on each link separately and the change of speed between successive links, in the next run **ST#7** the ramps that have less demand than 400 hourly volume (i.e., 6 on-ramps on the west direction) were not metered because the change in speed between the links before and the links after the those ramps was not significant with ramp metering than without ramp metering.

The model was run and the metering rate for the 9 metered ramps was set to 6 seconds. The results of **ST#7** showed further improvement on both the freeway and the freeway corridor as also shown in Table 16. Figure 18 shows curves of change in average speed among the different strategies on three levels: the freeway corridor, the freeway only, and the ramp and surface links only.

6.3.2 Discussion of Results

Both Table 16 and Figure 18 show the last strategy **ST#7** as the best strategy to be used in case of the Ford Freeway in Detroit. The results indicate that this strategy will maximize the benefits of the system for the strategies tested.

For example the increase of the average speed over **ST#1** is about 14 %, the reduction in total delay is over 28 %, and the anticipated saving in time is about 13,000 vehicle-minutes per peak hour. Also shown in Figure 18 the change in speed for both the freeway alone and the ramp-surface nodes alone.

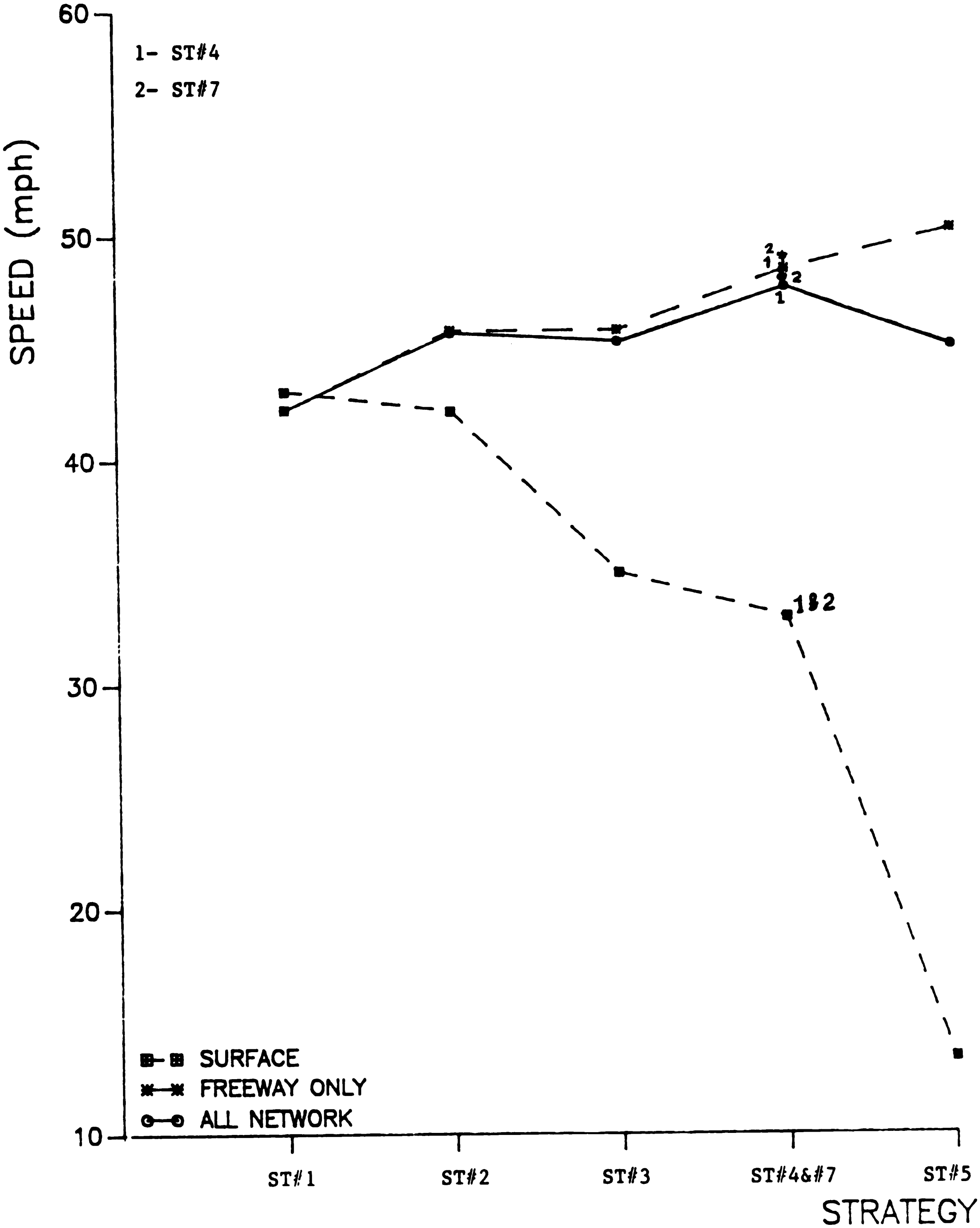


Figure 18. Comparing Average Speeds of Different Metering Strategies at Local On-Ramps Only

The constant improvement in speed on the freeway alone when the headway gets longer is clear, and also the sharp decrease in the speed of the ramp-surface roads. For example, the speed on the freeway increased from 48.4 mph (77.44 km/h) in **ST#4** to 50.2 mph (80.32 km/h) in **ST#5**. But at the same time the speed on the ramp-surface roads decreased from 32.9 mph (52.64 km/h) in **ST#4** to 13.3 mph (21.28 km/h) in **ST#5**, and that caused the decrease in the average speed of the whole corridor when the headway changed from 6 seconds to 7 seconds.

6.4 TESTING NEW STRATEGIES AT LOCAL AND FREEWAY ON-RAMPS

The next step after defining the best metering strategy to be applied at the local (non-freeway) on-ramps was to define the benefits of metering the on-ramp part of the freeway-to-freeway interchanges that connect the Ford Freeway with three freeways (i.e., the Jeffries, the Lodge, and the Chrysler) in the city of Detroit.

While testing the control strategies at freeway on-ramps, the metering rates of local on-ramps were kept the same as the rates that gave the best benefits in case of metering local on-ramps only (i.e., in **ST#7**).

6.4.1 Applying the Strategies w/ Existing Geometry

Three new runs were made with three different metering rates applied to the freeway on-ramps. The rates were 6 (**ST#8**), 5 (**ST#9**), and 4 second headway (**ST#10**) respectively. The first two runs **ST#8** and **ST#9** were crashed in the computer because the length of the queues on some of the freeway on-ramps were longer than the link length and the simulation was aborted. The results of the third run (i.e., **ST#10**) are presented on Tables 19, 20, and 21.

The critical ramp that caused the first two runs to crash is the on-ramp from the North Bound Lodge Freeway because of both the high traffic volume and the short storage space. To solve this problem without changing the existing geometry the model was run with all the controlled on-ramps with 6 second headway except North Bound Lodge on-ramp with 4 second headway **(ST#11)**.

This was done to allow more vehicles to enter the freeway and reduce the storage space needed. The results of this strategy **ST#11** are also presented in Tables 19, 20, and 21.

6.4.2 Applying the Strategies w/ Modified Geometry

The results of **ST#11** did not reflect any improvement over the results of **ST#10**, so the next step was to keep the same rates as in **ST#10** and modify the geometry of the North Bound Lodge on-ramp. This was done by increasing the length of the surface link before the metering signal on that ramp to accommodate more vehicles.

This modification represents in the real world either increasing the length of that interchange leg or adding a second lane to the interchange leg. The results of this strategy are also presented in Tables 19, 20, and 21.

TABLE 19. Comparing MOEs of Freeway-to-Freeway Control Strategies (All Network)

Strategy #	Veh-Minute	Total Delay min	Change in Delay	Speed mph	Change in Speed
ST#1					
No-Metering	105051	44399	0.0%	42.23	0.0%
ST#7					
6 sec. on ramps w/volume >400 vph	91958	31782	-28.4%	47.98	13.6%
ST#8, and ST#9		crashed			
ST#10					
ST#7+4 sec. on all freeway ramps.	94130	33301	-25.0%	47.40	12.2%
ST#11					
St#7+6 sec. on all freeway ramps except N.B. Lodge w/ 4 sec.	98641	38902	-12.4%	44.48	5.3%
ST#12					
St#10+Extra storage on N.B. Lodge.	90163	29426	-33.7%	49.37	16.9%

TABLE 20. Comparing MOEs of Freeway-to-Freeway Control Strategies (Freeway Only)

Strategy #	Veh-Minute	Volume veh/ln/hr	Density veh/ln-mile	Speed mph	Change in Speed
ST#1					
No-Metering	101410	1571	37.2	42.20	0.0%
ST#7					
6 sec. on ramps w/volume >400 vph	87214	1562	32.0	48.80	15.6%
ST#8, and ST#9		crashed			
ST#10					
ST#7+4 sec. on all freeway ramps.	87653	1581	32.2	49.10	16.3%
ST#11					
ST#7+6 sec. on all freeway ramps except N.B. Lodge w/ 4 sec.	89976	1554	33.0	47.10	11.6%
ST#12					
ST#10+Extra storage on N.B. Lodge.	83525	1575	30.7	51.40	21.8%

TABLE 21. Comparing MOEs of Freeway-to-Freeway Control Strategies (Ramp and Surface Links)

Strategy	Veh-Minute min	Moving/Total Time	Speed mph	Changes in Speed
ST#1				
No-Metering	3648.05	0.82	43.00	0.0%
ST#7				
6 sec. on ramps w/volume >400 vph	4743.78	0.62	32.80	-23.7%
ST#8, and **ST#9**				
ST#10				
ST#7+4 sec. on all freeway ramps.	6476.82	0.46	23.90	-44.4%
ST#11				
ST#7+6 sec. on all freeway ramps except N.B. Lodge w/ 4 sec.	8665.41	0.34	17.60	-59.1%
ST#12				
ST#10+Extra storage on N.B. Lodge.	6638.37	0.46	24.10	-43.9%

6.4.3 Discussion of Results

Figure 19 shows curves of change in average speed among the different metering strategies on three levels: the freeway corridor (all network), the freeway only, and the ramp and surface links only. Tables 15, 16, and 17, and Figure 19 all show that the best strategy that should be implemented is the last one, **ST#12**. This is because the simulated MOEs for this strategy indicates that it will give the best results on the freeway and on the freeway corridor as one network in terms of increasing the average speed and reducing the vehicle-minutes spent in the system. The negative points about this strategy are the longer waiting time on the surface streets, and the need to modify the number of lanes on the North Bound Lodge Freeway on-ramp that enter the East Bound Ford Freeway.

The longer waiting time is anticipated because of the high volumes traveling between the freeways that will affect this factor, but the overall benefits of **ST#12** more than compensate for that. There is also the possibility that traffic will change routes to avoid the long queues which will reduce considerably the waiting time at the ramps. This last possibility can not be tested with the model because it is unpredictable, but it can be observed in the field. For example, recently when the N.B. Lodge Freeway in Detroit was closed for repavement the expectations were that there will be a huge increase in delay on all the alternative routes. But the observed case was much different than that and no noticeable increase in delay were reported.

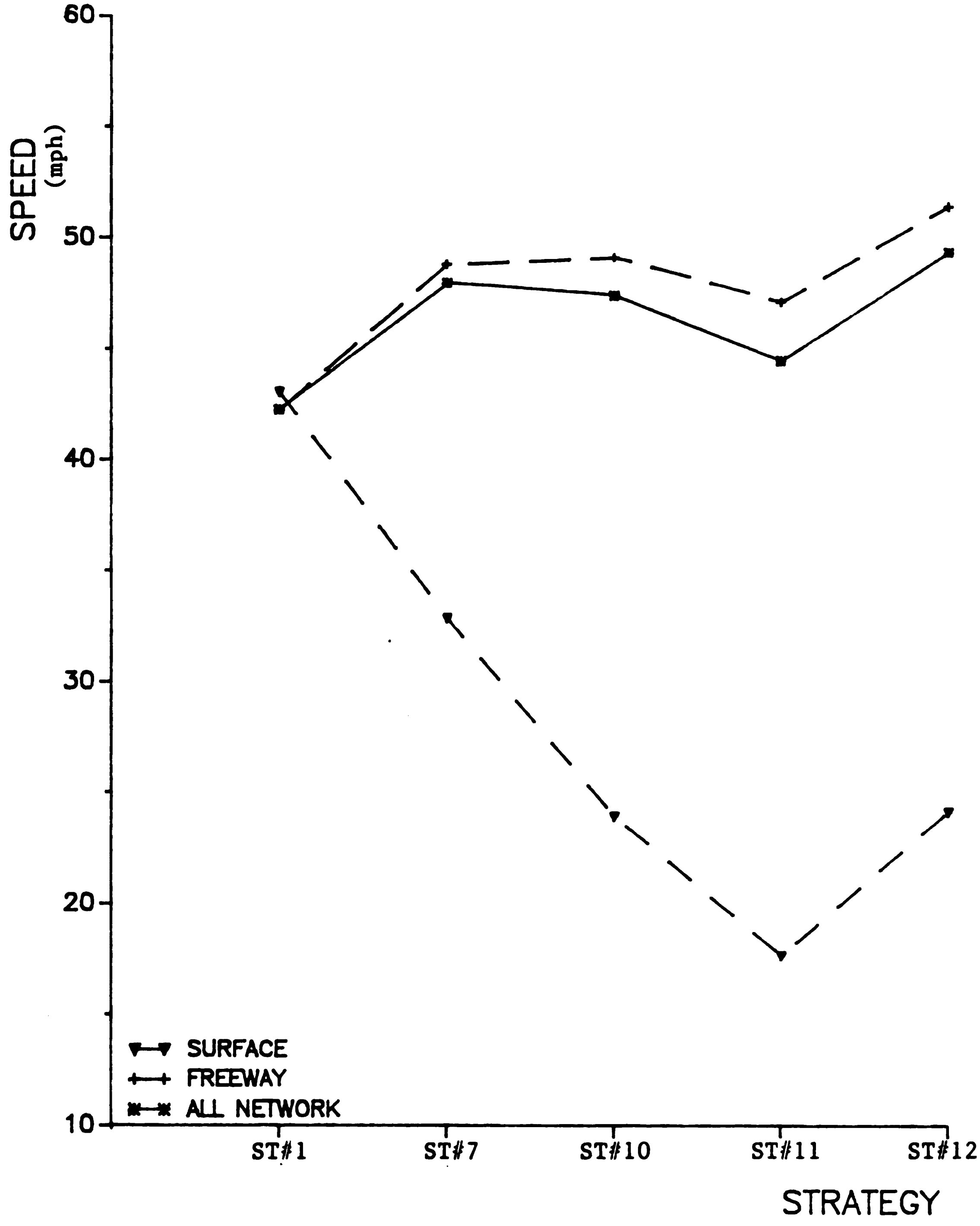


Figure 19. Comparing Average Speeds of Different Metering Strategies at Local and Freeway Interchanges On-Ramps

The results of the simulation runs show a 9.2 mph, or 22%, increase in the average speed on the main freeway from 42.2 mph without ramp-metering ST#1 to 51.4 mph when applying ST#12. The reduction in vehicle-minute on the freeway (by applying ST#12) was 17886 vehicle-minutes (about 300 vehicle-hour), or a 17% reduction of the vehicle-minute in ST#1. The average speed on the freeway corridor also increased by 7.14 mph, or 17%, from 42.23 mph in ST#1 to 49.37 mph in ST#12. The average speed on the surface roads dropped from 43 mph to 24 mph, but that reflected an increase of only 2990 vehicle-minute (about 50 vehicle-hour) on the surface roads. Which means that the final results reflect an overall 14888 vehicle-minute (about 250 vehicle-hour) reduction in time spent in the system.

The feasibility issue of modifying the lineage on some of the freeway on-ramps depends on the specific design of each on-ramp and the possibility of increasing the length of that ramp, or adding another storage lane before the metering signal. In the this study, since the focus was on the data from one afternoon peak hour on the East Bound Ford Freeway, there was a need to modify the geometry of the North Bound Lodge Freeway on-ramp because of the large volumes on that ramp. The modification was done by adding a second lane on the surface road behind the ramp metering signal to accommodate more vehicles which are waiting to enter the freeway. The existing geometry of this ramp indicates that it is possible to add another storage lane. As a matter of fact a second lane already exists on almost the entire length of that ramp but it is marked with yellow stripes to keep vehicles out of that space. This lane can be easily used without the need of any change in the geometry, just by removing the yellow stripes. So it is feasible to implement this strategy for the East Bound Ford Freeway afternoon peak-hours without any need for geometry modifications.

This might not be the case for other situations like the traffic on the West Bound Ford Freeway, or the morning peak-hours, or a different freeway in Detroit. For each case, different procedure or different type of modifications might be needed.

CHAPTER 7

SUMMARY, AND CONCLUSIONS

7.1 SUMMARY

1. The benefits of the ramp metering strategy currently used in Detroit (i.e., 4 second headway, **ST#2**) are significant. More than 7,850 vehicle-minutes per peak hour are being saved, about an 8 % increase in the average speed in the corridor is noticed, and the ratio of moving time to total trip time has been increased by about 8 % (from 0.58 in **ST#1** to 0.62 in **ST#2**).
2. The best metering strategy for the local on-ramps only (i.e., 6 second headway only on the ramps with peak hour volume over 400 vehicles, **ST#7**) is expected to significantly increase the benefits of the control system. Savings of more than 13,000 vehicle-minutes per peak hour are anticipated, an increase in the average speed of about 14 % is also expected, and the ratio of moving time to total trip time is expected to reach 0.65
3. The optimal control strategy that was found to maximize the benefits of the ramp metering system (i.e., **ST#12**) did include the following elements:

a. No-metering on the local on-ramps that have an hourly volume less than 400 vehicles.

b. 6 second metering headway (i.e., 10 vehicles per minute) was applied to the remaining local on-ramps.

c. 4 second metering headway (i.e., 15 vehicle per minute) was applied to the on-ramp leg of the freeway-to-freeway interchanges.

d. An additional storage lane was added to the on-ramp connecting the North Bound Lodge Freeway to the East Bound Ford Freeway.

4. The results of the optimal control strategy ST#12 show a 9.2 mph, or 22%, increase in the average speed on the main freeway from 42.2 mph without ramp-metering **ST#1** to 51.4 mph when applying **ST#12**. The reduction in vehicle-minute on the freeway was 17886 vehicle-minute (about 300 vehicle-hour), or 17%. The average speed on the freeway corridor also increased by 7.14 mph, or 17%, from 42.23 mph to 49.37 mph. The average speed on the surface roads dropped from 43 mph to 24 mph, but that reflected an increase of only 2990 vehicle-minute (about 50 vehicle-hour) on the surface roads. Which means that the final results reflect an overall 14888 vehicle-minute (about 250 vehicle-hour) reduction in time spent in the system.

7.2 CONCLUSIONS

1. INTRAS simulation model can be used effectively in simulating both present urban freeway operations and any new strategies to be implemented on those freeways, but the INTRAS User's Manual needs improvement.
2. INTRAS simulation model was calibrated and validated successfully for the City of Detroit. On the other hand, the current INTRAS model is unstructured, which makes it very difficult to change the internal logic during calibration, and one should be careful when doing that.
3. INTRAS simulation model is most sensitive to changes in driver sensitivity, or driver type, It is also sensitive to changes in both the control strategies and the traffic characteristics (i.e., volume, vehicle mix, volume/capacity ratio, and desired speed).
4. INTRAS is relatively expensive to operate as are most of the mainframe simulation models. However, it is the only feasible technique that can be used to test the new strategies from both economical and practical points of view.
5. Metering the freeway-to-freeway interchanges can be very effective in increasing the benefits of a ramp metering system, especially when there are more than one interchange in a limited space like the case in the City of Detroit.

APPENDICES

APPENDIX A

NETWORK DATA AND LINK-NODE DIAGRAM

A.1 LINK-NODE DIAGRAM

This diagram (i.e., Figure 20) shows the total network coded for the Ford Freeway (both eastbound and westbound included). Only the eastbound direction (i.e, the lower part in Figure 20) was used in this project to test the control strategies on its whole length, which is about 15 miles.

Some parts of the westbound direction were used during the calibration and validation process (i.e., the parts around the sampled locations on the westbound direction, like Mt Elliot, Van Dyke, John R., and Trumbull) along with the sampled locations on the eastbound (i.e., Linwood, and Gratiot).

A.2 NETWORK DATA

Eleven INTRAS card types were used to code and run the eastbound direction data. Those cards were:

Run Control Card -	Type 99
Simulation Title Card -	Type 00
Network Name Card -	Type 01
Link Geometry cards -	Type 02
Freeway Link Operation Cards -	Type 04
Ramp Link Operation Cards -	Type 05
Surface Link Operation Cards -	Type 06
Link Turning Movement Cards -	Type 08
Sign and Signal Control Cards -	Type 10
Volume Cards -	Type 20
Simulation Control Card -	type 60

The cards which include the data that were used to run the network with no-metering are listed later in this appendix.

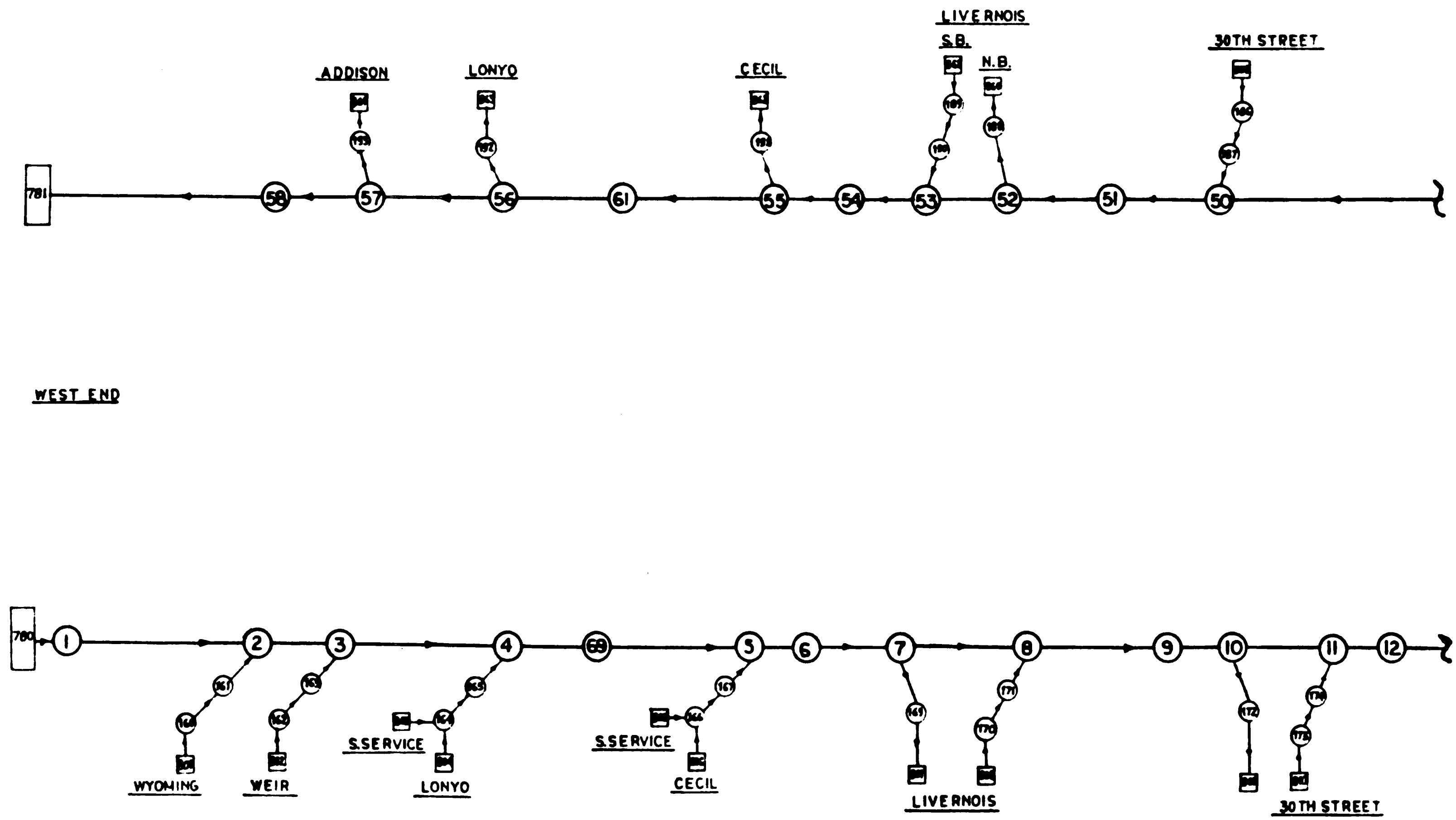


Figure 20. The Network Link-Node Diagram

Figure 20. Continue

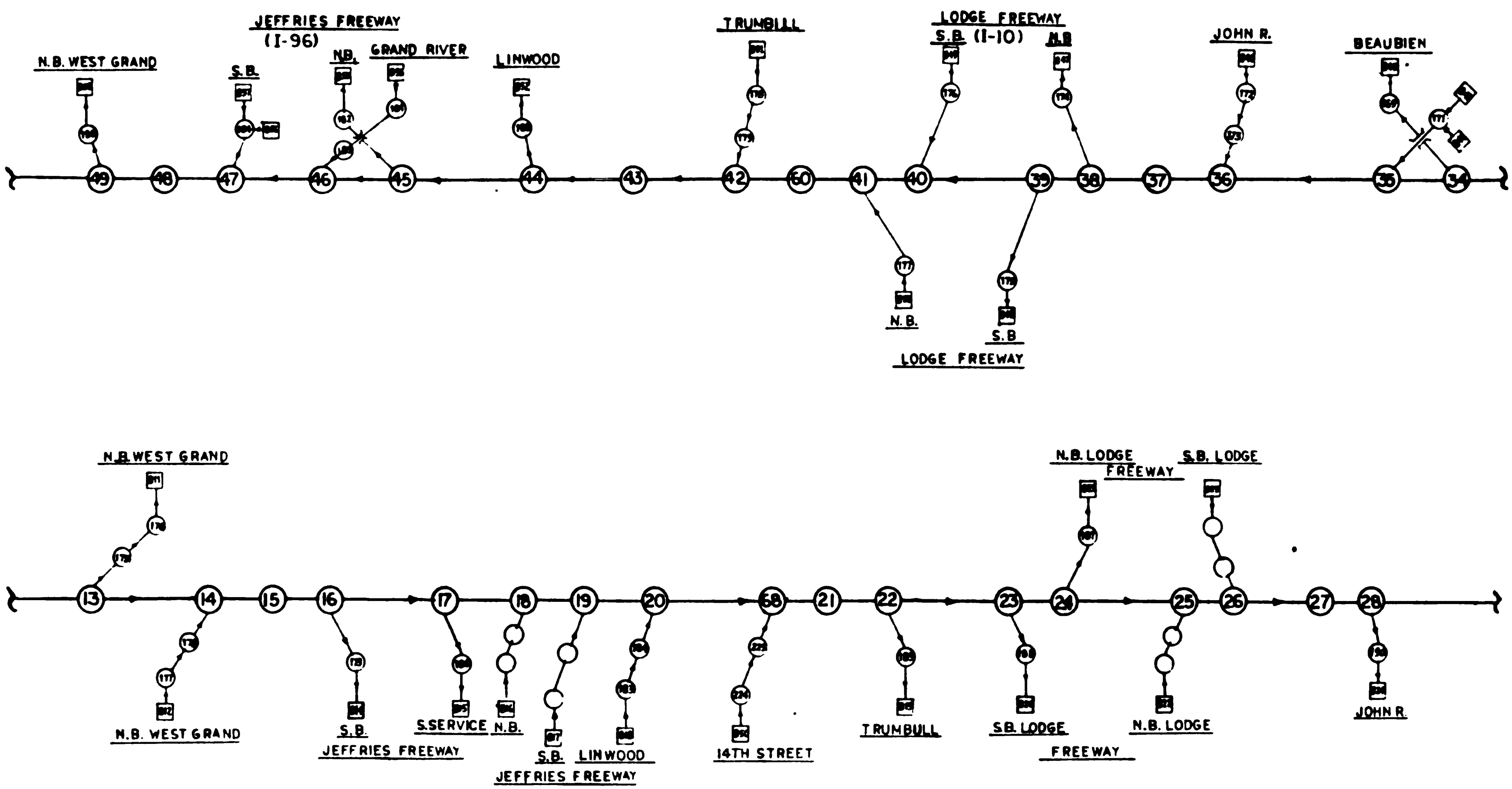
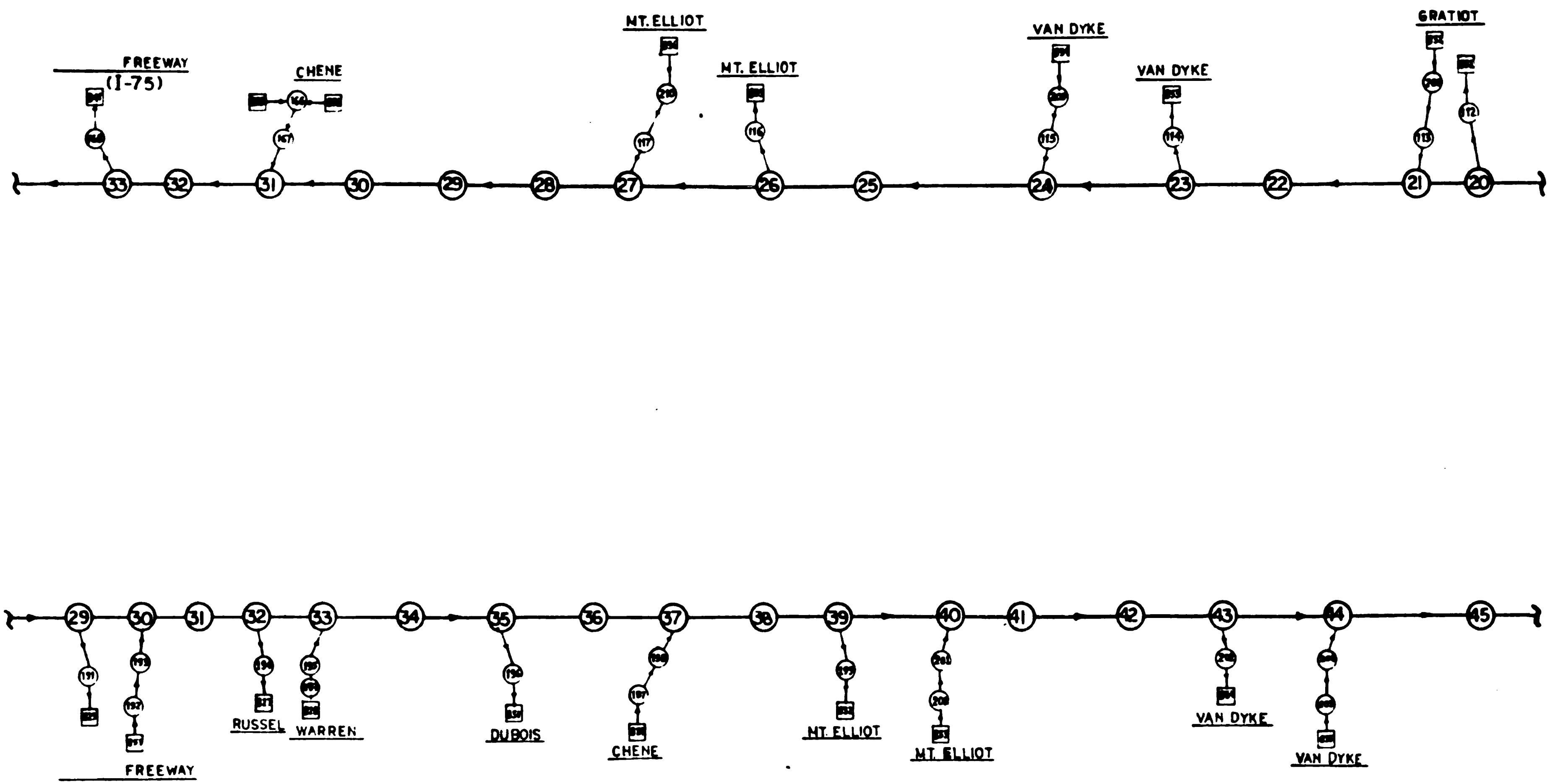


Figure 20. Continue



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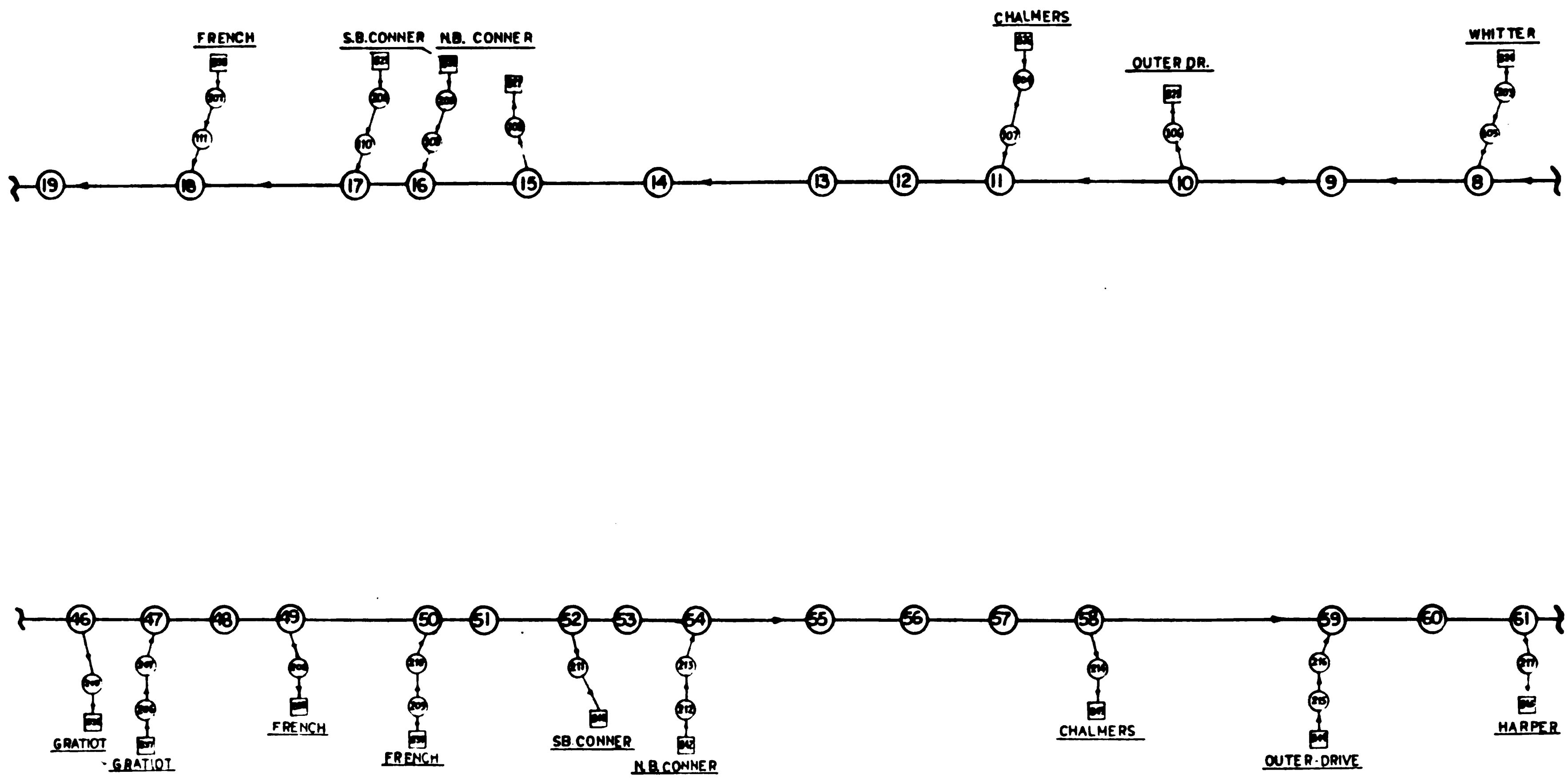
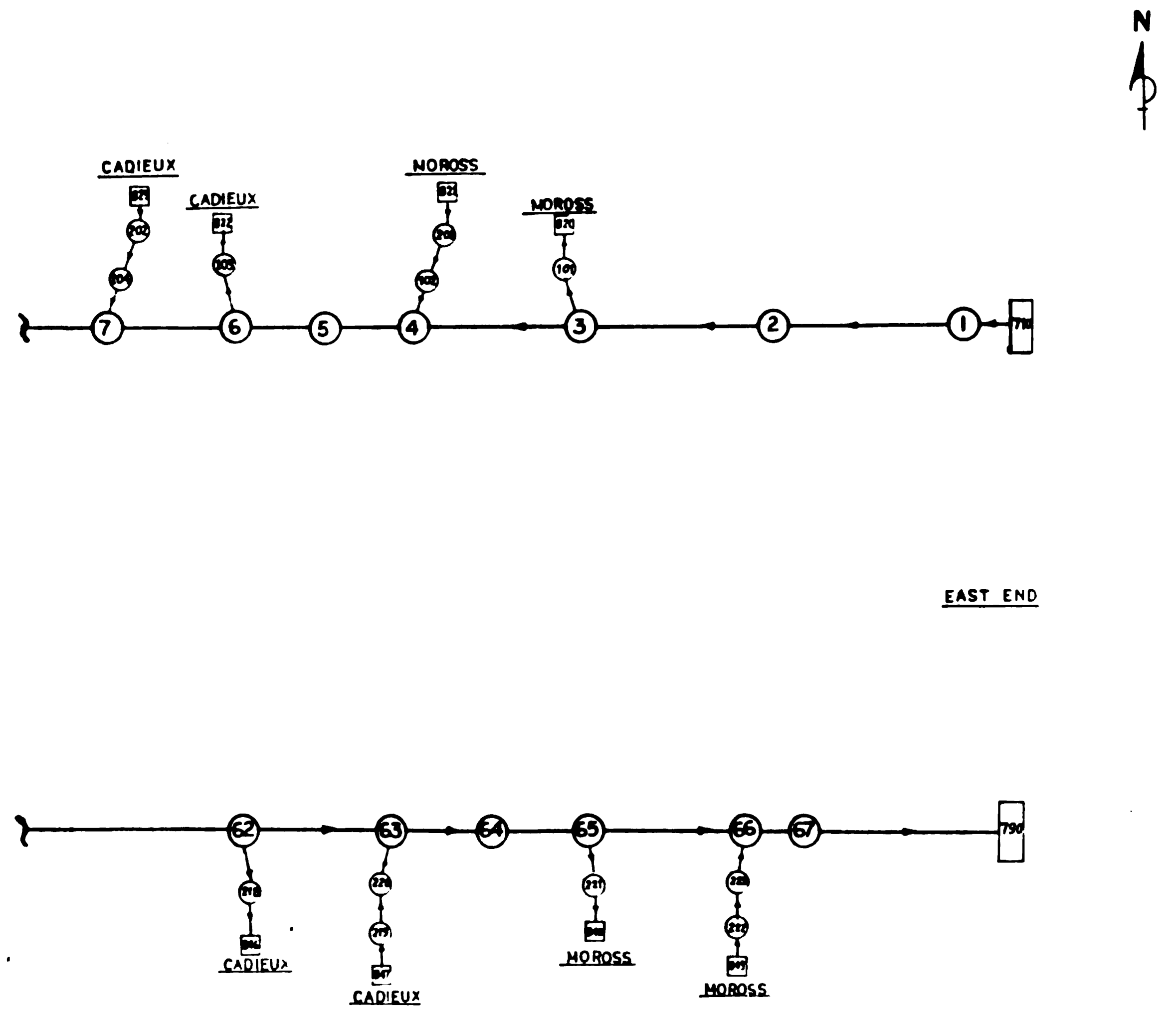
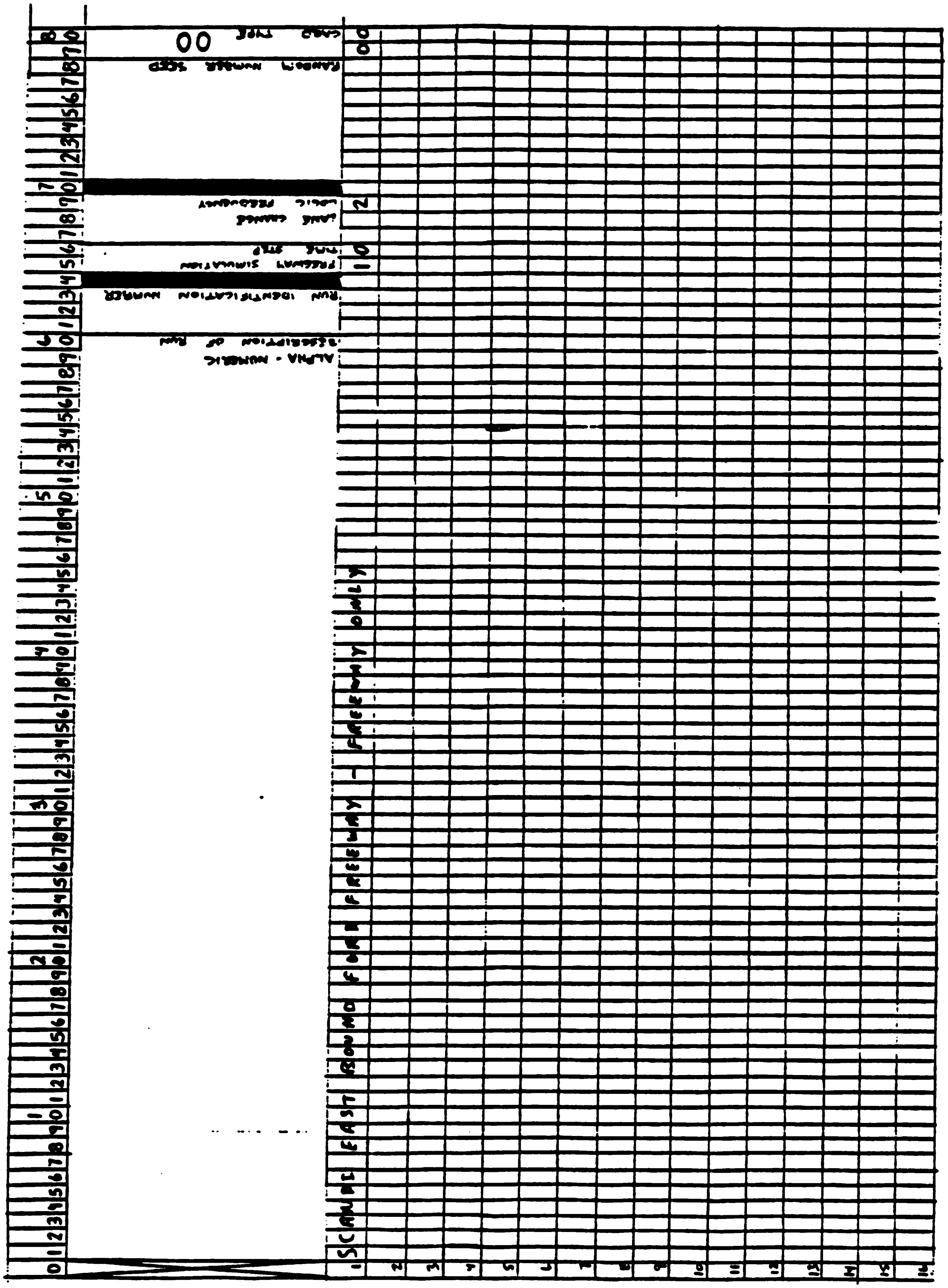


Figure 20. Continue



A.2 Network Data



Card type 01

Field	Card columns	Entry
Alpha-numeric description of data	1–60	WYOMING THROUGH MOROSS (780-790)-RAMP METERS OFF
Maximum length of initialization period	63–66	1200
Fill time flag	68	0
Simulation flag	69	0
Statistics flag	72	
Simulation starting time: hours	73–74	15
Simulation starting time: minutes	75–76	00
Simulation starting time: seconds	77–78	00
Card type	79–80	01

	Upstream Node	Downstream Node	Link Length	Link Type	Mean Free-Flow Speed	Number of Through Lanes	Grade	Node Receiving Left-Turn Traffic from Link	Node Receiving Through Traffic from Link	Node Receiving Right-Turn Traffic from Link	Exit Reaction Distance	Exit Node	Same as Columns 1-33 for Another Link	Card Type
1	780	1		3	75	3			2					02
2	1	2	2800	3	75	3			3					02
3	2	3	740	3	75	3			4					02
4	3	4	2590	3	75	3			69		64	7		02
5	4	69	1000	3	75	3	-1		5					02
6	69	5	2100	3	75	3			6					02
7	5	6	240	3	75	3			7					02
8	6	7	1000	3	75	3	+1		8	169	89	10		02
9	7	8	1500	3	75	3	-1		9					02
10	8	9	1850	3	75	3			10		78	13		02
11	9	10	500	3	75	3			11	172				02
12	10	11	1075	3	75	3			12					02
13	11	12	355	3	75	3			13					02
14	12	13	300	3	75	3		175	14		30	16		02
15	13	14	1500	3	75	3			15					02
16	14	15	530	3	75	3			16					02

	Upstream Node	Downstream Node	Link Length	Link Type	Mean Free-Flow Speed	Number of Through Lanes	Grade	Node Receiving Left-Turn Traffic from Link	Node Receiving Through Traffic from Link	Node Receiving Right-Turn Traffic from Link	Exit Reaction Distance	Exit Node	Same as Columns 1-33 for Another Link	Card Type
1	15	16	400	3	75	3			17	179				02
2	16	17	1520	3	75	3			18	180	1	17		02
3	17	18	725	3	75	3			19					02
4	18	19	670	3	75	7			20					02
5	19	20	850	3	75	3			68		53	22		02
6	20	68	1500	3	75	3	+2		21					02
7	68	21	300	3	75	3	-2		22					02
8	21	22	440	3	75	3			23	185	1	23		02
9	22	23	1520	3	75	3	+2		24	186	1	24		02
10	23	24	500	3	75	3	+2	187	25		50	28		02
11	24	25	1550	3	75	3			26					02
12	25	26	125	3	75	3			27					02
13	26	27	1000	3	75	3			28					02
14	27	28	360	3	75	3			29	190	27	29		02
15	28	29	2775	3	75	3			30	191	95	32		02
16	29	30	575	3	75	3			31					02

SAME AS COLUMNS 1 - 33 FOR ANOTHER LINK

	UPSTREAM NODE	DOWNSTREAM NODE	LINK LENGTH	LINK TYPE	MEAN FREE-FLOW SPEED	NUMBER OF THROUGH LANES	GRADE	NODE RECEIVING LEFT-TURN TRAFFIC FROM LINK	NODE RECEIVING THROUGH TRAFFIC FROM LINK	NODE RECEIVING RIGHT-TURN TRAFFIC FROM LINK	EXIT REACTION DISTANCE	EXIT NODE	CARD TYPE
1	30	31	400	3	75	3			32				02
2	31	32	480	3	75	3			33	194			02
3	32	33	660	3	75	3			34		14	35	02
4	33	34	1070	3	75	3	-3		35				02
5	34	35	1000	3	75	3	-3		36	196			02
6	35	36	1040	3	75	3			37				02
7	36	37	890	3	75	3			38		10	39	02
8	37	38	1000	3	75	3			39				02
9	38	39	840	3	75	3			40	199	0	43	02
10	39	40	1690	3	75	3	+4		41				02
11	40	41	755	3	75	3	-1		42				02
12	41	42	1650	3	75	3	+1		43				02
13	42	43	1025	3	75	3			44	202			02
14	43	44	1625	3	75	3			45		0	46	02
15	44	45	1925	3	75	3			46				02
16	45	46	1080	3	75	3	-1		47	205			02

	Upstream Node	Downstream Node	Link Length	Link Type	Mean Free-Flow Speed	Number of Through Lanes	Grade	Node Receiving Left-Turn Traffic from Link	Node Receiving Through Traffic from Link	Node Receiving Right-Turn Traffic from Link	Exit Reaction Distance	Exit Node	Same as Columns 1-33 for Another Link	Card Type
1	46	47	870	3	75	3			48		0	49		02
2	47	48	750	3	75	3			49					02
3	48	49	600	3	75	3	-1		50	208				02
4	49	50	1800	3	75	3	-1		51		30	52		02
5	50	51	300	3	75	3	-1		52					02
6	51	52	1080	3	75	3	+1		53	211				02
7	52	53	270	3	75	3	+1		54					02
8	53	54	870	3	75	3	-1		55		28	58		02
9	54	55	1660	3	75	3	+2		56					02
10	55	56	1080	3	75	3			57					02
11	56	57	1000	3	75	3	-2		58					02
12	57	58	910	3	75	3	+1		59	214				02
13	58	59	3530	3	75	3			60		12	61		02
14	59	60	1180	3	75	3			61					02
15	60	61	1000	3	75	3			62	217	88	62		02
16	61	62	3840	3	75	3			63	218	65	65		02

Card	Upstream Node	Downstream Node	Link Length	Link Type	Mean Free-Flow Speed	Number of Through Lanes	Grade	Node Receiving Left-Turn Traffic from Link	Node Receiving Through Traffic from Link	Node Receiving Right-Turn Traffic from Link	Exit Reaction Distance	Exit Node	Same as Columns 1-33 for Another Link	Card Type
1	62	63	1630	3	75	3			64					02
2	63	64	1000	3	75	3			65					02
3	64	65	970	3	75	3			66	221				02
4	65	66	1930	3	75	3			67					02
5	66	67	300	3	75	3			790					02
6	801	160		1	45	1			161					02
7	160	161	320	1	50	1	-4		2					02
8	161	2	270	2	55	1	-4		3					02
9	802	162		1	45	1			163					02
10	162	163	320	1	50	1	-4		3					02
11	163	3	230	2	55	1	-4		4					02
12	803	164		1	45	1			165					02
13	164	165	300	1	50	1	-3		4					02
14	165	4	270	2	55	1	-3		69					02
15	805	166		1	45	1			167					02
16	806	166		1	45	1			167					02

	Upstream Node	Downstream Node	Link Length	Link Type	Mean Free-Flow Speed	Number of Through Lanes	Grade	Node Receiving Left-Turn Traffic from Link	Node Receiving Through Traffic from Link	Node Receiving Right-Turn Traffic from Link	Exit Reaction Distance	Exit Node	Same as Columns 1-33 for Another Link	Card Type 02
1	166	167	280	1	50	1	-4		5					02
2	167	5	250	2	55	1	-4		6					02
3	7	169	580	2	55	1	+4		807					02
4	808	170		1	45	1			171					02
5	170	171	260	1	50	1	-4		8					02
6	171	8	210	2	55	1	-4		9					02
7	10	172	450	2	55	1	+4		809					02
8	810	173		1	45	1			174					02
9	173	174	325	1	50	1	-4		11					02
10	174	11	240	2	55	1	-4		12					02
11	13	175	240	2	55	1	+3		176					02
12	175	176	570	1	50	1	+3		811					02
13	812	177		1	45	1			178					02
14	177	178	380	1	50	1	-4		14					02
15	178	14	200	2	55	1	-4		15					02
16	16	179	720	2	55	2	+3		813					02

	UPSTREAM NODE	DOWNSTREAM NODE	LINK LENGTH	LINK TYPE	MEAN FREE-FLOW SPEED	NUMBER OF THROUGH LANES	GRADE	NODE RECEIVING LEFT-TURN TRAFFIC FROM LINK	NODE RECEIVING THROUGH TRAFFIC FROM LINK	NODE RECEIVING RIGHT-TURN TRAFFIC FROM LINK	EXIT REACTION DISTANCE	EXIT NODE	SAME AS COLUMNS 1-33 FOR ANOTHER LINK	CARD TYPE
1	17	180	800	2	55	1	+3		815					02
2	816	230		1	55	1			181					02
3	230	181	680	1	55	1			18					02
4	181	18	300	2	55	1			19					02
5	817	231		1	55	1			8182					02
6	231	182	1900	1	55	1			19					02
7	182	19	310	2	55	1	-3		20					02
8	818	183		1	45	1			184					02
9	183	184	250	1	50	1	-5		20					02
10	184	20	260	2	55	1	-5		68					02
11	850	224		1	45	1			225					02
12	224	225	150	1	50	1	-4		68					02
13	225	68	100	2	55	1	-4		21					02
14	22	185	570	2	55	1	+4		819					02
15	23	186	900	2	55	1	+3		820					02
16	24	187	1200	2	55	1	+4		821					02

SAME AS COLUMNS 1 - 33 FOR ANOTHER LINK

	UPSTREAM NODE	DOWNSTREAM NODE	LINK LENGTH	LINK TYPE	MEAN FREE-FLOW SPEED	NUMBER OF THROUGH LANES	GRADE	NODE RECEIVING LEFT-TURN TRAFFIC FROM LINK	NODE RECEIVING THROUGH TRAFFIC FROM LINK	NODE RECEIVING RIGHT-TURN TRAFFIC FROM LINK	EXIT REACTION DISTANCE	EXIT NODE	CARD TYPE 02
1	822	232		1	55	1			188				02
2	232	188	1000	1	55	1	-2		25				02
3	188	25	310	2	55	1	-3		26				02
4	823	233		1	55	1			189				02
5	233	189	1000	1	55	1	-3		26				02
6	189	26	300	2	55	1	-4		27				02
7	28	190	440	2	55	1	+3		824				02
8	29	191	500	2	55	2	+3		825				02
9	851	192		1	55	2			193				02
10	192	193	325	1	55	2	-3		30				02
11	193	30	200	2	55	2	-3		31				02
12	32	194	340	2	55	1	+2		827				02
13	828	237		1	45	1			195				02
14	237	195	200	1	50	1	-3		33				02
15	195	33	200	2	55	1	-3		34				02
16	35	196	650	2	55	1	+3		830				02

	Upstream Node	Downstream Node	Link Length	Link Type	Mean Free-Flow Speed	Number of Through Lanes	Grade	Node Receiving Left-Turn Traffic From Link	Node Receiving Through Traffic From Link	Node Receiving Right-Turn Traffic From Link	Exit Reaction Distance	Exit Node	SAME AS COLUMNS 1-33 FOR ANOTHER LINK	Card Type 02
1	871	197		1	45	1			198					02
2	197	198	200	1	50	1	-2		37					02
3	198	37	250	2	55	1	-2		38					02
4	39	199	520	2	55	1	+3		872					02
5	833	200		1	45	1			201					02
6	200	201	280	1	50	1	-2		40					02
7	201	40	240	2	55	1	-2		41					02
8	43	202	460	2	55	1	+2		834					02
9	835	203		1	45	1			204					02
10	203	204	380	1	50	1	-2		44					02
11	204	44	260	2	55	1	-2		45					02
12	46	205	1100	2	55	1	+2		836					02
13	837	206		1	45	1			207					02
14	206	207	660	1	50	1	-2		47					02
15	207	47	280	2	55	1	-2		48					02
16	49	208	530	2	55	1	+3		838					02

	UPSTREAM NODE	DOWNSTREAM NODE	LINK LENGTH	LINK TYPE	MEAN FREE-FLOW SPEED	NUMBER OF THROUGH LANES	GRADE	NODE RECEIVING LEFT-TURN TRAFFIC FROM LINK	NODE RECEIVING THROUGH TRAFFIC FROM LINK	NODE RECEIVING RIGHT-TURN TRAFFIC FROM LINK	EXIT REACTION DISTANCE	EXIT NODE	SAME AS COLUMNS 1-33 FOR ANOTHER LINK	CARD TYPE
														02
1	839	209		1	45	1			210					02
2	209	210	450	1	50	1	-3		50					02
3	210	50	260	2	55	1	-3		51					02
4	52	211	450	2	55	1	+3		840					02
5	842	212		1	45	1			213					02
6	212	213	380	1	50	1	-4		54					02
7	213	54	270	2	55	1	-4		55					02
8	58	214	625	2	55	1	+2		843					02
9	844	215		1	45	1			216					02
10	215	216	250	1	50	1	-4		59					02
11	216	59	250	2	55	1	-4		60					02
12	61	217	480	2	55	1	+4		845					02
13	62	218	640	2	55	1	+3		846					02
14	847	219		1	45	1			220					02
15	219	220	400	1	50	1	-2		63					02
16	220	63	250	2	55	1	-2		64					02

	Upstream Node	Downstream Node	Link Length	Link Type	Mean Free-Flow Speed	Number of Through Lanes	Grade	Node Receiving Left-Turn Traffic from Link	Node Receiving Through Traffic from Link	Node Receiving Right-Turn Traffic from Link	Exit Reaction Distance	Exit Node	Same as Columns 1-33 for Another Link	Card Type
1	652	221	440	2	55	1	+4		848					02
2	849	222		1	45	1			223					02
3	222	223	300	1	50	1	-3		66					02
4	223	66	290	2	55	1	-3		67					02
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														

SAME AS COLUMNS 1-39 FOR ANOTHER LINK

CARD TYPE 04

	UPSTREAM NODE	DOWNSTREAM NODE	RADIUS OF CURVATURE	FIRST AUXILIARY LANE CODE	FIRST AUXILIARY LANE LENGTH	SECOND AUXILIARY LANE CODE	SECOND AUXILIARY LANE LENGTH	RECEIVING LINK LANE CODE	NON-WEAVING LANES	SUPERELEVATION	PAVEMENT CODE	FREEWAY DATA STATION LOCATION	UPSTREAM NODE	DOWNSTREAM NODE	FIRST AUXILIARY LANE CODE	FIRST AUXILIARY LANE LENGTH	RECEIVING LINK LANE CODE	CARD TYPE
1	780	1						1				0	21	22	2	380	1	004
2	1	2						1				0	22	23	2	325	1	004
3	2	3		1	200			1				0	23	24	5	100	1	004
4	3	4		1	300			1				0	24	25			1	004
5	4	69		1	300			1				0	25	26	1	123	1	004
6	69	5	5729					1		2		0	26	27	1	400	1	004
7	5	6		1	240			1				0	27	28	2	125	1	004
8	6	7		2	250			1				0	28	29	2	200	1	004
9	7	8						1				0	29	30			1	004
10	8	9	2960	1	250			1		3		0	30	31	1	400	1	004
11	9	10		2	150			1				0	31	32	2	480	1	004
12	10	11						1				0	32	33			1	004
13	11	12	5700	1	200			1		2		0	33	34	1	250	1	004
14	12	13	5700	5	250			1		2		0	34	35	2	200	1	004
15	13	14						1				0	35	36			1	004
16	14	15		1	200			1				0	36	37			1	004

	Upstream Node	Downstream Node	Radius of Curvature	First Auxiliary Lane Code	First Auxiliary Lane Length	Second Auxiliary Lane Code	Second Auxiliary Lane Length	Receiving Link Lane Code	Non-Weaving Lanes	Superelevation	Pavement Code	Freeway Data Station Location	Same as Columns 1-39 for Another Link: Upstream Node	Downstream Node	Radius of Curvature	First Auxiliary Lane Code	First Auxiliary Lane Length	Receiving Link Lane Code	Superelevation	Card Type 04
1	15	16		2	300			1				0	37	38		1	200	1		004
2	16	17		2	200			1				0	38	39		2	250	1		004
3	17	18						1				0	39	40	2292			1	4	004
4	18	19		1	200			1				0	40	41		1	280	1		004
5	19	20		1	300			1				0	41	42	1910			1	4	004
6	20	68		1	150			1				0	42	43		2	250	1		004
7	68	21		1	300			1				0	43	44	3820			1	2	004
8	44	45		1	225			1				0	45	46		2	325	1		004
9	46	47						1				0	47	48	5209	1	250	1	2	004
10	48	49	5209	2	200			1		2		0	49	50				1		004
11	50	51	2865	1	300			1		3		0	51	52	2865	2	260	1	3	004
12	52	53						1				0	53	54				1		004
13	54	55		1	250			1				0	55	56				1		004
14	56	57						1				0	57	58	2865	2	300	1	3	004
15	58	59						1				0	59	60		1	350	1		004
16	60	61	2865	2	200			1		3		0	61	62		2	200	1		004

Line	Upstream Node	Downstream Node	Radius of Curvature	First Auxiliary Lane Code	First Auxiliary Lane Length	Second Auxiliary Lane Code	Second Auxiliary Lane Length	Receiving Link Lane Code	Non-Weaving Lanes	Superelevation	Pavement Code	Freeway Data Station Location	Same as Columns 1-39 for Another Link: Upstream Node	Downstream Node	Radius of Curvature	First Auxiliary Lane Code	First Auxiliary Lane Length	Receiving Link Lane Code	Superelevation	Card Type
1	62	67						1				0	67	64	5730	1	800	1	2	04
2	64	65	1820	2	225			1		2		0	65	66				1		04
3	66	67		1	700			1				0								04
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
12																				
13																				
14																				
15																				
16																				

CARD TYPE 04

	Upstream Node	Downstream Node	Downstream Node Type	Mean Queue Discharge Headway	Receiving Link Lane Code	Radius of Curvature	Superelevation	Pavement Code	Upstream Node	Downstream Node	Downstream Node Type	Mean Queue Discharge Headway	Receiving Link Lane Code	Radius of Curvature	Superelevation	Pavement Code	Card Type
									SAME AS COLS. 1-21 FOR ANOTHER LINK								05
1	161	2			8				22	185		22	1				05
2	163	3			8				23	186		22	1	395	6		05
3	165	4			8				24	183		22	1	2660	2		05
4	167	5			8				188	25			8	395	6		05
5	7	169		22	1	16210			189	26			8	2660	2		05
6	171	8			8	11010			28	190		22	1				05
7	10	172		22	1				29	191		22	1				05
8	174	11			8				193	30			8				05
9	13	175		22	1				32	194		22	1				05
10	178	14			8				195	33			8				05
11	16	179		22	1				35	196		22	1				05
12	17	180		22	1				198	37			8				05
13	181	18			8				39	199		22	1				05
14	182	19			8				201	40			8				05
15	184	20			8				43	202		22	1				05
16	225	68			8	740	8		204	44			8				05

Line	Upstream Node	Downstream Node	Downstream Node Type	Mean Queue Discharge Headway	Receiving Link Lane Code	Radius of Curvature	Superelevation	Pavement Code	Upstream Node	Downstream Node	Mean Queue Discharge Headway	Receiving Link Lane Code	Card Type
1	46	205		22	1	170	7						05
2	207	47			8	220	7		49	208	22	1	05
3	210	50			8				52	211	22	1	05
4	213	54			8				58	214	22	1	05
5	216	59			8				61	217	22	1	05
6	62	218		22	1				220	63		8	05
7	65	221		22	1				223	66		8	05
8													
9													
10													
11													
12													
13													
14													
15													
16													

SAME AS COLS. 1-21 FOR ANOTHER LINK

05

	Upstream node	Downstream node	Downstream node type	Mean queue discharge headway	Start-up lost time	Left-turn opposing traffic origin node	Right-turn pocket size	Left-turn pocket size	Lane 1 channelization code	Lane 2 channelization code	Lane 3 channelization code	Lane 4 channelization code	Lane 5 channelization code	Same as columns 1-27 for another link				Card type
1	801	160		24	20									822	232	24	20	06
2	160	161		24	20									823	233	24	20	06
3	802	162		24	20									851	192	24	20	06
4	162	163		24	20									192	193	24	20	06
5	803	164		24	20									828	237	24	20	06
6	237	195		24	20													06
7	804	164		24	20									831	197	24	20	06
8	164	165		24	20									197	198	24	20	06
9	806	166		24	20									833	200	24	20	06
10	805	166		24	20									200	201	24	20	06
11	166	167		24	20									835	203	24	20	06
12	808	170		24	20									203	204	24	20	06
13	170	171		24	20									837	206	24	20	06
14	810	173		24	20									206	207	24	20	06
15	173	174		24	20									839	209	24	20	06
16	812	177		24	20									209	210	24	20	06

Row	Upstream Node	Downstream Node	Downstream Node Type	Mean Queue Discharge Headway	Start-up Lost Time	Left-turn Opposing Traffic Origin Node	Right-turn Pocket Size	Left-turn Pocket Size	Lane 1 Channelization Code	Lane 2 Channelization Code	Lane 3 Channelization Code	Lane 4 Channelization Code	Lane 5 Channelization Code	Same as columns 1-27 for another link: Upstream Node	Downstream Node	Mean Queue Discharge Headway	Start-up Lost Time	Card Type 90
1	177	178		24	20									842	212	24	20	06
2	175	176		24	20									212	213	24	20	06
3	818	182		24	20									844	215	24	20	06
4	183	184		24	20									215	216	24	20	06
5	850	224		24	20									847	219	24	20	06
6	224	225		24	20									219	220	24	20	06
7	816	230		24	20									849	222	24	20	06
8	817	231		24	20									222	223	24	20	06
9	230	181		24	20									231	182	24	20	06
10	272	188		24	20									233	189	24	20	06
11																		
12																		
13																		
14																		
15																		
16																		

	Upstream node	Downstream node	Percent left-turn traffic at downstream node	Percent through traffic at downstream node	Percent right-turn traffic at downstream node	Same as columns 1-15 for another link: Upstream	Downstream	Left	Through	Right	Same as columns 1-15 for another link: Upstream	Downstream	Left	Through	Right	Same as columns 1-15 for another link: Upstream	Downstream	Left	Through	Right	Same as columns 1-15 for another link	[redacted]	Card type
1	780	1		100																			08
2	1	2		100		801	160		100		160	161		100		161	2		100				08
3	2	3		100		802	162		100		162	163		100		163	3		100				08
4	3	4		100		803	164		100		164	165		100		165	4		100				08
5	4	69		100		804	164		100					100									08
6	69	5		100		805	166		100		166	167		100		167	5		100				08
7	5	6		100		806	166		100					100									08
8	6	7		91	9	7	169		100														08
9	7	8		100		808	170		100		170	171		100		171	8		100				08
10	8	9		100																			08
11	9	10		97	3	10	172		100														08
12	10	11		100		810	173		100		173	174		100		174	11		100				08
13	11	12		100																			08
14	12	13	2	98		813	175		100		175	176		100									08
15	13	14		100		812	177		100		177	178		100		178	14		100				08
16	14	15		100																			08

	Upstream Node	Downstream Node	Percent Left-Turn Traffic at Downstream Node	Percent Through Traffic at Downstream Node	Percent Right-Turn Traffic at Downstream Node	Same as Columns 1-15 for Another Link					Same as Columns 1-15 for Another Link					Same as Columns 1-15 for Another Link					Same as Columns 1-15 for Another Link					Card Type
1	704	4		100		804	160		100		160	161		100												08
2	15	16		77	23	16	179		100																	08
3	16	17		98	2	17	180		100																	08
4	17	18		100		816	230		100		230	181		100		181	18		100							08
5	19	19		100		817	231		100		271	182		100		182	19		100							08
6	19	20		100		818	187		100		183	184		100		184	20		100							08
7	20	68		100		850	224		100		224	225		100		225	68		100							08
8	68	21		100																						08
9	21	22		98	2	22	185		100																	08
10	22	23		90	10	23	186		100																	08
11	23	24	17	83		24	187		100																	08
12	24	25		100		822	212		100		232	188		100		188	25		100							08
13	25	26		100		823	233		100		233	189		100		189	26		100							08
14	26	27		100																						08
15	27	28		099	3	28	190		100																	08
16	28	29		69	31	29	191		100																	08

	Upstream node	Downstream node	Percent left-turn traffic at downstream node	Percent through traffic at downstream node	Percent right-turn traffic at downstream node	Same as columns 1-15 for another link					Same as columns 1-15 for another link					Same as columns 1-15 for another link					Same as columns 1-15 for another link						Card type
1	29	30		100		851	192		100		192	193		100		193	30		100							[redacted]	08
2	30	31		100																							08
3	31	32		97	3	32	194		100																		08
4	32	33		100		828	237		100		237	195		100		195	33		100								08
5	33	34		100																							08
6	34	35		96	4	35	196		100																		08
7	35	36		100																							08
8	36	37		100		831	197		100		197	198		100		198	37		100								08
9	37	38		100																							08
10	38	39		94	6	39	199		100																		08
11	39	40		100		833	200		100		200	201		100		201	40		100								08
12	40	41		100																							08
13	41	42		100																							08
14	42	43		90	10	43	202		100																		08
15	43	44		100		435	203		100		203	204		100		204	44		100								08
16	44	45		100																							08

	UPSTREAM NODE	DOWNSTREAM NODE	PERCENT LEFT-TURN TRAFFIC AT DOWNSTREAM NODE	PERCENT THROUGH TRAFFIC AT DOWNSTREAM NODE	PERCENT RIGHT-TURN TRAFFIC AT DOWNSTREAM NODE	SAME AS COLUMNS 1-15 FOR ANOTHER LINK					CARD TYPE
1	45	46		91	9	46	205		100		08
2	46	47		100		837	206		100		08
3	47	48		100							08
4	48	49		96	4	49	208		100		08
5	49	50		100		839	209		100		08
6	50	51		100							08
7	51	52		086	14	52	211		100		08
8	52	53		100							08
9	53	54		100		842	212		100		08
10	54	55		100							08
11	55	56		100							08
12	56	57		100							08
13	57	58		85	15	56	214		100		08
14	58	59		100		844	215		100		08
15	59	60		100							08
16	60	61		92	8	61	217		100		08

	SAME AS COLUMNS 1-15 FOR ANOTHER LINK					SAME AS COLUMNS 1-15 FOR ANOTHER LINK					SAME AS COLUMNS 1-15 FOR ANOTHER LINK				
2	206	207		100		204	48		100						
5	209	210		100		210	50		100						
9	212	213		100		213	54		100						
14	215	216		100		216	59		100						

	UPSTREAM NODE	DOWNSTREAM NODE	PERCENT LEFT-TURN TRAFFIC AT DOWNSTREAM NODE	PERCENT THROUGH TRAFFIC AT DOWNSTREAM NODE	PERCENT RIGHT-TURN TRAFFIC AT DOWNSTREAM NODE	SAME AS COLUMNS 1-15 FOR ANOTHER LINK			SAME AS COLUMNS 1-15 FOR ANOTHER LINK			SAME AS COLUMNS 1-15 FOR ANOTHER LINK			SAME AS COLUMNS 1-15 FOR ANOTHER LINK	CARD TYPE
1	61	62		88	12	62	218	100								08
2	62	63		100		847	219	100	219	220	100	220	63	100		08
3	63	64		100												08
4	64	65		88	12	65	221	100								08
5	65	66		100		849	222	100	222	223	100	223	66	100		08
6	66	67		100												08
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																

	NODE NUMBER	ACTUATED SIGNAL INDEX	INTERVAL 1 OFFSET	UPSTREAM NODE OF APPROACH LINK 1	UPSTREAM NODE OF APPROACH LINK 2	UPSTREAM NODE OF APPROACH LINK 3	UPSTREAM NODE OF APPROACH LINK 4	INTERVAL 1 CODE - APPROACH 1	INTERVAL 1 CODE - APPROACH 2	INTERVAL 1 CODE - APPROACH 3	INTERVAL 1 CODE - APPROACH 4	INTERVAL 1 DURATION	SAME AS COLS. 27-33 FOR INTERVAL 2	SAME AS COLS. 27-33 FOR INTERVAL 3	SAME AS COLS. 27-33 FOR INTERVAL 4	SAME AS COLS. 27-33 FOR INTERVAL 5	SAME AS COLS. 27-33 FOR INTERVAL 6	CARD TYPE 10
1	1	0	720					1										10
2	2	0		1	161			1	0									10
3	3	0		2	163			1	0									10
4	4	0		3	165			1	0									10
5	69	0		4				1										10
6	5	0		69	167			1	0									10
7	6	0		5				1										10
8	7	0		6				1										10
9	8	0		7	171			1	0									10
10	9	0		8				1										10
11	10	0		9				1										10
12	11	0		10	174			1	0									10
13	12	0		11				1										10
14	13	0		12				1										10
15	14	0		13	178			1	0									10
16	15	0		14				1										10

	Node Number	Actuated Signal Index	Interval 1 Offset	Upstream Node of Approach Link 1	Upstream Node of Approach Link 2	Upstream Node of Approach Link 3	Upstream Node of Approach Link 4	Interval 1 Code - Approach 1	Interval 1 Code - Approach 2	Interval 1 Code - Approach 3	Interval 1 Code - Approach 4	Interval 1 Duration	Same as Cols. 27-33 for Interval 2	Same as Cols. 27-33 for Interval 3	Same as Cols. 27-33 for Interval 4	Same as Cols. 27-33 for Interval 5	Same as Cols. 27-33 for Interval 6	Card Type 10
1	16	0		15				1										10
2	17	0		16				1										10
3	18	0		17	181			1	0									10
4	19	0		18	182			1	0									10
5	20	0		19	184			1	0									10
6	68	0		20	225			1	0									10
7	21	0		68				1										10
8	22	0		21				1										10
9	23	0		22				1										10
10	24	0		23				1										10
11	25	0		24	198			1	0									10
12	26	0		25	189			1	0									10
13	27	0		26				1										10
14	28	0		27				1										10
15	29	0		28				1										10
16	30	0		29	193			1	0									10

	Node Number	Actuated Signal Index	Interval 1 Offset	Upstream Node of Approach Link 1	Upstream Node of Approach Link 2	Upstream Node of Approach Link 3	Upstream Node of Approach Link 4	Interval 1 Code - Approach 1	Interval 1 Code - Approach 2	Interval 1 Code - Approach 3	Interval 1 Code - Approach 4	Interval 1 Duration	Same as cols. 27-33 for Interval 2	Same as cols. 27-33 for Interval 3	Same as cols. 27-33 for Interval 4	Same as cols. 27-33 for Interval 5	Same as cols. 27-33 for Interval 6	Card Type
1	31	0		30				1										10
2	32	0		31				1										10
3	33	0		32	195			1	0									10
4	34	0		33				1										10
5	35	0		34				1										10
6	36	0		35				1										10
7	37	0		36	198			1	0									10
8	38	0		37				1										10
9	39	0		38				1										10
10	40	0		39	201			1	0									10
11	41	0		40				1										10
12	42	0		41				1										10
13	43	0		42				1										10
14	44	0		43	204			1	0									10
15	45	0		44				1										10
16	46	0		45				1										10

	Node Number	Actuated Signal Index	Interval 1 Offset	Upstream Node of Approach Link 1	Upstream Node of Approach Link 2	Upstream Node of Approach Link 3	Upstream Node of Approach Link 4	Interval 1 Code - Approach 1	Interval 1 Code - Approach 2	Interval 1 Code - Approach 3	Interval 1 Code - Approach 4	Interval 1 Duration	Same as cols. 27-33 for Interval 2	Same as cols. 27-33 for Interval 3	Same as cols. 27-33 for Interval 4	Same as cols. 27-33 for Interval 5	Same as cols. 27-33 for Interval 6	Card Type
1	47	0		46	207			1	0									10
2	48	0		47				1										10
3	49	0		48				1										10
4	50	0		49	210			1	0									10
5	51	0		50				1										10
6	52	0		51				1										10
7	53	0		52				1										10
8	54	0		53	213			1	0									10
9	55	0		54				1										10
10	56	0		55				1										10
11	57	0		56				1										10
12	58	0		57				1										10
13	59	0		58	216			1	0									10
14	60	0		59				1										10
15	61	0		60				1										10
16	62	0		61				1										10

	Node Number	Actuated Signal Index	Interval 1 Offset	Upstream Node of Approach Link 1	Upstream Node of Approach Link 2	Upstream Node of Approach Link 3	Upstream Node of Approach Link 4	Interval 1 Code - Approach 1	Interval 1 Code - Approach 2	Interval 1 Code - Approach 3	Interval 1 Code - Approach 4	Interval 1 Duration	Same as Cols. 27-33 for Interval 2	Same as Cols. 27-33 for Interval 3	Same as Cols. 27-33 for Interval 4	Same as Cols. 27-33 for Interval 5	Same as Cols. 27-33 for Interval 6	Card Type 10
1	63	0		62	220			1	0									10
2	64	0		63				1										10
3	65	0		64				1										10
4	66	0		65	223			1	0									10
5	67	0		66				1										10
6	160	0		801				1										10
7	161	0		160				1										10
8	162	0		802				1										10
9	163	0		162				1										10
10	164	0		804	803			1	0									10
11	165	0		164				1										10
12	166	0		806	805			1	0									10
13	167	0		166				1										10
14	169	0		7				1										10
15	170	0		808				1										10
16	171	0		170				1										10

	NODE NUMBER	ACTUATED SIGNAL INDEX	INTERVAL 1 OFFSET	UPSTREAM NODE OF APPROACH LINK 1	UPSTREAM NODE OF APPROACH LINK 2	UPSTREAM NODE OF APPROACH LINK 3	UPSTREAM NODE OF APPROACH LINK 4	INTERVAL 1 CODE - APPROACH 1	INTERVAL 1 CODE - APPROACH 2	INTERVAL 1 CODE - APPROACH 3	INTERVAL 1 CODE - APPROACH 4	INTERVAL 1 DURATION	SAME AS COLS. 27-33 FOR INTERVAL 2	SAME AS COLS. 27-33 FOR INTERVAL 3	SAME AS COLS. 27-33 FOR INTERVAL 4	SAME AS COLS. 27-33 FOR INTERVAL 5	SAME AS COLS. 27-33 FOR INTERVAL 6	CARD TYPE
1	172	0		10				1										10
2	173	0		810				1										10
3	174	0		173				1										10
4	175	0		17				1										10
5	176	0		175				1										10
6	177	0		812				1										10
7	178	0		177				1										10
8	179	0		16				1										10
9	180	0		17				1										10
10	181	0		230				1										10
11	182	0		231				1										10
12	220	0		816				1										10
13	231	0		817				1										10
14	183	0		818				1										10
15	184	0		183				1										10
16	224	0		850				1										10

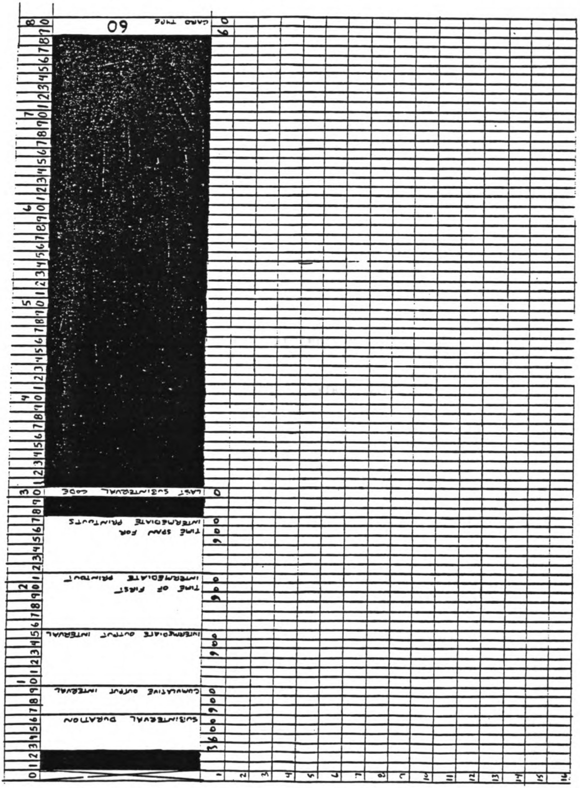
	NODE NUMBER	ACTUATED SIGNAL INDEX	INTERVAL 1 OFFSET	UPSTREAM NODE OF APPROACH LINK 1	UPSTREAM NODE OF APPROACH LINK 2	UPSTREAM NODE OF APPROACH LINK 3	UPSTREAM NODE OF APPROACH LINK 4	INTERVAL 1 CODE - APPROACH 1	INTERVAL 1 CODE - APPROACH 2	INTERVAL 1 CODE - APPROACH 3	INTERVAL 1 CODE - APPROACH 4	INTERVAL 1 DURATION	SAME AS COLS. 27-33 FOR INTERVAL 2	SAME AS COLS. 27-33 FOR INTERVAL 3	SAME AS COLS. 27-33 FOR INTERVAL 4	SAME AS COLS. 27-33 FOR INTERVAL 5	SAME AS COLS. 27-33 FOR INTERVAL 6	CARD TYPE
1	225	0		224				1										10
2	185	0		22				1										10
3	186	0		23				1										10
4	187	0		24				1										10
5	188	0		232				1										10
6	189	0		233				1										10
7	232	0		822				1										10
8	233	0		823				1										10
9	190	0		28				1										10
10	191	0		29				1										10
11	192	0		851				1										10
12	193	0		192				1										10
13	194	0		32				1										10
14	237	0		828				1										10
15	195	0		237				1										10
16	196	0		35				1										10

	NODE NUMBER	ACTUATED SIGNAL INDEX	INTERVAL 1 OFFSET	UPSTREAM NODE OF APPROACH LINK 1	UPSTREAM NODE OF APPROACH LINK 2	UPSTREAM NODE OF APPROACH LINK 3	UPSTREAM NODE OF APPROACH LINK 4	INTERVAL 1 CODE - APPROACH 1	INTERVAL 1 CODE - APPROACH 2	INTERVAL 1 CODE - APPROACH 3	INTERVAL 1 CODE - APPROACH 4	INTERVAL 1 DURATION	SAME AS COLS. 27-33 FOR INTERVAL 2	SAME AS COLS. 27-33 FOR INTERVAL 3	SAME AS COLS. 27-33 FOR INTERVAL 4	SAME AS COLS. 27-33 FOR INTERVAL 5	SAME AS COLS. 27-33 FOR INTERVAL 6	CARD TYPE
1	197	0		831				1										10
2	198	0		197				1										10
3	199	0		39				1										10
4	200	0		833				1										10
5	201	0		200				1										10
6	202	0		43				1										10
7	203	0		835				1										10
8	204	0		203				1										10
9	205	0		46				1										10
10	206	0		837				1										10
11	207	0		206				1										10
12	208	0		49				1										10
13	209	0		839				1										10
14	210	0		209				1										10
15	211	0		52				1										10
16	212	0		842				1										10

	NODE NUMBER	ACTUATED SIGNAL INDEX	INTERVAL 1 OFFSET	UPSTREAM NODE OF APPROACH LINK 1	UPSTREAM NODE OF APPROACH LINK 2	UPSTREAM NODE OF APPROACH LINK 3	UPSTREAM NODE OF APPROACH LINK 4	INTERVAL 1 CODE - APPROACH 1	INTERVAL 1 CODE - APPROACH 2	INTERVAL 1 CODE - APPROACH 3	INTERVAL 1 CODE - APPROACH 4	INTERVAL 1 DURATION	SAME AS COLS. 27-33 FOR INTERVAL 2	SAME AS COLS. 27-33 FOR INTERVAL 3	SAME AS COLS. 27-33 FOR INTERVAL 4	SAME AS COLS. 27-33 FOR INTERVAL 5	SAME AS COLS. 27-33 FOR INTERVAL 6	CARD TYPE 10
1	213	0		212				1										10
2	214	0		58				1										10
3	215	0		844				1										10
4	216	0		215				1										10
5	217	0		61				1										10
6	218	0		62				1										10
7	219	0		847				1										10
8	220	0		219				1										10
9	221	0		65				1										10
10	222	0		849				1										10
11	223	0		222				1										10
12		0						1										10
13		0						1										10
14		0						1										10
15		0						1										10
16		0						1										10

	UPSTREAM NODE	DOWNSTREAM NODE	FLOW RATE	PERCENT VEHICLE TYPE 2	PERCENT VEHICLE TYPE 3	PERCENT VEHICLE TYPE 4	PERCENT VEHICLE TYPE 5	PERCENT VEHICLES LANE 2	PERCENT VEHICLES LANE 3	PERCENT VEHICLES LANE 4	PERCENT VEHICLES LANE 5	SAME AS COLUMNS 1-33 FOR ANOTHER LINK	CARD TYPE
													20
1	780	1	3041	5		7	2						20
2	801	160	300	5		2							20
3	802	162	601	5		3							20
4	803	164	50	5		2							20
5	804	164	153	5		4							20
6	805	166	50	5		2							20
7	806	166	148	5		2							20
8	808	170	403	5		3							20
9	810	173	204	5		5							20
10	812	173	426	5		2							20
11	816	220	421	5		8							20
12	817	231	327	5		5							20
13	818	183	235	5		6							20
14	850	224	108	5		6							20
15	822	232	950	5		4	2						20
16	823	233	648	5		5	2						20

	Upstream Node	Downstream Node	Flow Rate	Percent Vehicle Type 2	Percent Vehicle Type 3	Percent Vehicle Type 4	Percent Vehicle Type 5	Percent Vehicles Lane 2	Percent Vehicles Lane 3	Percent Vehicles Lane 4	Percent Vehicles Lane 5	Same as columns 1-33 for another link	Card Type
1	851	192	1195	5	6	1							20
2	828	237	600	5	10								20
3	831	197	480	5	12								20
4	832	200	566	5	16								20
5	835	207	290	5	9								20
6	837	206	498	5	7								20
7	839	209	126	5	5								20
8	842	212	478	5	2								20
9	844	215	467	5	4								20
10	847	219	750	5	3								20
11	849	222	976	5	3								20
12													
13													
14													
15													
16													


CARD TYPE
60
LAST SUBINTERVAL CODE
0
TIME SPAN FOR INTERMEDIATE PRINTOUTS
900
TIME OF FIRST INTERMEDIATE PRINTOUT
900
INTERMEDIATE OUTPUT INTERVAL
900
CUMULATIVE OUTPUT INTERVAL
900
SUBINTERVAL DURATION
3600

APPENDIX B

EXAMPLES OF INTRAS OUTPUTS

MSU

** 8550 **

TRAFFIC

ABDUL HAMAD

TECH SERVICES

CARD DATA LIST

```
SCANDI WB FORD FREEWAY -- MT. ELLIOT                                  10  2          0
  FILE ME 1-1     4/16/87 CALIBRATION SEGMENT W/R.M. OFF             300  1     73000 1
701 26     3753       27                  26 27 15803753 -4     28                    2
836210      1451       117                210117  4201501 -3    27                    2
117 27  2402551 -3     28                  27 28  8503753       29                    2
 28 29 10003753       702                                                             2
701 26                      1           0 26 27  2292                 1    4        0 4
 27 28         1  260       1           0 28 29                       1             0 4
117 27        8                                                                       5
836210 24 20                                                                          6
210117 24 20                                                                          6
701 26    100     26 27   100   836210   100   210117   100   117 27   100          8
 27 28    100     28 29   100                                                         8
 26  0    701               1                                                        10
 27  0     26117            10                                                       10
 28  0     27               1                                                        10
 29  0     28               1                                                        10
210  0    836               1                                                        10
117  0    210               1                                                        10
701 26   5832   5    10                                                              20
836210    720   5    12                                                              20
  1 11  2 10  3 .9  4  8  5  7  6  6  7  5  8  4  9  3 10  2                         43
   300300   300    300  0                                                            60
```

SCANDI WB FORD FREEWAY -- MT. ELLIOT

FILE ME 1-1   4/16/87 CALIBRATION SEGMENT W/R.M. OFF

SUBINTERVAL 1

FREEWAY LINKS

L	LINK	LANE	SPAN	AUXILIARY LANES FIRST LGH A D F	AUXILIARY LANES SECOND LGH A D F	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	CURVATURE RAD P EL	RT. LANE OF SEP. PAIR FIRST	SECOND	REC LANE	IDENTIFICATION
1	(701, 26)	3	0	0 0 0 0	0 0 0 0	75	0	0/ 0	100/ 27	0/ 0	0 1 0	0	0	1	
2	(26, 27)	3	1578	0 0 0 0	0 0 0 0	75	-4	0/ 0	100/ 28	0/ 0	2200 1 4	0	0	1	
3	(27, 28)	3	849	258 8 0 0	0 0 0 0	75	0	0/ 0	100/ 29	0/ 0	0 1 0	0	0	1	
4	(28, 29)	3	999	0 0 0 0	0 0 0 0	75	0	0/ 0	100/702	0/ 0	0 1 0	0	0	1	

RAMP LINKS

L	LINK	LANE	SPAN	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	TYPE OF DWNSTREAM INTRSECTN	MEAN QUEUE DISCHGE HEADWAY	LOST TIME	CURVATURE RAD P EL	ON/OFF RAMP	REC LANE	IDENTIFICATION
1	(117, 27)	1	240	55	-4	0/ 0	100/ 28	0/ 0	1	0	0	0 1 0	ON	8	

SURFACE LINKS

L	LINK	LANE	SPAN	POCK L	R	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	TYPE OF DWNSTREAM INTRSECTN	LOST TIME	MEAN QUEUE DISCH HEAD	OPP LINK	LANE CHAN. 1 2 3 4 5	IDENTIFICATION
1	(836,210)	1	0	0	0	45	0	0/ 0	100/117	0/ 0	1	20	24	0	0 0 0 0 0	
2	(210,117)	1	420	0	0	50	-4	0/ 0	100/ 27	0/ 0	1	20	24	0	0 0 0 0 0	

SUBINTERVAL 1
TRIP TABLE

ORIGIN NODE	DEST/PCT	DEST/PCT	DEST/PCT	DEST/PCT	DEST/PCT	DEST/PCT	DEST/PCT	DEST/PCT	DEST/PCT

* VALUE WAS SPECIFIED ON TYPE 9 CARD DURING THIS SUBINTERVAL

FILL TIME COMPLETED
SIMULATION TO PROCEED

```
****    ERROR 607. PARAMETERS =     8.      1.     272.
****    ERROR 607. PARAMETERS =     8.      1.     272.
```

CUMULATIVE OUTPUT AT TIME 7 35 0
RAMP AND SURFACE LINK STATISTICS

L	LINK	VEH OUT	CURR CONT	AVG CONT	VEH-MILES	VEH-MIN	SPEED MPH	SECONDS/VEHICLE TOTAL TIME	MOVE TIME	DELAY TIME	M/T	VEH-MIN/ VEH-MILE TOTAL	DELAY	PERCENT QUEUE DELAY	AVG SAT PCT	CYCLE FAILURE	LINK TYPE
1	(117, 27)	60	0	0.6	2.73	3.14	52.1	3.1	3.0	0.1	0.96	1.15	0.05	0	0	0	RAMP
2	(210, 117)	60	1	1.2	4.77	5.92	48.4	5.9	5.8	0.1	0.98	1.24	0.03	0	5	0	SURFACE
AVERAGES AND TOTALS			1	1.8	7.50	9.06	49.7				0.97	1.21	0.04	0	0	0	

CUMULATIVE OUTPUT AT TIME 7 35 0
FREEWAY LINK STATISTICS

L	LINK	VEH OUT	LANE CHNG	CURR CONT	AVG CONT	VEH-MILES	VEH-MIN	SECONDS/VEHICLE TOTAL TIME	SECONDS/VEHICLE MOVE TIME	SECONDS/VEHICLE DELAY TIME	M/T	VEH-MIN/VEH-MILE TOTAL	VEH-MIN/VEH-MILE DELAY	VOLUME VEH/LN/HR	DENSITY VEH/LN-MILE	SPEED MILE/HR
2	(26, 27)	421	147	83	90.9	122.57	454.62	66.5	14.5	52.0	0.22	3.71	2.90	1640.	101.4	16.2
3	(27, 28)	480	220	40	38.9	77.33	194.26	24.2	7.7	16.5	0.32	2.51	1.71	1747.	73.1	23.9
4	(28, 29)	494	115	26	25.6	92.54	128.15	15.7	9.1	6.6	0.58	1.38	0.58	1956.	45.2	43.3
AVERAGES AND TOTALS			482	149	155.4	292.44	777.02				0.30	2.66	1.85	1759.	77.9	22.6

NETWORK STATISTICS INCLUDING RAMP AND SURFACE LINKS

VEHICLE-MILES = 299.94, VEHICLE-MINUTES = 786.08, MOVING/TOTAL TRIP TIME =0.310,

AVERAGE CONTENT = 157.2, CURRENT CONTENT = 150, SPEED(MPH) = 22.89,

TOTAL DELAY(VEH-MIN) = 542.19, TRAVEL TIME(MIN)/VEH-MILE = 2.62, DELAY TIME(MIN)/VEH-MILE = 1.81

CARD DATA LIST

```
SCANDI WB FORD FREEWAY -- MT. ELLIOT                                10  2          0
   MT FILE 3-2      9/18/86   VALIDATION SEGMENT W/R.M. OFF        300  1   150000 1
701 26      3753        27                 26 27 15803753 -4    28                 2
836210      1451       117                210117  4201501 -3    27                 2
117 27  2402571 -3      28                 27 28  8503703       29                 2
 28 29 10003753        702                                                         2
701 26                     1             0 26 27  2292               1    4      0 4
 27 28        1  260       1             0 28 29                     1           0 4
117 27      8                                                                      5
836210 24 20                                                                       6
210117 24 20                                                                       6
701 26     100     26 27   100   836210    100    210117    100   117 27   100     8
 27 28     100     28 29   100                                                     8
 26  0    701              1                                                      10
 27  0      26117          10                                                     10
 28  0      27             1                                                      10
 29  0      28             1                                                      10
210  0     836             1                                                      10
117  0     210             1                                                      10
701 26    4674  5     3                                                           20
836210     732  5     3                                                           20
  1 11  2 10  3  9  4  8  5  7  6  6  7  5  8  4  9  3 10  2                      43
   600600   600   600   600  0                                                    60
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SCANDI WB FORD FREEWAY -- MT. ELLIOT

MT FILE 3-2 9/18/86 VALIDATION SEGMENT W/R.M. OFF

SUBINTERVAL 1

FREEWAY LINKS

L	LINK	LANE	SPAN	AUXILIARY LANES FIRST LGH	A	D	F	SECOND LGH	A	D	F	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	CURVATURE RAD	P	EL	RT. LANE OF SEP. PAIR FIRST	SECOND	REC LANE	IDENTIFICATION
1	(701, 26)	3	0	0	0	0	0	0	0	0	0	75	0	0/ 0	100/ 27	0/ 0	0	1	0	0	0	1	
2	(26, 27)	3	1578	0	0	0	0	0	0	0	0	75	-4	0/ 0	100/ 28	0/ 0	2200	1	4	0	0	1	
3	(27, 28)	3	849	258	8	0	0	0	0	0	0	70	0	0/ 0	100/ 29	0/ 0	0	1	0	0	0	1	
4	(28, 29)	3	999	0	0	0	0	0	0	0	0	75	0	0/ 0	100/702	0/ 0	0	1	0	0	0	1	

RAMP LINKS

L	LINK	LANE	SPAN	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	TYPE OF DWNSTREAM INTRSECTN	MEAN QUEUE DISCHGE HEADWAY	LOST TIME	CURVATURE RAD	P	EL	ON/OFF RAMP	REC LANE	IDENTIFICATION
1	(117, 27)	1	240	57	-4	0/ 0	100/ 28	0/ 0	1	0	0	0	1	0	ON	8	

SURFACE LINKS

L	LINK	LANE	SPAN	POCK L	R	MEAN FREE FLOW SPEED	GRADE	PERCENT OF VOLUME/ DESTINATION NODES LEFT	THRU	RIGHT	TYPE OF DWNSTREAM INTRSECTN	LOST TIME	MEAN QUEUE DISCH HEAD	OPP LINK	LANE CHAN. 1	2	3	4	5	IDENTIFICATION
1	(836,210)	1	0	0	0	45	0	0/ 0	100/117	0/ 0	1	20	24	0	0	0	0	0	0	
2	(210,117)	1	420	0	0	50	-4	0/ 0	100/ 27	0/ 0	1	20	24	0	0	0	0	0	0	

LINK STATISTICS AT TIME 15 10 O

LINK TYPE	LINK	OCC.	VEH DIS	TURN MOVEMENT LEFT	THRU	RT.	CURRENT NUMBER OF VEHICLES IN LANE 1	2	3	4	5	6	7	8	6	DELAY/ VEH.	QUEUE DLY(P)	CYC FLR	SURFACE LINK CURRENT CHANNELIZATION					AVG SPEED	SIG CODE	LANE CHNG
FRWY	(701, 26)	5	780	0	780	0	2	2	1	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0.0	0	0
FRWY	(26, 27)	38	780	0	780	0	15	14	9	0	0	0	0	0	0	14.8	0	0	0	0	0	0	0	36.4	0	156
FRWY	(27, 28)	36	898	0	902	0	15	12	7	0	0	0	0	2	0	10.2	0	0	0	0	0	0	0	31.2	0	246
FRWY	(28, 29)	23	901	0	898	0	5	7	11	0	0	0	0	0	0	3.5	0	0	0	0	0	0	0	53.7	0	196
RAMP	(117, 27)	1	122	0	122	0	1	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	51.7	0	0
SURF	(836,210)	1	122	0	122	0	1	0	0	0	0	0	0	0	0	-0.1	0	0	0	0	0	0	0	0.0	1	0
SURF	(210,117)	1	122	0	122	0	1	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	47.8	1	0

CUMULATIVE OUTPUT AT TIME 15 10 0
FREEWAY LINK STATISTICS

L	LINK	VEH OUT	LANE CHNG	CURR CONT	AVG CONT	VEH-MILES	VEH-MIN	SECONDS/VEHICLE TOTAL TIME	SECONDS/VEHICLE MOVE TIME	SECONDS/VEHICLE DELAY TIME	M/T	VEH-MIN/VEH-MILE TOTAL	VEH-MIN/VEH-MILE DELAY	VOLUME VEH/LN/HR	DENSITY VEH/LN-MILE	SPEED MILE/HR
2	(26, 27)	780	156	38	37.7	228.75	376.72	29.5	14.5	15.0	0.49	1.65	0.84	1531.	42.0	36 4
3	(27, 28)	898	246	36	27.7	144.14	277.32	18.6	8.3	10.2	0.45	1.92	1.06	1628.	52.2	31.2
4	(28, 29)	901	196	23	19.1	170.97	191.00	12.7	9.2	3.5	0.73	1.12	0.31	1807.	33.6	53.7
AVERAGES AND TOTALS			598	97	84.5	543.87	845.04				0.53	1.55	0.73	1635.	42.3	38.6

NETWORK STATISTICS INCLUDING RAMP AND SURFACE LINKS

VEHICLE-MILES = 559.09, VEHICLE-MINUTES = 863.63, MOVING/TOTAL TRIP TIME =0.539,

AVERAGE CONTENT = 86.4, CURRENT CONTENT = 99, SPEED(MPH) = 38.84,

TOTAL DELAY(VEH-MIN) = 397.86, TRAVEL TIME(MIN)/VEH-MILE = 1.54, DELAY TIME(MIN)/VEH-MILE = 0.71

MSU

** 6295 **

TRAFFIC

ABDUL HAMAD

TECH SERVICES

CARD DATA LIST

```
SCANDI EAST BOUND FORD FREEWAY - FREEWAY ONLY                     10  2         0
   WYOMING THROUGH MOROSS (780-790)-RAMP METERS OFF             1200 00    150000 1
780  1     3753         2                                                       2
  1  2 28003753         3                                                       2
  2  3  7403753         4                                                       2
  3  4 25903753         69     64  7                                            2
  4 69 10003753 -1      5                                                       2
 69  5 21003753         6                                                       2
  5  6  2403753         7                                                       2
  6  7 10003753 +1      8169 89 10                                              2
  7  8 15003753 -1      9                                                       2
  8  9 18503753         10     78 13                                            2
  9 10  5003753 +1      11172                                                   2
 10 11 10753753         12                                                      2
 11 12  3553753         13                                                      2
 12 13  3003753     175 14     30 16                                            2
 13 14 15003753         15                                                      2
 14 15  5303753         16                                                      2
 15 16  4003753         17179                                                   2
 16 17 15203753         18180   1 17                                            2
 17 18  7253753         19                                                      2
 18 19  6703753         20                                                      2
 19 20  8503753         68     53 22                                            2
 20 68 15003753 +2      21                                                      2
 68 21  3003753 -2      22                                                      2
 21 22  4403753         23185   1 23                                            2
 22 23 15203753 +2      24186   1 24                                            2
 23 24  5003753 +2187 25       50 28                                            2
 24 25 15503753         26                                                      2
 25 26  1253753         27                                                      2
 26 27 10003753         28                                                      2
 27 28  3603753         29190 27 29                                             2
 28 29 23753753         30191 85 32                                             2
 29 30  5753753         31                                                      2
 30 31  4003753         32                                                      2
 31 32  4803753         33194                                                   2
 32 33  6603753         34     14 35                                            2
 33 34 10703753 -3      35                                                      2
 34 35 10003753 -3      36196                                                   2
 35 36 10403753         37                                                      2
 36 37  8903753         38     10 39                                            2
 37 38 10003753         39                                                      2
 38 39  8403753         40199                                                   2
 39 40 16903753 +4      41      0 43                                            2
 40 41  7553753 -1      42                                                      2
 41 42 16503753 +1      43                                                      2
 42 43 10253753         44202                                                   2
 43 44 16253753         45      0 46                                            2
 44 45 19253753         46                                                      2
 45 46 10803753 -1      47205                                                   2
 46 47  8703753         48      0 49                                            2
 47 48  7503753         49                                                      2
 48 49  6003753 -1      50208                                                   2
 49 50 18003753 -1      51     30 52                                            2
 50 51  3003753 -1      52                                                      2
 51 52 10803753 +1      53211                                                   2
 52 53  2703753 +1      54                                                      2
 53 54  8703753 -1      55     28 58                                            2
 54 55 16603753 +2      56                                                      2
 55 56 10803753         57                                                      2
 56 57 10003753 -2      58                                                      2
 57 58  9103753 +1      59214                                                   2
 58 59 35303753         60     12 61                                            2
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59 60	11803753		61	2
60 61	10003753		62217 88 62	2
61 62	38403753		63218 65 65	2
62 63	16303753		64	2
63 64	10003753		65	2
64,65	9703753		66221	2
65 66	19303753		67	2
66 67	3003753		790	2
801160	1451		161	2
160161	3201501	-4	2	2
161 2	2702551	-4	3	2
802162	1451		163	2
162163	3201501	-4	3	2
163 3	2302551	-4	4	2
803164	1451		165	2
804164	1451		165	2
164165	3001501	-3	4	2
165 4	2702551	-3	69	2
805166	1451		167	2
806166	1451		167	2
166167	2801501	-4	5	2
167 5	2502551	-4	6	2
7169	5802551	+4	807	2
808170	1451		171	2
170171	2601501	-4	8	2
171 8	2102551	-4	9	2
10172	4502551	+4	809	2
810173	1451		174	2
173174	3251501	-4	11	2
174 11	2402551	-4	12	2
13175	2402551	+3	176	2
175176	5701501	+3	811	2
812177	1451		178	2
177178	3801501	-4	14	2
178 14	2002551	-4	15	2
16179	7402552	+3	813	2
17180	8002551	+3	815	2
816230	1551		181	2
230181	6801551		18	2
181 18	3002551		19	2
817231	1551		182	2
231182	1900155l		19	2
182 19	3102551	-3	20	2
818183	1451		184	2
183184	2501501	-5	20	2
184 20	2602551	-5	68	2
850224	1451		225	2
224225	1501501	-4	68	2
225 68	1002551	-4	21	2
22185	5702551	+4	819	2
23186	9002551	+3	820	2
24187	12002551	+4	821	2
822232	1551		188	2
232188	11001551	-2	25	2
188 25	2502551	-3	26	2
823233	1551		189	2
233189	10001551	-3	26	2
189 26	3002551	-4	27	2
28190	4402551	+3	824	2
29191	5002552	+3	825	2
851192	1552		193	2
192193	3251552	-3	30	2
193 30	2002552	-3	31	2
32194	3402551	+2	827	2
828237	1451		195	2
237195	2001501	-3	33	2

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195 33   200255 1  3       34                                                                        2
 35 96   650255 1 +3      830                                                                        2
831197       145 1        198                                                                        2
197198   200150 1 -2       37                                                                        2
198 37   250255 1 -2       38                                                                        2
 39199   520255 1 +3      832                                                                        2
833200       145 1        201                                                                        2
200201   280150 1 -2       40                                                                        2
201 40   240255 1 -2       41                                                                        2
 43202   460255 1 +2      834                                                                        2
835203       145 1        204                                                                        2
203204   380150 1 -2       44                                                                        2
204 44   260255 1 -2       45                                                                        2
 46205  1100255 1 +2      836                                                                        2
837206       145 1        207                                                                        2
206207   660150 1 -2       47                                                                        2
207 47   280255 1 -2       48                                                                        2
 49208   530255 1 +3      838                                                                        2
839209       145 1        210                                                                        2
209210   450150 1 -3       50                                                                        2
210 50   260255 1 -3       51                                                                        2
 52211   450255 1 +3      840                                                                        2
842212       145 1        213                                                                        2
212213   380150 1 -4       54                                                                        2
213 54   270255 1 -4       55                                                                        2
 58214   625255 1 +2      843                                                                        2
844215       145 1        216                                                                        2
215216   250150 1 -4       59                                                                        2
216 59   250255 1 -4       60                                                                        2
 61217   480255 1 +4      845                                                                        2
 62218   640255 1 +3      846                                                                        2
847219       145 1        220                                                                        2
219220   500150 1 -2       63                                                                        2
220 63   150255 1 -2       64                                                                        2
 65221   440255 1 +4      848                                                                        2
849222       145 1        223                                                                        2
222223   300150 1 -3       66                                                                        2
223 66   290255 1 -3       67                                                                        2
780  1                          1          0 21 22      2  380        1          0 4
  1  2                          1          0 22 23      2  325        1          0 4
  2  3        1  200            1          0 23 24      6  100        1          0 4
  3  4        1  300            1          0 24 25                    1          0 4
  4 69        1  300            1          0 25 26      1  123        1          0 4
 69  5   5729                   1    2     0 26 27      1  400        1          0 4
  5  6        1  240            1          0 27 28      2  125        1          0 4
  6  7        2  250            1          0 28 29      2  200        1          0 4
  7  8                          1          0 29 30                    1          0 4
  8  9  29601    250            1    3     0 30 31      1  400        1          0 4
  9 10        2  150            1          0 31 32      2  480        1          0 4
 10 11                          1          0 32 33                    1          0 4
 11 12  57001    200            1    2     0 33 34      1  250        1          0 4
 12 13  57005    250            1    2     0 34 35      2  200        1          0 4
 13 14                          1          0 35 36                    1          0 4
 14 15        1  200            1          0 36 37                    1          0 4
 15 16        2  300            1          0 37 38      1  200        1          0 4
 16 17        2  200            1          0 38 39      2  250        1          0 4
 17 18                          1          0 39 40  2292              1    4     0 1
 18 19        1  200            1          0 40 41      1  280        1          0 4
 19 20        1  300            1          0 41 42  1810              1    4     0 4
 20 68        1  150            1          0 42 43      2  250        1          0 4
 68 21        1  300            1          0 43 44  3820              1    2     0 4
 44 45        1  225            1          0 45 46      2  325        1          0 4
 46 47                          1          0 47 48 52081   250        1    2     0 4
 48 49  52082    200            1    2     0 48 50                    1          0 4
 50 51  28651    300            1    3     0 51 52 28652   260        1    3     0 4
 52 53                          1          0 53 54                    1          0 4
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 54 55       1  250        1          0 55 56                      1        0 4
 56 57                     1          0 57 58  28652  300          1    3   0 4
 58 59                     1          0 59 60      1  350          1        0 4
 60 61  28652  200         1    3     0 61 62      2  200          1        0 4
 62 63                     1          0 63 64  57301  300          1    2   0 4
 64 65  38202  225         1    2     0 65 66                      1        0 4
 66 67      1  300         1          0                                       4
161  2      8                           22185 22  1                           5
163  3      8                           23186 22  1   395 6                   5
165  4      8                           24187 22  1  2660 2                   5
167  5      8                          188 25     8   395 6                   5
  7169 22'  1   16210                  189 26     8  2660 2                   5
171  8      8   11010                   28190 22  1                           5
 10172 22   1                           29191 22  1                           5
174 11      8                          193 30     8                           5
 13175 22   1                           32194 22  1                           5
178 14      8                          195 33     8                           5
 16179 22   1                           35196 22  1                           5
 17180 22   1                          198 37     8                           5
181 18      8                           39199 22  1                           5
182 19      8                          201 40     8                           5
184 20      8                           43202 22  1                           5
225 68      8   740 8                  204 44     8                           5
 46205 22   1   170 7                                                         5
207 47      8   220 7                   49208 22  1                           5
210 50      8                           52211 22  1                           5
213 54      8                           58214 22  1                           5
216 59      8                           61217 22  1                           5
 62218 22   1                          220 63     8                           5
 65221 22   1                          223 66     8                           5
801160 24 20                           822232 24 20                           6
160161 24 20                           823233 24 20                           6
802162 24 20                           851192 24 20                           6
162163 24 20                           192193 24 20                           6
803164 24 20                           828237 24 20                           6
237195 24 20                                                                  6
804164 24 20                           831197 24 20                           6
164165 24 20                           197198 24 20                           6
806166 24 20                           833200 24 20                           6
805166 24 20                           200201 24 20                           6
166167 24 20                           835203 24 20                           6
808170 24 20                           203204 24 20                           6
170171 24 20                           837206 24 20                           6
810173 24 20                           206207 24 20                           6
173174 24 20                           839208 24 20                           6
812177 24 20                           209210 24 20                           6
177178 24 20                           842212 24 20                           6
175176 24 20                           212213 24 20                           6
818183 24 20                           844215 24 20                           6
183184 24 20                           215216 24 20                           6
850224 24 20                           847219 24 20                           6
224225 24 20                           219220 24 20                           6
816230 24 20                           849222 24 20                           6
817231 24 20                           222223 24 20                           6
230181 24 20                           231182 24 20                           6
232188 24 20                           233189 24 20                           6
780  1    100                                                                 8
  1  2    100  801160   100  160161   100   161  2   100                      8
  2  3    100  802162   100  162163   100   163  3   100                      8
  3  4    100  803164   100  164165   100   165 .4   100                      8
  4 69    100  804164   100                                                   8
 69  5    100  805166   100  166167   100   167  5   100                      8
  5  6    100  806166   100                                                   8
  6  7     91 9  7169   100                                                   8
  7  8    100  808170   100  170171   100   171  8   100                      8
  8  9    100                                                                 8
```

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 9 10     97  3 10172   100                                      8
10 11    100   810173   100   173174   100   174 11   100        8
11 12    100                                                     8
12 13  2 98     13175   100   175176   100                       8
13 14    100   812177   100   177178   100   178 14   100        8
14 15    100                                                     8
15 16     77 23 16179   100                                      8
16 17     98  2 17180   100                                      8
17 18    100   816230   100   230181   100   181 18   100        8
18 19    100   817231   100   231182   100   182 19   100        8
19 20    100   818183   100   183184   100   184 20   100        8
20 68    100   850224   100   224225   100   225 68   100        8
68 21    100                                                     8
21 22     98  2 22185   100                                      8
22 23     90 10 23186   100                                      8
23 24 17 83     24187   100                                      8
24 25    100   822232   100   232188   100   188 25   100        8
25 26    100   823233   100   233189   100   189 26   100        8
26 27    100                                                     8
27 28     97  3 28190   100                                      8
28 29     69 31 29191   100                                      8
29 30    100   851192   100   192193   100   193 30   100        8
30 31    100                                                     8
31 32     97  3 32194   100                                      8
32 33    100   828237   100   237195   100   195 33   100        8
33 34    100                                                     8
34 35     96  4 35196   100                                      8
35 36    100                                                     8
36 37    100   831197   100   197198   100   198 37   100        8
37 38    100                                                     8
38 39     94  6 39199   100                                      8
39 40    100   833200   100   200201   100   201 40   100        8
40 41    100                                                     8
41 42    100                                                     8
42 43     90 10 43202   100                                      8
43 44    100   835203   100   203204   100   204 44   100        8
44 45    100                                                     8
45 46     91  9 46205   100                                      8
46 47    100   837206   100   206207   100   207 47   100        8
47 48    100                                                     8
48 49     96  4 49208   100                                      8
49 50    100   839209   100   209210   100   210 50   100        8
50 51    100                                                     8
51 52     86 14 52211   100                                      8
52 53    100                                                     8
53 54    100   842212   100   212213   100   213 54   100        8
54 55    100                                                     8
55 56    100                                                     8
56 57    100                                                     8
57 58     85 15 58214   100                                      8
58 59    100   844215   100   215216   100   216 59   100        8
59 60    100                                                     8
60 61     92  8 61217   100                                      8
61 62     88 12 62218   100                                      8
62 63    100   847219   100   219220   100   220 63   100        8
63 64    100                                                     8
64 65     88 12 65221   100                                      8
65 66    100   849222   100   222223   100   223 66   100        8
66 67    100                                                     8
 1  0    780              1                                     10
 2  0       1161         10                                     10
 3  0       2163         10                                     10
 4  0       3165         10                                     10
69  0      4              1                                     10
 5  0     69167          10                                     10
 6  0      5              1                                     10
```

7	0	6	1	10
8	0	7171	10	10
9	0	8	1	10
10	0	9	1	10
11	0	10174	10	10
12	0	11	1	10
13	0	12	1	10
14	0	13178	10	10
15	0	14	1	10
16	0	15	1	10
17	0	16	1	10
18	0	17181	10	10
19	0	18182	10	10
20	0	19184	10	10
68	0	20225	10	10
21	0	68	1	10
22	0	21	1	10
23	0	22	1	10
24	0	23	1	10
25	0	24188	10	10
26	0	25189	10	10
27	0	26	1	10
28	0	27	1	10
29	0	28	1	10
30	0	29193	10	10
31	0	30	1	10
32	0	31	1	10
33	0	32195	1	10
34	0	33	1	10
35	0	34	1	10
36	0	35	1	10
37	0	36198	10	10
38	0	37	1	10
39	0	38	1	10
40	0	39201	10	10
41	0	40	1	10
42	0	41	1	10
43	0	42	1	10
44	0	43204	10	10
45	0	44	1	10
46	0	45	1	10
47	0	46207	10	10
48	0	47	1	10
49	0	48	1	10
50	0	49210	10	10
51	0	50	1	10
52	0	51	1	10
53	0	52	1	10
54	0	53213	10	10
55	0	54	1	10
56	0	55	1	10
57	0	56	1	10
58	0	57	1	10
59	0	58216	10	10
60	0	59	1	10
61	0	60	1	10
62	0	61	1	10
63	0	62220	10	10
64	0	63	1	10
65	0	64	1	10
66	0	65223	10	10
67	0	66	1	10
160	0	801	1	10
161	0	160	1	10
162	0	802	1	10
163	0	162	1	10

164	0	804803	10	10
165	0	164	1	10
166	0	806805	10	10
167	0	166	1	10
169	0	7	1	10
170	0	808	1	10
171	0	170	1	10
172	0	10	1	10
173	0	810	1	10
174	0	173	1	10
175	0	13	1	10
176	0	175	1	10
177	0	812	1	10
178	0	177	1	10
179	0	16	1	10
180	0	17	1	10
181	0	230	1	10
182	0	231	1	10
230	0	816	1	10
231	0	817	1	10
183	0	818	1	10
184	0	183	1	10
224	0	850	1	10
225	0	224	1	10
185	0	22	1	10
186	0	23	1	10
187	0	24	1	10
188	0	232	1	10
189	0	233	1	10
232	0	822	1	10
233	0	823	1	10
190	0	28	1	10
191	0	29	1	10
192	0	851	1	10
193	0	192	1	10
194	0	32	1	10
237	0	828	1	10
195	0	237	1	10
196	0	35	1	10
197	0	831	1	10
198	0	197	1	10
199	0	39	1	10
200	0	833	1	10
201	0	200	1	10
202	0	43	1	10
203	0	835	1	10
204	0	203	1	10
205	0	46	1	10
206	0	837	1	10
207	0	206	1	10
208	0	49	1	10
209	0	839	1	10
210	0	209	1	10
211	0	52	1	10
212	0	842	1	10
213	0	212	1	10
214	0	58	1	10
215	0	844	1	10
216	0	215	1	10
217	0	61	1	10
218	0	62	1	10
219	0	847	1	10
220	0	219	1	10
221	0	65	1	10
222	0	849	1	10
223	0	222	1	10

```
780   1   3041   5      7   2                                                          20
801160     300   5      2                                                              20
802162     601   5      3                                                              20
803164      50   5      2                                                              20
804164     153   5      4                                                              20
805166      50   5      2                                                              20
806166     148   5      2                                                              20
808170     403   5      3                                                              20
810173     204   5      5                                                              20
812177     426   5      2                                                              20
816230     421   5      8                                                              20
817231     327   5      5                                                              20
818183     235   5      6                                                              20
850224     108   5      6                                                              20
822232     950   5      4   2                                                          20
823233     648   5      5   2                                                          20
851192    1195   5      6   1                                                          20
828237     600   5     10                                                              20
831197     480   5     12                                                              20
833200     566   5     16                                                              20
835203     290   5      9                                                              20
837206     498   5      7                                                              20
839209     126   5      5                                                              20
842212     438   5      2                                                              20
844215     467   5      4                                                              20
847219     750   5      3                                                              20
849222     976   5      3                                                              20
  1  11   2  10  3   9  4   8   5   7   6   6   7   5   8   4   9   3  10   2          43
   3600900     900      900      900  0                                                60
```

CUMULATIVE OUTPUT AT TIME 4 0 0
RAMP AND SURFACE LINK STATISTICS

L	LINK	VEH OUT	CURR CONT	AVG CONT	VEH-MILES	VEH-MIN	SPEED MPH	SECONDS/VEHICLE TOTAL TIME	MOVE TIME	DELAY TIME	M/T	VEH-MIN/VEH-MILE TOTAL	DELAY	PERCENT QUEUE DELAY	AVG SAT PCT	CYCLE FAILURE	LINK TYPE
1	(161, 2)	300	0	0.3	15.34	17.78	51.8	3.6	3.4	0.1	0.96	1.16	0.04	0	0	0	RAMP
2	(163, 3)	601	1	0.5	26.20	30.54	51.5	3.0	2.9	0.1	0.96	1.17	0.05	0	0	0	RAMP
3	(165, 4)	203	1	0.2	10.39	13.40	46.5	4.0	3.5	0.5	0.88	1.29	0.15	0	0	0	RAMP
4	(167, 5)	198	0	0.2	9.38	12.53	44.9	3.8	3.2	0.6	0.84	1.34	0.21	0	0	0	RAMP
5	(7,169)	350	2	0.9	38.50	56.47	40.9	9.7	7.3	2.3	0.76	1.47	0.35	0	0	0	RAMP
6	(171, 8)	403	1	0.3	16.04	18.53	51.9	2.8	2.6	0.1	0.95	1.16	0.05	0	0	0	RAMP
7	(10,172)	139	0	0.3	11.85	20.24	35.1	8.7	5.8	2.9	0.67	1.71	0.57	0	0	0	RAMP
8	(174, 11)	204	0	0.2	9.27	10.79	51.5	3.2	3.0	0.1	0.95	1.16	0.05	0	0	0	RAMP
9	(13,175)	69	0	0.1	3.14	4.93	38.2	4.3	3.2	1.1	0.75	1.57	0.39	0	0	0	RAMP
10	(178, 14)	427	0	0.3	16.14	18.75	51.7	2.6	2.5	0.1	0.96	1.16	0.05	0	0	0	RAMP
11	(16,179)	804	4	3.1	113.00	187.70	36.1	14.0	9.5	4.5	0.68	1.66	0.53	0	4	0	RAMP
12	(17,180)	54	0	0.2	8.18	11.79	41.6	13.1	10.3	2.8	0.79	1.44	0.31	0	0	0	RAMP
13	(181, 18)	421	1	0.4	23.92	26.76	53.6	3.8	3.8	0.0	1.00	1.12	0.00	0	0	0	RAMP
14	(182, 19)	327	0	0.4	19.19	21.91	52.6	4.0	4.0	0.0	0.99	1.14	0.01	0	0	0	RAMP
15	(184, 20)	235	0	0.2	11.57	13.50	51.4	3.4	3.3	0.1	0.96	1.17	0.05	0	0	0	RAMP
16	(225, 68)	108	0	0.0	2.05	2.49	49.3	1.4	1.3	0.1	0.92	1.22	0.10	0	0	0	RAMP
17	(22,185)	69	0	0.2	7.45	10.34	43.2	9.0	7.2	1.8	0.80	1.39	0.28	0	0	0	RAMP
18	(23,186)	442	2	1.8	75.26	105.17	42.9	14.3	11.4	2.9	0.80	1.40	0.28	0	2	0	RAMP
19	(24,187)	500	1	3.1	113.23	187.71	36.2	22.6	15.5	7.1	0.68	1.66	0.52	0	5	0	RAMP
20	(188, 25)	949	0	1.9	44.53	113.79	23.5	7.3	3.2	4.1	0.44	2.56	1.44	67	8	0	RAMP
21	(189, 26)	649	0	0.7	36.83	43.12	51.2	4.0	3.8	0.2	0.95	1.17	0.06	0	0	0	RAMP
22	(28,190)	114	1	0.3	9.57	17.58	32.7	9.2	5.6	3.6	0.61	1.84	0.72	0	0	0	RAMP
23	(29,191)	1453	1	4.6	137.56	273.83	30.1	11.3	6.4	4.9	0.56	1.99	0.87	0	8	0	RAMP
24	(193, 30)	1195	2	0.9	45.30	52.00	52.3	2.6	2.5	0.1	0.97	1.15	0.03	0	0	0	RAMP
25	(32,194)	107	0	0.2	6.89	10.36	39.9	5.8	4.5	1.4	0.77	1.50	0.35	0	0	0	RAMP
26	(195, 33)	600	1	0.4	22.73	26.76	51.0	2.7	2.6	0.1	0.95	1.18	0.05	0	0	0	RAMP
27	(35,196)	204	0	0.6	25.11	34.98	43.1	10.3	8.2	2.1	0.80	1.39	0.28	0	0	0	RAMP
28	(198, 37)	480	1	0.5	22.73	27.47	49.7	3.4	3.2	0.2	0.93	1.21	0.09	0	0	0	RAMP
29	(39,199)	312	0	0.8	30.69	45.08	40.9	8.7	6.5	2.2	0.75	1.47	0.37	0	0	0	RAMP
30	(201, 40)	566	0	0.5	25.73	30.52	50.6	3.2	3.0	0.2	0.94	1.19	0.07	0	0	0	RAMP

31	(43,202)	516	0	1.2	44.95	71.51	37.7	8.3	5.9	2.1	0.71	1.59	0.46	0	4	0	RAMP
32	(204, 44)	290	0	0.3	14.28	16.84	50.9	3.5	3.3	0.2	0.94	1.18	0.07	0	0	0	RAMP
33	(46,205)	458	4	2.2	95.80	130.56	41.0	17.0	14.0	3.1	0.82	1.36	0.25	0	4	0	RAMP
34	(207, 47)	499	0	0.5	26.42	31.10	51.0	3.7	3.6	0.2	0.95	1.18	0.06	0	0	0	RAMP
35	(49,208)	184	0	0.5	18.47	28.97	38.3	9.4	6.8	2.7	0.72	1.57	0.44	0	0	0	RAMP
36	(210, 50)	126	1	0.1	6.19	7.06	52.7	3.4	3.3	0.1	0.97	1.14	0.03	0	0	0	RAMP
37	(52,211)	643	0	1.4	54.80	85.86	38.3	8.0	5.8	2.3	0.72	1.57	0.44	0	4	0	RAMP
38	(213, 54)	438	1	0.4	22.38	25.90	51.8	3.6	3.5	0.1	0.98	1.16	0.03	0	0	0	RAMP
39	(58,214)	685	1	2.1	81.19	125.34	38.9	11.0	8.0	2.9	0.73	1.54	0.41	0	6	0	RAMP
40	(216, 59)	467	0	0.4	22.11	25.47	52.1	3.3	3.1	0.1	0.96	1.15	0.05	0	0	0	RAMP
41	(61,217)	364	2	0.8	33.20	50.37	39.6	8.3	6.2	2.1	0.74	1.52	0.39	0	0	0	RAMP
42	(62,218)	512	1	1.6	62.06	98.62	37.8	11.6	8.1	3.4	0.70	1.59	0.47	0	3	0	RAMP
43	(220, 63)	750	0	0.4	21.31	25.87	49.4	2.1	1.9	0.2	0.92	1.21	0.10	0	0	0	RAMP
44	(65,221)	551	1	1.2	45.90	73.32	37.6	8.0	5.6	2.4	0.70	1.60	0.48	0	5	0	RAMP
45	(223, 66)	976	0	1.1	53.61	65.75	48.9	4.0	3.7	0.4	0.91	1.23	0.11	0	7	0	RAMP
2	(160,161)	300	1	0.4	18.19	23.08	47.3	4.6	4.5	0.1	0.98	1.27	0.02	0	0	0	SURFACE
4	(162,163)	601	1	0.8	36.42	46.36	47.1	4.6	4.6	0.1	0.98	1.27	0.02	0	0	0	SURFACE
7	(164,165)	204	1	0.3	11.56	20.41	34.0	6.0	4.3	1.7	0.71	1.77	0.81	0	0	0	SURFACE
10	(166,167)	198	1	0.3	10.50	19.53	32.3	5.9	4.0	1.9	0.67	1.86	0.61	0	0	0	SURFACE
12	(170,171)	404	0	0.4	19.87	25.16	47.4	3.7	3.7	0.1	0.98	1.27	0.03	0	0	0	SURFACE
14	(173,174)	204	1	0.3	12.56	15.87	47.5	4.7	4.6	0.1	0.98	1.26	0.02	0	0	0	SURFACE
15	(175,176)	69	0	0.2	7.45	10.85	41.2	9.4	8.5	1.0	0.90	1.46	0.15	0	0	0	SURFACE
17	(177,178)	426	0	0.6	30.66	38.50	47.8	5.4	5.4	0.1	0.99	1.26	0.02	0	0	0	SURFACE
19	(230,181)	421	0	1.0	54.20	60.78	53.5	8.7	8.7	0.0	1.00	1.12	0.00	0	3	0	SURFACE
21	(231,182)	326	2	2.2	117.62	132.84	53.1	24.4	24.4	0.0	1.00	1.13	0.00	0	2	0	SURFACE
23	(183,184)	235	0	0.2	11.13	14.32	46.6	3.7	3.6	0.1	0.98	1.29	0.03	0	0	0	SURFACE
25	(224,225)	108	0	0.1	3.07	4.04	45.6	2.2	2.2	0.1	0.96	1.32	0.05	0	0	0	SURFACE
27	(232,188)	948	6	4.3	198.03	257.97	46.1	16.3	14.0	2.3	0.86	1.30	0.18	28	7	0	SURFACE
29	(233,189)	648	2	2.3	122.62	140.29	52.4	13.0	12.6	0.4	0.97	1.14	0.03	0	4	0	SURFACE
31	(192,193)	1195	2	1.4	73.60	83.07	53.2	4.2	4.1	0.0	0.99	1.13	0.01	0	3	0	SURFACE
33	(237,195)	600	0	0.5	22.73	29.29	46.6	2.9	2.8	0.1	0.97	1.29	0.03	0	0	0	SURFACE
35	(197,198)	480	0	0.4	18.18	23.96	45.5	3.0	2.8	0.2	0.94	1.32	0.07	0	0	0	SURFACE
37	(200,201)	566	1	0.6	30.03	38.70	46.6	4.1	3.9	0.2	0.96	1.29	0.05	0	0	0	SURFACE

39	(203,204)	290	0	0.4	20.87	26.80	46.7	5.5	5.4	0.2	0.97	1.28	0.04	0	0	0	SURFACE
41	(206,207)	498	1	1.3	62.25	79.20	47.2	9.5	9.4	0.2	0.98	1.27	0.02	0	3	0	SURFACE
43	(209,210)	126	0	0.2	10.74	13.38	48.1	6.4	6.3	0.1	0.99	1.25	0.02	0	0	0	SURFACE
45	(212,213)	438	0	0.7	31.52	40.07	47.2	5.5	5.4	0.1	0.99	1.27	0.02	0	0	0	SURFACE
47	(215,216)	467	1	0.5	22.11	27.97	47.4	3.6	3.5	0.1	0.98	1.26	0.03	0	0	0	SURFACE
49	(219,220)	750	3	1.5	71.01	91.34	46.6	7.3	7.0	0.3	0.96	1.29	0.05	0	4	0	SURFACE
51	(222,223)	976	2	1.2	55.43	74.94	44.4	4.6	4.2	0.4	0.92	1.35	0.11	0	7	0	SURFACE
AVERAGES AND TOTALS			55	60.8	2612.77	3648.05	43.0				0.82	1.40	0.25	8	0	0	

32 (29, 30)	4099	241	23	8.3	443.96	498.30	7.3	5.2	2.1	0.72	1.12	0.32	1364	25.5	53.5
33 (30, 31)	5295	887	21	8.5	405.69	508.74	5.7	3.7	2.0	0.64	1.25	0.45	1342	28.1	47.8
34 (31, 32)	5272	585	45	11.1	475.33	665.15	7.6	4.4	3.2	0.58	1.40	0.59	1307.	30.5	42.9
35 (32, 33)	5147	577	45	19.6	633.30	1178.08	14.0	6.0	7.9	0.43	1.86	1.06	1689.	52.4	32.3
36 (33, 34)	5684	1880	74	50.6	1136.15	3037.32	32.4	9.8	22.7	0.30	2.67	1.87	1737	77.4	22.4
37 (34, 35)	5651	1310	55	53.3	1053.84	3195.15	31.4	9.2	25.2	0.27	3.03	2.22	1742	88.0	19.8
38 (35, 36)	5420	1248	65	60.8	1045.88	3648.78	41.2	9.5	31.7	0.23	3.49	2.68	1773.	103.1	17.2
39 (36, 37)	5405	1745	76	60.6	892.08	3634.40	41.1	8.1	33.0	0.20	4.07	3.27	1768	120.1	14.7
40 (37, 38)	5862	2426	66	59.3	1089.95	3558.45	36.7	9.2	27.5	0.25	3.24	2.43	1818.	98.0	18.5
41 (38, 39)	5826	1825	58	48.7	918.76	2923.35	30.4	7.7	22.7	0.25	3.18	2.37	1752	92.9	18.9
42 (39, 40)	5490	3645	90	100.0	1723.12	6000.53	66.8	15.6	51.3	0.23	3.48	2.67	1796	104.2	17.2
43 (40, 41)	6055	2272	40	35.9	866.11	2151.62	21.3	6.9	14.3	0.33	2.48	1.67	1802	74.6	24.2
44 (41, 42)	6065	1471	44	46.7	1894.44	2804.08	27.8	15.2	12.6	0.55	1.48	0.67	2021.	49.9	40.5
45 (42, 43)	6054	1385	25	24.9	1171.47	1496.62	14.9	9.4	5.4	0.63	1.28	0.47	1864.	39.7	47.0
46 (43, 44)	5545	968	26	30.6	1699.99	1837.72	19.9	14.9	5.0	0.75	1.08	0.27	1843	33.2	55.5
47 (44, 45)	5835	1561	47	39.2	2114.02	2352.73	24.3	17.7	6.6	0.73	1.11	0.30	1862.	34.5	53.9
48 (45, 46)	5846	1390	7	23.9	1187.07	1436.03	14.8	9.9	4.9	0.67	1.21	0.40	1759.	35.5	49.6
49 (46, 47)	5410	360	1	16.0	887.49	962.42	10.7	8.0	2.7	0.74	1.08	0.28	1795.	32.4	55.3
50 (47, 48)	5917	1027	13	17.6	838.41	1058.37	10.8	6.9	3.9	0.64	1.27	0.46	1767.	37.3	47.4
51 (48, 49)	5916	816	12	13.7	669.05	822.57	8.4	5.5	2.9	0.66	1.23	0.42	1768.	36.2	48.8
52 (49, 50)	5712	878	53	34.4	1944.18	2061.25	21.7	16.5	5.2	0.76	1.06	0.25	1901.	33.6	56.6
53 (50, 51)	5834	279	6	6.3	327.69	377.46	3.9	2.8	1.2	0.70	1.15	0.34	1442.	27.7	52.1
54 (51, 52)	5822	2076	24	25.7	1181.85	1539.82	16.0	10.0	6.0	0.62	1.30	0.49	1784.	38.7	46.1
55 (52, 53)	5176	147	6	5.4	264.46	326.80	3.8	2.5	1.3	0.65	1.24	0.43	1724.	35.5	48.6
56 (53, 54)	5162	444	22	16.7	849.59	1002.95	11.7	7.9	3.7	0.68	1.18	0.38	1719.	33.8	50.8
57 (54, 55)	5589	1640	39	36.5	1752.92	2188.86	23.5	15.3	8.2	0.65	1.25	0.44	1771.	36.9	48.1
58 (55, 56)	5598	726	20	22.4	1141.57	1343.82	14.4	10.0	4.5	0.69	1.18	0.36	1860.	36.5	51.0
59 (56, 57)	5603	570	20	19.2	1056.89	1154.67	12.4	9.2	3.2	0.74	1.09	0.28	1862.	33.9	54.9
60 (57, 58)	5607	1717	18	19.5	955.84	1169.35	12.6	8.4	4.2	0.66	1.22	0.41	1667.	34.0	49.0
61 (58, 59)	4924	1613	47	55.7	3287.23	3344.97	10.8	32.2	8.6	0.79	1.02	0.22	1640.	27.8	59.0
62 (59, 60)	5375	1140	26	21.9	1196.68	1313.23	14.7	10.8	3.9	0.73	1.10	0.29	1626.	29.7	54.7
63 (60, 61)	5367	1233	26	19.8	1009.30	1186.13	13.3	9.2	4.2	0.69	1.18	0.37	1668.	32.7	51.1
64 (61, 62)	4988	2853	79	64.0	3820.87	3842.50	16.3	35.0	11.3	0.76	1.06	0.26	1632.	28.9	56.5

CUMULATIVE OUTPUT AT TIME 4. 0. 0
FREEWAY LINK STATISTICS

L	LINK	VEH OUT	LANE CHNG	CURR CONT	AVG CONT	VEH-MILES	VEH-MIN	SECONDS/VEHICLE TOTAL TIME	MOVE TIME	DELAY TIME	M/T	VEH-MIN/VEH-MILE TOTAL	DELAY	VOLUME VEH/LN/HR	DENSITY VEH/LN-MILE	SPEED MILE/HR
2	(1, 2)	3044	469	22	22.5	1608.87	1352.15	26.7	25.9	0.9	0.97	0.84	0.03	1012.	14.2	71.4
3	(2, 3)	3344	625	6	7.3	467.23	436.41	7.8	6.8	1.0	0.87	0.93	0.12	1023.	15.9	64.2
4	(3, 4)	3942	1837	33	31.3	1933.00	1876.59	28.6	23.9	4.6	0.84	0.97	0.16	1265.	20.5	61.8
5	(4, 69)	4160	792	4	12.8	784.68	768.65	11.1	9.3	1.9	0.83	0.98	0.16	1257.	20.5	61.3
6	(69, 5)	4148	1088	32	26.4	1648.41	1585.33	23.0	19.5	3.5	0.85	0.96	0.15	1382.	22.1	62.4
7	(5, 6)	4352	297	0	3.4	187.23	205.16	2.8	2.2	0.6	0.78	1.04	0.22	1085.	18.8	57.7
8	(6, 7)	4347	1305	19	15.0	817.98	898.82	12.5	9.3	3.2	0.74	1.10	0.28	1331.	24.4	54.6
9	(7, 8)	3998	689	21	19.0	1132.30	1140.03	17.2	13.9	3.3	0.81	1.01	0.18	1329.	22.3	59.6
10	(8, 9)	4402	1426	19	26.0	1539.39	1558.58	21.3	17.1	4.2	0.80	1.01	0.20	1403.	23.7	59.3
11	(9, 10)	4400	568	8	7.2	412.50	432.52	5.9	4.6	1.3	0.77	1.05	0.24	1325.	23.2	57.2
12	(10, 11)	4255	383	20	14.2	864.80	853.12	12.0	9.9	2.2	0.82	0.99	0.18	1417.	23.3	60.8
13	(11, 12)	4460	354	4	5.2	298.60	311.62	4.2	3.3	0.9	0.78	1.04	0.23	1255.	21.8	57.7
14	(12, 13)	4465	322	3	4.3	252.31	256.23	3.5	2.8	0.7	0.80	1.02	0.20	1159.	19.6	59.1
15	(13, 14)	4406	871	21	21.1	1243.17	1267.95	17.4	14.0	3.4	0.81	1.02	0.20	1459.	24.8	58.8
16	(14, 15)	4830	866	15	10.6	479.71	635.60	7.9	4.9	3.0	0.62	1.32	0.50	1421.	31.4	45.3
17	(15, 16)	4832	1777	6	8.1	361.41	484.38	6.1	3.7	2.4	0.61	1.34	0.52	1275.	28.5	44.8
18	(16, 17)	4022	976	12	20.9	1155.71	1255.73	18.7	13.9	4.8	0.74	1.09	0.28	1284.	23.3	55.2
19	(17, 18)	3972	258	4	8.9	544.29	534.87	8.1	6.6	1.5	0.82	0.98	0.18	1325.	21.7	61.1
20	(18, 19)	4386	846	16	10.1	556.54	608.79	8.3	6.1	2.2	0.74	1.09	0.29	1333.	24.3	54.9
21	(19, 20)	4718	954	8	13.6	756.27	818.54	10.4	7.8	2.7	0.75	1.08	0.28	1403.	25.3	55.4
22	(20, 68)	4946	1234	35	26.0	1403.36	1560.10	18.9	13.8	5.1	0.73	1.11	0.30	1593.	29.5	54.0
23	(68, 21)	5048	251	7	5.2	286.43	311.76	3.7	2.8	0.9	0.74	1.09	0.28	1260.	22.9	55.1
24	(21, 22)	5042	387	14	7.7	416.33	461.20	5.5	4.0	1.5	0.73	1.11	0.29	1299.	24.0	54.2
25	(22, 23)	4973	2032	19	27.8	1418.76	1670.15	20.3	13.9	6.4	0.69	1.18	0.37	1536.	30.1	51.0
26	(23, 24)	4539	1401	4	9.5	423.59	570.47	7.6	4.5	3.1	0.59	1.35	0.55	1404.	31.5	44.6
27	(24, 25)	4061	1472	20	31.9	1173.47	1912.47	28.7	14.2	14.5	0.49	1.63	0.83	1334.	36.2	36.8
28	(25, 26)	5016	1320	7	8.8	116.75	527.13	6.3	1.1	5.2	0.18	4.52	3.72	1253.	94.3	13.3
29	(26, 27)	5673	2332	31	31.3	1076.69	1880.98	19.8	9.2	10.7	0.46	1.75	0.94	1674.	48.7	34.3
30	(27, 28)	5688	556	2	9.0	384.67	540.07	5.7	3.3	2.4	0.57	1.40	0.60	1688.	39.5	42.7
31	(28, 29)	5559	4641	45	55.4	2488.11	3324.32	36.0	21.7	14.3	0.60	1.34	0.53	1795.	40.0	44.9

65	(62, 63)	4476	900	21	23.5	1376.85	1407.05	18.9	14.9	4.0	0.79	1.02	0.22	1488.	25.3	58.7
66	(63, 64)	5219	1461	27	19.8	985.88	1185.53	13.7	9.2	4.5	0.67	1.20	0.40	1579.	31.6	49.9
67	(64, 65)	5230	1466	7	19.1	953.36	1143.93	13.2	8.9	4.3	0.67	1.20	0.39	1607.	32.1	50.0
68	(65, 66)	4675	920	33	33.6	1700.20	2013.13	26.0	17.5	8.4	0.67	1.18	0.39	1551.	30.6	50.7
69	(66, 67)	5640	1677	18	16.6	322.59	998.05	10.5	2.7	7.8	0.26	3.09	2.30	1419.	73.2	19.4
AVERAGES AND TOTALS			81688	1781	1690	271325.64	********				0.57	1.42	0.61	1571.	37.2	42.2

NETWORK STATISTICS INCLUDING RAMP AND SURFACE LINKS

VEHICLE-MILES =73938.41, VEHICLE-MINUTES =********, MOVING/TOTAL TRIP TIME =0.577,

AVERAGE CONTENT = 1751.0, CURRENT CONTENT = 1836. SPEED(MPH) = 42.23,

TOTAL DELAY(VEH-MIN) =44399.56, TRAVEL TIME(MIN)/VEH-MILE = 1.42, DELAY TIME(MIN)/VEH-MILE = 0.60

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END : S295

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