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ANALYZING THE FREQ3CP
FREEWAY OPERATIONS SIMULATION MODEL

by

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Research Report Number 210-3
Evaluation of Urban Freeway Modifications

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ABSTRACT

This report is intended to more thoroughly describe the FREQ3CP freeway simulation and priority ramp control computer program and its application on Interstate Highway 10 West in Houston, Texas. A procedure for obtaining the freeway and ramp traffic operations data (speeds and volumes) is described along with the presentation of the traffic data in its computer program compatible form. The calibrated computer program model of the peak period freeway traffic operations for both the AM inbound and PM outbound directions is obtained when the simulation program results approximate the field measured traffic data. The background information for the implementation of an economic analysis computer program was collected, updated and structured. Travel time, vehicle operating and accident costs were selected to be implemented along with fuel consumption and pollution emission data for Texas facilities.

Key Words: Freeway Operations Simulation, Calibrated Computer Model and Economic Measures

DISCLAIMER

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

SUMMARY

During the investigation into the inner functions of the FREQ3CP computer model for simulating freeway traffic operations, it was necessary to also investigate the other various activities associated with the process of collecting field data, preparing the diversified input parameters and analyzing the freeway simulation results. Studies into the merging, diverging, weaving and queueing analysis portions of the simulation model can be aided by referencing the 1965 Highway Capacity Manual but must be buffered with the basic assumptions and constraints imposed by the program's authors. While the FREQ3CP computer program models freeway congestion by accepted engineering methods, it was evident that users of the program can distort the program results by the choice of subsectional capacities and the Origin-Destination (O-D) input data.

Not all users will have well founded O-D data for every facility for which FREQ3CP could be used. A means of supplying this O-D data was provided in a synthetic method by a separate computer program, SYNODM. Given the demand data at each entry and exit point along the freeway system, the program synthesizes an O-D matrix such that total inputs and outputs are equal. While this scheme is intuitive in nature, it does provide data that are based on actual demand and the output can be used as direct input into the FREQ3CP program. The conformity of the simulated results and field measurements will be more closely assured and more confidence can be placed in the after studies, provided the user insures that the basic input information (primarily the O-D and subsectional capacities data) are accurate.

A method is demonstrated for presenting the simulated results and the

field measured data in a straight-forward manner. This method emphasizes the importance of the congested flow of traffic, i.e. traffic movement resulting from conditions where demand exceeds capacity. If the demand greatly exceeds the capacity over a period of time, then a congested queue of traffic will be formed and propagate upstream from the over-capacity area of freeway. It is this congestion that is important. The user can adjust capacities, O-D information or other program parameters that cause changes in the simulated congestion pattern, knowing that whenever an approximate conformity is reached with the field measured congestion pattern, a calibrated model has been derived. Also, the existence of a calibrated model will depend upon travel times and exit ramp flow being within reasonable limits.

Interstate Highway (I.H.) 10 West (Katy Freeway) in Houston, Texas, was chosen as a site on which the FREQ3CP simulation could be tested. Volume data were taken and converted by the SYNODM program. The inbound direction required 15 computer runs before calibration was reached while only 8 runs were used for the outbound direction. The additional required tests for calibration were conducted on travel times and exit ramp flows and no great discrepancies existed.

Detailed work was undertaken and completed to update the economic factors for time, vehicle operations, fuel consumption, air pollution emissions and accident data. These data are needed for a new program, ECOANA, which will provide economic measures based on the FREQ3CP simulated traffic operations. The engineer will be able to compare before and after economic measures thus enhancing the ability to provide realistic benefit-to-cost information.

IMPLEMENTATION STATEMENT

The FREQ3CP freeway traffic operations simulation and priority ramp control computer program is currently being used by the SDHPT to analyze the present peak period freeway traffic operations on Houston urban freeways. The program can be efficiently used to provide information that is needed in developing benefit/cost figures when investigating geometric improvements or entrance ramp control measures that alleviate peak period freeway congestion.

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GENERAL INFORMATION

PROBLEM DESCRIPTION

Congestion occurs when vehicular demand exceeds freeway capacity on some segment of a facility for a period of time. To eliminate congestion, two possible solutions are available: increase capacity in the bottle-neck section or reduce vehicular demand. In many cases, increasing capacity provides only a temporary solution. The reduced congestion has a tendency to encourage more vehicular demand by drawing more vehicles from the surrounding street system, thus creating an even more congested facility. Reducing vehicular demand by limiting access onto the freeway system tends to spread the excess demand to other time periods and parallel alternate routes. Another manner in which vehicular demand can be reduced is by increasing car pool usage and bus ridership. This may be accomplished by assigning priority lanes to multi-passenger vehicles and providing special bypass treatment at entrance ramp control systems. It is through the utilization of the FREQ3CP program that the evaluation of alternate control strategies can be investigated. The strategies can combine the freeway traffic operation simulation with priority ramp entry control to generate traffic patterns before and after the ramp control.

TRAFFIC PATTERN

The traffic congestion during peak demand periods follows the general pattern established by commuters from outlying residential areas to inner city business/industrial areas and back to outlying areas. Residential areas composed of single family dwellings dominate the basic land use on both sides of the Katy Freeway outside the West Loop interchange. Two large shopping

centers are located immediately adjacent to the south boundary of the study section at the Gessner and West Belt interchanges. Several large industrial complexes are also located near the West Loop interchange as well as strip developments composed of small business and industrial concerns along both sides of the freeway facilities. During the AM peak period, inbound traffic exiting at the West Loop may, for short periods of time, equal one-half of the total inbound traffic demand at the interchange. This large demand for the West Loop exit (both north and southbound) is due in part to the heavy congestion experienced on the adjacent parallel streets (Memorial Drive and Long Point). The normal freeway trip is more attractive than the alternate route travel. Even though the inbound service road is continuous from outside West Belt Boulevard through Silber Road, there are no convenient alternate outlets to the West Loop interchange. This fact is a major contributing factor to much of the inbound Katy Freeway traffic using the West Loop exit.

The PM peak period begins early (3:30 PM) due to the large demand of traffic entering from the West Loop entrance to the outbound Katy Freeway. The lane drop at the Wirt Road exit is the most prominent bottleneck area. From this point, congestion extends back through the West Loop interchange. After traffic congestion reaches Level of Service F in this area, outbound traffic increases its use of the continuous service road outside the West Loop interchange

FREEWAY LAYOUT

The I.H. 10 (Katy Freeway) in Houston was chosen to demonstrate the application of the FREQ3CP computer program model in Texas. The section chosen extends from the Washington Avenue interchange with Katy Freeway westward to the West Belt Boulevard interchange (approximately 8.4 miles). This section of freeway serves as the main artery for traffic movement in

the west and north sections of Houston. The study section (Figure 1) lies approximately 7.5 miles west of the downtown Central Business District. Approximately 1.1 miles west of the Washington Avenue interchange, the Katy Freeway connects with the West Loop (Interstate Highway 610). The West Loop section between Katy Freeway and U.S. 59 (Southwest Freeway) serves as a major connector in the west part of Houston with more than 200,000 vehicles using the facility daily. The Katy Freeway and West Loop interchange is a four-level major interchange with 2-lane connectors for West Loop northbound and southbound traffic connecting to Katy Freeway westbound and eastbound, respectively. The service roads are continuous from outside the West Belt Boulevard interchange to the West Loop interchange. Westbound the service Road is continuous starting just west of the West Loop interchange. Adjacent to the outbound service road on the north side is a seldom used single track railroad facility. The entire study section is of high-type freeway design with an emergency parking shoulder lane in both directions. Inside the West Loop interchange, the Katy Freeway has five 12-foot lanes with an additional emergency parking median lane in each direction. Inbound from the Wirt Road entrance ramp to the West Loop interchange, the freeway is composed of four 12-foot lanes. Outbound from the West Loop interchange, no median parking lane is provided from the Bingle-Voss overpass to the Campbell Road overpass. The study section is basically straight with only one horizontal curve of 3.2° at the Bingle overpass. The bottleneck sections and ramp merging problem areas will be discussed in following sections.

PROGRAM DESCRIPTION

FREQ3CP

The FREQ3CP program is the integration of a traffic performance simulation

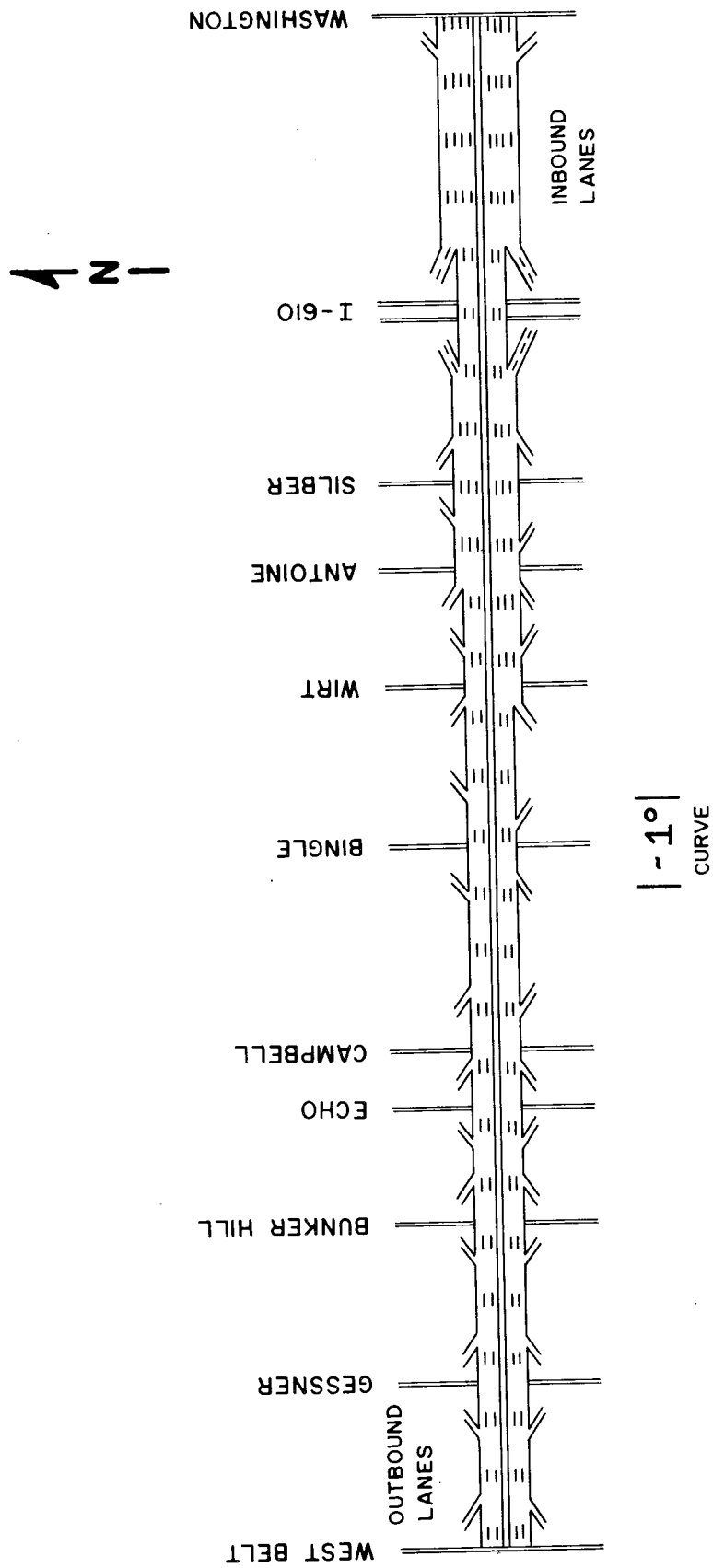


FIGURE 1. I.H. 10 WEST (KATY FREEWAY) LAYOUT

model and a decision model that employs a linear programming algorithm for priority entry control. The combined program enables freeway operations such as weaving, merging and diverging to be coupled with selected ramp control strategies which include an optional traffic diversion formulation. The simulation portion of the program is deterministic and macroscopic in nature, i.e. the behavior of individual vehicles is ignored in favor of the average behavior of vehicles in the mass. Because of non-dependency on the decision model, the freeway traffic performance can be simulated based solely on freeway design characteristics and traffic demand. An iterative process of successive approximations provides the decision model with a numerical solution that is based on "Newton's Approximation" method used in solving simultaneous equations. This process repeatedly modified a ramp's input within constraint limits and combines the freeway capacity, demand and weaving effect until an acceptable solution is reached. The acceptable solution may require that selected ramps be closed, controlled or not controlled while maximizing either vehicles, vehicle-miles, passengers or passenger-miles of travel. The basic assumptions used in building the combined program include:

- 1) Time can be divided into discrete, equally spaced intervals called time-slices;
- 2) Space (the length of the freeway) can be divided into homogeneous subsections, each of which exhibits the properties of constant capacity and demand over its length;
- 3) Traffic is treated as a compressible fluid where an individual vehicle is regarded as an integral part of the flow and is not considered individually;
- 4) Within a given time-slice, traffic demands remain constant

- and do not fluctuate over that time-slice;
- 5) Once traffic demands are loaded onto the freeway, the demands propagate downstream instantaneously, unless there are capacity constraints;
 - 6) Traffic diverted from one on-ramp will not enter other on-ramps;
 - 7) Traffic will not divert from one time-slice to another time-slice; and
 - 8) The demand pattern does not change.

A complete description of the assumptions and background criteria for their use in the program can be found in the report, "THE 'FREQ3' FREEWAY MODEL" (1).

Simulation Model - The simulation process of the FREQ3CP model begins in the first time-slice with the first subsection after all parameters and demand data have been read from cards and properly ordered. The traffic demand (including both origin and destination data) is compared with the capacity for this subsection. Optional logic can be engaged which causes the effects of weaving, merging and diverging to also be included in the traffic demand vs. capacity comparison. After comparison, the resultant traffic is considered to 'flow' from the first subsection to the second subsection and comparable capacity-demand-flow logic is executed for the second subsection. This iteration process is repeated until all sequential subsections have been analyzed. All subsections in the second time-slice are then analyzed. This procedure is continued until all time-slices have been analyzed.

Within each subsection, the flow-capacity ratio is calculated and speed/travel times can be estimated. However, if the demand equals or

exceeds the subsection capacity, a bottleneck condition exists. The excess demand is stored upstream of the subsection bottleneck, and the predicted downstream demand is likewise reduced. The backward moving shockwave is determined as is the new flow upstream of the bottleneck. The excess demand at this subsection is added to the origin/destination table for the next time-slice. Finally, the downstream subsection is interrogated as before. This "bottleneck" and subsequent shockwave logic becomes very complicated if multi-queues that join and split are experienced in the simulation. The logic devised in the simulation portion of FREQ3CP is capable of accommodating all variations of this shockwave and queue storage so long as the first subsection is sufficiently large to store the resultant vehicles. For this reason, the first subsection is often coded as being many thousands of feet longer than is realistic in order to retain all vehicles in the program. Because of this provision, the travel time, delay, etc., for the first subsection is often in error and must be accommodated in the analysis.

Decision Model - The user must indicate prior to the execution of the freeway operations simulation that the decision model is to be processed. This action causes all program options and time-slice information, that will be used as input during the decision model processing, to be stored on auxiliary storage files (magnetic tape or disk). The general intent of the optimization process is to select a priority entry control strategy (a set of allowable ramp metering rates and priority passenger occupancy cut-off levels) that maximizes an objective function (one of four possible choices in Table 1), subject to constraints such as no congestion on the freeway and reasonable ramp metering limits. Additional program capabilities (such as

Table 1
Decision Model Options

| ITEM | OPTION |
|------------------------|---|
| Objective | <ol style="list-style-type: none"> 1. Maximize vehicle input rate 2. Maximize vehicle miles of travel 3. Maximize passenger input rate 4. Maximize passenger miles of travel |
| Constraints | <ol style="list-style-type: none"> 1. Subsectional input demand \leq subsectional capacity 2. On-ramp input \leq on-ramp demand 3. On-ramp input ≥ 0 4. Time limit on delayed vehicles per on-ramp 5. All excess on-ramp demand equally spread to all on-ramps 6. Limit on number of vehicles that can merge in outside lane 7. Total excess capacity minimized 8. Maximum and minimum metering rates |
| Preset Ramp Strategies | <ol style="list-style-type: none"> 1. No control 2. Autos only 3. Priority vehicles only 4. Buses only 5. Ramp closed |
| Capacity Consideration | <ol style="list-style-type: none"> 1. Capacity buffer and level of service |

Table 1 - Decision Model Options continued

| | |
|---|---|
| <p>Diversion</p> | <ol style="list-style-type: none"> 1. No diversion 2. Partial diversion 3. Total diversion |
| <p>Formulation</p> | <ol style="list-style-type: none"> 1. Proportional diversion formulation 2. Short trip |
| <p>Mainline Input Fluctuation</p> | <ol style="list-style-type: none"> 1. Flow fluctuation considered 2. Flow fluctuation not considered |
| <p>No of O-D Patterns</p> | <ol style="list-style-type: none"> 1. One O-D pattern for buses and autos 2. Two O-D patterns, one for buses, one for autos 3. Three O-D patterns, one for buses, one for autos with one passenger, and one for autos with 2 or more passengers 4. Four O-D patterns, one for buses, one for autos with 2 passengers, one for autos with 3 or more passengers 5. Five O-D patterns, as above, except with separate O-D patterns for autos with 3, and 4 or more passengers, respectively 6. Six O-D patterns, one for buses ... |

mainline fluctuations, excess capacity buffer, etc.) have been included within the decision model to insure that reasonable results can be expected. A general discussion of the program operations is included in the following paragraphs whereas a more complete description can be found in the reference material (2).

The decision model processing begins with the retrieval of the stored information on the remote file. If the objective to be optimized is number of passengers or passenger-miles of travel, the passenger occupancy classes by on-ramp (Appendix A) are used in conjunction with each of the O-D patterns (Table 1) by time-slice to develop passenger O-D tables. The other objectives do not require this passenger information. Vehicular and passenger trip tables are developed from the time-slice information and used in the optimization process.

If the mainline fluctuation is requested, the mainline input demand for each time-slice is increased to compensate for the variability in the normal freeway traffic flow at the input to the study section. Since the on-ramp inputs will be under a fixed time control sequence and the mainline freeway input will not, a certain measure of assurance that the resulting freeway operations will be congestion-free is offered by exercising this program capability. By not specifying mainline fluctuation, no modification to the O-D data is done prior to the optimization process.

The remaining logic may be repeatedly executed depending upon the use of the weaving analysis option. By not specifying the use of weaving analysis, each subsectional capacity is used as set forth in the original input data list, although there may be some excess capacity added as per the capacity buffer option. Thus, the optimized solution set of ramp metering rates is

obtained in just one program pass per time-slice. Incorporating the weaving analysis may require multiple program passes because of the variability of subsectional capacities. Each program pass produces the optimized ramp metering rates; given each on-ramp demand and subsectional capacity. These metering rates may cause the weaving effect to significantly change the subsectional capacity from that previously used. Because a capacity may have changed, the process must be optimized again. This iteration process of setting a trial capacity (based on ramp metering rates and the weaving effect), finding a resultant set of metering rates and using these metering rates for weaving analysis and finding a different capacity could go on indefinitely. The program authors have provided a test that determines when the iteration process should end. The subsectional capacity used to find the optimized ramp control strategy is tested against the subsectional capacity that is found after applying the optimized on-ramp inputs (metering rates) to the weaving effect and the last prior-used subsection capacity. If these two capacities are within 24 vehicles per hour, an equilibrium solution is said to have been reached and the processing ends. If any of the subsectional capacities are not within the limit, another iteration of the optimization process is conducted and the test once again applied. The equilibrium solution represents a point where only very minor improvements can be expected in the optimizing of the objective.

After the subsectional capacities are established (with or without the weaving analysis option), the maximum and minimum metering rate limits, as well as any preset ramp strategy options, are established from the remote storage file. Each on-ramp demand is compared against the maximum metering rate and any excess is retained for queueing and possible diversion in

future program steps. Low occupancy, short trip traffic may be further identified for possible diversion if the short trip formulation option is requested. Otherwise, the excess demand will be equally proportioned among all occupant and trip-length classes. The minimum metering rates (along with any preset ramp strategy options) are used to test the feasibility of the existence of a linear programming (L.P.) solution. One constraint in the L.P. model is that demand cannot exceed capacity. The L.P. program does not provide for any violation of a constraint. If the on-ramp inputs are limited to the minimum metering rates and demand is still greater than capacity, a realistic solution set cannot exist. Therefore the user must reduce the appropriate minimum metering rates or utilize a preset ramp strategy (i.e. ramp closed option) to ensure that the L.P. algorithm can be properly executed.

Just prior to entering into the execution of the optimization procedure, the constraints, upper bounds and other internal coefficients necessary to solve for the designated objective in the L.P. model are established. The exact requirements and procedures for satisfactorily solving each objective are slightly different but can be grouped into a general mathematical procedure known as an upper bounding linear programming formulation using the Simplex Method (3). The solution set derived represents the allowable on-ramp demands that can enter the freeway without congestion developing anywhere within the study system; subject to the constraints and designated objective. The optimized demand set must be adapted to reflect the desired objective, such as denoting passengers and priority cut-off levels if passenger inputs were optimized. The resultant optimal strategy must be transformed into an O-D table and new overall demands and occupancy

percentage for each on-ramp computed.

After developing the appropriate information, the capacity test for an equilibrium solution is conducted if the weaving analysis was requested. If more processing is necessary because of the equilibrium solution comparison, the program reverts back to the weaving analysis section and another optimization solution set is constructed. If the equilibrium test indicated that all capacities are within 24 vehicles per hour (or no weaving analysis is requested), the priority ramp control and passenger occupancy information is printed and stored on the remote storage facility if post-control freeway operations simulation is requested.

If the user specified that post-control simulation was to be executed, then the combined FREQ3CP program would again perform the simulation model. This freeway operations simulation would use the modified O-D tables that reflected the results of the decision model's priority ramp control algorithms. By using this option, the user would have available before and after freeway operations data from which detailed comparisons can be made. These comparisons would provide support to the user in the choice of priority ramp control operation and ramp metering constraints.

Program Outputs

The basic structure and form of the FREQ3CP data printouts are presented in Appendix A. The title page indicates the diversion formulation and the primary maximization objective. Following the title page is the overall layout of the study system. Each subsection is numbered and number of lanes contained, capacity and the subsection length is given. The truck factor, design speed, and whether the subsection begins with an entrance ramp or ends with an exit ramp is indicated. Also denoted are special ramps such

as left-hand entrance, two-lane exit ramps, etc., as well as comment space provided so that descriptive information may be used to properly identify the subsection. The next accompanying page contains the passenger occupancy distribution for each entrance ramp. These three pages contain the basic data concerning the overall simulation while the following pages concern specific information per time-slice.

Three separate pages make up the time-slice data; first is the optional O-D table specifying the distribution of each origin's volume into the various downstream destination points, second is the study system's freeway operations, and third is yet another optional table specifying the travel time from each entry point to each downstream exit point. The O-D table is given in vehicles per hour and is the basic input information used by the freeway simulation program. The freeway operation is structured by subsection with the original O-D data supplied as well as adjusted O-D data. The O-D data are the result of the demand-capacity-flow comparison as well as any weaving, merging, and diverging logic that is used. If weaving is specified, then the weaving effect is listed. Calculated items per subsection include the volume/capacity ratio, density, speed, travel time and queueing effect (length and storage rate). Also included are the study system measures which include the effects of the present time-slice as well as the cumulative effects of all previous time-slices. Travel time data (in minutes) are given from each entrance to all downstream exit points. This table can be used to trace the average vehicle through the study system when overall travel time exceeds one time-slice or may be used to analyze a particular subsection. The first (O-D) table and the last (travel time) table are optional program listings for the simulation program.

Immediately following the results of the freeway simulations for all time-slices are the results from the decision model. The output data from the decision model are composed of three pages of information. The combined O-D table includes all vehicle types as well as the maximum and minimum metering limits. This O-D table is composed of the original O-D table as retained from the simulation run in this time-slice as well as the priority vehicles included in the earlier occupancy table. Each on-ramp is shown in the second page of the decision model printout by number. The original demand in both vehicles and passengers is shown along with the performance of the control strategy being employed. Accompanying the control strategy table are the current and cumulative freeway performance measures of effectiveness. Contained on the last page of the decision model printout are two tables pertaining to the excess demand determined by the control strategy. The first chart indicates the demand diverted from each on-ramp to each destination. Following this chart is the excess demand that was transferred from this time-slice to the next time-slice. The printout of this final page, along with the first page of the decision model data are optional.

Program Inputs

The FREQ3CP priority entry control program requires that various input data be provided. The more important information for the simulation submodel includes 1) origin - destination (O-D) data, 2) subsection and ramp capacities, 3) subsectional lengths, and 4) passenger occupancy data. Important additional data required by the Control submodel are 1) type of optimization required, 2) maximum and minimum metering rate, 3) priority entry limits and 4) preset ramp control strategies. All of the critical information used in the FREQ3CP model must originate from actual field studies. These studies provide the basis for establishing the O-D tables as well as capacities, distance

measurements, etc. Suggested methods for obtaining this information included: 1) studying aerial photographs of the study system taken during the congested peak periods, 2) conducting volume counts at all entry and exit points along the study system, 3) determining the location of bottlenecks and bottleneck capacities, 4) obtaining origin-destination traffic patterns, and 5) conducting travel time (tachograph) runs throughout the peak period over the study section. The first four methods can produce data that are directly implementable into the program input stream while the last method yields information to which the simulation results can be compared and calibrated.

Aerial data are useful in determining traffic densities, queue dimensions, and in locating capacity reducing freeway incidents. In obtaining entrance ramp volume data, care must be exercised to insure that demand is recorded; not just the traffic flow past a point. The traffic demand at the mainline entry point into the study section should be counted sufficiently far enough upstream of any extended queue storage to insure free-flow conditions at the count station. Extended queues should likewise be observed at entrance ramps and volume counts taken upstream of any queues. During the volume data collection, a vehicle equipped with a tachograph and a special event record indicator should conduct travel runs through the study section. A series of such runs should be conducted over several incident-free peak periods so that a group of travel time runs can be made preferably with the maximum starting headway time equal to or less than 10 minutes. During each travel time run, the special event record indicator is activated when the vehicle is directly even with the location of each entry or exit ramp plus any other special location that would need identifications. As the FREQ3CP program requires that the study section be divided into subsections and the peak into time-slices, the resultant tachograph chart at the end of each travel run can be interpreted as an average speed between each special event (as the tachograph's rate of turning movement is constant). Thus, the

tachograph travel runs can yield a composite picture of the relative speeds and travel times in each subsection throughout the peak period. This composite speed contour can be used in comparing the simulation results with the actual field data to help determine when the computer model is calibrated.

To supply the required passenger and bus occupancy input data for the FREQ3CP program, it is necessary to gather the passenger occupancy data either by manual observations at the freeway entrance ramps or as a part of an O-D survey. The computer program model determines the priority cutoff level of each ramp based on the passenger occupancy data. The program provides for up to 4 optional occupancy tables and one bus occupancy table. Each bus is assumed to have 6 or more passengers. The required passenger occupancy table reflects the percentage of occupants at each entrance ramp that have from one to six or more passengers per vehicle and is to be used with only one O-D table. If two O-D tables are used, the first table refers to single occupant vehicles while the second O-D table refers to buses. (During the collection of volume data at the freeway mainline input and at each entrance ramp, the occupancy data for 1, 2, and 3 or more occupants per vehicle were obtained as well as the number of buses using the entry point).

The normal course to follow in the development of the origin-destination (O-D) table would have required an O-D survey to be conducted by using questionnaires passed out at each entry point and tabulating the returned documents. An alternate method may be used that includes the use of a synthetic origin-destination trip distribution analysis program. The separate computer program SYNDOM uses the entry and exit volumes as input data and distributes each entrance ramp volume to all downstream exit ramps based on three options. The distribution may be based on the inputs (entrance volumes), outputs (exit volumes) or a combination of both. The

output of the program is an O-D matrix in punched computer card format suitable for input into the FREQ3CP program.

Using either field measurements or construction plans, the distance of each subsection can be obtained. These subsectional distances must be included as a part of the study section data program input. Along with these data, the capacity of each subsection must be known. Two methods are described as being useful in determining capacity; field observation and use of the Highway Capacity Manual (HCM) (2). As the simulation model must compare demand versus capacity, the more realistic each subsection capacity is (particularly the bottleneck subsections), the fewer iterations will be needed before the model is calibrated. Field observations of flow rates through critical bottlenecks include roadway and traffic factors whereas the HCM procedures must be applied before a 'text book' value can be given to capacity. The HCM provides a maximum theoretical limit of 2,000 vph per lane whereas actual flow rates may exceed this value thus making the capacity greater than 2,000 vph per lane. Projecting the highest 15-minute flow rates to hourly rates at bottleneck locations can render good first estimates for inclusion as subsectional capacity. Another of the optional inputs that can be included and does affect capacity considerations is the weaving effect. If field measurements are used to arrive at a capacity setting, weaving should not be used as it is included when measuring flow in the field. If the weaving analysis is desired, caution should be exercised in setting the "straight-pipe" capacity as it is normally greater than HCM values. Also, the weaving effect is more pronounced as volume increases, thus creating more severe bottleneck flow operations. It is suggested that the use of weaving be restricted unless a particular

subsection experiences pronounced weaving problems.

Additional input required for subsectional characteristics are the selection of the speed-flow curves and the indications for special ramps. Each subsection may have one of five prespecified speed-flow curves which are included within the FREQ3CP program. Three of the included curves are from the HCM and the remaining two curves were developed from data taken on California freeways. Up to nine speed-flow curves may be installed by the user if the supporting volume and speed data are available. Also, the user may specify the existence of a special ramp, such a left-hand entry and exit or two-lane entrance. Such ramps do not have merging solutions in the HCM and are, therefore, not to be included in the merging analysis.

Other data items that must be specified before proper FREQ3CP program execution are discussed in the related literature. Their meaning and usage are beyond the scope of this report. At many points in the following articles, these unnamed items are mentioned whenever their value and use directly affect the simulation model results.

SYNODM

The computer program SYNODM is available for producing synthetic origin-destination data from entry/exit ramp volume data. This program, separate and independent from the FREQ3CP, requires the entrance and exit ramp volumes to be punched on computer cards for input data and arranged in time-slice formats. The punched cards output is in O-D formats and suitable for direct entry into FREQ3CP. Input parameters into SYNODM includes the number of entrance and exit ramps, the number of subsections, and the relative positioning of the entrance to exit ramps by subsection. A maximum of 20 entrance and 20 exit ramps may be processed.

The basic distributive equation is

$$OD(I,J) = \frac{REMO(I) \times EXIT(J)}{SUMO} \times SCALEF \quad (1)$$

where: $OD(I,J)$ = the O-D matrix element that indicates the portion of the demand in this time-slice at origin I destined for exit J contingent upon origin I being upstream of exit J,
 $REMO(I)$ = the remaining demand at origin I after previous exit allocations have been extracted and prior to distribution to exit J,
 $EXIT(J)$ = the exiting volume at this ramp during this time-slice,
 $SUMO$ = the sum of all available upstream entrance ramp demands that may be distributed to EXIT J, and
 $SCALEF$ = the distributive option selected by the user and based on total output, total input or both.

The sequential process begins with the selection of the first exit ramp. All entrance ramp demands ($REMO(I)$ values) upstream of this exit are summed and retained in $SUMO$. Then each entrance ramp demand, upstream of the exit, is distributed based on Equation 1. Immediately after the $OD(I,J)$ value is calculated, the remaining demand at entrance I is reduced by the demand allocated to this exit J ($REMO(I) - OD(I,J)$). By this correction, $REMO(I)$ has only the remaining demand destined downstream of exit J. After all entrances upstream of the exit ramp in question have been distributed, then the new demand data are processed and the distributive iteration process renewed.

The distribution may be modified in one of three methods according to the value used for $SCALEF$. If the user chooses to have the distribution calibrated on the total output volume, then $SCALEF$ is set equal to 1.

Exactly as many vehicles are distributed to each exit ramp as found in each EXIT(J) value. If the distribution is to be calibrated based on the total input volume, then each exit volume is modified by the ratio of total input volume to total output volume ($SCALEF = \text{total input} / \text{total output}$). This means that more or less traffic will be found at each exit than initially used in the EXIT(J) value. Finally, the user may choose to have the total input and output set equal to each other before the distribution is processed. To do so, the program 1) sets $SCALEF = 1$; 2) determines whichever (total input or total output) is greater; and 3) reduces the other main-lane value by the difference between the two quantities. If total output is greater, the mainline freeway output volume (the last EXIT(J) element) is reduced by the difference between total output and total input. If the total input is greater, the mainline freeway input volume (the first REMO(I) element) is reduced by the difference. No change is required if the total input and output are equal. In this third optional procedure, all modifications are made prior to the distribution process and only to the main freeway lane values.

The decision as to which distributive option should be utilized may depend in part on the confidence placed on the collected volume data. Providing all other parameters being equal, the more accurate the `FREQ3CP` input data, the fewer computer program runs should be needed before calibration is reached. From the experience gained in developing the calibrations on I.H. 10, the following general guidelines were determined:

1. If the O-D data are distributed based on total output, the simulation results tend to cause congestion patterns to develop later and last longer than the base data,

2. O-D data distributed on total input information tends to cause congestion patterns to develop and decline earlier than base data and
3. O-D data developed from correcting the total input or total output by the difference between the two values has a tendency to cause both of the above conditions.

If the total input is greater, the congestion pattern is delayed in time because the mainline input values are decreased and the congestion development is hindered. If total output is the greater of the two values, congestion patterns may tend to remain at or near previous levels due to decreased volume output, thus postponing the decline of the freeway queue. The severity of this apparent shift of the simulated congestion pattern versus the base data does depend on the difference between total input and total output. If there are small differences between the two quantities in all time periods, the simulated congestion patterns should be reasonably close to the base data. Large differences can produce severe skewing of the congestion pattern.

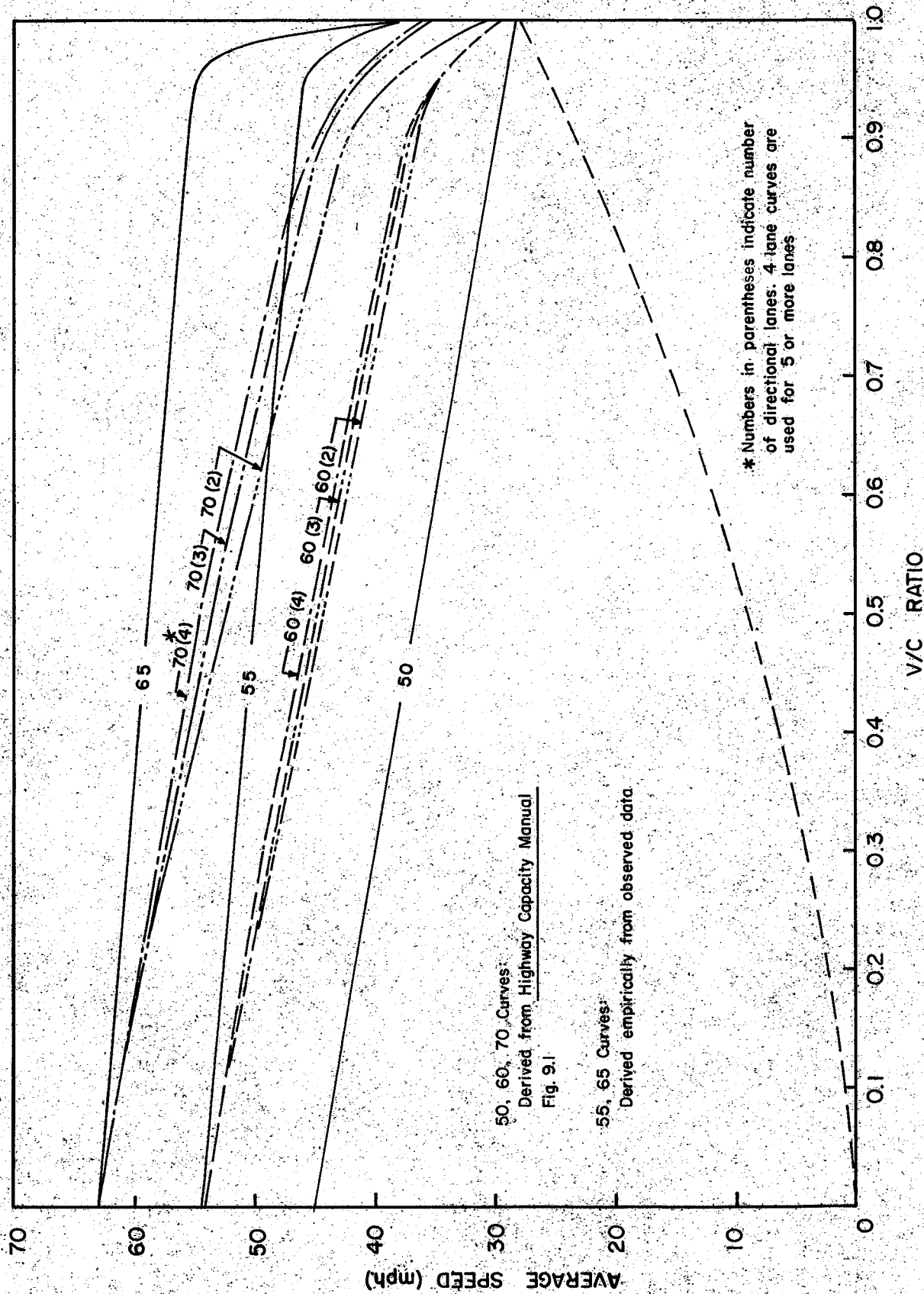
The SYNODM program distributes each entrance ramp demand to all downstream exits, a distribution which may not always be realistic. An unrealistic example would be a situation where an entrance ramp has an extensive queue or merging problem, the next exit ramp only a short distance downstream, heavy freeway congestion in this short section between the ramps and a continuous service road between the two ramps. In this case, traffic destined for this immediate exit ramp would proceed along the service road instead of using the entrance ramp. Therefore, the SYNODM program was altered so that pairs of entrance-to-next-exit combinations could be coded

to eliminate the distribution to the next exit. The altered program bypasses the next exit and uses all further downstream exits in its distribution. Simulation runs were executed based on both altered and unaltered SYNODM results and indicated approximately one percent difference in total travel.

CALIBRATION

GENERAL

The initial approach selected in analyzing the simulation results against the field measurements was to plot speed versus time for both methods on the same graph. Four speed ranges were chosen; namely, over 40 mph, 30 to 40 mph, 20 to 30 mph and under 20 mph. After attempting to analyze several simulation runs and the field data in this manner, it became questionable as to whether these multicontoured plots would be useful. From the FREQ3CP instructions, it was noted that queueing and congestion are only formed after a subsection experiences a demand greater than its capacity. Therefore, a direct approach would be to utilize the simulation model's congestion results. This required that the field measured data be interpreted accordingly. To accomplish this task, the tachograph data and field notes were used to construct a speed versus time graph where all speeds under 35 mph were enclosed in a speed contour; this contour became the base congestion data to which the simulation results could be quickly and accurately compared. The validity of this method can be interpreted by examining Figure 2. Queues are formed when the V/C ratio reaches 1.0. Thereafter, the speeds selected for those V/C ratios less than 1.0, but still within the congestion, come from only one curve



50, 60, 70 Curves:
 Derived from Highway Capacity Manual
 Fig. 9.1

55, 65 Curves:
 Derived empirically from observed data

* Numbers in parentheses indicate number of directional lanes. 4 lane curves are used for 5 or more lanes

Fig. 2 - The Five Speed - Volume / Capacity Ratio (s-V/C) Curve Families Self - Contained in the FREQ3 Model

regardless of which speed curve is selected (or user entered). This means that the simulation's congestion and the base data should be comparable in time and space provided the queue propagates in the same manner within the computer model as it does in the real world situation. While the authors of the FREQ3CP model have not attached determinative proof of the validity of the queueing theory incorporated within the model, areas which have been approximated or contain assumed results are clearly documented and adhere to accepted engineering practices (2).

Inbound Interstate Highway (I.H.) 10

To assist in the description of the evaluation procedures conducted on the FREQ3CP model, the inbound I.H. 10 base data contour has been included on each simulation run graph as a shaded background profile. This data base represents the combining of the tachograph data and field notes into a generally inclusive contour that depicts those subsections and time periods where the average freeway speed is equal to or less than 35 mph. Whereas one travel run by the instrumented vehicle will produce speed results unique to that subsection, time period and traffic conditions, the combining of several travel runs will enable a more comprehensive picture of the overall traffic pattern.

Subsections 1 through 8 (Figure 3) include the outer portion of the inbound study section, which has a higher design speed than the older inner sections. No critical entry and exit conditions exist in these outer subsections thus a capacity of 5,850 vehicles per hour (vph) was assigned to these 3-lane freeway sections. A minor bottleneck exists in Subsection 9, where the Echo entrance and the Bingle exit ramps are close together. Considerable weaving does take place in this short section;

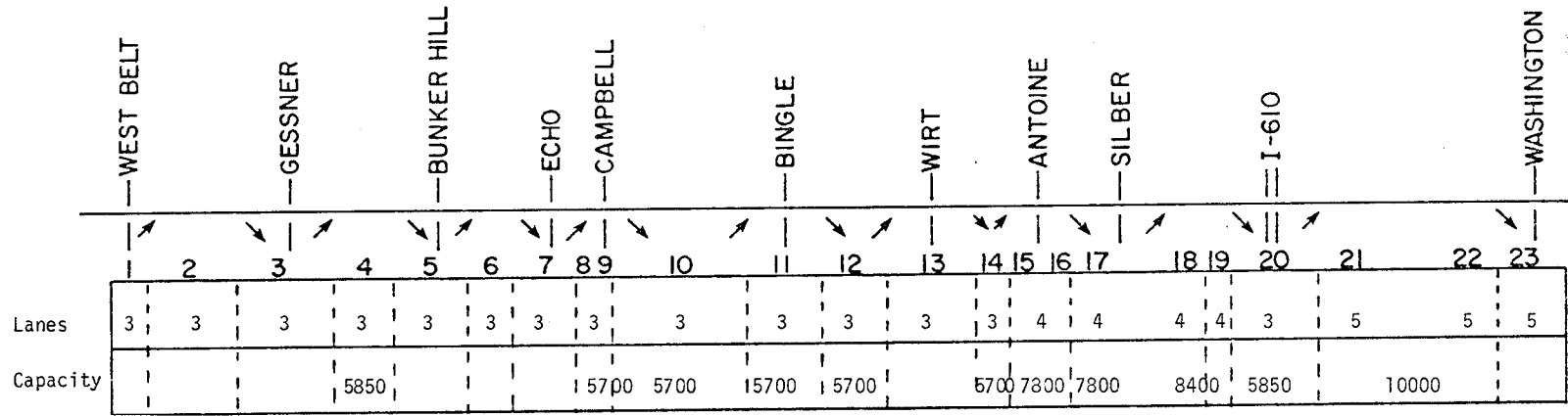


Figure 3. Inbound I.H. 10 Subsectional Configuration

such as capacities, special ramps, speed curves, etc., from run-to-run are denoted in Table 2. This table should be used along with the referenced figure number to better clarify the resulting congestion pattern.

Figure 4 - Congestion developed earlier at Subsection 13 than the base data, but the secondary bottleneck at Subsections 8 and 19 did not expand the congestion pattern. Overall congestion extended past the study period.

Figure 5 - Used the same capacities as in Figure 3 but changed all speed curves in each subsection to 55 mph. Congestion developed early at all three bottlenecks, but was not sufficiently acute to form the overall base data pattern.

Figure 6 - To test effects of weaving, capacities in Subsections 10 through 14 were set at 5,850 vph and all other capacities remained as in Figure 4. Even though the capacities were not set at the theoretical limit of 2,000 vph per lane, the weaving effect could be noted. The congestion pattern is drastically deformed and queues extended outside Subsection 1 (queue extensions outside the limits of Subsection 1 will cause the simulation program to yield inaccurate patterns).

Figure 7 - Subsections 10 and 11 had capacity reductions from 5,700 to 5,600 vph. All other capacities were reset as in Figure 4. Using no weaving, the capacity reduction should cause congestion to begin earlier in Subsections 8 and 9. The congestion pattern did develop earlier at the desired areas, but the total effect did not produce the queue formed by the base data.

Figure 8 - In an attempt to get the base data congestion pattern, capacities in Subsections 18 and 19 were reduced from 8,400 to 8,200 vph.

TABLE 2
Inbound I.H. 10 General Input Parameters for Calibration Computer Runs

| SUBSECTION | LANES | FIGURE 4 | FIGURE 5 | FIGURE 6 | FIGURE 7 | FIGURE 8 | FIGURE 9 | FIGURE 10 | FIGURE 11 | FIGURE 12 | FIGURE 13 | FIGURE 14 | FIGURE 15 | FIGURE 16 | FIGURE 17 | FIGURE 18 |
|------------|-------|---|-----------------------------|---------------------|---------------------------------|---------------------|---|--------------------------------|--|-----------------------|------------------|---------------------------------|---------------------------------|------------------------------------|---------------------------|--|
| 1 | 3 | 5850 | S | | 6000 | | S | S | | S | S | S | | S | S | 5750 |
| 2 | 3 | 5850 | A | | | | A | A | | A | A | A | | A | A | 5700 |
| 3 | 3 | 5850 | M | | | | M | M | | M | M | M | | M | M | 5700 |
| 4 | 3 | 5850 | E | | | | E | E | | E | E | E | | E | E | 5700 |
| 5 | 3 | 5850 | | | | | | | | | | | | | | 5700 |
| 6 | 3 | 5850 | | | | | | | | | | | | | | 5700 |
| 7 | 3 | 5850 | | | | | | | | | | | | | | 5700 |
| 8 | 3 | 5850** | | | | | | | | | | ** | | | | 5700 |
| 9 | 3 | *5700 | | 5850 | 5600 | | | | | | | | | | | 5600 |
| 10 | 3 | *5700 | | 5850 | 5700 | | | | | | | | | | | 5600 |
| 11 | 3 | *5700 | | 5850 | 5700 | | | | | | | | | | | 5700 |
| 12 | 3 | *5700 | | 5850 | 5700 | | | | | | | | | | | 5700 |
| 13 | 3 | *5700 | | 5850 | 5700 | | | | | | | | | | | 5700 |
| 14 | 4 | *7800** | | | | | | | | | | | | | | 7800 |
| 15 | 4 | *7800 | | | | | | | | | | | | | | 7800 |
| 16 | 5 | 8400 | | | | 8200 | | | 8000 | ** | | ** | 7800 | | | 7800 |
| 17 | 5 | 8400 | | | | 8200 | | | 8000 | ** | | ** | 7800 | | | 7800 |
| 18 | 3 | 5850 | | | | | | | | | | | | | | 5850 |
| 19 | 5 | 10000** | | | | | | ** | | ** | | ** | | | | 10000 |
| 20 | 5 | 10000 | | | | | | | | | | | | | | 10000 |
| | | *65 mph curve except * which is 55 mph. **Special ramps. '0-D Table #2. '6 TS/Hr. | *All speed curves = 55 mph. | 'Weaving Considered | 'No weaving Revised capacities. | 'Revised capacities | 'Used 0-D Table #3. 'Modified 0-D table Silber to IH 610. | '0-D Table #2 '1 special ramp. | 'Revised capacities. 'Changed Silber split | 'Added special ramps. | 'Put in weaving. | 'Weaving '1 extra special ramp. | 'No weaving. 'Revised capacity. | 'Put in 60% of 60-40 Silber split. | 'Same except for 4 TS/Hr. | 'Reduced outer capacities. 'Put in Ramp 8 limit. |

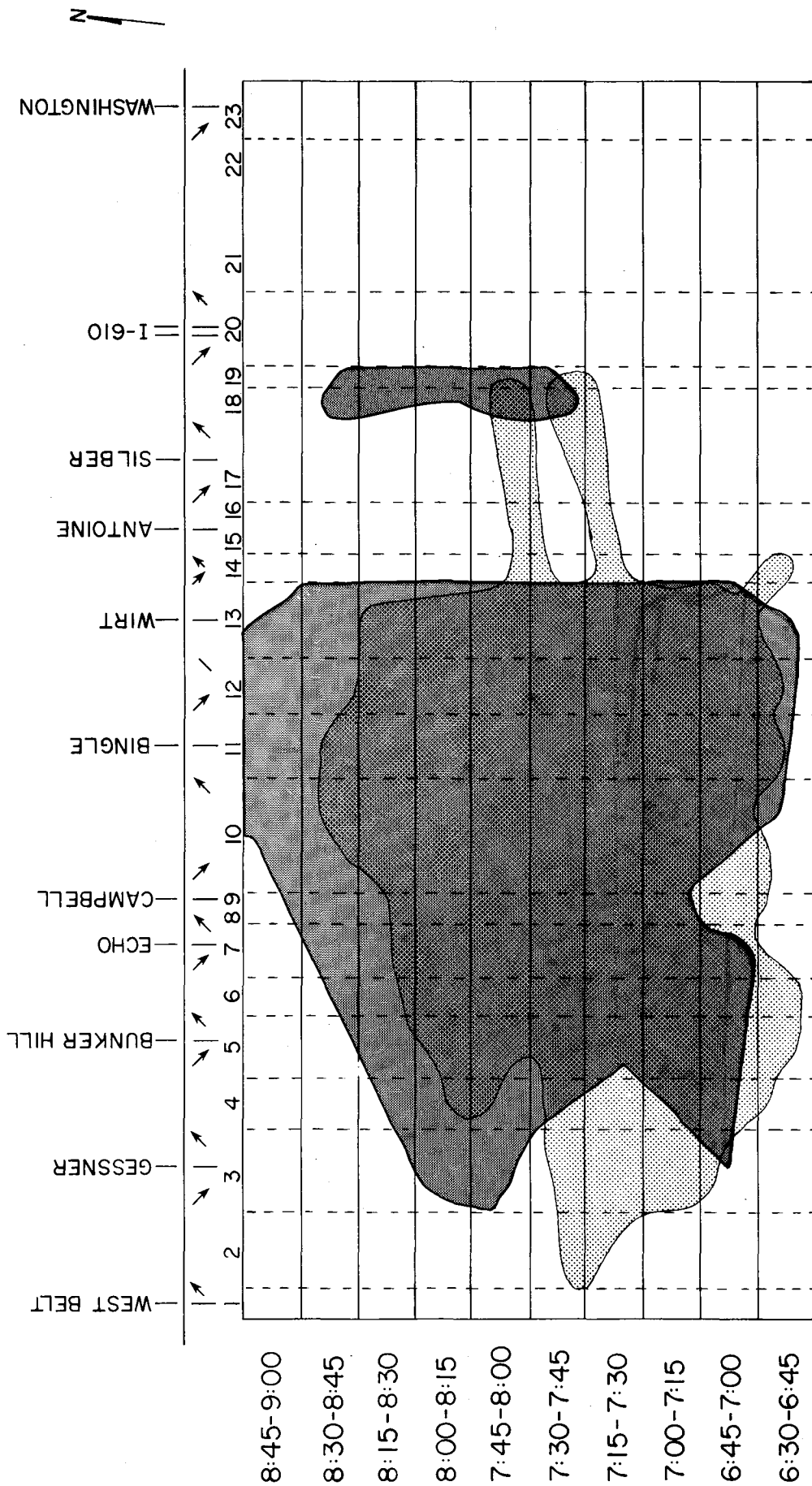


FIGURE 4. RUN 1 - INBOUND I.H. 10

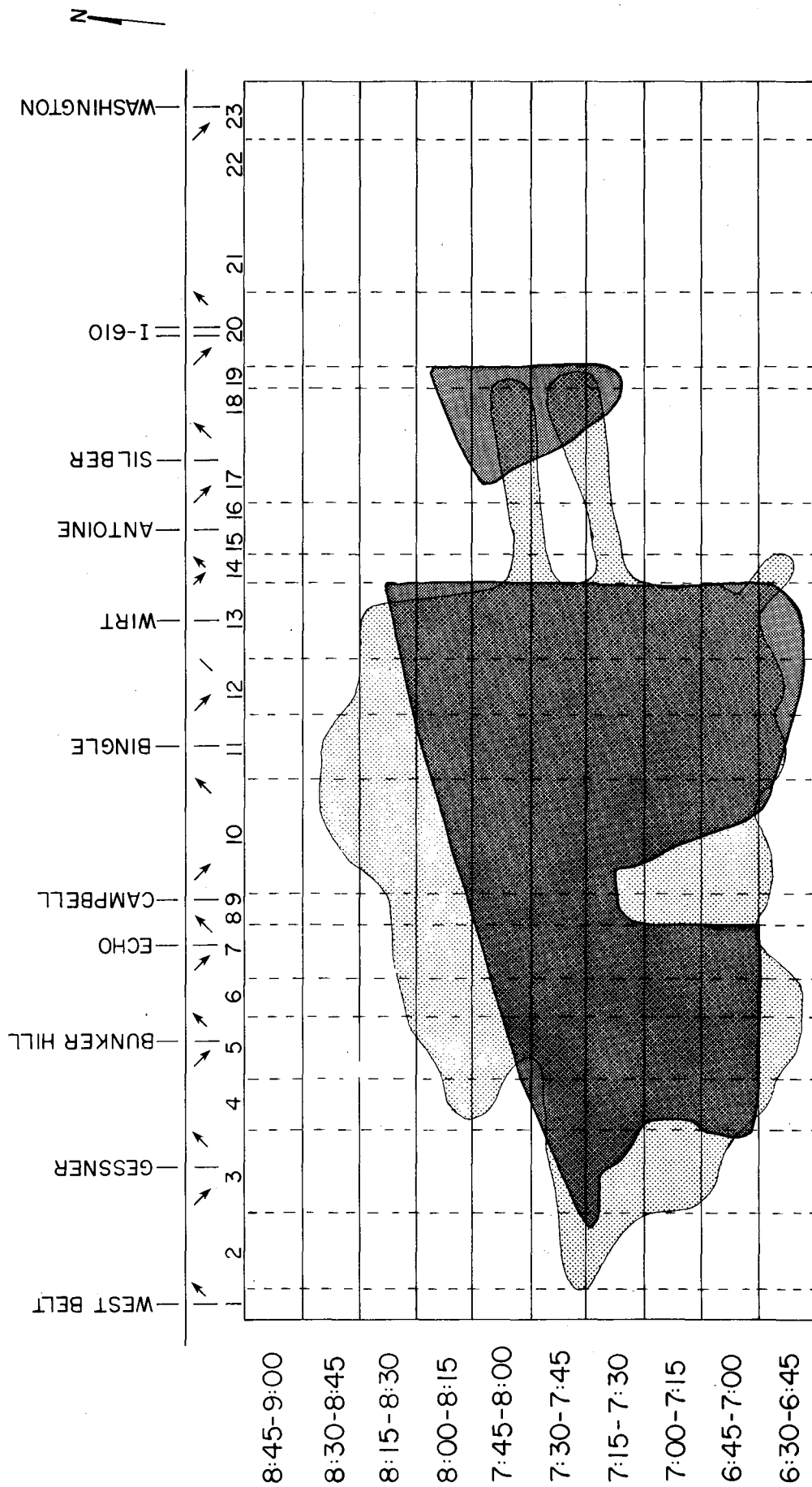


FIGURE 5. RUN 2-INBOUND I.H. 10

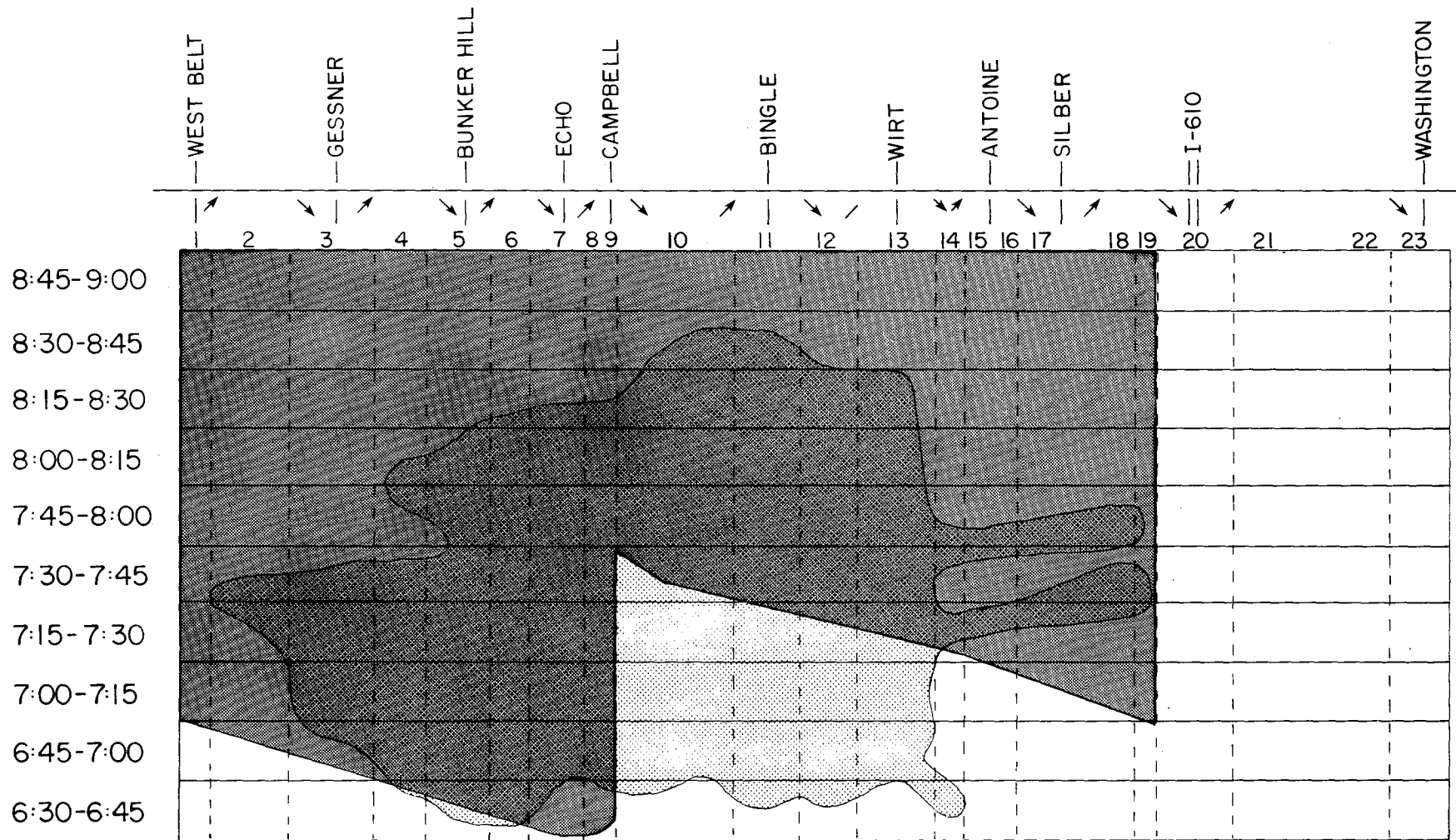


FIGURE 6. RUN 3-INBOUND I.H. 10

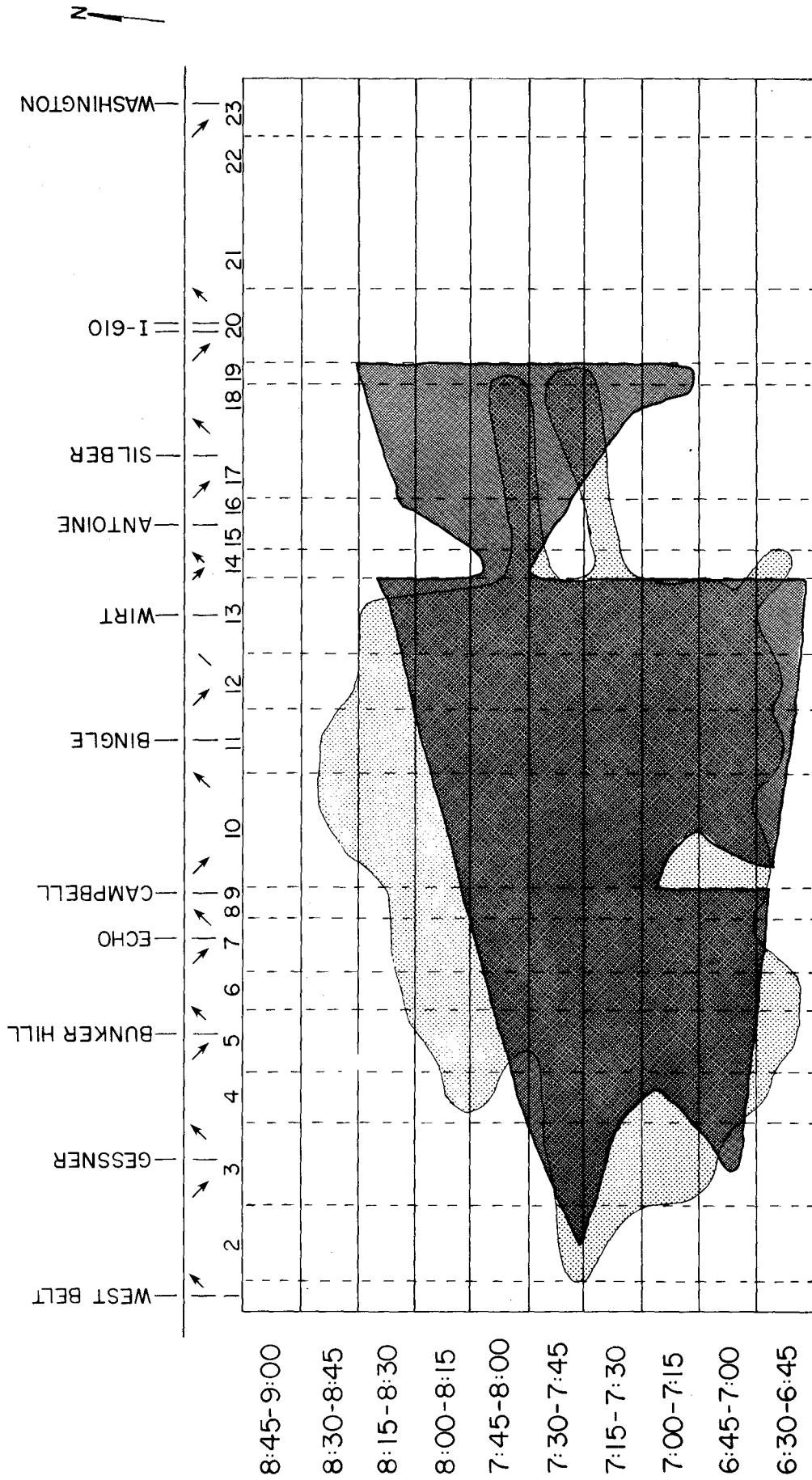


FIGURE 8. RUN 5 - INBOUND I.H. 10

Resultant congestion had the same basic (upstream of Subsection 14) shape as the base data but the congestion was too extensive at and upstream of Subsections 18 and 19.

Figure 9 - Noting that the congestion pattern had ended several time-slices before it should have, a new O-D data set was used. Previously, the O-D distribution had been made based on the total input. The new O-D distribution (previously obtained from the SYNODM program) is based on the assumption that whichever is greater, total input or output, then the larger mainline flow is modified by the difference between total input and output before the synthetic distribution takes place. Also field observation revealed that the percentage of traffic entering at Silber and exiting to I.H. 610 was 60 percent with the remaining 40 percent destined to freeway travel past I.H. 610. Examination of the O-D data revealed that the synthetic distribution placed 40 percent to I.H. 610 and 60 percent to freeway travel. Therefore, each Silber entrance ramp distribution was revised to reflect the above field observed percentages. The resultant congestion pattern did not fully develop early in the study period, lasted much too long, and the bottleneck at Silber entrance (Subsection 18) was too critical.

Figure 10 - The O-D data set was changed back to the distribution based on total input and the Silber entrance ramp distribution was modified in each time-slice from a 40 percent-60 percent split to I.H. 610 exit ramp to a 60 percent-40 percent split. The Echo and Wirt entrance ramps were not designated as special ramps but I.H. 610 entrance remained so designated. The bizarre congestion pattern that resulted can only be explained by the fact that not enough demand was placed upon the system.

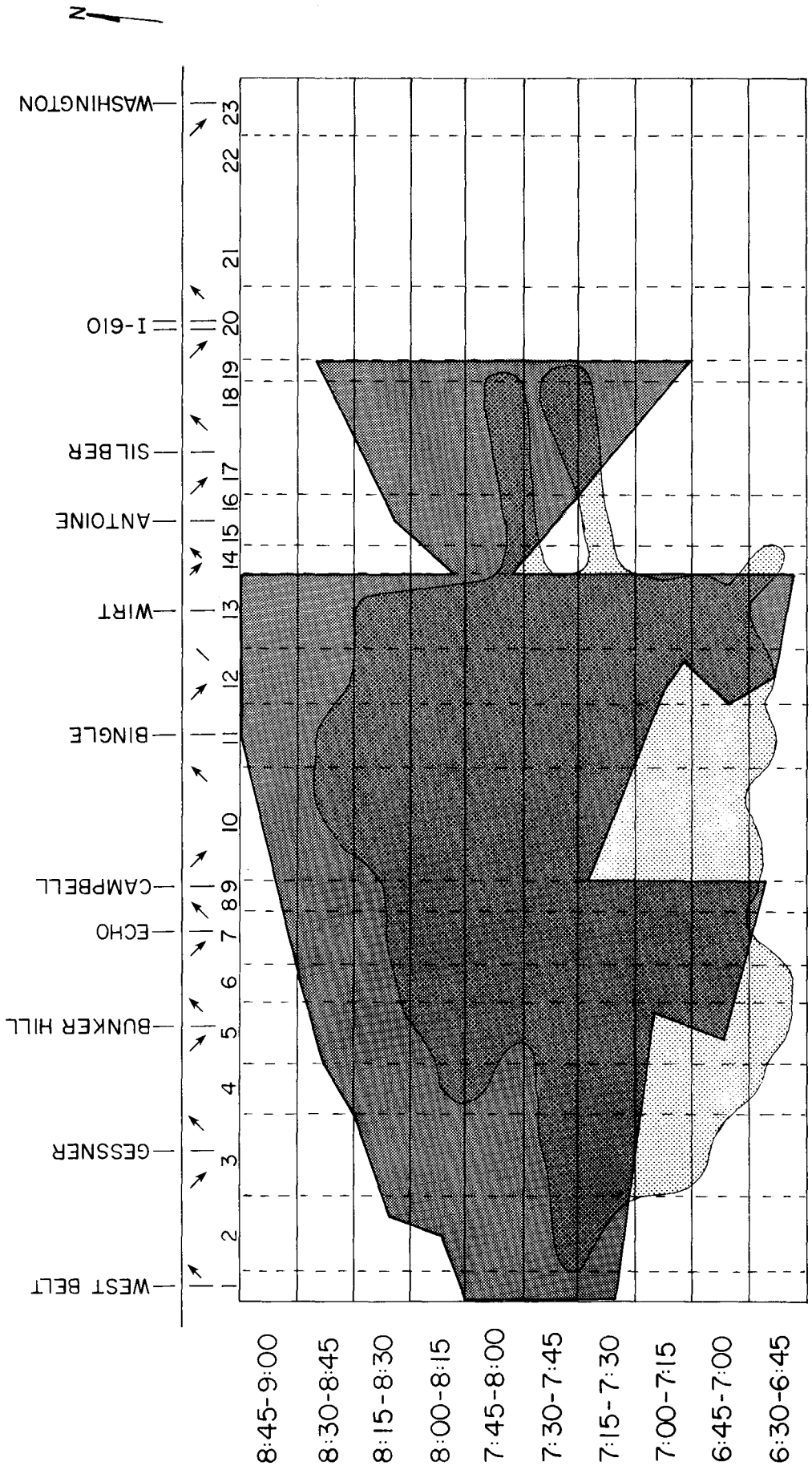


FIGURE 9. RUN 6 - INBOUND I.H. 10

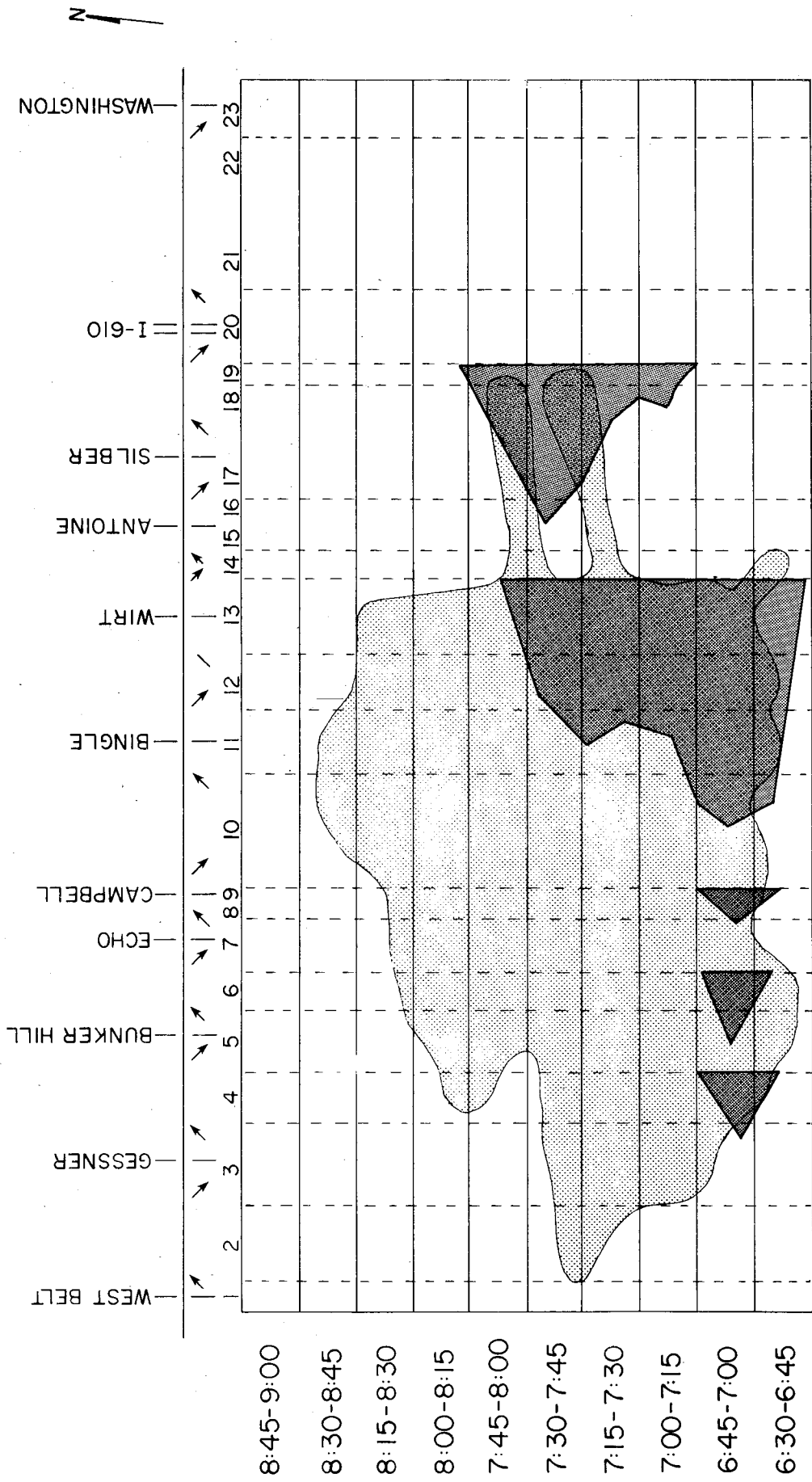


FIGURE 10. RUN 7-INBOUND I.H. 10

Figure 11 - Capacities in Subsections 18 and 19 were lowered from 8,200 to 8,000 vph. Instead of 5 lanes in these two subsections as was used to support the larger capacities, 4 lanes were used. Also, only 70 percent of the revised 60-40 percent Silber entrance ramp split was used. This was an attempt to reduce the extension of the congestion immediately upstream of Subsection 18. The simulation run showed very little congestion developed for only one-half of the study period and none was experienced upstream of Subsection 18.

Figure 12 - Both the Silber entrance and I.H. 610 exit ramps were entered as special ramps (no merging/diverging analysis). The resultant congestion pattern reflected only a small change from Figure 10.

Figure 13 - Just to evaluate the effects of weaving, a simulation run was made on the Figure 11 data setup. The resultant congestion pattern upstream of Subsection 9 remained as found in Figure 6. The weaving analysis, as shown in Figure 13, did not produce the extended congestion from the Subsection 19 bottleneck area as it had in Figure 6.

Figure 14 - This simulation run produced an almost identical congestion pattern as Figure 13 even though the Echo entrance ramp was included as a special ramp (no merging analysis).

Figure 15 - Disregarding the weaving effect and revising the capacities in Subsections 18 and 19 from 8,000 to 7,800 vph produced this congestion pattern which matches well in the early and late stages of the study period. Congestion was too extensive in and around the Silber entrance to the I.H. 610 exit ramp, making the overall simulation slightly off of the actual base data.

Figure 16 - Revision of the distribution of Silber entrance to I.H. 610

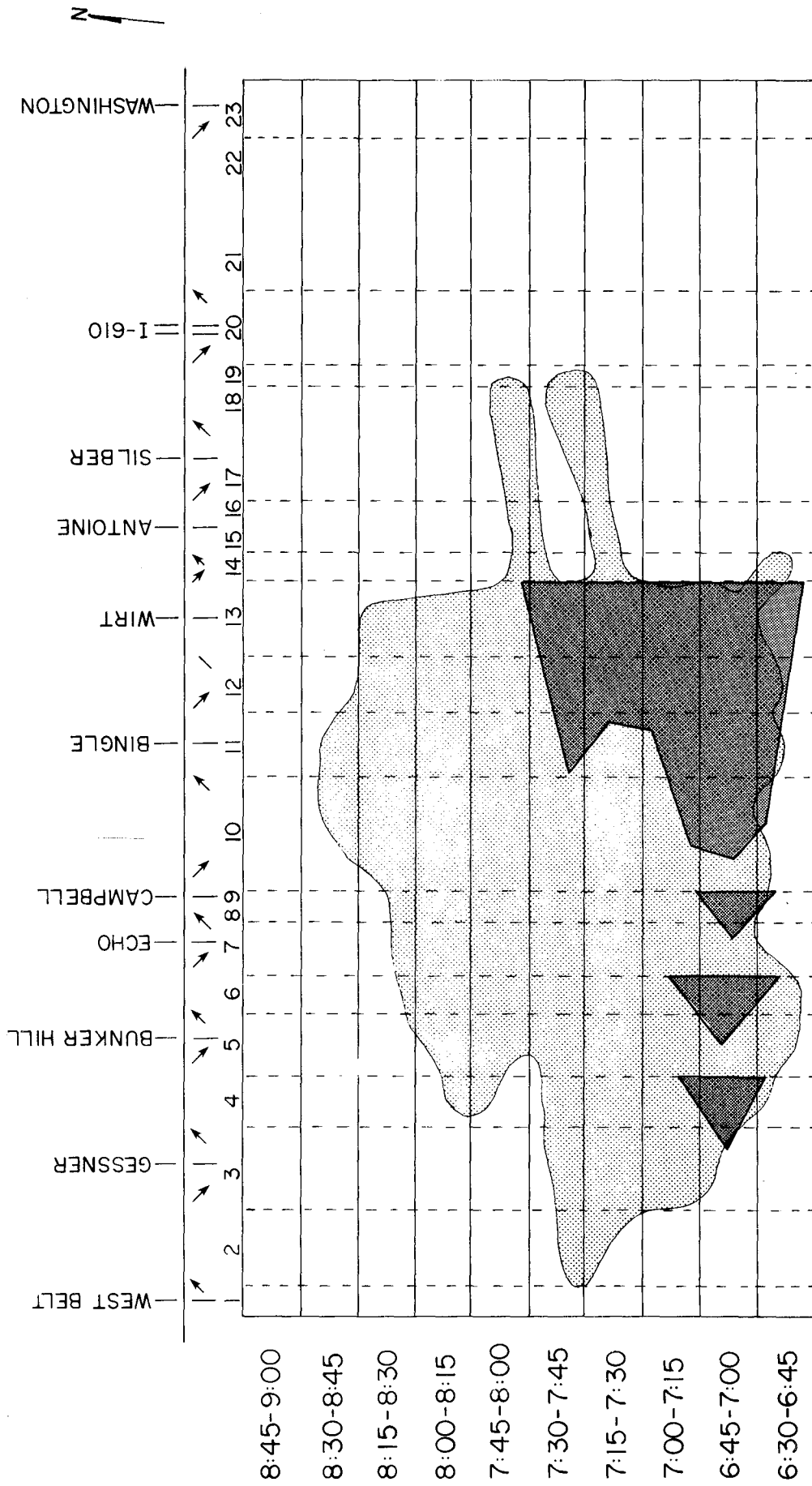


FIGURE II. RUN 8 - INBOUND I.H. 10

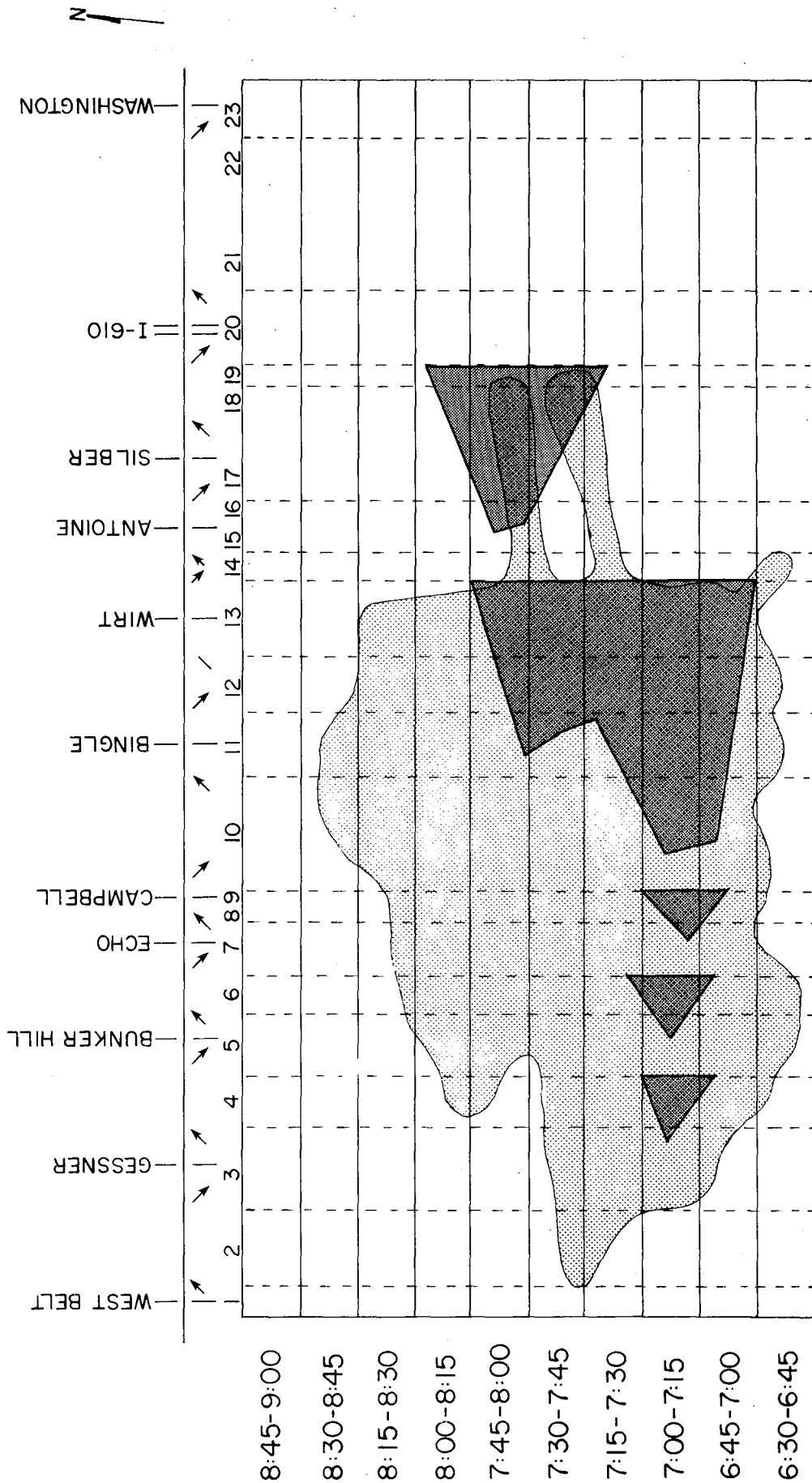


FIGURE 12. RUN 9 - INBOUND I.H. 10

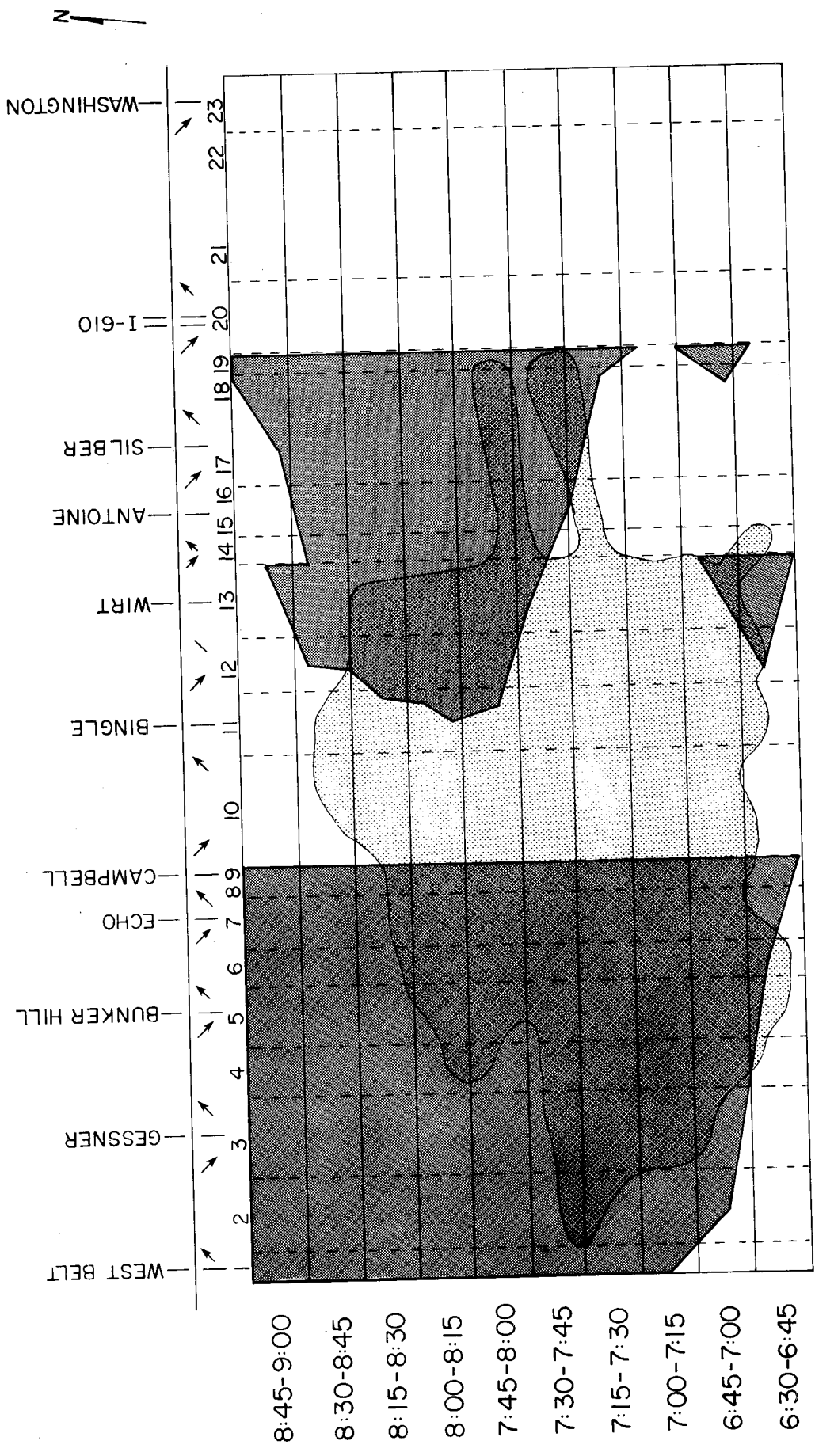


FIGURE 13. RUN 10-INBOUND I.H. 10

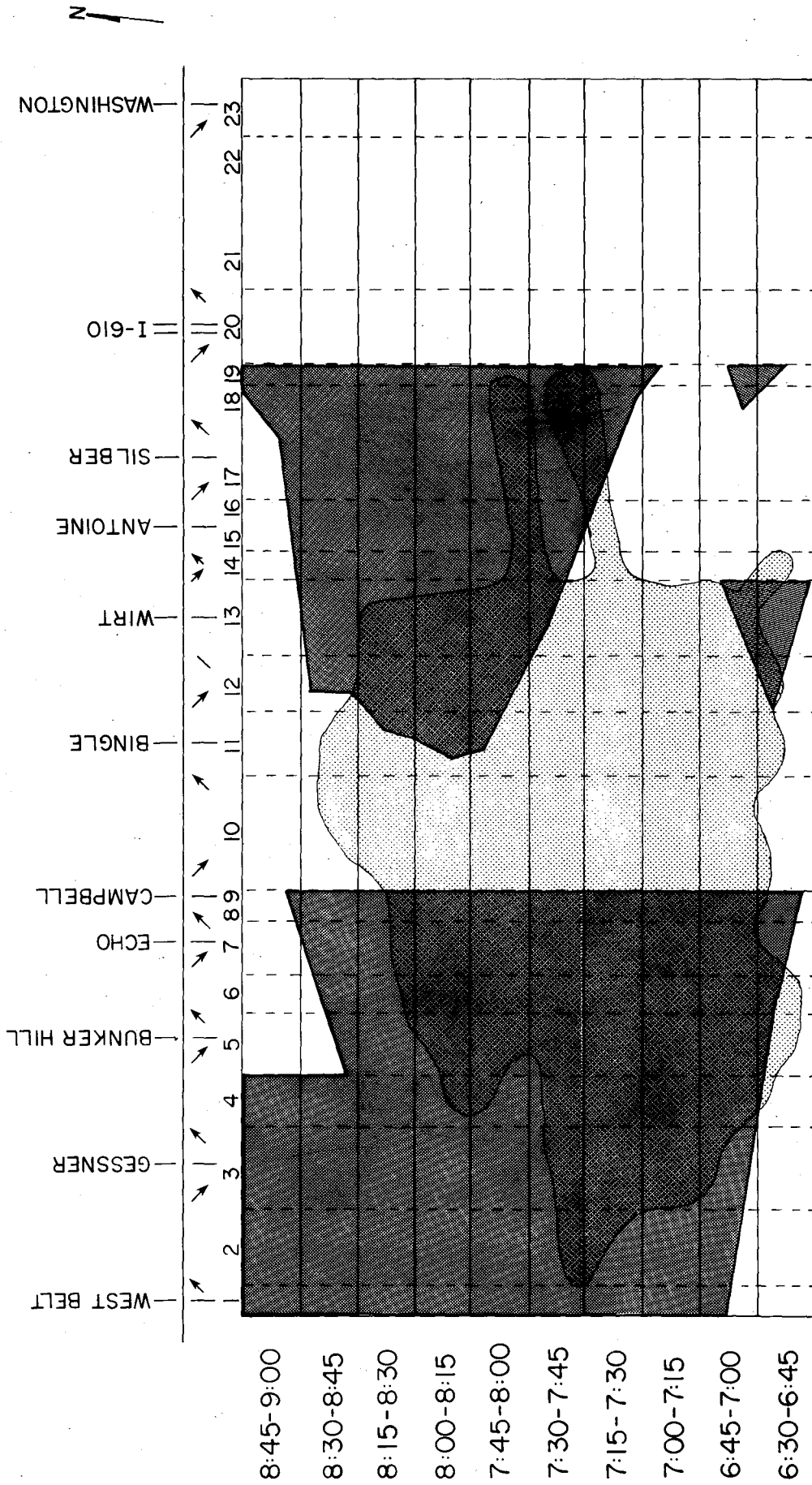


FIGURE 14. RUN II - INBOUND I.H. 10

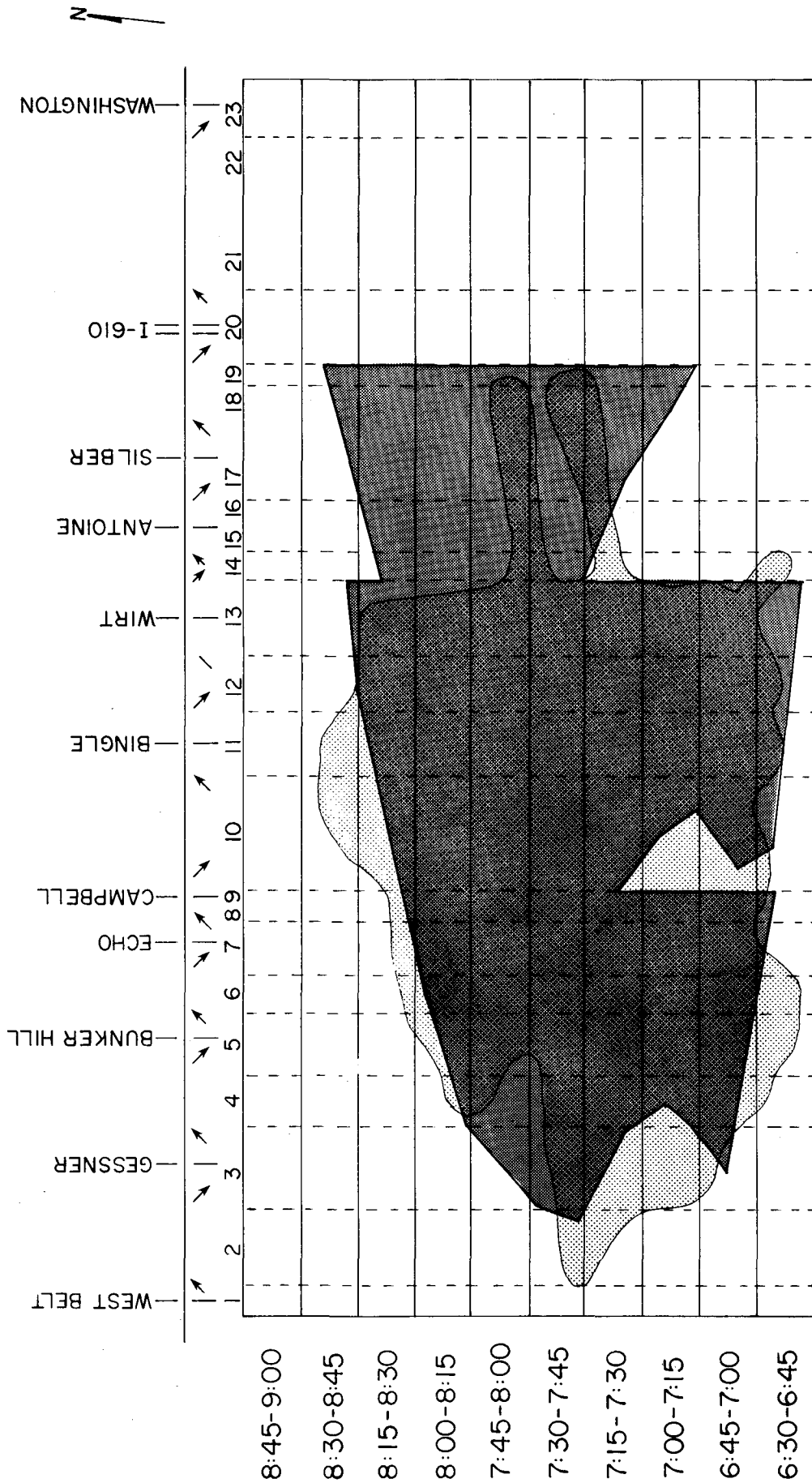


FIGURE 15. RUN 12-INBOUND I.H. 10

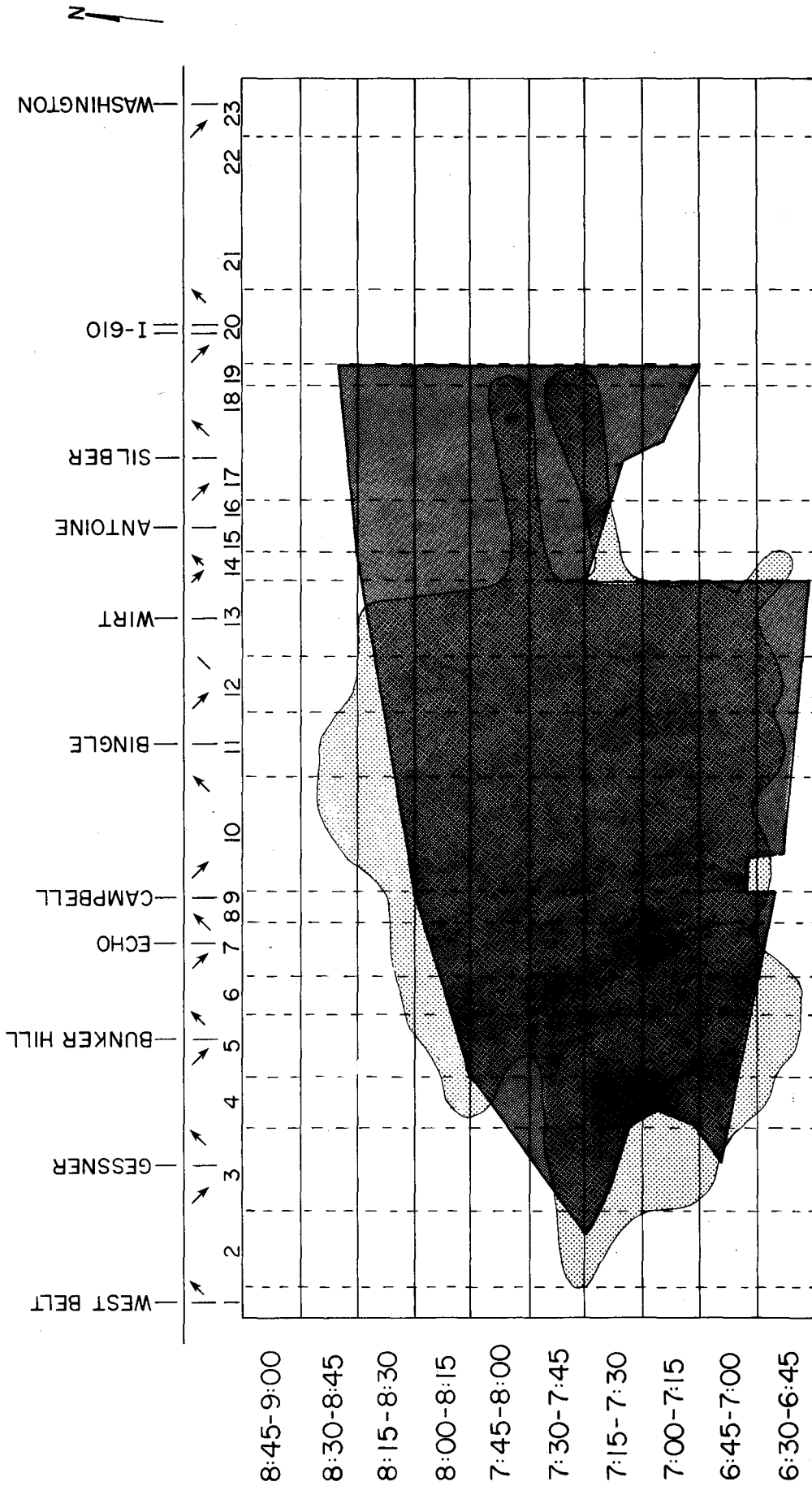


FIGURE 16. RUN 13-INBOUND I.H. 10

exit was studied. Previously 70 percent of the 60-40 percent split was used. In this run only 60 percent of the 60 percent in a 60-40 split was used. The resultant congestion pattern matches well with the field data except towards the end of the study period.

Figure 17 - All simulation runs previous to this run were based on 10-minute time-slice O-D data. In this run all input data remained the same, except 15-minute O-D data were used. The distribution of Silber entrance to I.H. 610 exit was modified as per the previous study. The general congestion pattern matches the Figure 16 results very closely.

Figure 18 - Using the 15-minute time-slices but limiting the Wirt entrance ramp to a maximum input of 1,700 vph produced a congestion pattern that matches very closely with the field data. In fact, this represents the point where a calibrated model was attained. Even though the congestion never quite reached Subsection 2, it did build early and end in the correct time periods.

The only questionable portion of the simulated congestion pattern is in Subsections 14 through 19. Two methods could be used to correct this extended (in time) congestion. The first method would be to have some type of variable capacity for subsections 18 and 19. This can be achieved by using the weaving analysis, but the weaving analysis has to be used throughout the study system. Without weaving analysis, the only other way to achieve this variability would be to modify the O-D data. The O-D data, as used, had been modified somewhat and any other modification was undesirable. Therefore, it is assumed that the extra delay in this area is not sufficiently large enough to affect the outcome of the evaluation.

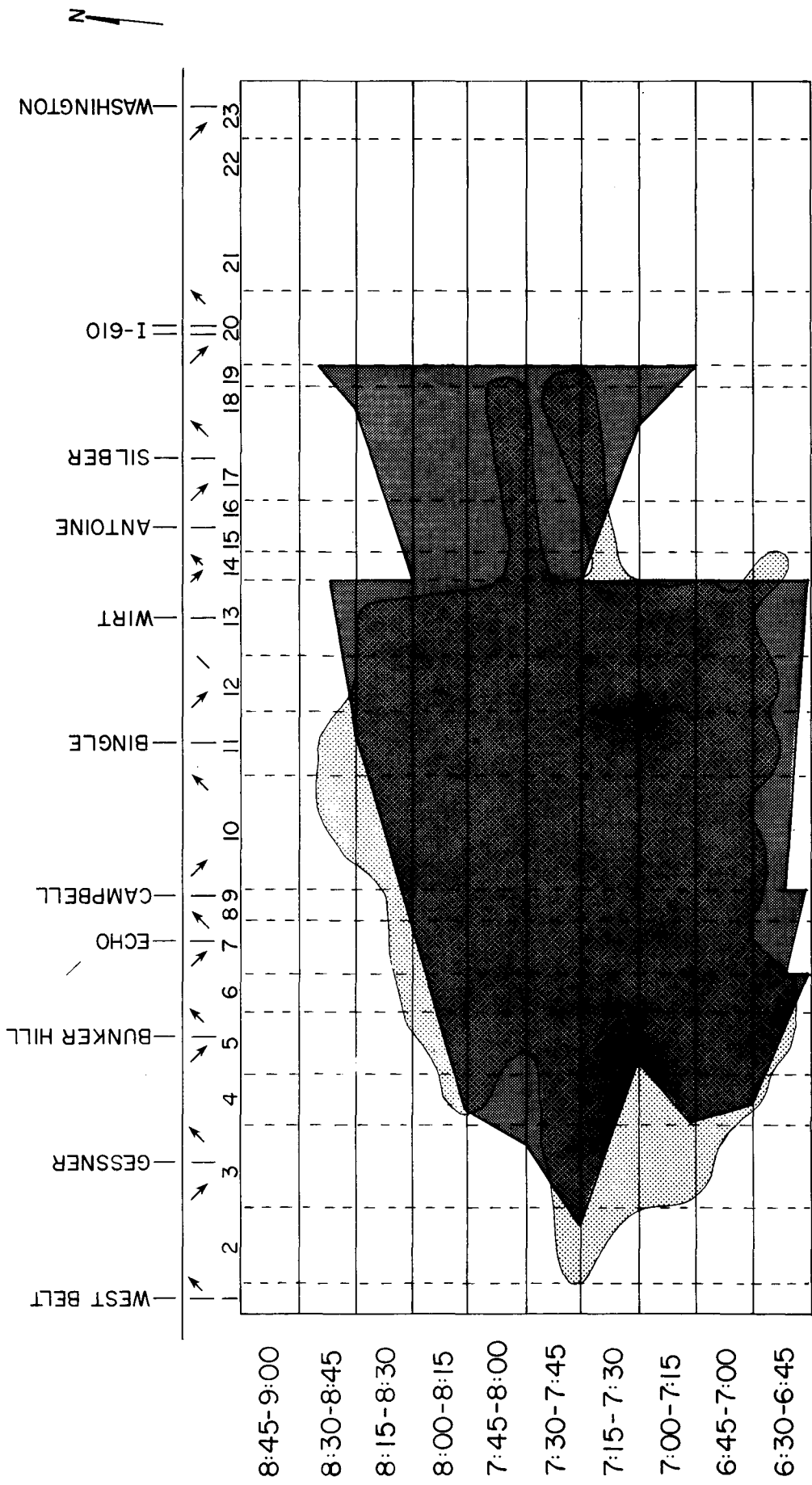


FIGURE 17. RUN 14-INBOUND I.H. 10

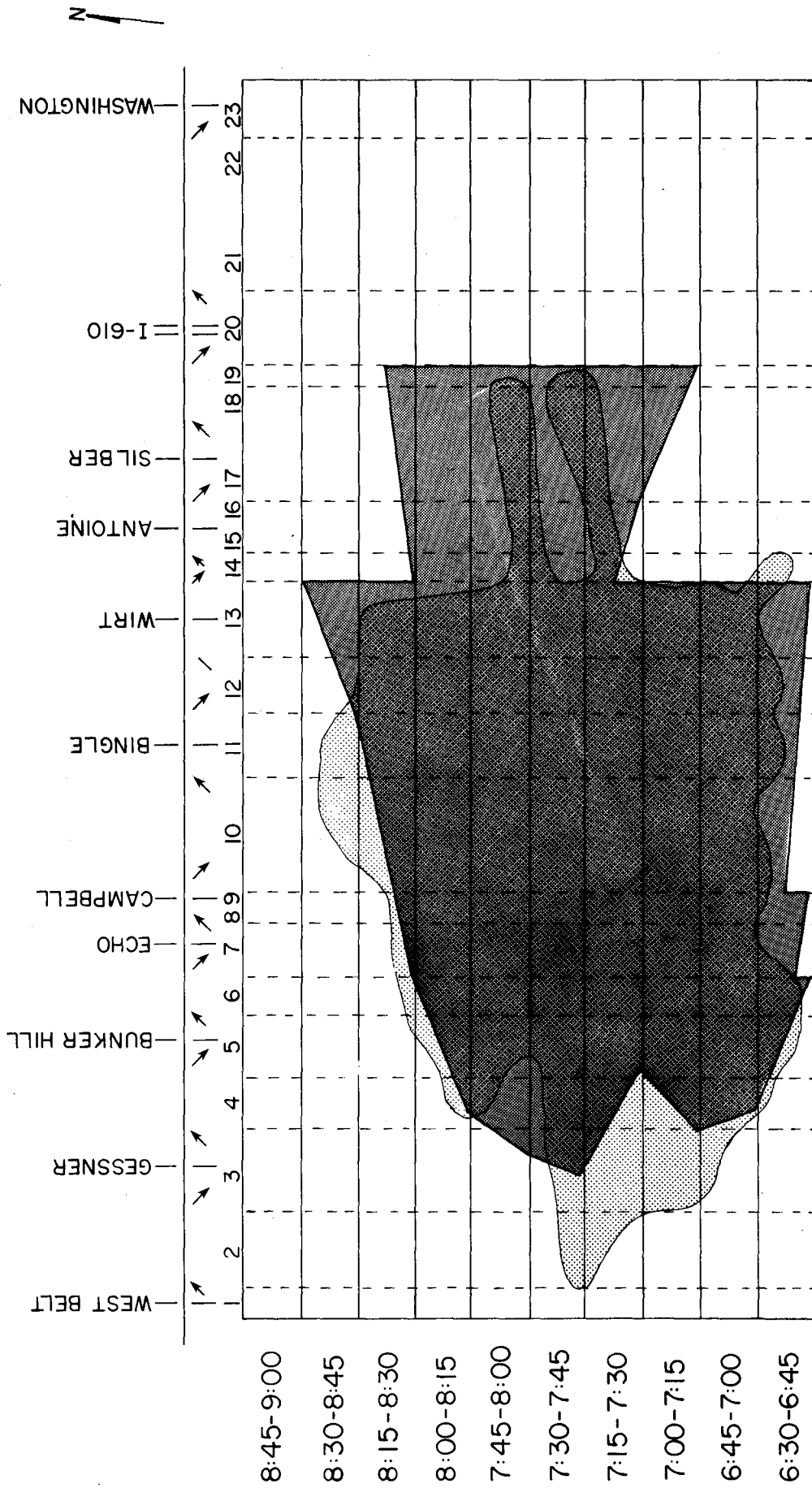
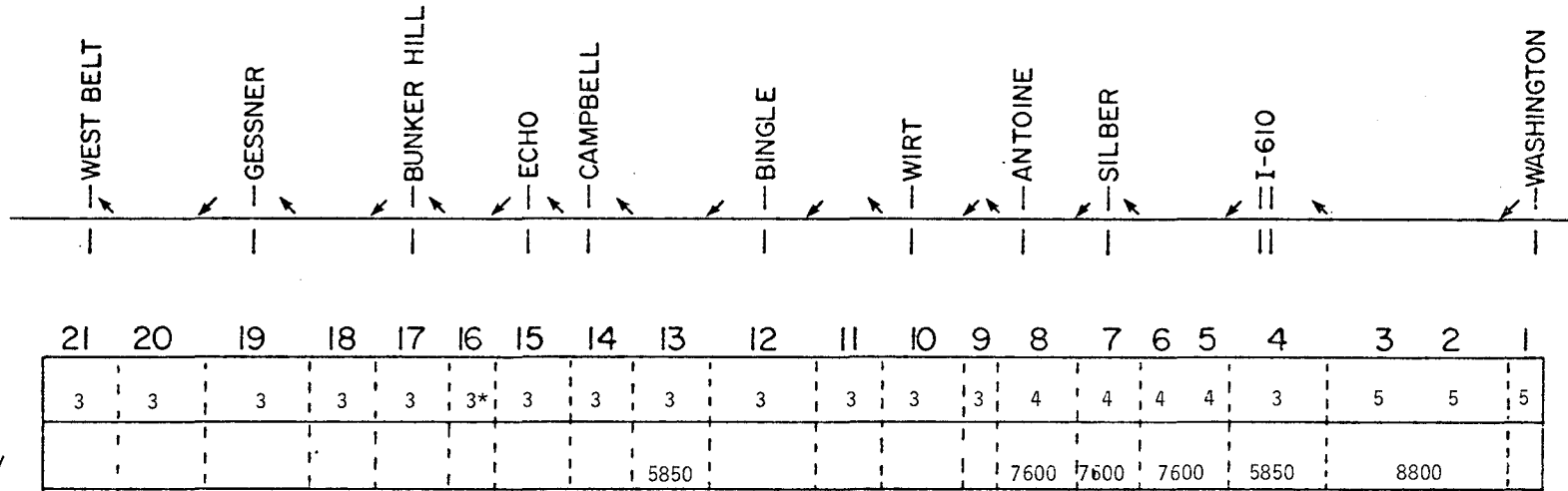


FIGURE 18. RUN 15 - INBOUND I.H. 10

Outbound Interstate Highway (I.H.) 10

The tachograph data taken during the instrumented vehicle runs on the outbound Katy Freeway supplied the information needed to complete the base congestion contour. This congestion contour, as was described for the inbound calibration, was constructed by including all speeds under 35 mph on a time-slice by subsection plot. It is shown as the enclosed shaded background area on the congestion Figures 20 through 27. Of interest, are two subsections where severe bottlenecks are evident (Figure 19). Subsection 13 is bounded by the Bingle entrance to Campbell exit. It is basically a level 3-lane freeway section that doesn't have a emergency parking median lane. Adding to the subsection's flow constraints during peak PM traffic, this narrow section does not permit good sight distance. Upstream of this subsection are two entrance ramps that add as much or more demand than exits at the Bingle exit ramp. Downstream of Subsection 12 are two heavy volume exit ramps plus the freeway widens at the Campbell overpass and has the emergency parking lane on both the median and shoulder lanes. Flow rates just upstream of the Campbell exit ramp in Subsection 13 are greater than the flow rates upstream in Subsection 10 which is the second bottleneck area. At the end of Subsection 8, a freeway lane is dropped. The lane reduction causes severe congestion because of the last minute weaving for the through outbound traffic. Before this traffic in Subsection 9 can adjust headways and gain speed, more demand is added at the Antoine entrance ramp. This added demand and resulting congestion extends to the Bingle-Voss exit (end of Subsection 10). In the peak period, the congestion in Subsection 10 and its extension upstream normally occurs earlier than in Subsection 13 because of the large demand



*Denotes Error - See Text, Run H

Figure 19. Outbound I.H. 10 Subsectional Configuration

for I.H. 10 westbound traffic from the I.H. 610 entrance ramp. As the subsections become loaded, the congestion queues develop rapidly and join, eventually extending from Subsection 13 to Subsections 3 and 2. The overall outline of the congestion period generally indicates that the freeway's maximum queue develops in a 15-minute period and then gradually diminishes over more than one hour.

Table 3 contains the general comments concerning each of the calibration runs attempted during the outbound I.H. 10 analysis. The merging/diverging analysis was disengaged for off-ramp 1 and on-ramp 3 because each is a 2-lane ramp with a traffic capacity greater than the general ramp limit. The 55 mph speed-flow curve was selected because of the experience gained during the inbound calibration as well as the fact that the outbound traffic lanes exhibit the same basic characteristics as do the inbound traffic lanes.

Figure 20 - Weaving was selected for this analysis and the subsectional capacities established were slightly under the 2,000 vehicles per lane maximum. O-D data in 10-minute time-slices were chosen with the expectation of rapid congestion buildup. As can be seen in Figure 20, the weaving analysis produced severe bottlenecks in Subsections 5 and 6 and at Subsection 16. The early development of the queue in Subsection 6 inhibited much of the traffic demand from ever reaching the outer subsections. Once the congestion queue extends outside Subsection 1, the simulation program is not able to retain the expelled vehicles and does not function properly. Therefore, the simulation results past 5:00 PM are unusable. To accomplish a calibrated run using the weaving analysis would have required significant changes in the O-D tables and subsectional capacities. Therefore, the weaving analysis was disabled.

TABLE 3
Outbound I.H. 10 General Input Parameters for Calibration Computer Runs

| SUBSECTION | LANES | FIGURE 20 | FIGURE 21 | FIGURE 22 | FIGURE 23 | FIGURE 24 | FIGURE 25 | FIGURE 26 | FIGURE 27 |
|------------|-------|--|--------------|--------------|--------------|-----------|-----------|-----------|--|
| 1 | 5 | 8800 | S | | | S | | | 8800 |
| 2 | 5 | 8800 | A | | | A | | | 8800 |
| 3 | 5 | 8800 | M | | | M | | | 8800 |
| 4 | 3 | 5850 | E | 5700 | | e | | | 5700 |
| 5 | 4 | 7600 | | 7200 | | | | | 7200 |
| 6 | 4 | 7600 | | 7200 | | | | | 7200 |
| 7 | 4 | 7600 | | 7200 | | | | | 7200 |
| 8 | 4 | 7600 | | 7200 | | | | | 7200 |
| 9 | 3 | 5850 | | 5700 | 5650 | | | | 5600 |
| 10 | 3 | 5850 | | 5700 | 5650 | | | | 5600 |
| 11 | 3 | 5850 | | 5700 | 5650 | | | | 5600 |
| 12 | 3 | 5850 | | 5700 | 5650 | | | | 5600 |
| 13 | 3 | 5850 | | 5700 | 5600 | | 5650 | | 5600 |
| 14 | 3 | 5850 | | 5700 | 5650 | | | 5750 | 5700 |
| 15 | 3 | 5850 | | 5700 | | | | 5750 | 5700 |
| 16 | 3 | 5850 | | 5700 | | | | 5750 | 4 Lanes/6500 |
| 17 | 3 | 5850 | | | | | | | 5800 |
| 18 | 3 | 5850 | | | | | | | 5800 |
| 19 | 3 | 5850 | | | | | | | 5800 |
| 20 | 3 | 5850 | | | | | | | 5800 |
| 21 | 3 | 5850 | | | | | | | 5800 |
| | | *General ramp limit = 1500. *Exit 1 = 3600. *Entrance 3 = 3300. *55 mph curve. *Weaving *6 TS/Hr. | *No weaving. | *No weaving. | *No weaving. | 4 TS/Hr. | | | *No weaving. *4 TS/Hr. *55 mph curve. *Entrance 3 = 3000. |

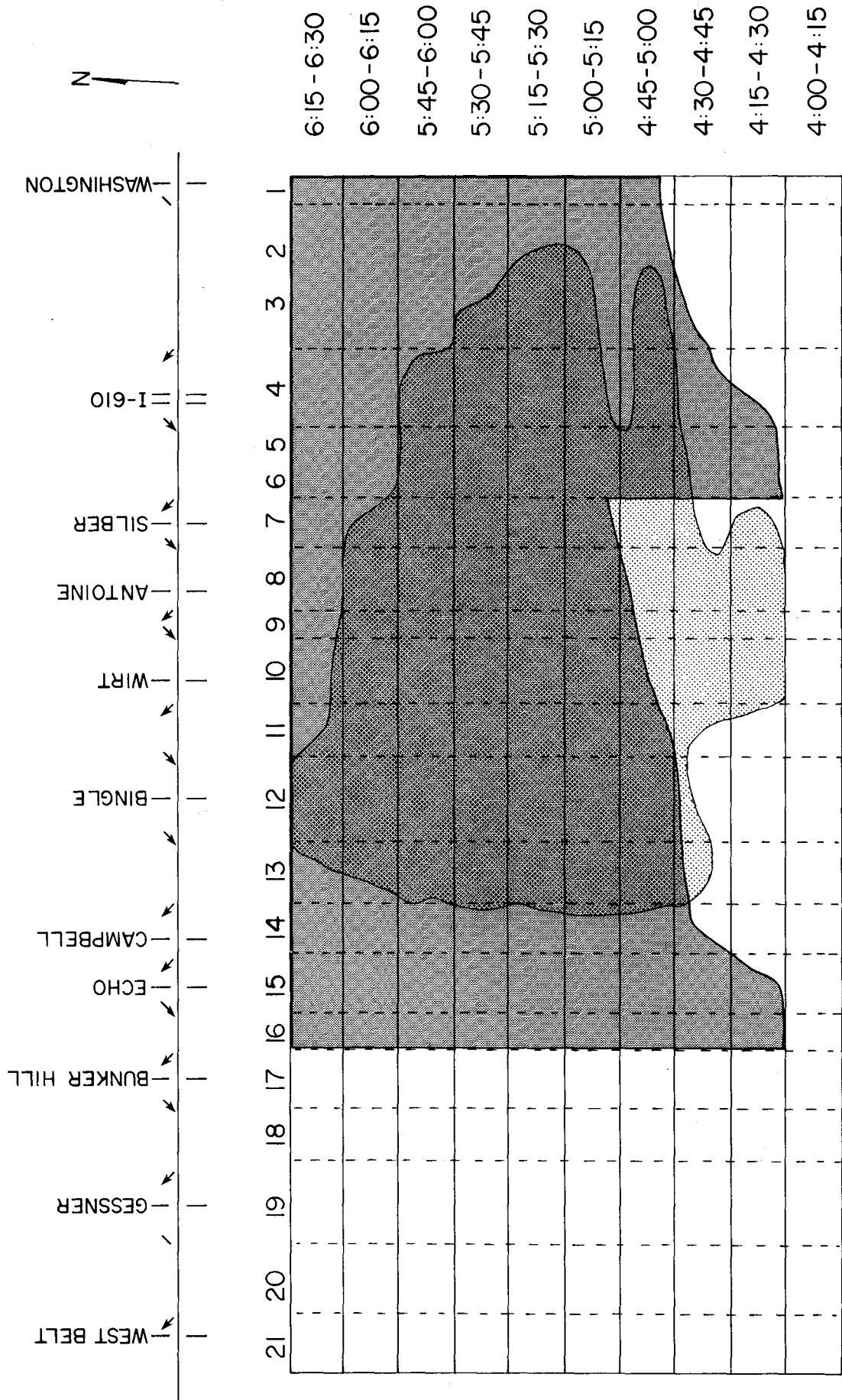


FIGURE 20. RUN A-OUTBOUND I.H. 10

Figure 21 - Identical input parameters and data were used for this run except the weaving analysis was disengaged. Congestion developed too late in Subsection 10 but properly in Subsection 13. The extended congestion in Subsection 16 should not have occurred. Also, the overall size of the congestion did not approach the base data contour.

Figure 22 - The capacities in Subsections 4 through 16 were reduced from that used in Figure 21. Congestion developed (without weaving analysis) in the bottleneck areas in the right time periods except for Subsection 16. The overall queue did not extend as far nor last as long as the base data configuration. Queue development at Subsection 16 was also evident, but should not have occurred.

Figure 23 - Adjustments were made to the capacities in Subsections 9 through 14. By reducing the capacities upstream of Subsection 16, traffic demand should be reduced and queue formation eliminated in Subsection 16. Analysis of the simulation results in this run indicates that congestion developed earlier than desired and still occurred in Subsection 16. Queue extension was sufficient but did not reduce rapidly enough during the last time periods.

Figure 24 - Noting the acute changes in the congestion pattern in Figure 23 plus the fact that 10 minutes input data were used, this run was made using O-D data from the 15-minute time-slice. The overall outline of the congestion pattern did smooth out but did not provide a calibrated model of the base data.

Figure 25 - The capacity in Subsection 13 was raised and the simulation program executed again. Only a slight improvement was noted in the queue formation.

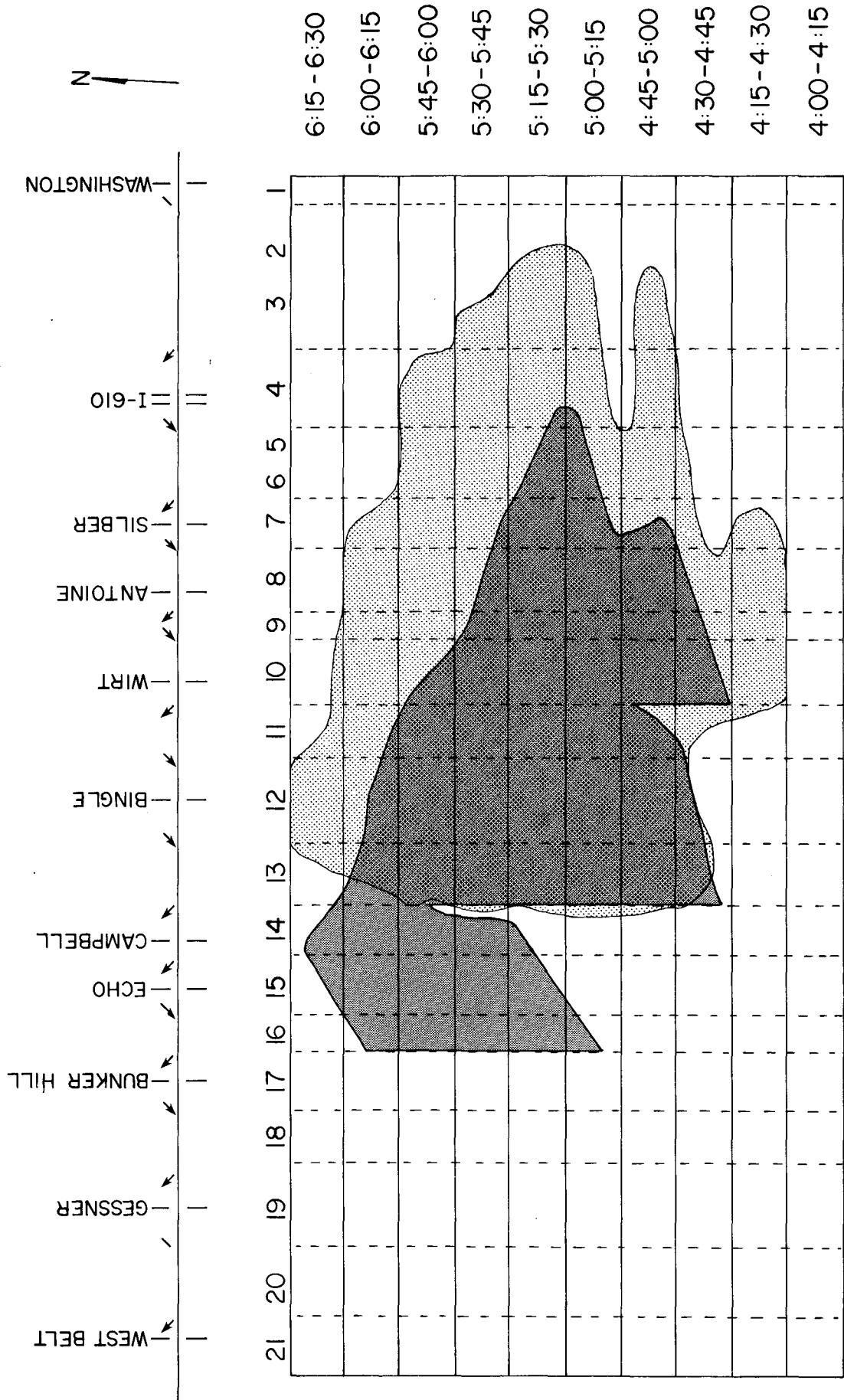


FIGURE 21. RUN B - OUTBOUND I.H. 10

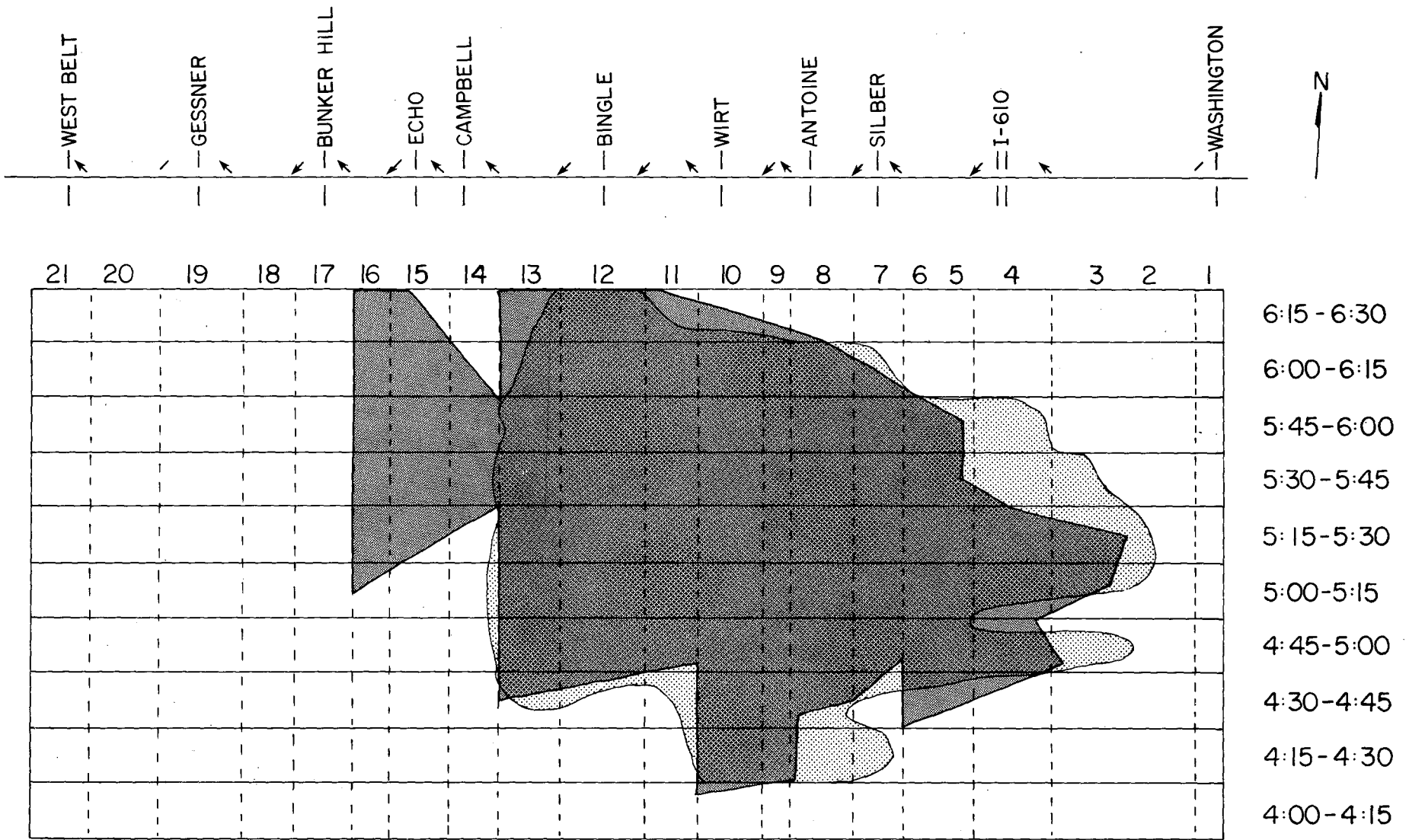


FIGURE 22. RUN C - OUTBOUND I.H. 10

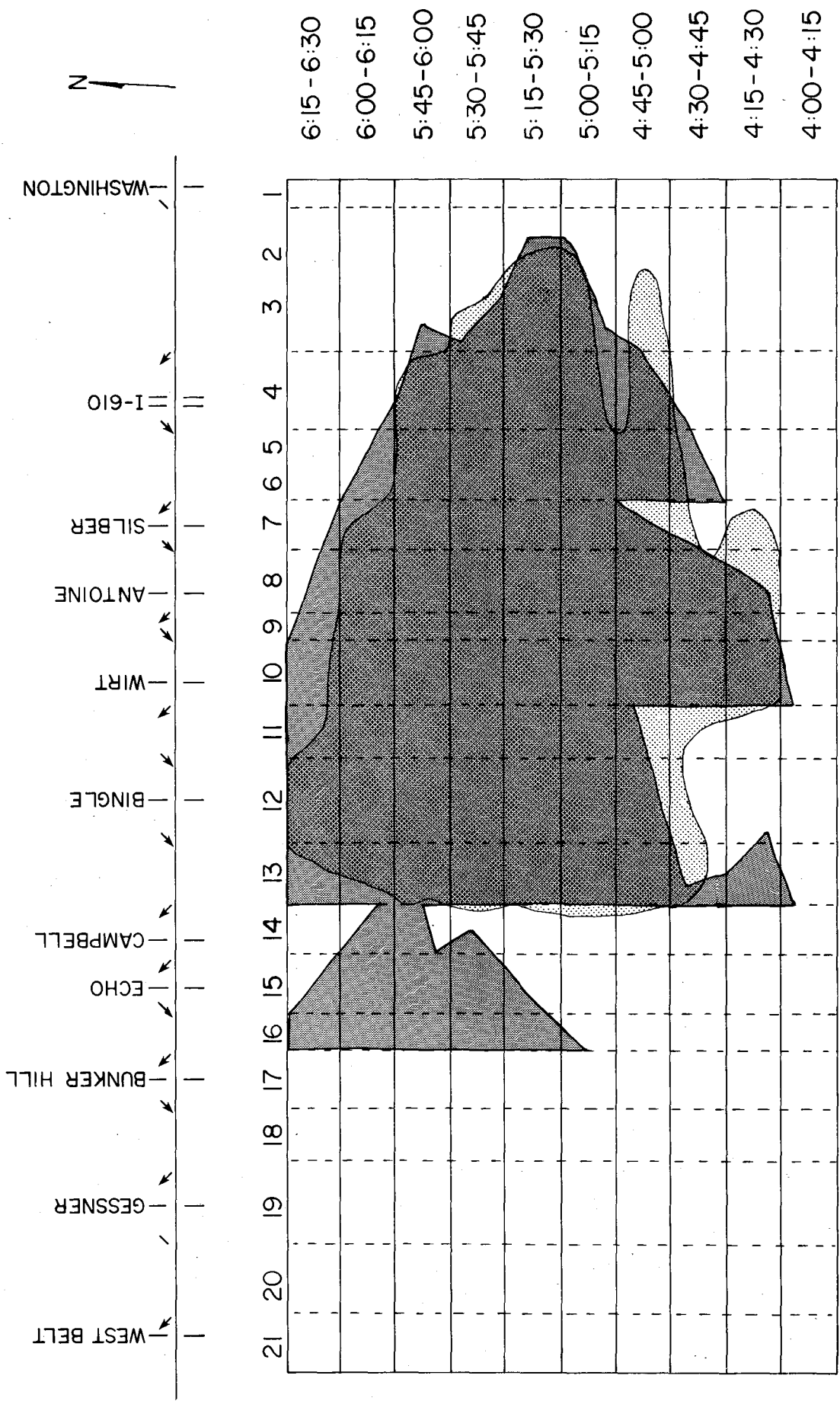


FIGURE 23. RUN D - OUTBOUND I.H. 10

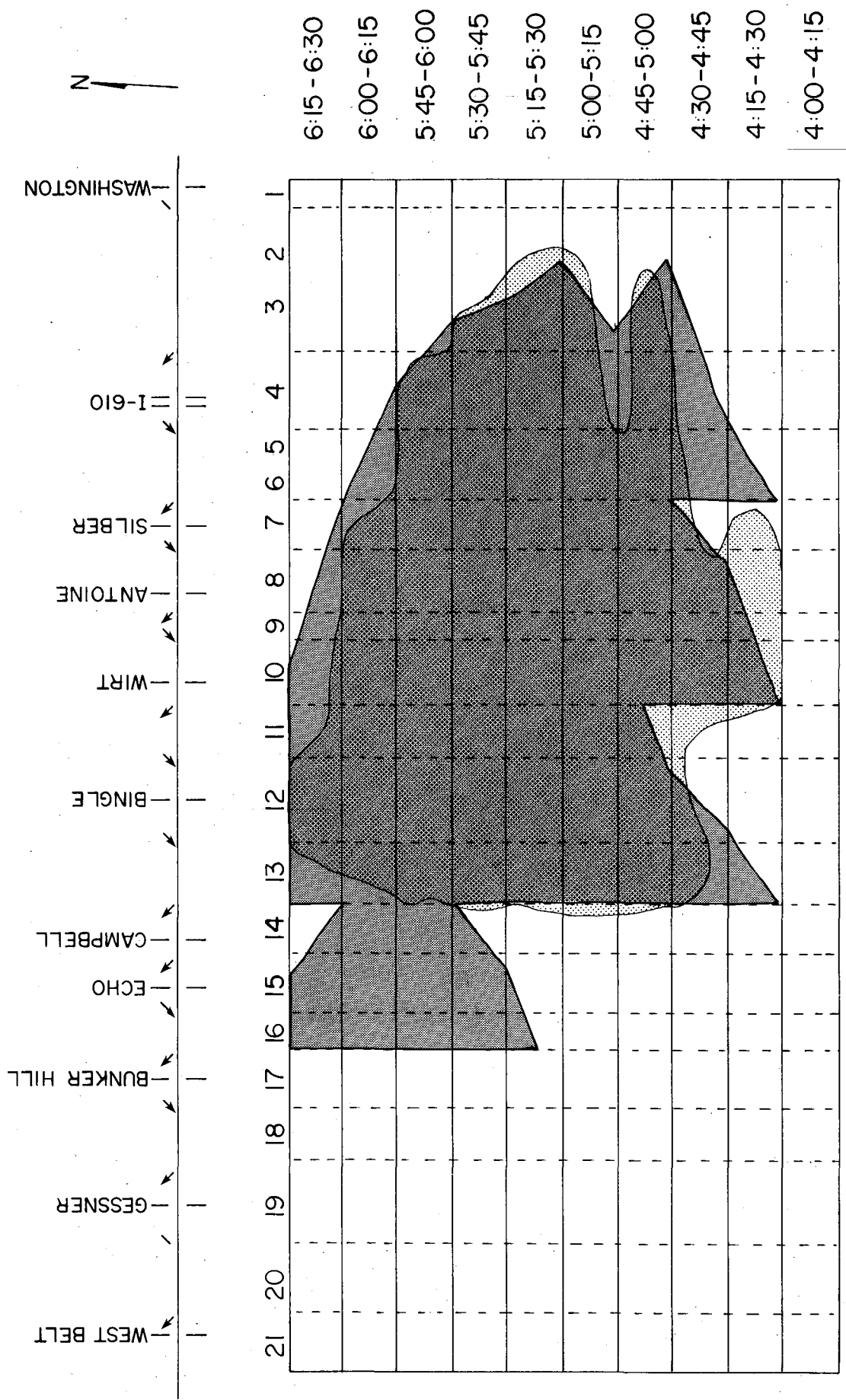


FIGURE 24. RUN E - OUTBOUND I.H. 10

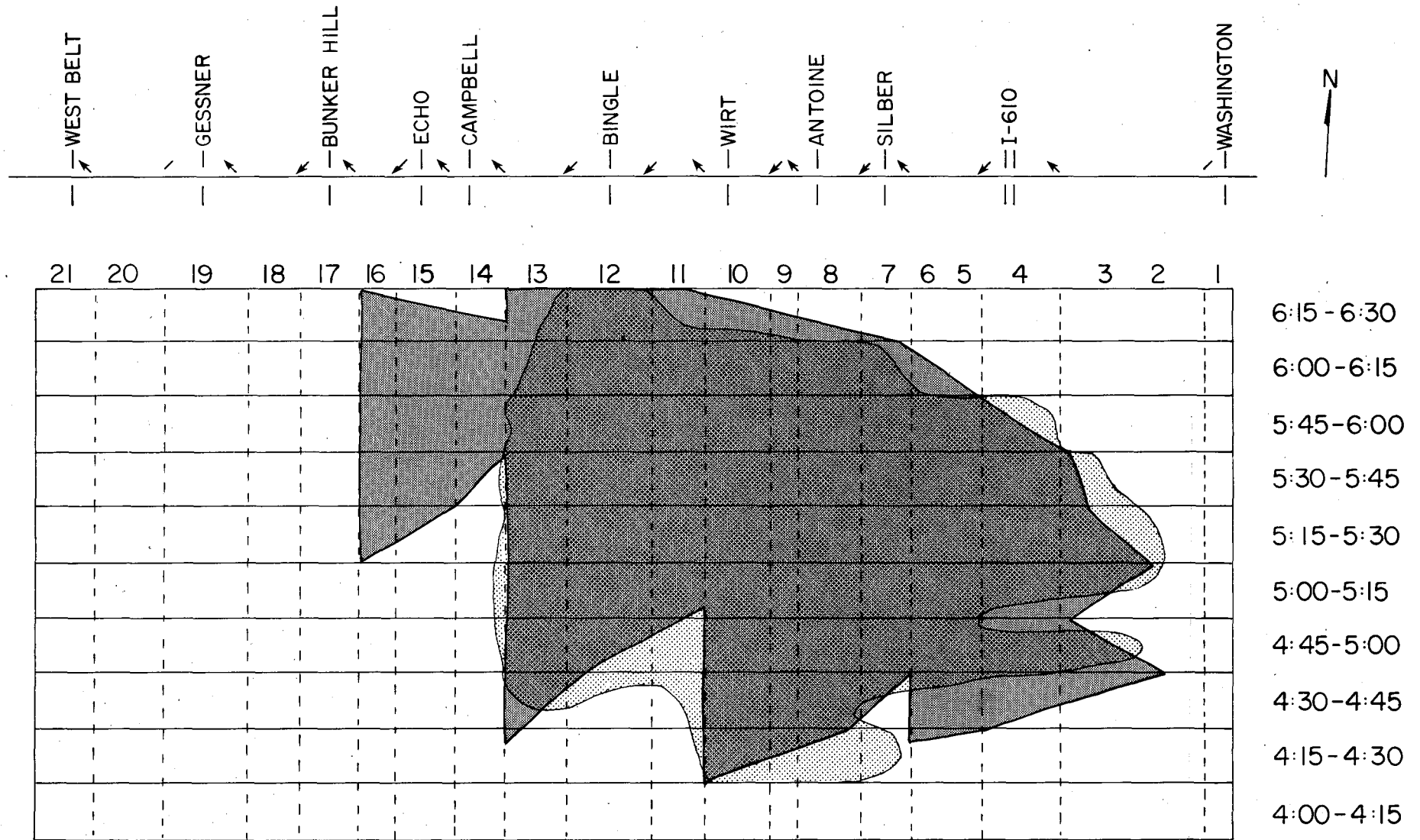


FIGURE 25. RUN F-OUTBOUND I.H. 10

Figure 26 - Instead of trying to reduce upstream capacities so that demand would be held back, the downstream capacities were raised to help accommodate the demand. Capacities in Subsections 14, 15 and 16 were raised above those in the upstream subsections. This was attempted so that the queue would not form from Subsection 16. Also, the queue formations were beginning in the appropriate time periods as well as the overall contour conforming to the base data. Therefore, the subsectional capacities from 13 and upstream were assumed to be correctly adjusted. The simulation results indicated that the congestion pattern conformed nicely except for the continued queueing in Subsection 16.

Another problem that had been occurring needed to be eliminated. Entrance ramp 3 (traffic entering from I.H. 610 in Subsection 5) normally had a queue on the entrance ramp during the field studies. With the ramp capacity set at 3,300 vehicles per hour, the simulation program did not delay the entrance ramp traffic, instead the delay was placed on the upstream freeway traffic. By adjusting downward the ramp capacity for entrance ramp 3 to 3,000 vehicles per hour, delay was placed on the entrance ramp demand and a ramp queue developed. Although this adjustment was small, the delayed input at entrance ramp 3 did help create more demand after 5:00 PM.

Figure 27 - Concern over the inability to adjust the subsectional capacities so that the queue formation was eliminated in Subsection 16 lead to an investigation of the field site. Even though the entire study section had been visisted several times before the computer simulation began, the correct number of lanes for this subsection was overlooked. From the Echo entrance to the Bunker Hill exit is an extra lane for the accelerating/

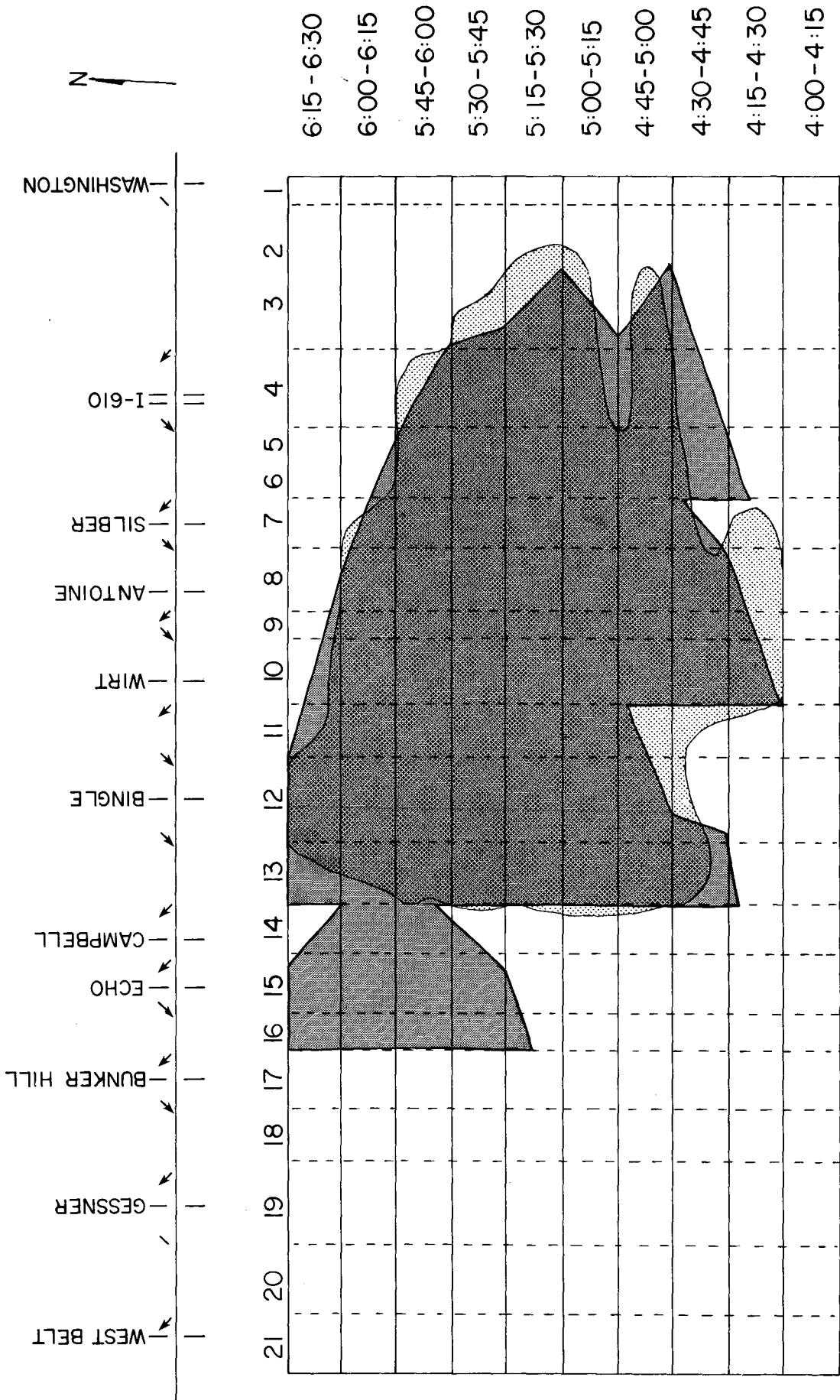


FIGURE 26. RUN G-OUTBOUND I.H. 10

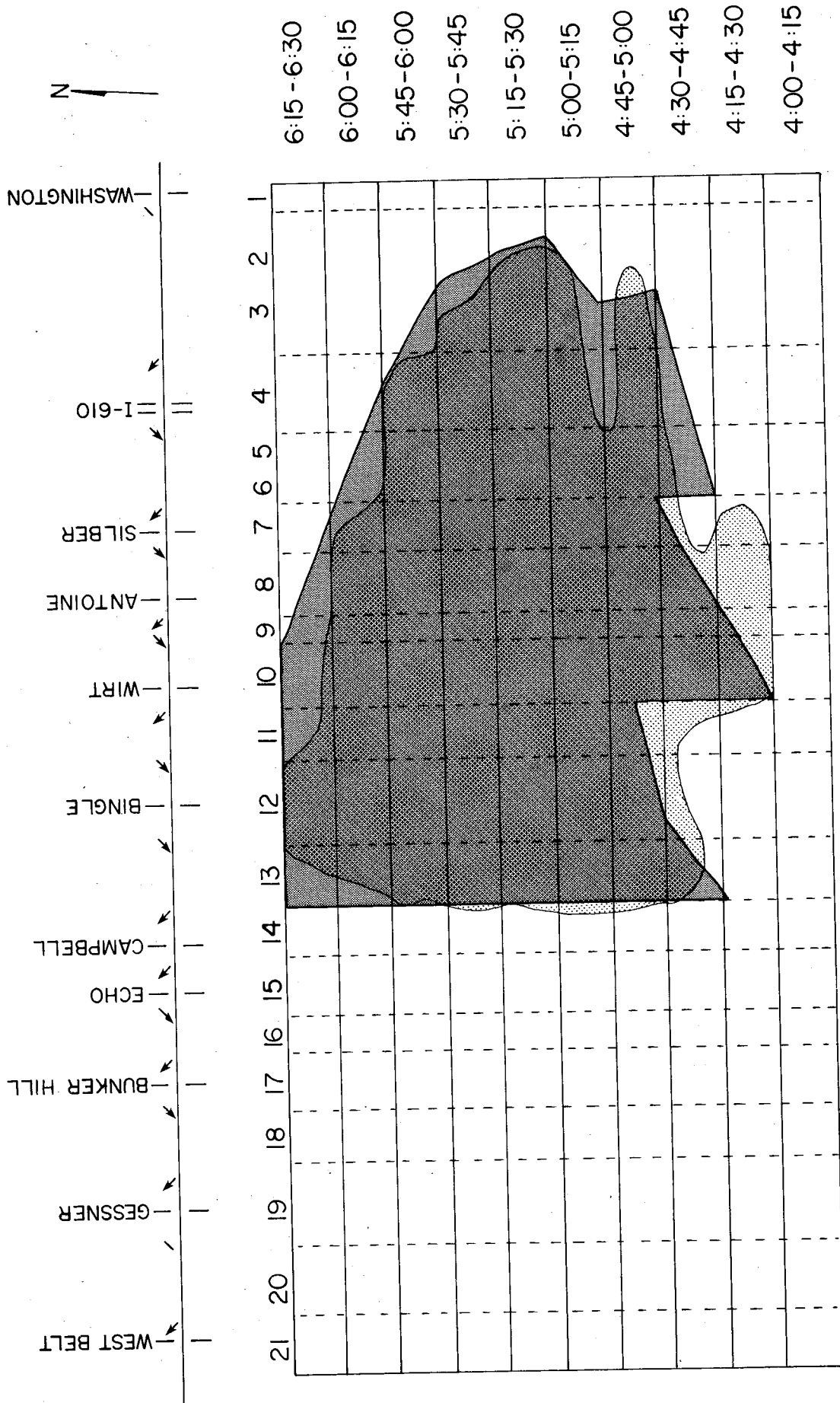


FIGURE 27. RUN H-OUTBOUND I.H. 10

decelerating traffic. In effect, this subsection has 4 not 3 lanes. Readjusting capacities and installing the revised entrance ramp 3 capacity produced the results as presented in Figure 27. The congestion patterns and base data begin in Subsections 13 and 10 in the correct time periods. The queue formation in Subsections 6 and 8 begins one time period too soon. Overall, the congestion pattern extends slightly over and remains less than one time-slice too long. Analysis of possible changes that would result in a closer simulation fit to the base data contour indicated that some of the entering traffic at I.H. 610 entrance (entrance 3-Subsection 5) would have to be shifted from one time-slice to the next. Since several more runs would possibly be needed to adjust this changed O-D pattern, the decision was made to let this simulation result represent the calibrated model.

CALIBRATION SUMMARY

Within the user documentation of the FREQ3CP simulation program, suggestions are given as to what should constitute a calibrated simulation model. Although it would be advantageous for first time users to have firm "cook-book" directions to follow, the very nature of the simulation process almost negates this possibility. Specific guidelines are given with respect to capacities, merging analysis, weaving, etc., that assist in the initial program settings but the decision as to when a calibrated simulation model has been reached is not always a cut and dried situation. Three of the more important criteria pointed out in the instructions are as follows:

1. The simulated travel times by subsection should be within 10 percent of the field measured data by subsection;
2. The simulated travel time (or speed) contour map should

generally conform to field measured data especially with respect to bottleneck locations, length of congestion and time of congestion and

3. The simulated off-ramp volumes should contain no great discrepancies with actual field data.

The close equality of travel times between the simulated results and field measurements is required to insure that the selected speed curve is realistic for the freeway facility in question. It will not mean as much for just obtaining a before simulation; particularly where extensive congestion is present, as it will when requiring an after simulation and comparing the program results. It is after some type of control (entrance ramp), capacity improvement (lane addition) or demand adjustments that an unrealistic speed curve will cause inaccurate travel times, and thus, unreliable total travel time measurements. A speed curve chosen which yields higher speeds (lower travel times) will yield lower total travel times. Lower speeds taken from a lower-than-normal speed curve will yield higher than normal total travel times. When comparing before and after conditions, the speed curve utilized becomes an important ingredient of the model's input.

The relative shape of the simulated congestion contour is largely controlled by the O-D data and the subsectional capacities. Prudent use of the capacities, merging/diverging analysis, weaving analysis and other program options should enable simulated congestion patterns to be derived that correspond to the field measured patterns. The more attention given to the correct matching of these congestion shapes, the more confidence can be placed in the after control simulation results. The quantity of

FREQ3CP program runs that must be executed before a calibrated congestion model is derived will depend on the accuracy of the O-D information used and the manner in which the field measurements are taken. If questionable field measurements and O-D data are used, the probability of reaching calibrated results in only a few program runs is small. Therefore, the more accurate the total input to the model, the closer will be the initial simulation results and the field measurements.

While the developers of the FREQ3CP model did not dwell on discussions concerning the importance of the simulated off-ramp volumes corresponding to actual field data, it should be pointed out why this should be accomplished. The basic reason has to be taken from one of the assumptions for employment of the linear programming analysis, i.e., traffic will not divert from one time-slice to another time-slice. During periods of congestion free operation, vehicles are entered, propagated and dispensed as per normal program operation. However, ramp vehicles stored in queues due to congestion are delayed, and thus, added to the next O-D pattern. Whenever a sufficient number of ramp vehicles are delayed, the following O-D patterns may cause the off-ramp outputs to be significantly different than the field data. Therefore, some of O-D trips in the affected time-slices will have to be shifted to subsequent time-slices. This shifting has to be done externally as the program is unable to automatically compensate for these revisions. If the O-D data are not modified, the output results of the simulation model can cause too much on-ramp delay, possibly too many diverted vehicles and excessive travel time values, as well as not providing realistic exit ramp flows. Therefore, as a check against the simulation procedures, the off-ramp volumes between the model and field data should be compared and

no great discrepancies should exist.

In this study, the attempts to check all three of the major conditions after each of the first few simulation runs became laborious. After the decision was made to concentrate on the congestion patterns, the other two conditions became less important during the development of the calibrated models. Since the congestion contours generated were the direct results of demands versus capacities buffered by the other program options, confidence in the final calibrated models was gained primarily because of the extensive amount of time that the studied freeway sections were congested. Subsection travel times and exit ramp volumes were examined after calibration had been reached. As per program instructions, the simulation results produced travel times that were within 10 percent of the field measurements for both the inbound and outbound analysis. Although several simulated exit ramps experienced up to a 20 percent volume deviation from the same time period field measurements, the overall deviations were 8.5 percent for the inbound and 2.3 percent for the outbound simulations, respectively. Both were considered to be within reasonable limits and conformed to expected limitations.

First time users of the FREQ3CP computer program should exercise great care in the proper arrangement of the input card deck, as well as correctly aligning each datum element on each card. The computer program, during data input, expects certain information to appear in a definite order even if blank cards have to be included. If the information is not as expected, the program may abort or continue to function; yielding inaccurate results. Some program aborts are easily identified, and corrective measures can be readily taken, while other aborts do not lend themselves to pointing out which data caused the error. In the case of the latter condition, assistance

in determining the cause of the error can be obtained from the State Department of Highways and Public Transportation Division of Automation (File D-19) personnel. Also, input errors that do not cause an abort produce results that are, normally, very apparent. The user will invariably make some mistakes in constructing the initial program card deck, but if each card is coded correctly and the card deck arranged as per instructions, a minimal number of errors will be experienced.

BENEFITS

The extensive range of analysis capabilities contained in the FREQ3CP freeway simulation and priority ramp control computer program were not examined in the study. Instead, the study was directed at obtaining a working knowledge of the model, calibrating the model to a Texas freeway facility, and assisting the State Department of Highways and Public Transportation District 12 office in the study of the I.H. 10 (Katy Freeway) operations. The investigative work conducted, in cooperation with District 12, on I.H. 10 provided the freeway facility on which the freeway simulation could be tested. Since the primary interest was in obtaining the characteristics of the freeway operations after a period of years with a constant freeway demand growth (with no ramp control operations being contemplated), the benefits to be derived from an analysis of the decision model results would have been inconclusive. Before the total FREQ3CP program can be analyzed, a calibrated simulation of existing freeway operations must be obtained, an optimized ramp control strategy developed with the computer model, the ramp control strategy applied to the actual ramp control operations in the field and the resulting freeway operations compared with the after-control freeway simulation results. An alternate freeway facility has been

chosen on which actual isolated entrance ramp controllers will be installed. This is the Interstate Highway (I.H.) 45 (North Freeway) in Houston that also will have the Contra-Flow Bus Operations. It is on this freeway facility that the decision model will be tested and the results reported.

Although many of the input parameters were not analyzed in this study as to their effects upon the simulation model's results, the overall output from the FREQ3CP computer program provides to the traffic engineer, for the first time, viable traffic operations on a variable time and distance bases. Once the initial calibrated freeway traffic operations have been obtained, the traffic engineer can examine the various ramp control sequences, maximizing either vehicles or passengers; with or without bypass buses/ carpools; at all or selected entrance ramps. After receiving the optimized metering conditions necessary to solve congestion, the controlled freeway operations can, once again, be simulated with the installed metering system operational. With the before and after simulation results, along with the diverted demand, the traffic engineer can produce more accurate estimates of the costs/benefits to be derived from various control configurations. Even alternative operations such as lane additions, extended acceleration/deceleration facilities, bus/carpool bypass operations and ramp reversals can be modelled and analyzed at the traffic engineer's discretion.

While the exact computing costs for a calibrated simulation model depend upon the number of entrance/exit ramps, a typical computer run time cost for one of the development runs on I.H. 10 was approximately \$20-\$25. Less than half of this cost was associated with run time on the computer (rate = \$18/minute) and the remaining cost allocated to data transmission and printing (\$.004/line transmitted or printed). Cost figures are based on the 1977

rates for usage of the data processing equipment in both the Houston Urban Office and Division of Automation within the State Department of Highways and Public Transportation.

The actual computing, data transmission and printing costs are minor in comparison to the manpower costs associated with conducting the traffic data collection, preparing the traffic data for the SYNODM and FREQ3CP computer programs and analyzing the FREQ3CP program results. The extent of these manpower costs will depend upon the surveying methods employed and previously described in this report. This is assuming that suitable freeway traffic data are not already available. Normally one person can prepare or supervise the preparation of the traffic data into suitable computer format. The analysis of the program results should be conducted by person(s) knowledgeable with the program inputs, outputs and capabilities.

WORKING EXAMPLE

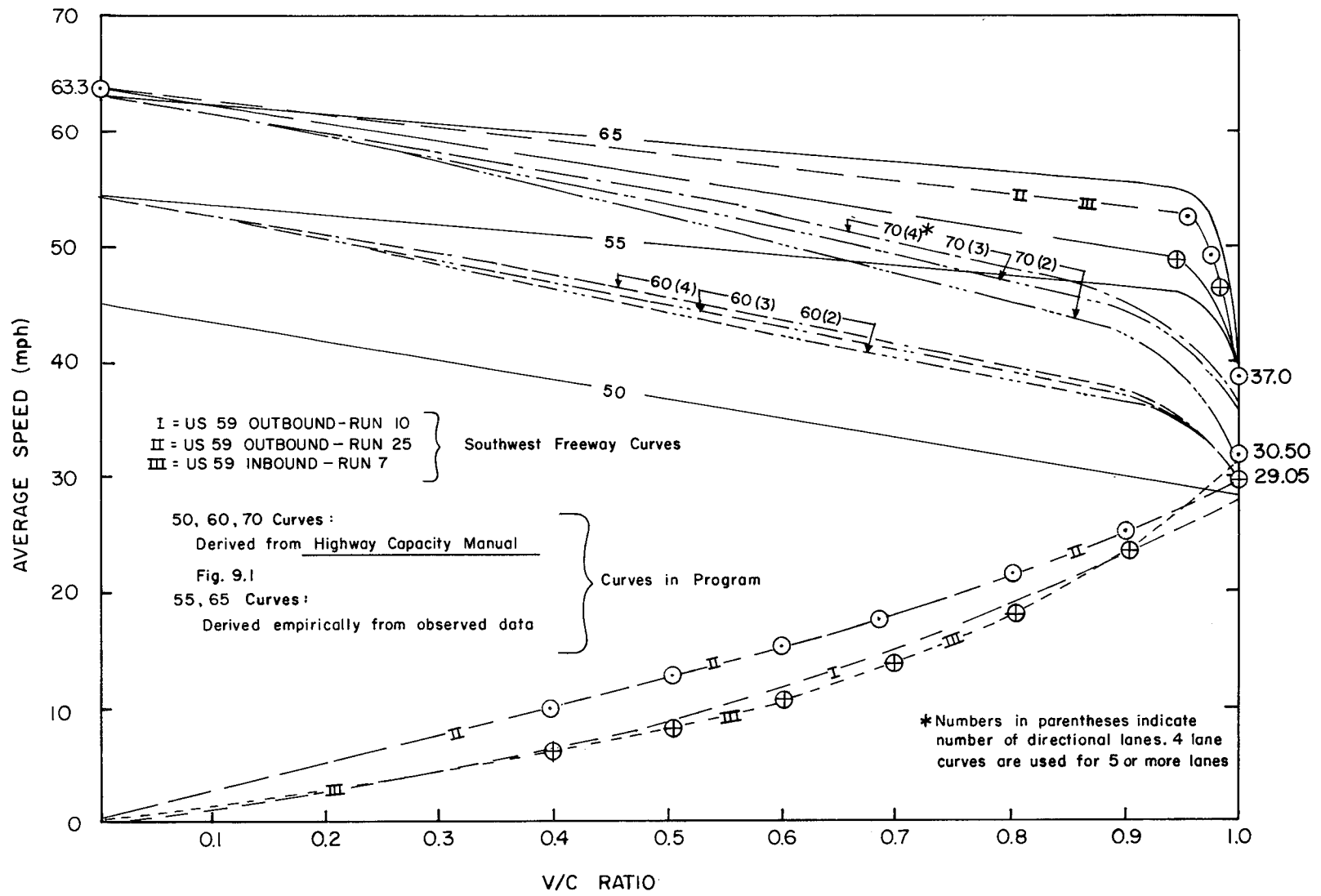
The Houston Urban Office of the State Department of Highways and Public Transportation required information on the present traffic operations in both directions on the Southwest Freeway (U.S. 59 South) in Houston, Texas prior to formulating definite improvement plans for various segments of the facility. To utilize the FREQ3CP computer model to the fullest extent, the collection of traffic data was required. Besides the normal volumes on all entrance and exit ramps, traffic was counted at the critical bottleneck locations, tachograph data runs were conducted in both directions over several days, traffic observers were stationed in tall buildings adjacent to the facility to record impeditive information and aerial photography data were taken during the two days of the traffic counting sessions. From these extensive data, the ramp volumes were used as input to the SYNODM synthetic O-D

distribution program. The tachograph data provided speeds, travel times, and congestion information, and the aerial photography data provided selective speeds and densities. As an example, the outbound PM peak period is discussed.

Inspection of the Calibration Log and sample data given in Appendix B for the outbound direction will indicate that 26 program runs were executed before the calibrated simulation was reached. A particularly difficult problem was encountered in this work because of the large demand at the I.H. 610 entrance ramp (Appendix C), an extensive ramp queue at this location, and the inability to firmly establish an overall capacity in this merging area. After several initial runs, in which the FREQ3CP program's 55 mph speed-V/C curve was used (without the weaving analysis), but in which the congestion patterns would not match, the decision was made to develop a speed-V/C curve based on the freeway facility. Using the speeds from the tachograph data and the V/C ratios from the simulation data, a regression analysis was executed which yielded a new curve (noted in Run 7, Appendix B). This new speed curve (Figure 28) provided better comparative data. When the simulated congestion pattern could not be significantly modified by just changing subsectional capacities, use of the weaving analysis was introduced. Several more speed-V/C curves were developed as well as multiple capacity changes. Each run produced results that were refinements from previous runs until the point was reached where a calibrated simulation model was obtained within the guidelines previously described.

Considerable effort was expended on these calibrations because of the desire to confidently use the results for modeling future traffic patterns. Extensive plans were developed and simulated from which the results were tabulated and compared. In this manner, the optimum benefit-to-cost ratios

Figure 28. A User Developed Speed vs. Volume/Capacity Curves



The Five Speed-Volume/Capacity Ratio (s-V/C)
Curve Families Self-Contained in the FREQ3 Model

3. Accident Costs,
4. Fuel Consumed and
5. Air Pollution Emissions.

The values of time and vehicle operating unit costs were selected from Research Report 202-2(6). Appropriate accident costs were selected from the AASHTO Redbook (4). Fuel consumption rates were generated from the 202-2 Research Report and the AASHTO Redbook. Pollution emissions data were taken from an Environmental Protection Agency Report (8) and altered to reflect typical vehicle emissions on Texas facilities.

The above five measures reflect time and vehicle operating costs, fuel consumed and pollution emissions of vehicles on the freeway proper, on the ramps and on diversion routes. On the freeway, they reflect costs, etc., due to constant speed travel, speed changes and stops within each subsection and due to speed changes between subsections. On the ramps, they reflect the costs, etc., due to vehicles stopped on the entrance and exit ramps. On the diversion route, they reflect costs, etc., due to constant speed travel, speed changes and stops/starts at intersections. Also, the measures reflect costs, etc., for single directional travel.

Initially, the economic analysis package was to be an integral part of FREQ3CP. Due to the present program size, execution time, and the probability of using the simulation and linear programming parts of FREQ3CP more often than the economic section, the decision was made to create a new program, to execute separately from FREQ3CP. Since the new economic analysis program, ECOANA (pronounced E'-co-an-na'), needs specific data from the freeway simulation computer model, data files will be established that will allow one-way communications between the programs. During the

execution of each time-slice's data within FREQ3CP, 1) the delay in each subsection, at each on-ramp and off-ramp, 2) the travel in each subsection, 3) the average speed by subsection, 4) the volume-to-capacity ratio by subsection, 5) the number of vehicles diverted from the freeway's entrance ramps, and 6) the total travel and total travel time must be stored on a permanent computer file. If, after execution and analysis of the FREQ3CP simulation program and the user determines that an economic analysis is needed, the ECOANA program will be run using the data just stored during the FREQ3CP execution. Data on the common computer file are retained until the next FREQ3CP simulation. The other information that will be needed by the ECOANA program will come from card input or supplementary permanent computer files. It is in these permanent files that the economic cost or usage tables (not present in this report) will be retained. The FREQ3CP information, the economic information, and assumptions upon which the different measures in the economic package are based will be discussed in succeeding paragraphs.

TIME COSTS

The portion of the economic package described here pertains to peak period time costs. The FREQ3CP output (simulation) data, economic data (values of time) and assumptions required to calculate the total time cost for on-freeway, ramp and diversion route travel are covered below:

On-Freeway Travel Time Costs

The FREQ3CP output required to calculate within subsection and between subsection travel time costs on the freeway proper are the following data by subsection and time-slice in the form of:

- Total vehicle-miles and passenger miles and
- Average speed.

The economic data required are the values of time by vehicle type for those moving vehicle groups described in Table 4. These values are to be presented in dollars (\$) per hour for the driver and passenger, because they are different for each vehicle type, except Vehicle Type 1.

The assumptions and given data required to generate time costs are as follows:

- Percentage distribution of the four vehicle types,
- Number of passengers per vehicle for Vehicle Types 1 and 4,
- Percentage distribution of vehicles and number of passengers are the same for all subsections over all time-slices,
- Total passenger-hours generated by the FREQ3CP program include trucks driver-hours and
- FREQ3CP output data take into account the time required for speed changes and stops within subsections and between subsections.

Ramp Travel Time Costs

To calculate ramp travel time costs resulting from input and output delay, the cumulated total input and output delay in vehicle-hours and passenger-hours for all time-slices must be obtained as output from the FREQ3CP program.

The economic data required for the calculation are the values of time, in dollars per hour, for drivers and passengers waiting in stopped vehicles by vehicle types.

The assumptions and given data are the same as those required for the on-freeway calculations, except for the following:

- Time while vehicles are moving on the ramp is not calculated and

TABLE 4
VEHICLE TYPES FOR ECOANA

| Vehicle Type Number | Vehicle Type Description |
|------------------------|---|
| 1 | Automobiles, pickups, and panel trucks (2-axle, 4-tire) |
| 2 | Single-unit trucks (other than 2-axle, 4-tire) |
| 3 | Truck-tractor-semitrailer or trailer combinations |
| 4 | Buses |

- Value of time while waiting in vehicle is worth more than the value of time in a moving vehicle due to increased mental anguish and patience required.

Diversion Route Travel Time Costs

Travel time costs for persons voluntarily or involuntarily diverted from the freeway's main lanes during the peak period can be calculated from cumulative data for all time-slices combined. The following FREQ3CP output or given data are needed to make such calculations.

- Number of vehicle-miles and passenger-miles traveled by vehicles diverted from the freeway's main lanes and
- Average speed (mph) on the diversion route.

The economic data required for calculating diversion travel time costs are the values of time (dollars per hour) for drivers and passengers in moving vehicles.

The same assumptions required for freeway and ramp travel time costs apply in the calculation of diversion travel time costs, except for the following:

- Average diversion speed takes into account the time required for speed changes and stops and
- Average diversion speed is the same for all subsections and time-slices.

VEHICLE OPERATING COSTS

Vehicle operating costs during peak periods can be estimated for simulated freeway travel on the freeway's main lanes, the ramps and the diversion routes using the FREQ3CP outputs, economic data and assumptions indicated below. For the vehicle operating cost calculations,

Vehicle Types 2 and 4 are combined.

On-Freeway Vehicle Operating Costs

The FREQ3CP output required to calculate the on-freeway vehicle operating costs for within and between subsection travel consists of the following individual subsection data per time-slice:

- Average speed (mph),
- Volume-to-capacity ratio (v/c) and
- Total vehicle-miles of travel.

The economic or given data required are the vehicle operating unit costs by average speed, vehicle type, and level of service. Also, the v/c ratios (range) applicable for each level of service will be given. The v/c ratios vary somewhat depending upon the number of lanes of capacity.

The following assumptions apply to the vehicle operating cost calculations:

- The unit costs account for speed changes and stops that are normally experienced by vehicles on freeways and
- The percentage of vehicles by type must be assumed by the user.

Ramp Vehicle Operating Costs

To calculate ramp vehicle operating costs resulting from input and output ramp delay, the cumulated total input and output delay in vehicle-hours for all time-slices must be obtained as output from the FREQ3CP program.

The economic data required for calculating vehicle operating costs resulting from ramp delay will be given as the idling costs by vehicle type.

The assumptions and given data required for the ramp vehicle operating costs are as follows:

- Percentage distribution by vehicle type is given and is the same over all subsections and time-slices and
- Vehicle operating costs while the vehicle is moving is not calculated.

Diversion Route Vehicle Operating Costs

Vehicle operating costs of vehicles diverted from the freeway on to a service road on another parallel street during the peak period can be calculated from data for all subsections and time-slices combined. The following FREQ3CP output or given data are needed to make such calculations:

- Number of vehicle-miles traveled by vehicles diverted from the freeway's main lanes,
- The uniform (approach) speed (mph) between intersections on the diversion route,
- Number of stops per vehicle-mile at intersections,
- Average vehicle-hours per stop,
- Number of speed changes (including stops) per vehicle-mile and
- Average speed (mph) reduction caused by speed change.

The economic data required for calculating diverted vehicle operating costs are as follows:

- Running unit costs on city streets by vehicle type and uniform speed,
- Excess running unit costs of speed cycle changes on city streets by vehicle type and initial speed and
- Idling costs, by vehicle type.

The assumptions required for calculating diverted vehicle operating costs are as follows:

- The uniform or initial speed, average vehicle-hours per stop and

the average speed reduction due to speed changes are the same for all subsections and time-slices and

- The percentage distribution by vehicle type is given by the user and is the same over all subsections and time-slices.

FUEL CONSUMPTION

Fuel consumption of vehicles operating during a peak period can be estimated for simulated travel on the freeway (within and between subsections), ramps and the diversion route using the same FREQ3CP outputs and assumptions as is described above to estimate total vehicle operating costs. Only the units of the economic data change from cents-per-mile to gallons-per-mile, and the vehicle operating costs are replaced with the vehicle operating fuel consumption rates.

VEHICLE POLLUTION EMISSIONS

The three principal pollutants emitted by motor vehicles are: (1) carbon monoxide, (2) hydrocarbons and (3) nitrogen oxides. The Federal pollution rate standards, as of April 1, 1975, for the above pollutants will be used. Particulates and sulfur oxides are pollutants of lesser importance but are also emitted by motor vehicles. Pollution rates are available for all five of these pollutants from an Environmental Protection Agency (EPA) study (8).

The pollution rates to be used in the economic package are based on those from the above study and were adjusted to represent the temperature and attitude conditions in Texas. The fraction of in-user vehicles by model year (vehicle age) weighted on the basis of annual miles driven was developed from nationwide statistics and was used to adjust the pollution rates. Speed correction factors were used to generate the pollution rates

for average speeds of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 and 55 miles per hour. Actually, the pollution rates for speeds above 45 miles per hour are out of the range of the supporting data and should be used with caution. The speed correction factors are based on a composite of driving modes (idle, cruise, acceleration, deceleration) encountered at lower speeds in urban areas as well as at higher speeds in rural areas. The hot and cold correction factor varies according to vehicle type. For light-duty vehicles (automobiles, pickups, and panel trucks), the pollution rates represent a 20 percent cold and 80 percent hot operation. For heavy-duty gasoline and diesel powered trucks, the pollution rates represent a 100 percent warmed-up operation.

Type 1 vehicles are represented by the EPA's light-duty vehicles (including pickups and panel trucks). Types 2 and 4 vehicles are represented by the EPA's heavy-duty gasoline trucks and buses. Type 3 vehicles are represented by the EPA's heavy-duty diesel trucks.

Vehicle pollution emissions can be calculated for simulated travel on the freeway's main lanes, ramps and diversion routes by using the appropriate FREQ3CP output data, assumptions and pollution emission rates described in this section.

On-Freeway Pollution Emissions

The FREQ3CP output data required to calculate on-freeway pollution emissions for within and between subsection travel per subsection and time-slice are as follows:

- * Total vehicle miles of travel and
- * Average speed.

Pollution rates have not been related to level of service or the v/c

ratio. However, the pollution emissions for a particular level of service could be determined by identifying the v/c ratio which corresponds to the average speed and then referring to level of service data file.

The economic or given data required to calculate the emissions of the three primary pollutants are the pollution emission rates by vehicle type and average speed. To calculate the particulate and sulfur oxide emissions, based only on total vehicle-miles, use the pollution rates given in a data file.

The following assumptions apply to the vehicle emission calculations:

- ' The vehicle emission rates account for speed changes and stops normally experienced by vehicles on freeways in Texas and
- ' The percentage of vehicles by type must be assumed by the user.

Ramp Vehicle Pollution Emissions

To calculate ramp vehicle pollution emissions resulting from input or output delay, the same FREQ3CP output, economic data, and assumptions or given data as described earlier for estimating ramp vehicle operating costs are used here. However, the pollution rates data will be substituted for the unit idling costs data. Note: The idling pollution emissions for particulate and sulfur oxide are not available and, therefore, cannot be calculated.

Diversion Route Vehicle Pollution Emissions

Pollution emissions resulting from diverting vehicles from the freeway's main lanes onto a service road or on another parallel street during the peak period can be calculated from data for all subsections and time-slices combined.

The following FREQ3CP output or given data are needed to calculate total

diverted vehicle pollution emissions:

- Number of vehicle-miles traveled by diverted vehicles and
- Average speed.

The economic data necessary to calculate diverted vehicle pollution emissions will be given in the pollution rates data files.

The assumptions applicable for calculating diverted vehicle pollution emissions are the same as those used for calculating on-freeway vehicle pollution emissions.

ACCIDENT COSTS

This portion of the economic package pertains to motor vehicle accident costs experienced by the persons and vehicles directly involved (in collision) in an accident. Such costs include direct out-of-pocket costs as well as certain indirect costs such as the loss of future gross earnings of accident victims killed or permanently disabled and costs for loss of services to home and family, and cost of pain and suffering of victims partially disabled from the accident. Other costs resulting from an accident such as extra time costs, extra vehicle operating costs, additional fuel consumed and air pollution emissions are not covered here. The literature does contain procedures for estimating extra time costs due to accidents or bottlenecks on a freeway (9 & 10), but considerable time would be required to implement them here. Also, procedures for estimating extra vehicle operating costs, extra fuel consumption, and air pollution emissions due to accidents have not been fully developed.

If the FREQ3CP program has the capacity for generating the output required to calculate such extra costs due to an accident, then the unit time costs, vehicle operating costs, etc., presented earlier in this

package can be used essentially in the same form as previously described to make such estimates.

The FREQ3CP output data, economic data, assumption or given data and calculations required to determine accident costs for on-freeway, on-ramp and diversion route accidents are covered below.

On-Freeway and Ramp Accident Costs

Accidents costs experienced by persons and vehicles directly involved in an accident on the freeway's main lanes and ramps require the following FREQ3CP output:

- Number of vehicle-miles by highway type and accident location, i.e., number of lanes and whether rural, urban or metered urban for all subsections and time-slices.

The economic data required to determine accident costs due to the accident vehicles and occupants are as follows:

- Motor vehicle accident unit costs by severity and location accident and
- Motor vehicle accident rates by highway type and location of accident, if actual accident rate is not known.

The assumptions and given data required to generate such accident costs are as follows:

- Percentage distribution of accidents by severity of accident (the percentage distribution used in the Highway Economic Evaluation Model HEEM (11) for Texas urban freeways, particularly in Houston, is 0.4% fatal accidents, 14.6% injury accidents and 85.0% property damage only accidents),
- The accident unit costs are not adjusted for unreported accidents,

- The accident unit costs are the same for wet and dry days and
- The accident unit costs are representative of actual accident costs in Texas.

Diversion Route Accident Costs

Accident costs experienced by persons and vehicles directly involved in an accident on a diversion route can be estimated by using essentially the same FREQ3CP output, economic data, and assumptions or given data as outlined above with the following exceptions:

- The accident rates for a 2-lane undivided conventional highway would be the most appropriate for a diversion route and
- If the actual percentage distribution of accidents by severity of accident is not known, the urban 2-lane distribution, based on California data (12), might be more appropriate than that used in the HEEM Model (11).

The resulting accident cost estimate must be generated before and after the freeway improvement to determine the total diversion route savings (dis-savings), if any, resulting from such an improvement. Then, the net savings of the freeway improvement can be generated by adding (subtracting) the diversion route accident savings (dis-savings) to the on-freeway accident savings.

CALCULATING TOTAL BENEFITS FROM IMPROVEMENT

The ECOANA program will provide for calculating the total benefits to be derived over the first year and/or over the expected life of the freeway improvement. In the case of dollar benefits, the annual savings resulting from changes in time, vehicle operating, and accident costs less maintenance and/or operating costs will be calculable. Then, the present

value of the annual savings over the life of the project can be compared with the estimated installation costs of the improvement to derive a benefit/cost ratio.

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APPENDIX A

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FFFFFFFF RRRRRRRR EEEEEEEE QQQQQQQQQ 33333333 CCCCCCCC PPPPPPP
FFFFFFFF RRRRRRRR EEEEEEEE QQQQQQQQQQQQQQQ 33333333 CCCCCCCCCCCCC PPPPPPPP
FFF RRR RRR EEE QQQQQQ QQQQQQ 333 CCCCC CCCC PPP PPP
FFF RRR RRR EEE QQQQQ QQQQQ 333 CCCCC CCCC PPP PPP
FFFFFF RRRRRRRR EEEEE QQQQQ QQQQQ 333333 CCCCC CCCC PPPPPPPP
FFFFFF RRRRRRRR EEEEE QQQQQ QQQQQ 33333333 CCCC PPPPPPPP
FFF RRRRRR EEE QQQQQ QQQ QQQQQ 333 CCCCC CCCC PPP
FFF RRR RRR EEE QQQQQQ QQQQQQ 333 333 CCCCC CCCC PPP
FFF RRR RRR EEEEEEEE QQQQQQQQQQQQQQQ 3333KHDSR0 WVAICIOFTEHRAN PPP
FFF RRR RRR EEEEEEEE QQQQQQQQQQ QQQQ 33333333 CCCCCCCC PPP

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*FIXED-TIME PRIORITY ENTRY CONTROL STRATEGY BY LINEAR PROGRAMMING, UPPER BOUNDING METHOD.
 *PROPORTIONAL TRIP DIVERSION FORMULATION,
 ASSUMING SOME OF THE TRAFFIC DIVERTED TO OTHER ROUTES
 *PROGRAM OBJECTIVE= MAXIMIZE VEHICLE INPUT RATE,

FREWAY DESIGN PARAMETERS

FREQ3 INBOUND SIMULATION RUN (KOPT=2) IH=10 WEST (KATY FREEWAY) HOUSTON, TEXAS

INPUT DATA

23 SUBSECTIONS
 4.00 TIME=SLICES PER HOUR
 0 USER=SUPPLIED SPEED FLOW CURVES
 0 GROWTH PERIODS AT RATE 0.0
 NO WEAVING ANALYSIS

| SUB SEC | NO. LNS | SSEC CAP, | SSEC LENGTH | TRK FAC | DESIGN SPEED | ORG DES | LFT RMP | SUBSECTION LOCATION |
|---------|---------|-----------|-------------|---------|--------------|---------|---------|---|
| 1 | 3 | 6000. | 25000. | 1,030 | 55 | 0 | 0 | MAINLINE ORIGIN TO WEST BELT ON |
| 2 | 3 | 5850. | 2774. | 1,030 | 55 | 0D | 0 | WEST BELT ON TO GESSNER OFF |
| 3 | 3 | 5850. | 2840. | 1,030 | 55 | 0 | 0 | GESSNER OFF TO GESSNER ON |
| 4 | 3 | 5850. | 1897. | 1,030 | 55 | 0D | 0 | GESSNER ON TO BUNKER HILL OFF |
| 5 | 3 | 5850. | 2105. | 1,030 | 55 | 0 | 0 | BUNKER HILL OFF TO BUNKER HILL ON |
| 6 | 4 | 6650. | 1363. | 1,030 | 55 | 0D | 0 | BUNKER HILL ON TO BLALOCK = ECHO OFF |
| 7 | 3 | 5850. | 1879. | 1,030 | 55 | 0 | 0 | BLALOCK = ECHO OFF TO BLALOCK = ECHO ON |
| 8 | 4 | 6650. | 500. | 1,030 | 55 | 0 | 1 | BLALOCK = ECHO ON TO |
| 9 | 4 | 6650. | 425. | 1,030 | 55 | 0 | 0 | BREAK TO BINGLE = VOSS OFF |
| 10 | 3 | 5600. | 4070. | 1,030 | 55 | 0 | 0 | BINGLE = VOSS OFF TO CAMPBELL ON |
| 11 | 3 | 5600. | 2260. | 1,030 | 55 | 0D | 0 | CAMPBELL ON TO WIRT OFF |
| 12 | 3 | 5700. | 1940. | 1,030 | 55 | 0 | 0 | WIRT OFF TO BINGLE = VOSS ON |
| 13 | 3 | 5750. | 2530. | 1,030 | 55 | 0D | 0 | BINGLE = VOSS ON TO ANTOINE OFF |
| 14 | 3 | 5700. | 909. | 1,030 | 55 | 0 | 0 | ANTOINE OFF TO WIRT ON |
| 15 | 4 | 7800. | 1000. | 1,030 | 55 | 0 | 1 | WIRT ON TO |
| 16 | 4 | 7800. | 862. | 1,030 | 55 | 0 | 0 | BREAK TO SILBER OFF |
| 17 | 4 | 7800. | 2909. | 1,030 | 55 | 0 | 0 | SILBER OFF TO SILBER ON |
| 18 | 4 | 7800. | 1215. | 1,030 | 55 | 0 | 1 | SILBER ON TO |
| 19 | 4 | 7800. | 600. | 1,030 | 55 | 0 | 1 | BREAK TO IH = 610 OFF (2 LANES) |
| 20 | 3 | 5400. | 2765. | 1,030 | 55 | 0 | 0 | IH = 610 OFF TO IH = 610 ON (3 LANES MERGE |
| 21 | 5 | 10000. | 3000. | 1,030 | 55 | 0 | 2 | IH = 610 ON TO |
| 22 | 5 | 10000. | 2380. | 1,030 | 55 | 0 | 0 | BREAK TO WASHINGTON OFF |
| 23 | 5 | 10000. | 2050. | 1,030 | 55 | 0 | 0 | WASHINGTON OFF TO MAINLINE OUTPUT |

* INDICATES USER SUPPLIED SPEED=FLOW CURVE NUMBER

RAMP LIMITS =1500.

OFF=RAMP 4 LIMIT=1700.
 OFF=RAMP 8 LIMIT=3200.
 ON=RAMP 8 LIMIT=1700.
 ON=RAMP 10 LIMIT=4000.

DISTRIBUTION OF PASSENGER OCCUPANCY

| | OCC1 | OCC2 | OCC3 | OCC4 | OCC5 | BUS |
|-----|-------|-------|-------|------|------|-----|
| U 1 | 0,820 | 0,180 | 0,0 | 0,0 | 0,0 | 0,0 |
| U 2 | 0,815 | 0,147 | 0,038 | 0,0 | 0,0 | 0,0 |
| U 3 | 0,822 | 0,143 | 0,035 | 0,0 | 0,0 | 0,0 |
| U 4 | 0,832 | 0,130 | 0,038 | 0,0 | 0,0 | 0,0 |
| U 5 | 0,798 | 0,161 | 0,041 | 0,0 | 0,0 | 0,0 |
| U 6 | 0,833 | 0,130 | 0,037 | 0,0 | 0,0 | 0,0 |
| U 7 | 0,856 | 0,122 | 0,022 | 0,0 | 0,0 | 0,0 |
| U 8 | 0,820 | 0,152 | 0,028 | 0,0 | 0,0 | 0,0 |
| U 9 | 0,800 | 0,166 | 0,034 | 0,0 | 0,0 | 0,0 |
| U10 | 0,830 | 0,150 | 0,020 | 0,0 | 0,0 | 0,0 |

BUS OCCUPANCY

| U 1 | U 2 | U 3 | U 4 | U 5 | U 6 | U 7 | U 8 | U 9 | U10 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 40. | 40. | 40. | 40. | 40. | 40. | 40. | 40. | 40. | 40. |

*FREEWAY PERFORMANCE SIMULATION-BEFORE CONTROL

TIME SLICE 1 (6 30 - 6 45 AM)

TIME SLICE 1 OF 10
 GROWTH PERIOD 0 OF 0
 OCCUPANCY 1.20

REVISED ON-RAMP LIMIT = RAMP NO, 8 TO 1700, VEHICLES PER HOUR

REVISED ON-RAMP LIMIT = RAMP NO, 10 TO 4000, VEHICLES PER HOUR

ORIGIN - DESTINATION TABLE (VEHICLES PER HOUR)

| ORIGINS DOWN | DESTINATIONS ACROSS | | | | | | | | | | |
|-----------------|---------------------|-----|-----|-----|-----|----|-----|------|-----|------|-------|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | SUM |
| 1 | 308 | 232 | 68 | 308 | 80 | 40 | 88 | 1264 | 128 | 1644 | 4160 |
| 2 | 56 | 44 | 12 | 56 | 16 | 8 | 16 | 232 | 24 | 300 | 764 |
| 3 | 0 | 76 | 24 | 100 | 28 | 12 | 28 | 420 | 44 | 548 | 1280 |
| 4 | 0 | 0 | 12 | 48 | 12 | 8 | 12 | 192 | 20 | 252 | 556 |
| 5 | 0 | 0 | 0 | 48 | 12 | 8 | 16 | 200 | 20 | 260 | 564 |
| 6 | 0 | 0 | 0 | 0 | 16 | 8 | 16 | 248 | 24 | 324 | 636 |
| 7 | 0 | 0 | 0 | 0 | 0 | 8 | 16 | 208 | 20 | 272 | 524 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 356 | 36 | 464 | 880 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 548 | 40 | 328 | 916 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 168 | 2112 | 2280 |
| SUM | 364 | 352 | 116 | 560 | 164 | 92 | 216 | 3668 | 524 | 6504 | 12560 |

ROW SUMS = TOTAL INPUT DEMANDS, COLUMN SUMS = TOTAL OUTPUT DEMANDS

QUEUE COLL. SECTION 11 T2= 0,244
 QUEUE COLL. SECTION 10 T2= 0,127

| SUB SEC | NO. LNS | SSEC LENGTH | U-D DATA ORG. DES. DEM. | DEMANDS ORG. DES. VOL. | ADJUSTED VOLUMES ORG. DES. VOL. | FRWY CAP. | WEAVE EFF | V/C | DENS. V/M/L | SPEED MPH | TRAVEL TIME | QUEUE= LENGTH | STORAGE RATE | | | | |
|------------|------------|----------------|----------------------------|---------------------------|------------------------------------|--------------|--------------|-------|----------------|--------------|----------------|------------------|-----------------|------|------|-------|-------|
| 1 | 3 | 25000. | 4160. | 0. | 4160. | 4160. | 0. | 0,69 | 28,7 | 48,3 | 5,89 | 0. | 0. | | | | |
| 2 | 3 | 2774. | 764. | 364. | 4924. | 764. | 364. | 4924. | 5850. | 0. | 0,84 | 35,0 | 47,0 | 0,67 | 0. | 0. | |
| 3 | 3 | 2840. | 0. | 0. | 4560. | 0. | 0. | 4560. | 5850. | 0. | 0,78 | 32,0 | 47,5 | 0,68 | 0. | 0. | |
| 4 | 3 | 1897. | 1280. | 352. | 5840. | 1280. | 345. | 4621. | 5850. | 0. | 0,79 | 36,7 | 42,0 | * | 0,51 | 591. | 1111. |
| 5 | 3 | 2105. | 0. | 0. | 5488. | 0. | 0. | 4275. | 5850. | 0. | 0,73 | 37,5 | 38,0 | ** | 0,63 | 2105. | 1111. |
| 6 | 4 | 1363. | 556. | 116. | 6044. | 556. | 114. | 4831. | 6650. | 0. | 0,73 | 39,5 | 30,6 | ** | 0,51 | 1363. | 1111. |
| 7 | 3 | 1879. | 0. | 0. | 5928. | 0. | 0. | 4717. | 5850. | 0. | 0,81 | 57,9 | 27,2 | ** | 0,79 | 1879. | 1111. |
| 8 | 4 | 500. | 564. | 0. | 6492. | 564. | 0. | 5281. | 6650. | 0. | 0,79 | 49,0 | 26,9 | ** | 0,21 | 500. | 1111. |
| 9 | 4 | 425. | 0. | 560. | 6492. | 0. | 551. | 5281. | 6650. | 0. | 0,79 | 50,8 | 26,0 | ** | 0,19 | 425. | 1111. |
| 10 | 3 | 4070. | 0. | 0. | 5932. | 0. | 0. | 4730. | 5600. | 0. | 0,84 | 61,7 | 25,6 | ** | 1,81 | 4070. | 870. |
| 11 | 3 | 2260. | 636. | 164. | 6568. | 636. | 140. | 5366. | 5600. | 0. | 0,96 | 53,5 | 33,4 | ** | 0,77 | 2260. | 234. |
| 12 | 3 | 1940. | 0. | 0. | 6404. | 0. | 0. | 5226. | 5700. | 0. | 0,92 | 61,6 | 28,3 | ** | 0,78 | 1940. | 234. |
| 13 | 3 | 2530. | 524. | 92. | 6928. | 524. | 77. | 5750. | 5750. | 0. | 1,00 | 53,2 | 36,0 | | 0,80 | 0. | 0. |
| 14 | 3 | 909. | 0. | 0. | 6836. | 0. | 0. | 5673. | 5700. | 0. | 1,00 | 50,1 | 37,7 | | 0,27 | 0. | 0. |
| 15 | 4 | 1000. | 880. | 0. | 7716. | 880. | 0. | 6553. | 7800. | 0. | 0,84 | 34,9 | 47,0 | | 0,24 | 0. | 0. |
| 16 | 4 | 862. | 0. | 216. | 7716. | 0. | 183. | 6553. | 7800. | 0. | 0,84 | 34,9 | 47,0 | | 0,21 | 0. | 0. |
| 17 | 4 | 2909. | 0. | 0. | 7500. | 0. | 0. | 6370. | 7800. | 0. | 0,82 | 33,8 | 47,2 | | 0,70 | 0. | 0. |
| 18 | 4 | 1215. | 916. | 0. | 8416. | 916. | 0. | 7286. | 7800. | 0. | 0,93 | 39,5 | 46,1 | | 0,30 | 0. | 0. |
| 19 | 4 | 600. | 0. | 3668. | 8416. | 0. | 3198. | 7286. | 7800. | 0. | 0,93 | 39,5 | 46,1 | | 0,15 | 0. | 0. |
| 20 | 3 | 2765. | 0. | 0. | 4748. | 0. | 0. | 4088. | 5400. | 0. | 0,76 | 28,6 | 47,7 | | 0,66 | 0. | 0. |
| 21 | 5 | 3000. | 2280. | 0. | 7028. | 2280. | 0. | 6368. | 10000. | 0. | 0,64 | 26,1 | 48,8 | | 0,70 | 0. | 0. |
| 22 | 5 | 2380. | 0. | 524. | 7028. | 0. | 476. | 6368. | 10000. | 0. | 0,64 | 26,1 | 48,8 | | 0,55 | 0. | 0. |
| 23 | 5 | 2050. | 0. | 6504. | 6504. | 0. | 5892. | 5892. | 10000. | 0. | 0,59 | 24,0 | 49,2 | | 0,47 | 0. | 0. |

TOTAL 67273.

TOTAL 18,48

QUEUE LENGTH
VEHICLES

DELAY
VEH=HRS

| | | | | |
|---------|---|---------------|-------|------|
| ON-RAMP | 3 | INPUT POINT | 0,0 | 0,0 |
| | | MERGING POINT | 27,04 | 3,38 |
| | | TOTAL | 27,04 | 3,38 |

| | CURRENT TIME | INTERVAL | |
|----------------------|--------------|----------|--------|
| FREEWAY TRAVEL TIME= | 393. | VEH=HRS= | 471. |
| INPUT DELAY= | 3. | VEH=HRS= | 4. |
| OUTPUT DELAY= | 0. | VEH=HRS= | 0. |
| TOTAL TRAVEL TIME= | 396. | VEH=HRS= | 475. |
| TOTAL TRAV DISTANCE= | 16105. | VEH=MI.= | 19326. |

| | CUMULATIVE VALUES | |
|----------------------|-------------------|----------|
| FREEWAY TRAVEL TIME= | 393. | VEH=HRS= |
| INPUT DELAY= | 3. | VEH=HRS= |
| OUTPUT DELAY= | 0. | VEH=HRS= |
| TOTAL TRAVEL TIME= | 396. | VEH=HRS= |
| TOTAL TRAV DISTANCE= | 16105. | VEH=MI.= |

TRAVEL TIME FOR ONE TRIP IN MINUTES

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|----|------|------|------|-------|-------|-------|-------|-------|-------|-------|
| 1 | 6.56 | 7.75 | 8.89 | 10.07 | 12.65 | 14.22 | 14.95 | 16.10 | 18.01 | 18.48 |
| 2 | 0.67 | 1.86 | 3.00 | 4.18 | 6.76 | 8.34 | 9.06 | 10.21 | 12.12 | 12.60 |
| 3 | 0.0 | 0.51 | 1.65 | 2.83 | 5.41 | 6.99 | 7.71 | 8.86 | 10.77 | 11.24 |
| 4 | 0.0 | 0.0 | 0.51 | 1.69 | 4.27 | 5.84 | 6.57 | 7.72 | 9.63 | 10.10 |
| 5 | 0.0 | 0.0 | 0.0 | 0.40 | 2.98 | 4.55 | 5.28 | 6.42 | 8.34 | 8.81 |
| 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.77 | 2.35 | 3.07 | 4.22 | 6.13 | 6.60 |
| 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.80 | 1.52 | 2.67 | 4.58 | 5.06 |
| 8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.45 | 1.60 | 3.51 | 3.98 |
| 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.45 | 2.36 | 2.83 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.25 | 1.73 |

*OPTIMAL PRIORITY CONTROL STRATEGY

*TIME SLICE 1 OF 10

*STEADY STATE SOLUTION

1 OD TABLES USED TO DETERMINE PASSENGER OCCUPANCY

COMBINED ORIGIN-DESTINATION TABLE--ALL VEHICLES

ORIGIN-DESTINATION TABLE (VEHICLES PER HOUR)
DESTINATION ACROSS

ORIGIN
DOWN

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|-----------|-------|------|-------|------|------|------|------|-------|-------|-------|-------|
| 0 | | | | | | | | | | | |
| 1 | 308. | | 232. | 68. | 308. | 80. | 40. | 88. | 1264. | 128. | 1644. |
| 2 | 56. | 44. | | 12. | 56. | 16. | 8. | 16. | 232. | 24. | 300. |
| 3 | 0. | 76. | 24. | | 100. | 28. | 12. | 28. | 420. | 44. | 548. |
| 4 | 0. | 0. | 12. | 48. | | 12. | 8. | 12. | 192. | 20. | 252. |
| 5 | 0. | 0. | 0. | 48. | 12. | | 8. | 16. | 200. | 20. | 260. |
| 6 | 0. | 0. | 0. | 0. | 16. | 8. | | 16. | 248. | 24. | 324. |
| 7 | 0. | 0. | 0. | 0. | 0. | 8. | 16. | | 208. | 20. | 272. |
| 8 | 0. | 0. | 0. | 0. | 0. | 0. | 24. | 356. | | 36. | 464. |
| 9 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 548. | 40. | | 328. |
| 10 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 168. | 2112. | |
| SUM(DEST) | 364. | 352. | 116. | 560. | 164. | 92. | 216. | 3668. | 524. | 6504. | |
| SUM(ORIG) | 4160. | 764. | 1280. | 556. | 564. | 636. | 524. | 880. | 916. | 2280. | |

METERING LIMITS

| | 0 1 | 0 2 | 0 3 | 0 4 | 0 5 | 0 6 | 0 7 | 0 8 | 0 9 | 0 10 |
|---------|------|------|------|------|------|------|------|------|------|-------|
| MAXIMUM | MAIN | 900. | 900. | 900. | 900. | 900. | 900. | 900. | 900. | 4000. |
| MINIMUM | LINE | 180. | 240. | 180. | 240. | 240. | 240. | 120. | 240. | 0. |

| ON-RAMP NO. | CONTROL STRATEGY ON VEHICLE BASIS | | | | | NON-PRIORITY METERING RATE | PRESET CONTROL STRATEGY |
|----------------|-----------------------------------|------------------|---------------------------|----------------------------|----------------------|-------------------------------|-------------------------|
| | ORIGINAL (VEH) | DEMAND (PASS) | PRIORITY CUT-OFF LEVEL | FREWAY INPUT RATE (VEH) | INPUT RATE (PASS) | | |
| 1 | 4160. | 4992. | 0 | 4160. | 4992. | 0. | |
| 2 | 764. | 917. | 0 | 764. | 917. | 0. | |
| 3 | 1280. | 1536. | 0* | 900. | 1080. | 0. | |
| 4 | 556. | 667. | 0* | 293. | 351. | 0. | |
| 5 | 564. | 677. | 0* | 240. | 288. | 0. | |
| 6 | 636. | 763. | 0* | 240. | 288. | 0. | |
| 7 | 524. | 629. | 0* | 276. | 331. | 0. | |
| 8 | 880. | 1056. | 0 | 880. | 1056. | 0. | |
| 9 | 916. | 1099. | 0* | 900. | 1080. | 0. | |
| 10 | 2280. | 2736. | 0 | 2280. | 2736. | 0. | |
| TOTAL | 12560. | 15072. | | 10932. | 13119. | | NO METERING |

| | CURRENT TIME INTERVAL | | CUMULATIVE VALUES | |
|---|-----------------------|-------------------|-------------------|-------------------|
| TOTAL TRAVEL DISTANCE | 15807, VEH-MILES | 18969, PASS-MILES | 15807, VEH-MILES | 18969, PASS-MILES |
| TOTAL DEMAND | 3140, VEHICLES | 3768, PASSENGERS | 3140, VEHICLES | 3768, PASSENGERS |
| TOTAL INPUT VOLUME | 2733, VEHICLES | 3280, PASSENGERS | 2733, VEHICLES | 3280, PASSENGERS |
| TOTAL DIVERTED DEMAND | 241, VEHICLES | | 241, VEHICLES | |
| TOTAL DEMAND TRANSFERED TO THE NEXT TIME SLICE | 166, VEHICLES | | 166, VEHICLES | |

DEMAND (VEH/T,S.) DIVERTED TO ARTERIAL STREETS

| ON-RAMP NO. | DIVERTED DEMAND (VEH/T,S.) | DISTRIBUTION PATTERN | | | | | | | | | |
|----------------|----------------------------------|----------------------|----|----|-----|----|----|----|-----|----|------|
| | | DESTINATION NO. | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 2 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 3 | 20. | 0. | 1. | 0. | 2. | 0. | 0. | 0. | 7. | 1. | 9. |
| 4 | 41. | 0. | 0. | 1. | 4. | 1. | 1. | 1. | 14. | 1. | 19. |
| 5 | 61. | 0. | 0. | 0. | 5. | 1. | 1. | 2. | 22. | 2. | 28. |
| 6 | 79. | 0. | 0. | 0. | 0. | 2. | 1. | 2. | 31. | 3. | 40. |
| 7 | 39. | 0. | 0. | 0. | 0. | 0. | 1. | 1. | 16. | 1. | 20. |
| 8 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 9 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 10 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| SUM(DEST) | 241. | 0. | 1. | 1. | 10. | 5. | 3. | 6. | 89. | 9. | 116. |

DEMAND (VEH/T,S.) TRANSFERED TO THE NEXT TIME SLICE

| ON-RAMP NO. | TRANSFERED DEMAND (VEH/T,S.) | DISTRIBUTION PATTERN | | | | | | | | | |
|----------------|------------------------------------|----------------------|----|----|-----|----|----|----|-----|----|-----|
| | | DESTINATION NO. | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 2 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 3 | 75. | 0. | 4. | 1. | 6. | 2. | 1. | 2. | 25. | 3. | 32. |
| 4 | 24. | 0. | 0. | 1. | 2. | 1. | 0. | 1. | 8. | 1. | 11. |
| 5 | 20. | 0. | 0. | 0. | 2. | 0. | 0. | 1. | 7. | 1. | 9. |
| 6 | 20. | 0. | 0. | 0. | 0. | 1. | 0. | 1. | 8. | 1. | 10. |
| 7 | 23. | 0. | 0. | 0. | 0. | 0. | 0. | 1. | 9. | 1. | 12. |
| 8 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 9 | 4. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 2. | 0. | 1. |
| 10 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| SUM(DEST) | 166. | 0. | 4. | 2. | 10. | 3. | 2. | 4. | 59. | 6. | 76. |

*FREEWAY PERFORMANCE SIMULATION-AFTER CONTROL

TIME SLICE 1 (6 30 - 6 45 AM)

TIME SLICE 1 OF 10
 GROWTH PERIOD 0 OF 0
 OCCUPANCY 1.20

ORIGIN - DESTINATION TABLE (VEHICLES PER HOUR)

| ORIGINS DOWN | DESTINATIONS ACROSS | | | | | | | | | | SUM | |
|-----------------|---------------------|-----|-----|-----|-----|----|-----|------|-----|------|-------|----|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | 10 |
| 0 | | | | | | | | | | | | |
| 1 | 308 | 232 | 68 | 308 | 80 | 40 | 88 | 1264 | 128 | 1644 | 4160 | |
| 2 | 56 | 44 | 12 | 56 | 16 | 8 | 16 | 232 | 24 | 300 | 764 | |
| 3 | 0 | 71 | 22 | 93 | 26 | 11 | 26 | 393 | 41 | 513 | 1200 | |
| 4 | 0 | 0 | 8 | 33 | 8 | 5 | 8 | 134 | 14 | 176 | 390 | |
| 5 | 0 | 0 | 0 | 27 | 6 | 4 | 9 | 113 | 11 | 147 | 319 | |
| 6 | 0 | 0 | 0 | 0 | 8 | 4 | 8 | 124 | 12 | 163 | 319 | |
| 7 | 0 | 0 | 0 | 0 | 0 | 5 | 11 | 145 | 14 | 190 | 367 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 356 | 36 | 464 | 880 | |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 548 | 40 | 328 | 916 | |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 168 | 2112 | 2280 | |
| SUM | 364 | 347 | 110 | 518 | 145 | 79 | 191 | 3312 | 488 | 6039 | 11597 | |

ROW SUMS = TOTAL INPUT DEMANDS, COLUMN SUMS = TOTAL OUTPUT DEMANDS

| SUB SEC | NO. LNS | SSEC LENGTH | O-D DATA ORG. DES. DEM. | DEMANDS | ADJUSTED VOLUMES ORG. DES. VOL. | FRWY CAP. | WEAVE EFF | V/C | DENS. V/M/L | SPEED MPH | TRAVEL TIME | QUEUE-LENGTH | STORAGE RATE |
|--------------|---------|-------------|-------------------------|---------|---------------------------------|-----------|-----------|------|-------------|-----------|-------------|--------------|--------------|
| 1 | 3 | 25000. | 4160. | 0. | 4160. | 4160. | 0. | 0.69 | 28.7 | 48.3 | 5.89 | 0. | 0. |
| 2 | 3 | 2774. | 764. | 364. | 4924. | 764. | 364. | 0.84 | 35.0 | 47.0 | 0.67 | 0. | 0. |
| 3 | 3 | 2840. | 0. | 0. | 4560. | 0. | 0. | 0.78 | 32.0 | 47.5 | 0.68 | 0. | 0. |
| 4 | 3 | 1897. | 1200. | 347. | 5760. | 900. | 329. | 0.93 | 39.4 | 46.1 | 0.47 | 0. | 0. |
| 5 | 3 | 2105. | 0. | 0. | 5413. | 0. | 0. | 0.88 | 36.7 | 46.6 | 0.51 | 0. | 0. |
| 6 | 4 | 1363. | 390. | 111. | 5803. | 293. | 103. | 0.82 | 28.7 | 47.2 | 0.33 | 0. | 0. |
| 7 | 3 | 1879. | 0. | 0. | 5692. | 0. | 0. | 0.91 | 38.3 | 46.4 | 0.46 | 0. | 0. |
| 8 | 4 | 500. | 320. | 0. | 6012. | 240. | 0. | 0.84 | 29.6 | 47.0 | 0.12 | 0. | 0. |
| 9 | 4 | 425. | 0. | 519. | 6012. | 0. | 480. | 0.84 | 29.6 | 47.0 | 0.10 | 0. | 0. |
| 10 | 3 | 4070. | 0. | 0. | 5493. | 0. | 0. | 0.91 | 36.5 | 46.4 | 1.00 | 0. | 0. |
| 11 | 3 | 2260. | 320. | 146. | 5813. | 240. | 133. | 0.95 | 38.6 | 46.0 | 0.56 | 0. | 0. |
| 12 | 3 | 1940. | 0. | 0. | 5668. | 0. | 0. | 0.91 | 37.3 | 46.3 | 0.48 | 0. | 0. |
| 13 | 3 | 2530. | 368. | 79. | 6035. | 276. | 71. | 0.95 | 39.6 | 46.0 | 0.63 | 0. | 0. |
| 14 | 3 | 909. | 0. | 0. | 5956. | 0. | 0. | 0.95 | 39.0 | 46.0 | 0.22 | 0. | 0. |
| 15 | 4 | 1000. | 880. | 0. | 6836. | 880. | 0. | 0.80 | 33.2 | 47.3 | 0.24 | 0. | 0. |
| 16 | 4 | 862. | 0. | 191. | 6836. | 0. | 175. | 0.80 | 33.2 | 47.3 | 0.21 | 0. | 0. |
| 17 | 4 | 2909. | 0. | 0. | 6645. | 0. | 0. | 0.78 | 32.1 | 47.5 | 0.70 | 0. | 0. |
| 18 | 4 | 1215. | 916. | 0. | 7561. | 900. | 0. | 0.90 | 37.6 | 46.5 | 0.30 | 0. | 0. |
| 19 | 4 | 600. | 0. | 3313. | 7561. | 0. | 3075. | 0.90 | 37.6 | 46.5 | 0.15 | 0. | 0. |
| 20 | 3 | 2765. | 0. | 0. | 4249. | 0. | 0. | 0.73 | 27.2 | 48.0 | 0.65 | 0. | 0. |
| 21 | 5 | 3000. | 2280. | 0. | 6529. | 2280. | 0. | 0.62 | 25.4 | 48.9 | 0.70 | 0. | 0. |
| 22 | 5 | 2380. | 0. | 489. | 6529. | 0. | 465. | 0.62 | 25.4 | 48.9 | 0.55 | 0. | 0. |
| 23 | 5 | 2050. | 0. | 6040. | 6040. | 0. | 5736. | 0.57 | 23.3 | 49.3 | 0.47 | 0. | 0. |
| ----- | | | | | | | | | | | ----- | | |
| TOTAL 67273. | | | | | | | | | | | TOTAL 16.08 | | |

| | | QUEUE LENGTH VEHICLES | DELAY VEH-HRS | |
|---------|---|-----------------------|---------------|------|
| ON-RAMP | 3 | INPUT POINT | 75.00 | 9.38 |
| | | MERGING POINT | 0.0 | 0.0 |
| | | TOTAL | 75.00 | 9.38 |
| ON-RAMP | 4 | INPUT POINT | 24.39 | 3.05 |
| | | MERGING POINT | 0.0 | 0.0 |
| | | TOTAL | 24.39 | 3.05 |
| ON-RAMP | 5 | INPUT POINT | 20.00 | 2.50 |
| | | MERGING POINT | 0.0 | 0.0 |
| | | TOTAL | 20.00 | 2.50 |
| ON-RAMP | 6 | INPUT POINT | 20.00 | 2.50 |
| | | MERGING POINT | 0.0 | 0.0 |
| | | TOTAL | 20.00 | 2.50 |
| ON-RAMP | 7 | INPUT POINT | 22.97 | 2.87 |
| | | MERGING POINT | 0.0 | 0.0 |
| | | TOTAL | 22.97 | 2.87 |
| ON-RAMP | 9 | INPUT POINT | 4.00 | 0.50 |
| | | MERGING POINT | 0.0 | 0.0 |
| | | TOTAL | 4.00 | 0.50 |

| | CURRENT TIME | INTERVAL | CUMULATIVE VALUES |
|----------------------|-----------------|-----------------|---------------------------------|
| FREEWAY TRAVEL TIME= | 333, VEH-HRS= | 399, PASS-HRS | 333, VEH-HRS= 399, PASS-HRS |
| INPUT DELAY= | 21, VEH-HRS= | 25, PASS-HRS | 21, VEH-HRS= 25, PASS-HRS |
| OUTPUT DELAY= | 0, VEH-HRS= | 0, PASS-HRS | 0, VEH-HRS= 0, PASS-HRS |
| | | | |
| TOTAL TRAVEL TIME= | 354, VEH-HRS= | 424, PASS-HRS | 354, VEH-HRS= 424, PASS-HRS |
| TOTAL TRAV DISTANCE= | 15807, VEH-MI,= | 18969, PASS-MI, | 15807, VEH-MI,= 18969, PASS-MI, |

TRAVEL TIME FOR ONE TRIP IN MINUTES

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|----|------|------|------|------|-------|-------|-------|-------|-------|-------|
| 1 | 6.56 | 7.70 | 8.55 | 9.23 | 10.79 | 11.89 | 12.56 | 13.70 | 15.60 | 16.08 |
| 2 | 0.67 | 1.82 | 2.66 | 3.34 | 4.90 | 6.00 | 6.67 | 7.81 | 9.72 | 10.19 |
| 3 | 0.0 | 0.47 | 1.31 | 1.99 | 3.55 | 4.65 | 5.32 | 6.46 | 8.37 | 8.84 |
| 4 | 0.0 | 0.0 | 0.33 | 1.01 | 2.57 | 3.67 | 4.34 | 5.48 | 7.39 | 7.86 |
| 5 | 0.0 | 0.0 | 0.0 | 0.22 | 1.78 | 2.88 | 3.55 | 4.69 | 6.60 | 7.07 |
| 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.56 | 1.66 | 2.33 | 3.47 | 5.38 | 5.85 |
| 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.63 | 1.30 | 2.44 | 4.34 | 4.81 |
| 8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.45 | 1.59 | 3.49 | 3.96 |
| 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.44 | 2.35 | 2.82 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.25 | 1.72 |

APPENDIX B

LOG OF CALIBRATION RUNS
1977 FREQ3CP STUDY - OUTBOUND

| Run No. | Comments by Urban Office Personnel |
|---------|---|
| 1. | Coding of ramp limits in error. <u>Suggest that headings of ØD Table be revised to show subsection numbers as well as origin and destination numbers.</u> Capacities need revision. Used 55 mph speed - V/C curve. |
| 2. | Queues did not form as required. Merging analysis caused queue at Newcastle, 1-610 and Post Oak On-Ramps, creating congestion greater than actual. Recoded as 2 lane ramps to disconnect merge analysis. <u>Weaving in these areas is a real problem and should be considered in future programs.</u> |
| 3. | Queues did not form as required. Adjusted capacities of narrow lane sections to increase queue length. Deleted additional 50,000 ft. in S. Section #1 since queues do not extend that far. |
| 4. | Queues did not form as required. Adjusted capacities to extend queues and travel times to approach existing conditions. |
| 5. | Queues are a little short. Decrease capacities to lengthen. |
| 6. | Queues too long - Travel time too low -- try 70 mph speed - V/C curve. |
| 7. | Queues increased over Run #6. Some speeds improved. Regression analysis of speed versus V/C ratio indicated $Y = 63.3 - 14.0X$ where $Y = \text{speed}$ and $X = \text{V/C ratio}$ is curve to use for upper limb of speed - V/C curve. |
| 8. | Speeds much improved with actual speed - V/C curve. Dequeueing not rapid enough. Changed capacities at S. Sections 23 and 24. |
| 9. | Queues and speeds improved over Run #8 but dequeueing after Time Slice 8 still not rapid enough. Increase capacities of S. Sections 23-34 to 5,500. |
| 10. | Queues shorter than #9 but dequeueing after Time Slice #8 is better. <u>Ran new regression analysis on speed - V/C curve, linear above 37 mph, exponential below 37 mph.</u> Changed capacity of S. Section 19 and 20 to 7,500. |
| 11. | New speed - V/C curve improved speeds. Changed capacity of S. Sections 5 and 7 to 7,200 to increase queue lengths in Shepherd-Greenbriar area. |

Run No.

12. Travel times for Time Slices 1,2,3,6, and 9 are close. Others near revision. Queue length of Time Slice 8-13 need revision. Added Time Slice #15 to allow dequeuing. Changed capacities of S. Section 22 and 27 after study of cumulative volume curve.
13. Queues improved over Run #12. Travel times improved but some still more than 10% off. Revised S. Sections 4,6,8-15,23-24.
14. Queuing improved in Time Slices 1,2,3,6,7,8, and 9. Others need revision. Changed S. Sections 23,24,27,30, and 32 capacities.
15. Run #15 improved over #14 but still getting about half of Time Slice average speeds more than 10% difference from measured travel times. Queue lengths pretty good. Time of congestion good. Does not dequeue rapidly enough.
16. Used weaving effects with + 1975 VPH/Lane capacities. Weaving effects appear to magnify areas of congestion creating longer queues than actual. Merging analysis plus weaving effect seems to consider weaving twice. Modification to program could allow weaving effect in specific subsections where merging analysis is disconnected. Validity of disconnecting merging analysis is questionable without adding weaving analysis of S. Section disconnected.
17. Run without ramp queue from I-610. Origin #9 in ØD Table changed. Queues more consistent with actual in Time Slices 1-7. Dequeuing not fast enough.
18. Queues improving but still need more in Wesleyan-Edloe area. Decrease capacities in S. Sections 19,20,21, and 22, increases 27,30, and 32.
19. Travel times still off. Increase capacities of S. Sections 19,20, 27,30, and 32. Decrease capacities in S. Sections 21 and 22.
20. Same as 19.
21. Travel times improving. Increase capacity of S. Sections 27 and 28. Decrease 21 and 22.
22. Travel times improving. Decrease capacity S. Section 7, increase S. Sections 20 and 27.
23. Travel times improving. Increase S. Sections 21-24.
24. Travel times improving. Increase S. Sections 24-26, decrease S. Sections 5 and 7.

Run No.

- 25. Travel times good. Queue lengths good, Time of congestion good. Plotted speed contours to compare with actual speeds. Found good correlation. Model is considered calibrated for outbound side of freeway.

- 26. Run to check calibration after ramp queue corrections to ØD Table. Results better than Run #25 after minor adjustments to bottleneck capacities.

APPENDIX C

SOUTHWEST FWY OUTBOUND

FREeway DESIGN PARAMETERS

SOUTHWEST FWY OUTBOUND - MONTROSE TO BISSONNET - ALT, 0 - RAMP METERING - RUN 1

INPUT DATA

34 SUBSECTIONS
 4.00 TIME-SLICES PER HOUR
 1 USER-SUPPLIED SPEED FLOW CURVES
 0 GROWTH PERIODS AT RATE 0.0
 WEAVING EFFECTS CONSIDERED

| SUB SEC | NO. LNS | SSEC CAP, | SSEC LENGTH | TRK FAC | DESIGN SPEED | ORG DES | LFT RMP | SUBSECTION LOCATION |
|---------|---------|-----------|-------------|---------|--------------|---------|---------|--|
| 1 | 5 | 9900. | 3520. | 1,030 | 1 * | 0 | 0 | MONTROSE TO MANDELL 01 |
| 2 | 5 | 9900. | 1560. | 1,030 | 1 * | 0 | 0 | WOODHEAD |
| 3 | 5 | 9900. | 1210. | 1,030 | 1 * | 0 | 0 | SHEPHERD EXIT 01 |
| 4 | 4 | 7900. | 2200. | 1,030 | 1 * | 0 | 0 | GREENBRIAR ENTR 02 |
| 5 | 5 | 8700. | 520. | 1,030 | 1 * | 0D | 0 | KIRBY EXIT 02 |
| 6 | 4 | 7900. | 1200. | 1,030 | 1 * | 0 | 0 | KIRBY ENTR 03 |
| 7 | 5 | 8200. | 1750. | 1,030 | 1 * | 0D | 0 | BUFFALO SPDWY EXIT 03 |
| 8 | 4 | 7200. | 840. | 1,030 | 1 * | 0 | 0 | EDLOE FUT EXIT 04 |
| 9 | 4 | 7200. | 840. | 1,030 | 1 * | 0 | 0 | EDLOE TEMP EXIT 05 |
| 10 | 4 | 7200. | 730. | 1,030 | 1 * | 0 | 0 | BUFFALO SPDWY FUT ENTR 04 |
| 11 | 4 | 7200. | 1620. | 1,030 | 1 * | 0 | 0 | EDLOE TEMP ENTR 05 |
| 12 | 4 | 7200. | 1660. | 1,030 | 1 * | 0 | 0 | EDLOE FUT ENTR 06 |
| 13 | 4 | 7200. | 260. | 1,030 | 1 * | 0 | 0 | WESLAYAN ENTR 07 |
| 14 | 5 | 8000. | 1650. | 1,030 | 1 * | 0D | 0 | NEWCASTLE EXIT 06 |
| 15 | 5 | 8000. | 1240. | 1,030 | 1 * | 0 | 0 | NEWCASTLE ENTR 08 |
| 16 | 5 | 9000. | 1600. | 1,030 | 1 * | 0D | 2 | I-610 EXIT 07 |
| 17 | 3 | 5800. | 710. | 1,030 | 1 * | 0 | 0 | I-610 MAIN LANES |
| 18 | 3 | 5800. | 1110. | 1,030 | 1 * | 0 | 0 | I-610 ENTR 09 |
| 19 | 5 | 9600. | 550. | 1,030 | 1 * | 0 | 2 | POST OAK ENTR 010 |
| 20 | 5 | 9600. | 2790. | 1,030 | 1 * | 0D | 0 | CHIMNEY ROCK EXIT 08 |
| 21 | 4 | 6800. | 1860. | 1,030 | 1 * | 0 | 0 | CHIMNEY ROCK ENTR - FTNVH FUT EXIT 011D9 |
| 22 | 4 | 6800. | 1800. | 1,030 | 1 * | 0D | 0 | WESTPARK EXIT 010 |
| 23 | 3 | 5400. | 1080. | 1,030 | 1 * | 0 | 0 | CHIMNEY ROCK FUT ENTR 012 |
| 24 | 3 | 5450. | 1100. | 1,030 | 1 * | 0 | 0 | WESTPARK BRIDGE |
| 25 | 3 | 5450. | 1670. | 1,030 | 1 * | 0 | 0 | HILLCROFT EXIT 011 |
| 26 | 3 | 5450. | 3350. | 1,030 | 1 * | 0 | 0 | HILLCROFT ENTR 013 |
| 27 | 3 | 6500. | 2120. | 1,030 | 1 * | 0D | 0 | BELLAIRE EXIT 012 |
| 28 | 3 | 5400. | 3490. | 1,030 | 1 * | 0 | 0 | FONDREN EXIT 013 |
| 29 | 3 | 5400. | 2110. | 1,030 | 1 * | 0 | 0 | FONDREN ENTR 014 |
| 30 | 3 | 6300. | 1930. | 1,030 | 1 * | 0D | 0 | BEECHNUT - GESSNER EXIT 014 |
| 31 | 3 | 5400. | 3670. | 1,030 | 1 * | 0 | 0 | GESSNER ENTR 015 |
| 32 | 3 | 6300. | 3280. | 1,030 | 1 * | 0D | 0 | BISSONNET EXIT 015 |
| 33 | 3 | 5400. | 2560. | 1,030 | 1 * | 0 | 0 | BISSONNET ENTR 016 |
| 34 | 3 | 5400. | 1000. | 1,030 | 1 * | 0D | 0 | MAIN LANES SOUTH 016 |

* INDICATES USER SUPPLIED SPEED=FLOW CURVE NUMBER

RAMP LIMITS =1500,
 OFF-RAMP 7 LIMIT=4000,
 OFF-RAMP 8 LIMIT=1600,
 OFF-RAMP 15 LIMIT=1800,
 ON-RAMP 9 LIMIT=3300,