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Benchmark Study of the I-DYNEV Evacuation Time Estimate Computer Code

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Pacific Northwest Laboratory
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ABSTRACT

This report compares observed vehicle movement on a highway network during periods of peak commuter traffic with a simulation of the traffic flow made with the I-DYNEV computer model. The purpose of the comparison is to determine if the model can accurately simulate the patterns of vehicular movement and delay during congested commuter traffic.

The results indicate that the I-DYNEV model adequately simulates the patterns of vehicular movement and delay associated with an evacuation, provided that the model's capacity reduction factor is an input parameter. The current I-DYNEV model automatically reduces capacity by 15% of input capacity to account for congestion-induced losses in capacity. Because the study roadway did not have any capacity reduction due to congestion, the model underestimated capacity during congestion. Therefore, the use of a capacity reduction factor should be a decision made by the analyst, not the model. When I-DYNEV was used with a capacity reduction factor appropriate to the data set used (i.e., no reduction in capacity), I-DYNEV produced reasonable results.

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PREFACE

In order to evaluate the I-DYNEV model, two studies have been performed. This report compares observed vehicle movement on a highway network during peak commuter traffic with a simulation of the traffic flow produced using the I-DYNEV computer model. The other study, as documented in NUREG/CR-4874, PNL-6172, is entitled "The Sensitivity of Evacuation Time Estimates to Changes in Input Parameters for the I-DYNEV Computer Code." It identifies the key parameters affecting evacuation time estimates (ETEs), and studies the sensitivity of ETEs to changes in those parameters in two different evacuation networks.

SUMMARY

Evacuation of the general population from areas surrounding a nuclear power plant is one protective measure available to decision-makers if an accident occurs. To aid in the evaluation of evacuation time estimates, KLD Associates developed the I-DYNEV computer model, a formulation of the TRAFLO Level II simulation model, for the Federal Emergency Management Agency (FEMA). The simulation model describes traffic conditions on each network link at specified intervals of time. Portions of the TRAFLO Level II model have been previously validated using actual traffic data. The purpose of this study was to determine how closely I-DYNEV could simulate actual traffic data.

Since traffic data during an actual evacuation does not exist, an evacuation-like condition of commuter freeway traffic was observed. The observed freeway traffic characteristics were compared with the output of the I-DYNEV simulation model. The results of this study do not provide a complete validation of the I-DYNEV model, but do emphasize the critical parameters effecting the simulation. The report also compares the output of the I-DYNEV model with that of other traffic flow models.

One of the most critical input parameters for the model was the mean queue discharge headway (discharge headway), which is the time spacing between vehicles exiting the transportation network. Because the discharge headway is the means of setting roadway capacity, the value used for this parameter has a dramatic impact on the simulation's output.

Based on analysis of the actual commuter traffic, 1.765 sec would be the appropriate input value for the discharge headway. This is based on an observed rate of 2040 vehicles per lane per hour during the period of peak congestion. However, the model's inputs are limited to 0.1-sec increments. A headway of 1.7 sec was initially selected for input to I-DYNEV because a 1.8-sec headway represents less capacity than available and would have caused the code to predict excessive delays. When I-DYNEV calculates that the rate of vehicles exiting a roadway has become limited by the input value for the discharge headway, the model reduces the capacity of the roadway by 15%. Results of the model with the capacity reduction factor were not consistent with observed data. Consequently, in order to partially compensate for the 15% capacity reduction during congestion, I-DYNEV was also run with an input value of 1.5 sec for the mean queue discharge headway. During periods of congestion, I-DYNEV would reduce the capacity by 15%, or effectively increase the 1.5-sec headway to 1.725 sec. Therefore, the use of the 1.5-sec headway was an attempt to run I-DYNEV with an input value appropriate for the observed commuter traffic. This approach of adjusting capacity did not produce adequate results, so it was decided to run the model with the capacity reduction factor. A modified version of the I-DYNEV model, therefore, was used to evaluate the effect of the capacity reduction factor. Additional simulations were conducted with this version.

The analysis indicates that I-DYNEV underestimates roadway capacity when the roadway does not have any congestion-induced capacity reduction as was the case in the study roadway network. When the capacity reduction factor was set to 1 (no congestion-induced capacity reduction) to reflect the data set used in the evaluation, I-DYNEV produced reasonable results. It is, therefore, recommended that the capacity reduction factor be made an input parameter.

INTRODUCTION

Evacuation is one protective measure available to the general public if an accident occurs at a nuclear power plant. For decision-makers to recommend this protective action, an estimate of the time required for the evacuation is necessary. To estimate evacuation times, computer models such as I-DYNEV have been developed.

The objective of this study is to assess whether the I-DYNEV model is an adequate tool for estimating evacuation times by determining if the model can simulate patterns of vehicular movement and delay such as were observed during congested peak-period traffic on an urban freeway. This study is not intended to provide a complete validation of the I-DYNEV model. Such a validation would require observed data for many types of transportation networks. The results of this benchmark will apply only to the congested urban freeway observed.

The I-DYNEV model was developed for the Federal Emergency Management Agency (FEMA) to simulate traffic conditions that prevail over a transportation network as an evacuation progresses. Output of the model includes an estimate of evacuation time as well as a variety of measures of effectiveness including speed, vehicle counts, queues, and delays. The I-DYNEV model is an adaptation of the TRAFLO Level II simulation model that was developed by KLD Associates for the Federal Highway Administration (FHWA). Consequently, the model is based on previous traffic modeling codes as well as documented traffic modeling theory. The Federal Emergency Management Agency (FEMA) is demonstrating the model and providing training on its use to state and local agencies of emergency response and preparedness planning.

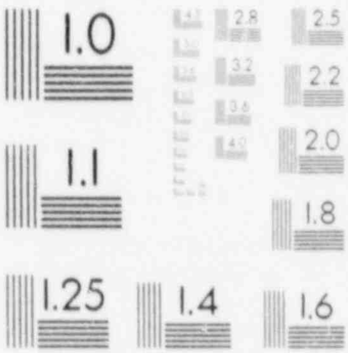
Few data are available concerning traffic behavior during an evacuation. Detailed comparisons, however, can be made between calculated evacuation times and those observed conditions that are similar to evacuations. Commuter traffic, athletic events at stadiums, and large construction projects provide conditions similar to evacuation traffic. The traffic from each of these occurrences often congests the roadway network resulting in vehicle queues and delays. The condition documented in this report is morning commuter traffic on a congested urban freeway.

The observed data included volume counts and speeds for a section of the congested freeway during the peak delay period. Data collected on the distances between vehicle counting locations, roadway geometries, traffic characteristics, and five-minute volumes at selected locations were used as input for I-DYNEV.

The output of the I-DYNEV model is compared to the patterns of vehicle movement and delay observed on the congested urban freeway. The results focus on three measures of effectiveness: the rate at which vehicles exited the system as a function of time; the rate at which vehicles were discharged from one roadway segment to the next as a fraction of time; the average speed of the vehicles on the network as a function of time. In addition, the I-DYNEV results are compared to the results calculated using other traffic simulation computer models.

The remaining sections of this report describe the urban freeway that served as the transportation network, the observed traffic data, I-DYNEV input requirements, and the study results and conclusions.

IMAGE EVALUATION TEST TARGET (MT-3)



150mm

6"

THE TRANSPORTATION NETWORK

The evacuation of persons from an area of potential danger occurs with surprising regularity in North America. Evacuations have occurred in both rural and urban areas. A major concern to decision-makers is the potential for significant traffic delays as a result of the transportation network becoming congested during an evacuation. Consequently, understanding the potential traffic management problems in the emergency planning zone (EPZ) surrounding a nuclear power plant is important to emergency planners.

The ability of a computer model to simulate the traffic patterns and delays associated with an evacuating population on a specific transportation network provides a means of understanding the potential traffic management problems in an area. To benchmark I-DYNEV, an evacuation-like condition was found where vehicles use a congested transportation network.

The evacuation-like condition observed for this study was commuter traffic on a specific section of freeway. A schematic of the freeway is presented in Figure 1. Data was collected on a 2.9-mile section of Interstate 35 in Travis County, just north of Austin, Texas. The site was a four-lane freeway (two lanes in each direction) in rolling terrain with 12-ft lanes, a 3-ft paved left shoulder, and a 10-ft paved right shoulder.

At the time of the data collection, a bottleneck occurred regularly during the morning peak commuter period southbound at the Rundberg Lane on-ramp. This high-volume ramp resulted in a regular breakdown of traffic flow at the merge point with Interstate 35. The bottleneck was well-defined, occurred daily, and frequently resulted in a traffic queue that extended nearly the length of the 2.9-mile highway section.

To describe and model the highway system observed, the network was divided into five segments for this study. Segment 1 was 2000-ft long, had two lanes, and extended from the starting point to the Braker on-ramp. Segment 2, the Braker on-ramp, was 500-f long and had one lane. Segment 3 was 9620-ft long, had two lanes, and extended from the intersection of the Braker on-ramp with the highway to the intersection of the Rundberg Lane on-ramp with the highway. Segment 4, the Rundberg Lane on-ramp, was 500-ft long and had one lane. Segment 5 was 3710-ft long, had two lanes, and extended from the Rundberg Lane on-ramp intersection to the end point. The relative distances and number of traffic lanes are shown in Table 1.

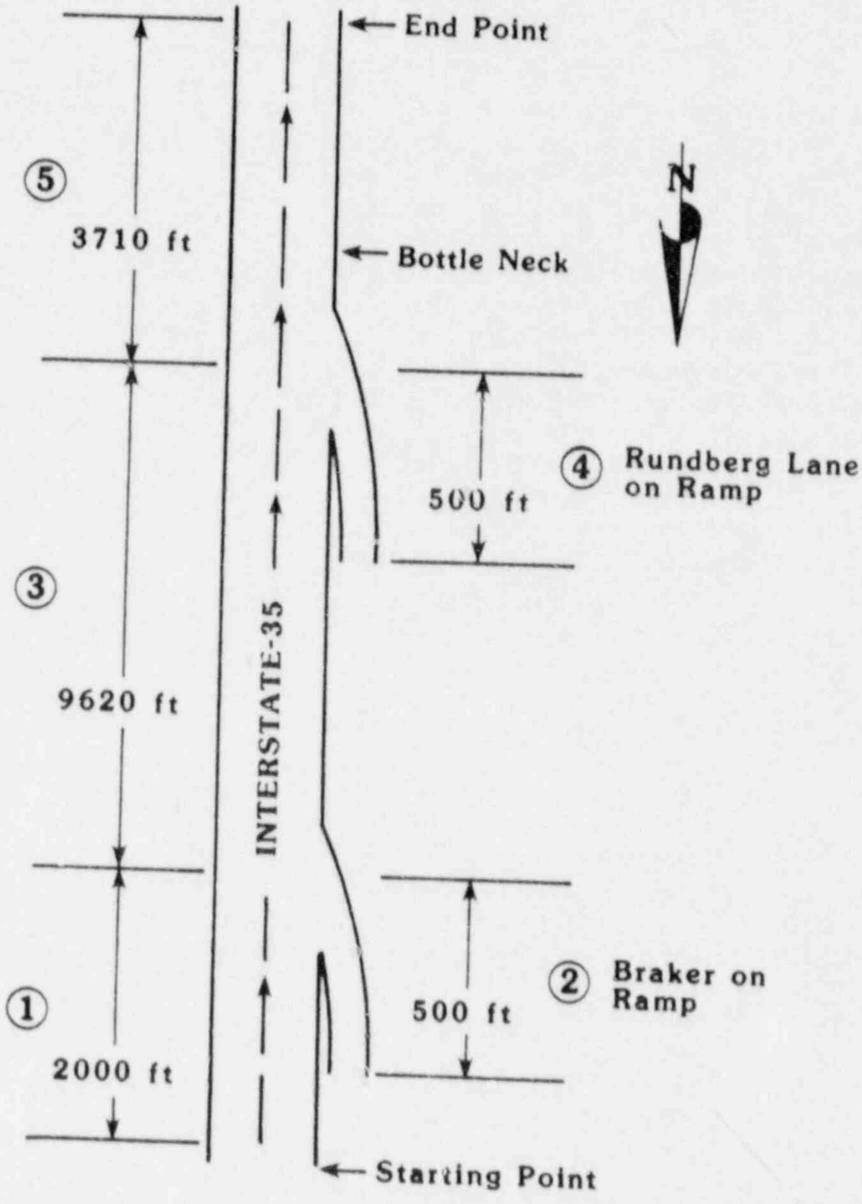


FIGURE 1. Schematic of the Urban Freeway Study Site (I-35 near Austin, Texas)

TABLE 1. Key Characteristics of Studied Roadway Network

Roadway Segment	Length ft	Nominal Speed, mph	Number of Lanes
1	2000	60	2
2	500	45	1
3	9620	60	2
4	500	45	1
5	3710	60	2

THE OBSERVED TRAFFIC DATA

The data collection and network observation was conducted from 6:30 a.m. to 8:30 a.m., on November 16, 1982. The weather was clear and the temperature was in the 40s (°F). Observers recorded traffic volumes at the starting point, endpoint, and each ramp along the transportation network for 5-min intervals. The traffic volumes and corresponding times for the three ingress segments of this highway system are shown in Table 2. In addition, the data collection included driving a car in the right-hand lane through the transportation network section beginning at each 5-min interval. The vehicle's progress was used to record the travel time between designated points along the freeway. The observations and moving car data yielded values for traffic volumes at the beginning and end of each freeway segment and travel times on each segment at 5-min intervals for 2 hours.

Although observed traffic data was available for 25 time periods, the I-DYNEV model is formatted to analyze only 19 time periods. In addition, I-DYNEV requires that a final time period be established during which traffic flow volumes entering from all origins and entry links are set

TABLE 2. Traffic Volumes Observed for Transportation Network per 5-Minute Interval

Time, a.m.	Starting Point	First On-Ramp	Second On-Ramp	Total Vehicles	End Point
6:35	57	21	45	123	120
6:40	104	25	67	196	196
6:45	138	25	72	235	224
6:50	128	34	68	230	253
6:55	151	33	74	258	224
7:00	157	32	62	251	245
7:05	163	34	97	294	304
7:10	191	50	103	344	332
7:15	218	59	125	402	360
7:20	263	61	109	433	332
7:25	224	65	106	395	361
7:30	229	48	122	399	342
7:35	215	55	105	375	345
7:40	201	47	95	343	335
7:45	176	51	104	331	354
7:50	159	32	106	297	351
7:55	126	39	120	285	325
8:00	116	37	82	235	349
8:05	172	42	72	292	322
8:10	125	42	85	252	300
8:15	163	42	85	290	273
8:20	150	54	91	295	301
8:25	155	33	86	274	287
8:30	158	42	80	280	275
Total Vehicles	3945	1003	2161	7109	7110

to zero. This procedure is required because the simulation is terminated when the network is emptied of vehicles. As a result of these limitations, only 18 time periods were available for I-DYNEV data input. Analysis of the 25 time periods of freeway data indicated that a simulation between 7:00 a.m. and 8:25 a.m. (18 five-min time periods) would encompass the peak congestion period and be adequate to evaluate the I-DYNEV model's performance. The solution, therefore, was to limit the I-DYNEV simulation to approximately 1.5 hours from 7:00 a.m. to 8:25 a.m..

The observed numbers of vehicles per 5-min interval entering the network via the main lanes (Segment 1), Braker on-ramp (Segment 2), and Rundberg on-ramp (Segment 4) are shown in Figure 2. Figure 3 illustrates the observed flow rate from Segment 5, which is the discharge of vehicles from the study section. The data presented in Figure 3 indicates the period maximum vehicle flow rate. The flow rate during this period ranged from approximately 330 to 360 vehicles per two lanes during 5 min. The average was 340 vehicles per two lanes during each 5 min, which corresponds to 2040 vehicles per lane-hour.

It should be noted that the data in Figure 3 and Table 2 indicate no congestion-induced capacity reduction. The onset of stop-and-go traffic (congested flow) was observed to begin at 7:09 a.m. At 7:15 a.m., traffic queues had begun forming on the main lanes and the Rundberg Lane on-ramp. Traffic volumes prior to and during the onset of congested flow were no higher than during the periods of uncongested flow. For example, the traffic volume at 7:25 a.m. was higher than the traffic volume at 7:10 a.m. or 7:15 a.m.

The means of representing a transportation network's capacity in I-DYNEV is the mean queue discharge headway, which is the minimum time spacing between vehicles exiting the transportation network. Based on analysis of the actual commuter traffic, 1.765 sec would be the appropriate input value for the discharge headway to represent a flow rate of 2040 vehicles per lane-hour. The input parameter for discharge headway to the I-DYNEV model can only be entered, however, in multiples of one-tenth of a second, which is generally adequate for simulations of this type, where many of the input values are estimates. A 1.7-sec discharge headway equivalent to 2100 vehicles per lane-hour was initially used. The model was also run with discharge headways of 1.8 and 1.5 sec, which are equivalent to 2000 and 2400 vehicles per lane-hour, respectively.

Other input parameters for I-DYNEV are described below. These include run control data, link characteristics, node characteristics, and a trip table. Where appropriate, the input values used were determined from the highway system or the observed commuter traffic data.

RUN CONTROL DATA

These data appear at the beginning of the input stream for each case executed and include the time interval of processing, length and number of output intervals, and computer run identifiers. These input parameters are not intended to influence the results. Therefore, these parameters describe information associated with the computer run and processing scheme.

FIGURE 2. Observed Number of Vehicles Entering Transportation Network via Segments 1, 2, and 4.

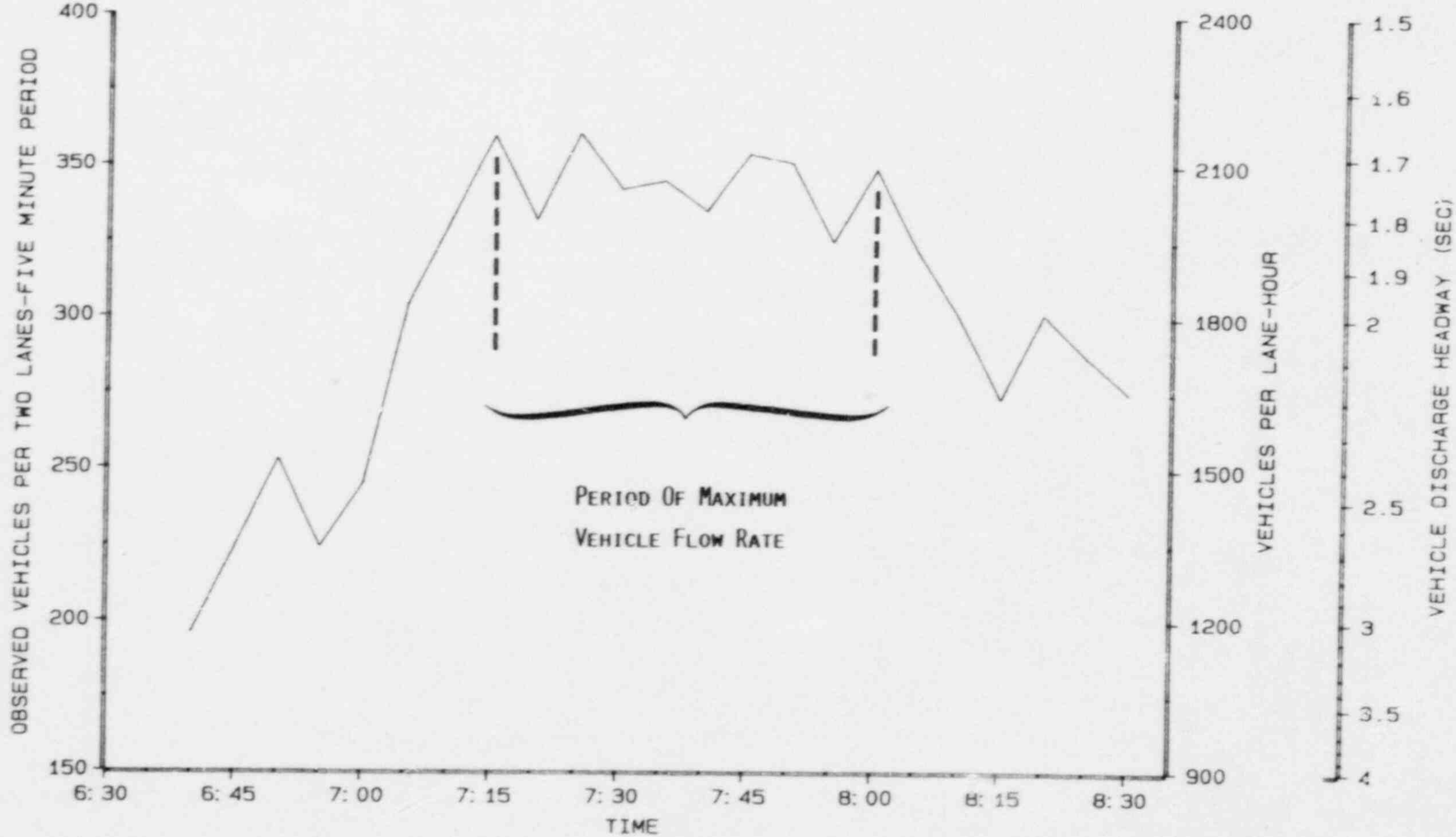


FIGURE 3. Observed Flow Rate as a Function of Time on Segment 5

LINK CHARACTERISTICS

The transportation network is described in terms of links and nodes, with a link representing a one-way section of roadway. Roadway characteristics, including number of lanes, length, grade, channelization, headways, and free-flow speed, are link descriptors that remain constant along a given link. Therefore, these parameters describe specific roadway segments.

NODE CHARACTERISTICS

Nodes are the end points of links. A node may also represent a point on a road where roadway characteristics change. When two or more links end in the same node, that node represents an intersection or merge area. Node characteristics include the sign or signal controls for intersections. These parameters, therefore, describe the interaction of specific roadway segments to form the transportation network.

TRIP TABLE

The network includes origin nodes and destination nodes. The origin nodes represent locations where a known number of vehicles begin their evacuation trips, and destinations are locations outside the EPZ. The trip table results from estimates of the number of evacuating vehicles by origin and their projected or assigned destination.

RESULTS

The results of this report are presented with two purposes. First, the output of the I-DYNEV model is compared to the patterns of vehicular movement and delay observed on the congested urban freeway to assess the model's accuracy of simulation. Second, the I-DYNEV results are compared to the results calculated using other traffic simulation computer models to provide a perspective of the model's accuracy of simulation.

ACCURACY OF SIMULATION

During the course of the many simulations performed, it was discovered that the rate at which vehicles were allowed to respond to the changing traffic conditions was affected by the input value for the time interval of processing. Traffic simulation codes provide output information by taking a "snapshot" of the status of vehicles on the network at discrete time intervals. Between these "snapshots," vehicles are processed through the network. As with I-DYNEV, the time interval of processing is often a value input by the user. This input value is not intended to affect the results.

Within the algorithms of I-DYNEV, the change in vehicle travel time over a link (roadway segment) in any processing is limited to 25% of the time interval of processing. Unless otherwise indicated, all simulations using the I-DYNEV code were done using a value of 150 sec for the time interval of processing. The exceptions were a sensitivity study of the time interval of processing.

Initial analysis of the results also indicated that the presence of the capacity reduction factor significantly impacted the results. Throughout the simulation, I-DYNEV calculated the discharge headway for each link according to the rate of vehicles exiting that link. I-DYNEV continuously compared this calculated value with the limiting value for the link, which was an input parameter. When I-DYNEV determined that the calculated value for the discharge headway reached the limiting value, the model reduced the capacity of the link by 15%. The intention of the capacity reduction factor is to simulate the effects of congestion.

In summary, limiting the rate of change in vehicle travel time over a link to 25% of the time interval of processing avoids radical fluctuation in the vehicle travel time. In effect, the algorithm dampens the potential oscillation of this variable. The capacity reduction factor affects the vehicle travel time by decreasing capacity during congested traffic conditions.

Using the discharge headway as the means of setting network capacity, I-DYNEV was run with five distinct capacity input values. First, I-DYNEV was run using a 1.7-sec discharge headway value. The 1.7-sec value was determined to be appropriate for the network (2100 vehicles per lane-hour), based on the peak vehicle discharge rate of 2040 vehicles per lane-hour.

Second, I-DYNEV was run using a 1.8-sec discharge headway value. The 1.8-sec value corresponds to 2000 vehicles per lane-hour. The 1.7- and 1.8-sec values bracket the observed value of 1.765 sec. For the 1.7- and 1.8-sec runs, the discharge headway would automatically be increased (capacity decreased) by 15% to approximately 2.0 and 2.1 sec, respectively, when the network capacity is reached.

Third, I-DYNEV was run using a 1.5-sec discharge headway value. The 1.5-sec value represents approximately a 15% reduction in the discharge headway value of 1.765 sec. Therefore, when the network capacity is reached based on a 1.5-sec discharge headway value, a 15% increase in the discharge headway would set the value to approximately 1.7 sec, which is the appropriate level. Trying to compensate for the model in this manner overestimates the initial capacity when the 1.5-sec discharge headway is in effect.

The fourth and fifth simulations of the traffic conditions were done using a modified version of the I-DYNEV code. In this version, the algorithm that increases the discharge headway by 15% when the network capacity is reached has been made an input parameter. The discharge headway of 1.7 sec in the modified version of the code would not change it during the simulation when the capacity reduction factor was set to 1 (no congestion-induced capacity reduction). For comparison purposes, this version was also run with a discharge headway of 1.8 sec. In subsequent discussion and figures the simulations are described and labeled as indicated in Table 3.

TABLE 3. I-DYNEV Simulations and Parameter Designations

Vehicle Discharge Headway, sec	With(W)/Without(WO) Capacity Reduction Factor	Time Interval of Processing, sec	I-DYNEV Run Designators
1.5	W	150	1.5,W
1.7	W	150	1.7,W, [150]
1.7	WO	60	1.7,WO, [60]
1.7	WO	150	1.7,WO, [150]
1.7	WO	300	1.7, WO, [300]
1.8	W	150	1.8, W
1.8	WO	150	1.8,WO

To demonstrate the effect of the input value for the time interval of processing and the capacity reduction factor, simulations were conducted for time intervals of 60, 150, and 300 sec using a discharge headway of

1.7 sec, both with and without the capacity reduction factor. The average speeds of the vehicles along the network as a function of time as simulated by I-DYNEV is illustrated in Figure 4, which indicates the differences between the various I-DYNEV simulations. Consequently, only I-DYNEV output is shown. Comparisons of I-DYNEV output with the observed data for the average speed of the vehicles along the network are discussed later in this report.

To determine the model's accuracy of simulation, three measures of traffic flow conditions are evaluated:

- the rate at which vehicles were discharged from one roadway segment to the next as a function of time
- the rate at which vehicles exited the network as a function of time
- the average speed of the vehicles on the network as a function of time.

Discharge From Segments

A comparison of the observed discharge of vehicles from one roadway segment to the next with that predicted by I-DYNEV is one means of evaluating the accuracy of I-DYNEV's simulation of vehicle movement. For each of the three vehicle entry points (at the beginning of Segments 1, 2, and 4), the observed data was used as input to describe the influx of vehicles onto these segments.

Results of the I-DYNEV simulations are presented for the discharge of vehicles from Segments 1 onto 3 (Figures 5a and 5b), Segments 2 onto 3 (Figures 6a and 6b), and Segments 4 onto 5 (Figures 7a and 7b). Figures 5a, 6a, and 7a each include three I-DYNEV simulations with the capacity reduction factor present. Figures 5b, 6b, and 7b represent improved results from I-DYNEV because changes were made to the input parameter for either vehicle discharge headway or capacity reduction factor.

The movement and delay of vehicles change dramatically as a function of time as vehicles discharge from Segment 3 onto Segment 5. This location is near the origin of the traffic bottleneck. I-DYNEV simulations using different vehicle discharge headway values both with and without the capacity reduction factor are presented in Figure 8.

Figures illustrating the discharge of vehicles from one segment onto the next indicate that the I-DYNEV run using a 1.5-sec discharge headway with the capacity reduction factor appears to provide the most accurate simulation of the observed data. This is especially true for vehicles discharging from Segment 3 onto Segment 5 and from Segment 1 onto Segment 3. This does not suggest, however that the capacity reduction factor is appropriate as will be shown later. Rather, the attempt was partially successful to compensate for the 15% reduction in capacity during congested conditions by inputting a capacity 15% greater than that observed. The runs without the capacity reduction factor, while not as good as the adjusted capacity with the capacity reduction factor, were very similar.

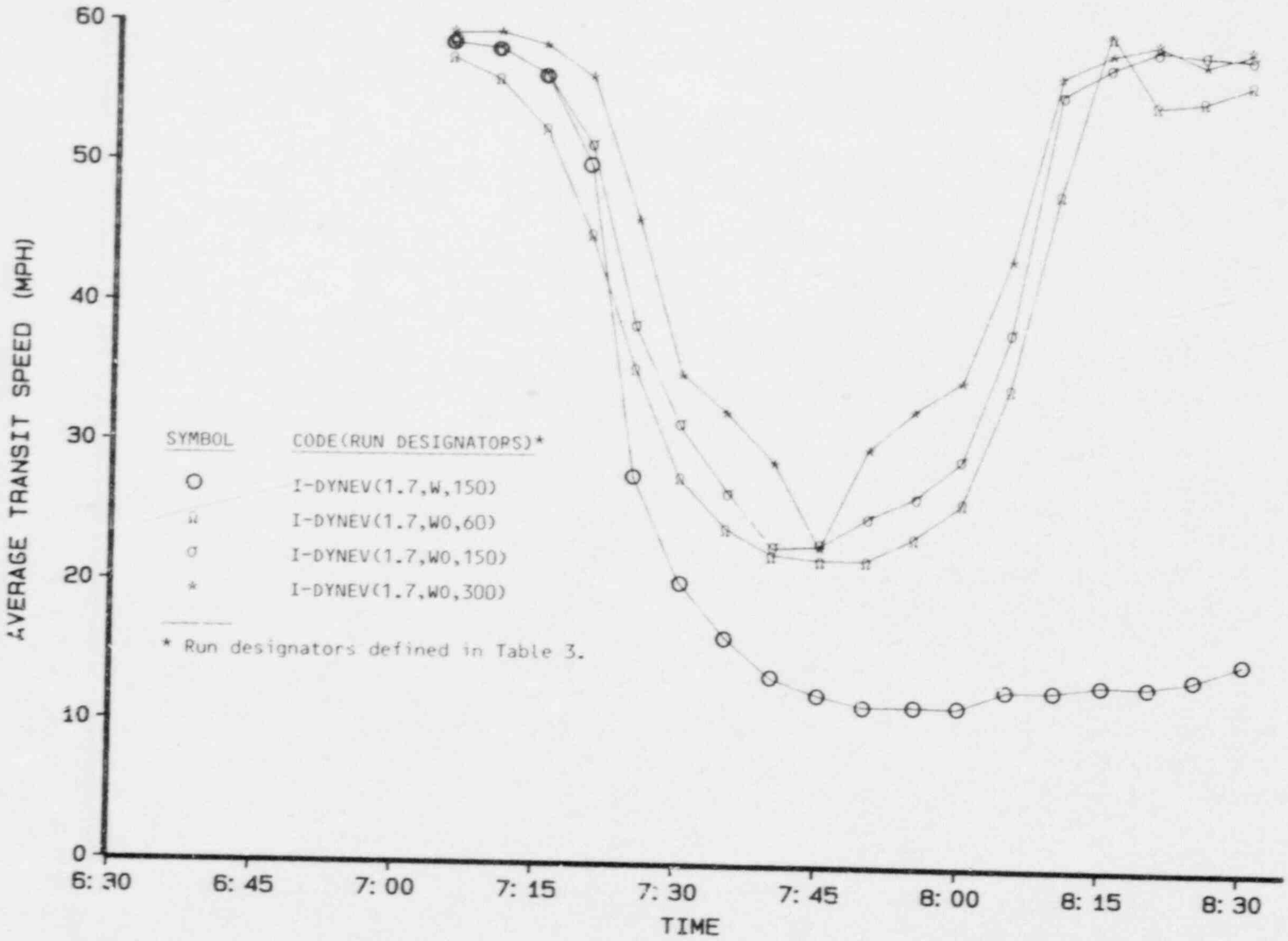


FIGURE 4. A Comparison of I-DYNEV Runs Varying the Time Interval of Processing and the Capacity Reduction Factor

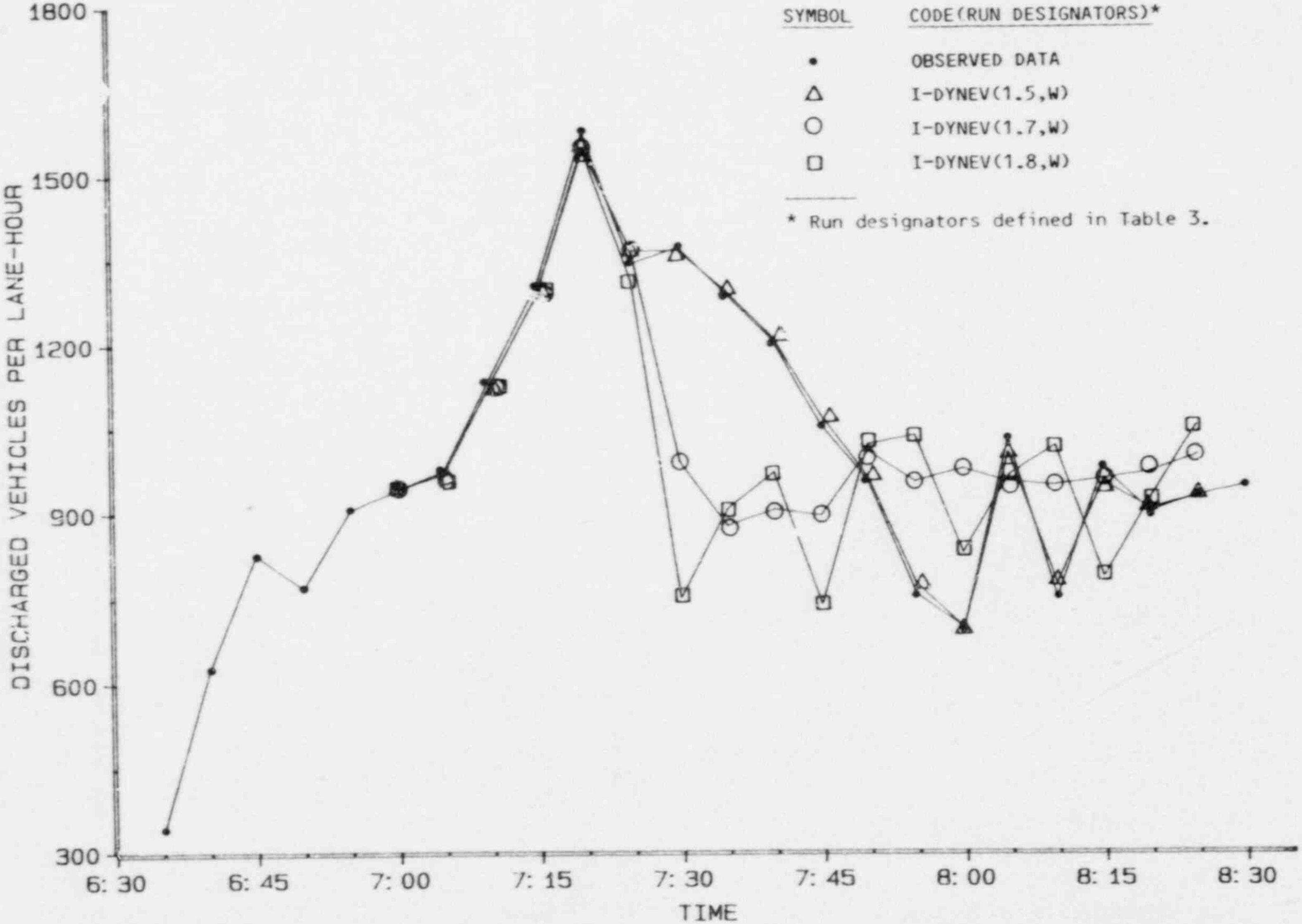


FIGURE 5a. Observed and Predicted Discharge Rate of Vehicles From Segment 1 onto Segment 3, With Capacity Reduction Factor

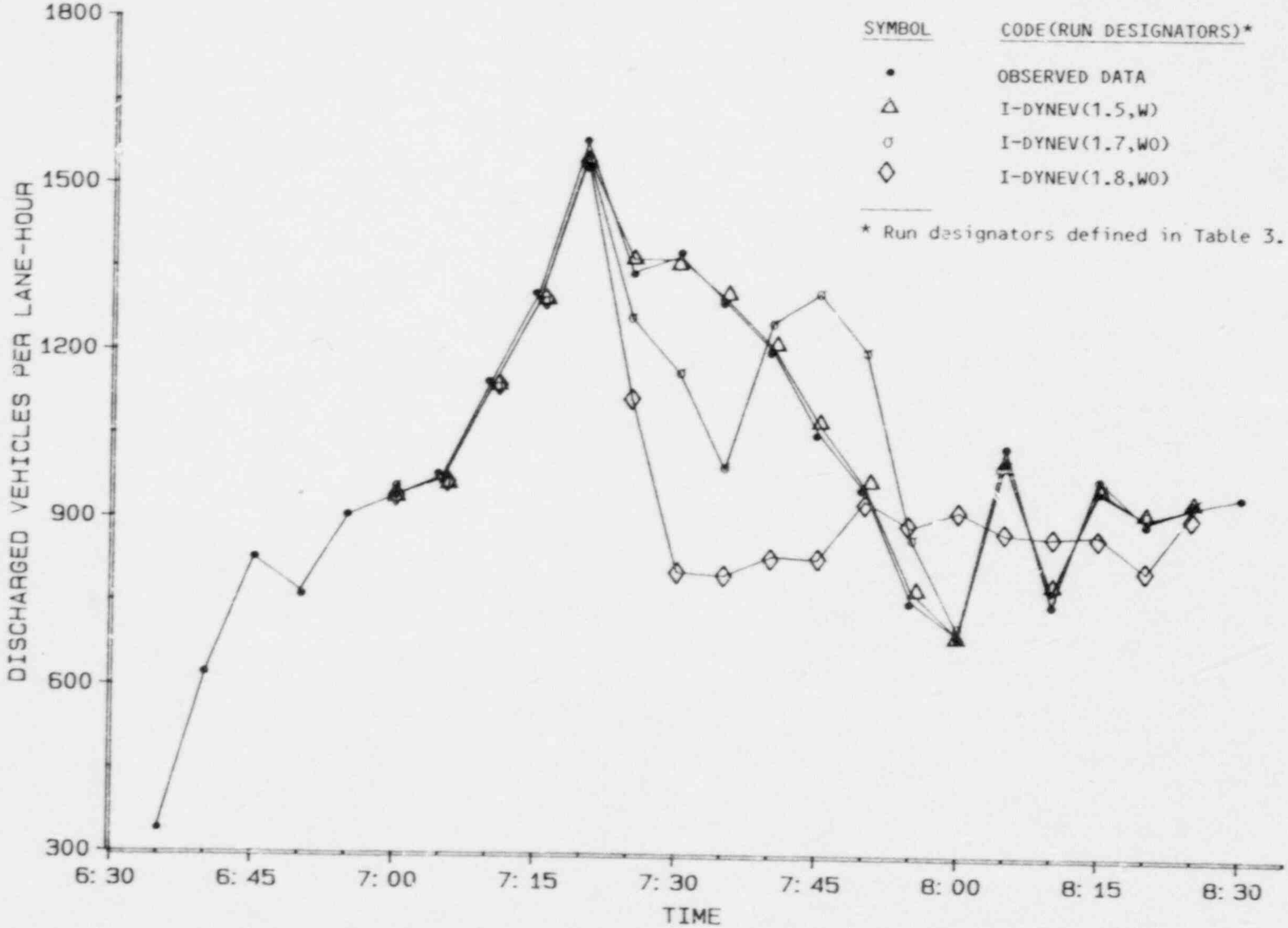


FIGURE 5b. Observed and Predicted Discharge Rate of Vehicles From Segment 1 onto Segment 3, Without Capacity Reduction Factor

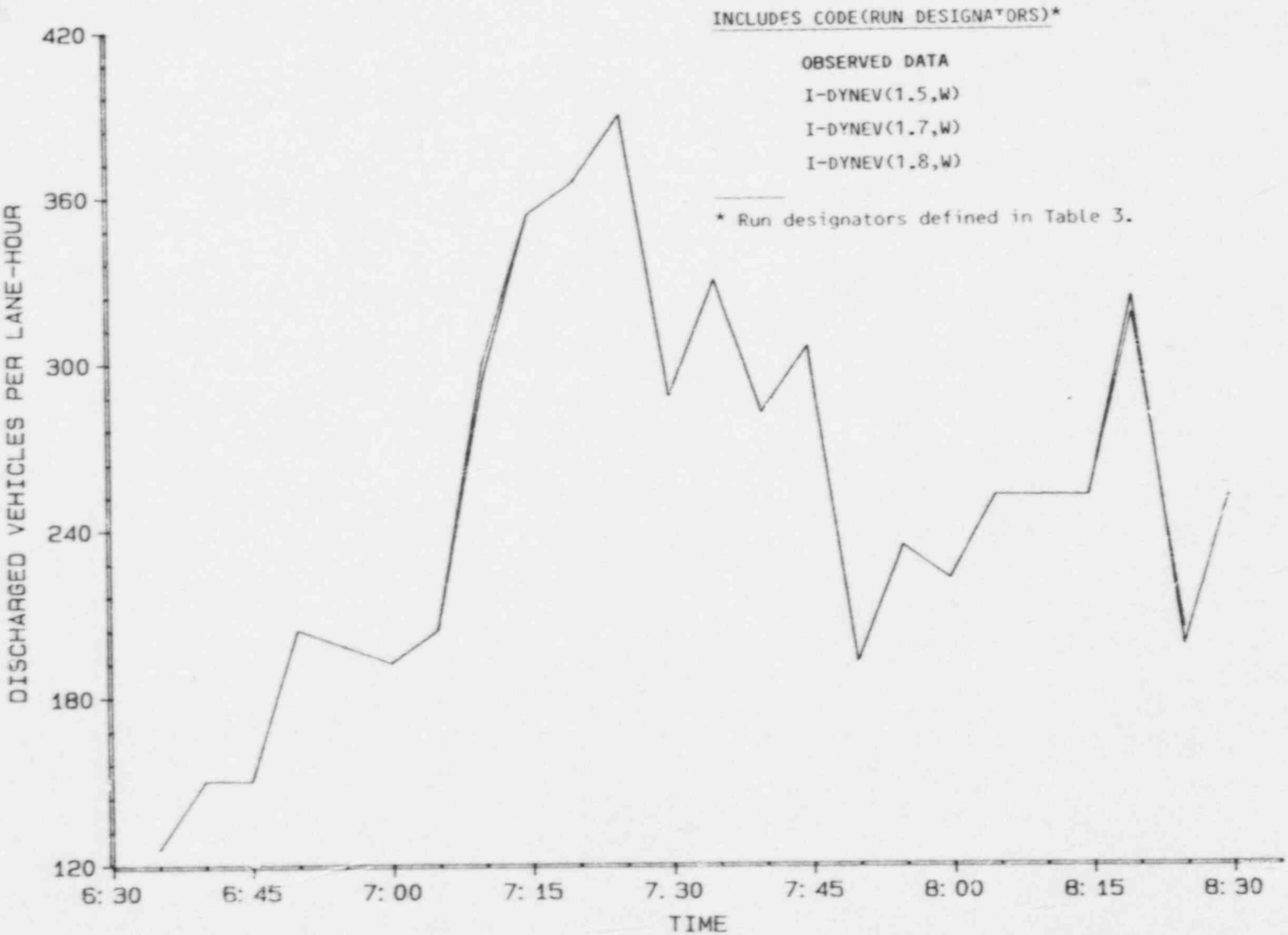


FIGURE 6a. Observed and Predicted Discharge Rate of Vehicles From Segment 2 onto Segment 3, With Capacity Reduction Factor

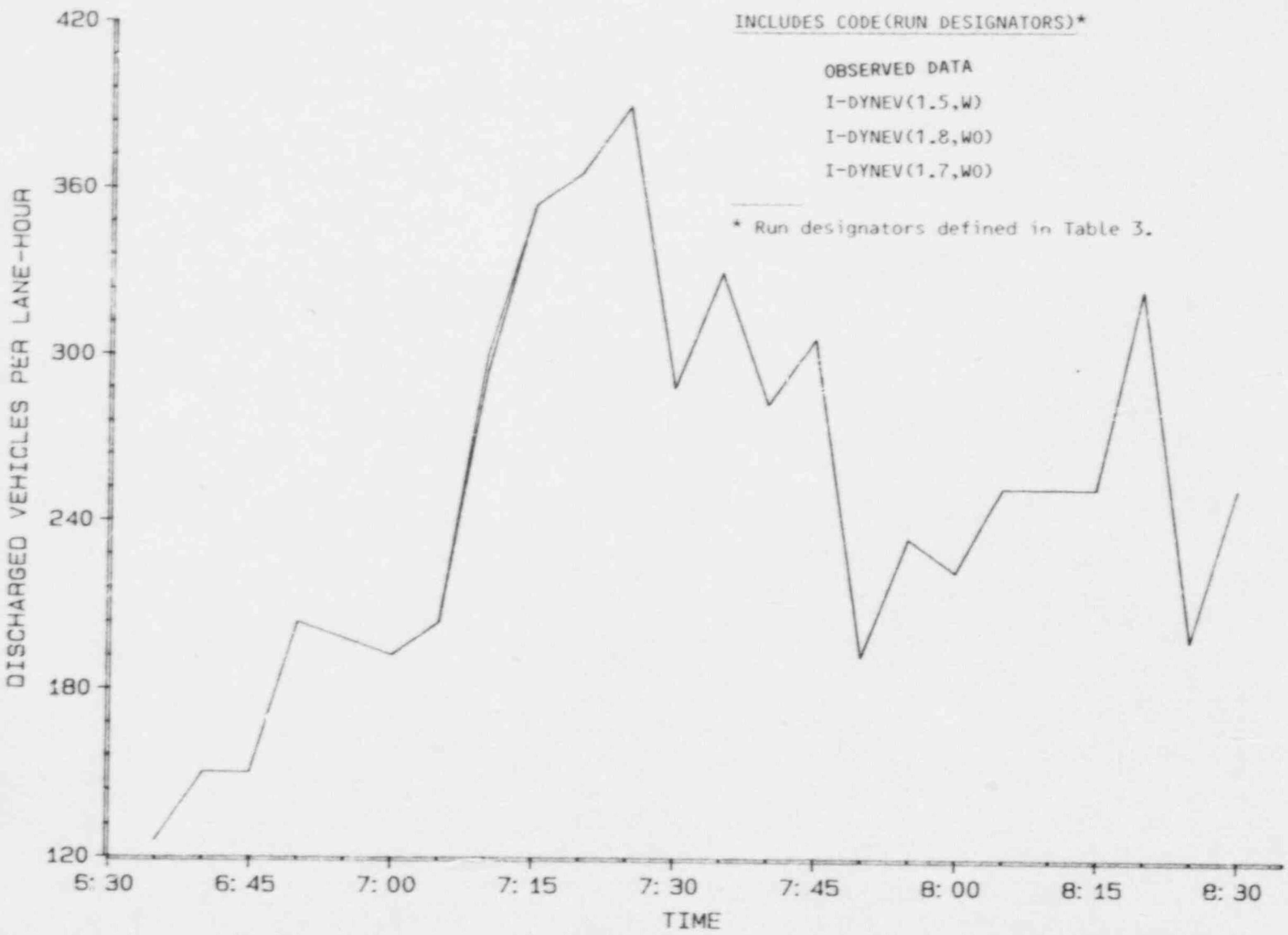


FIGURE 6b. Observed and Predicted Discharge Rate of Vehicles From Segment 2 onto Segment 3, Without Capacity Reduction Factor

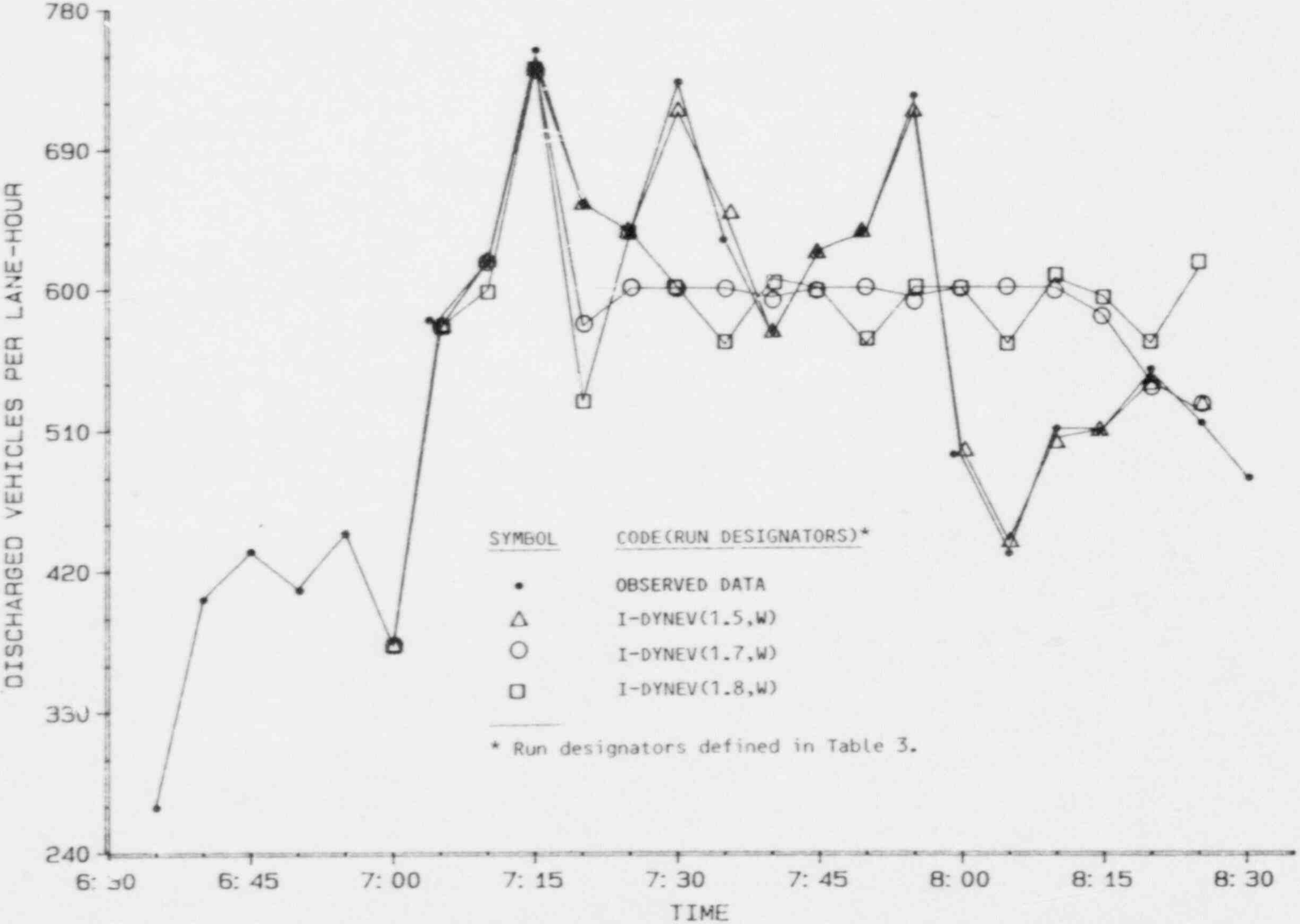


FIGURE 7a. Observed and Predicted Discharge Rate of Vehicles From Segment 4 onto Segment 5, With Capacity Reduction Factor

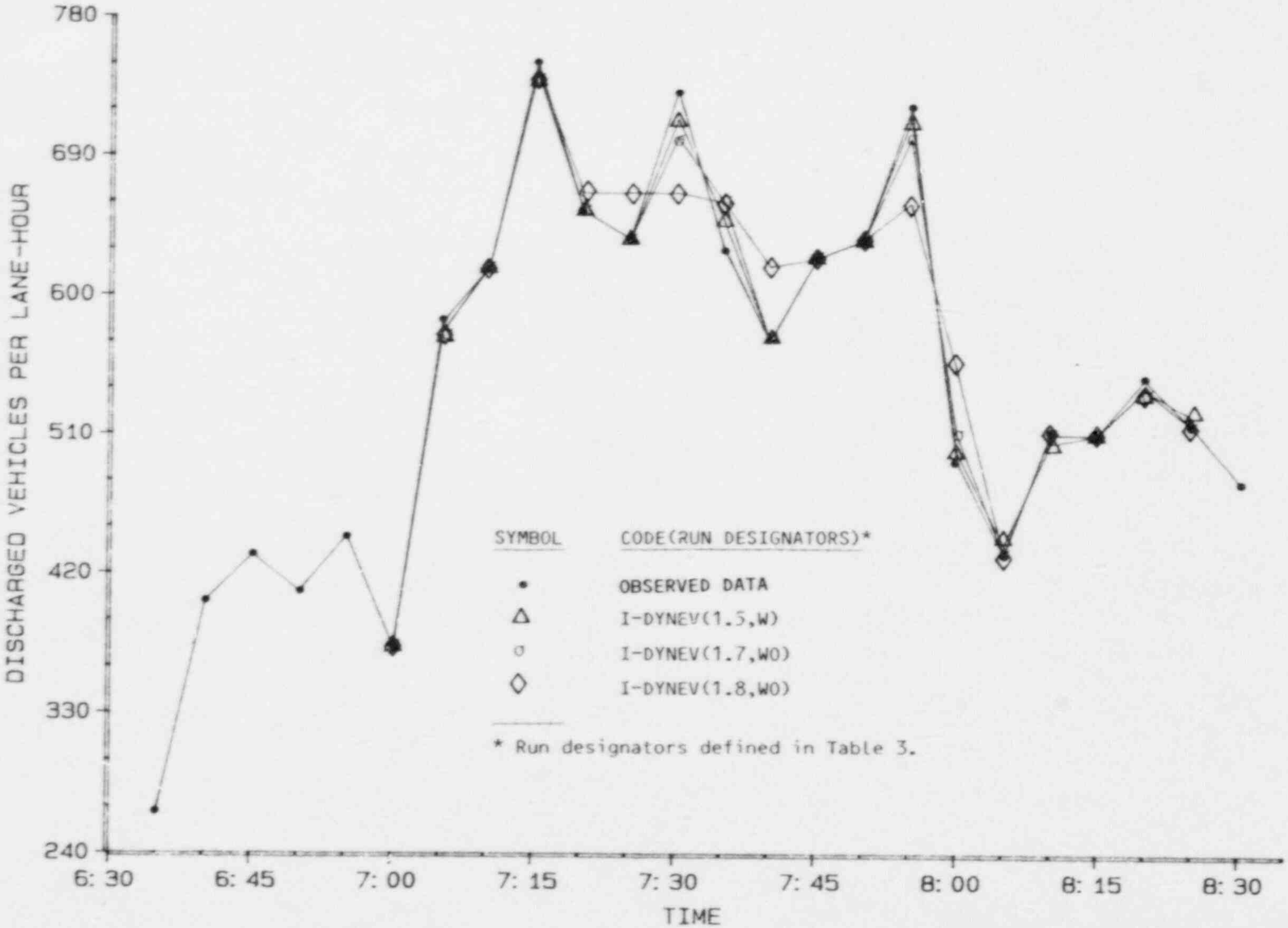


FIGURE 7b. Observed and Predicted Discharge Rate of Vehicles From Segment 4 onto Segment 5, Without Capacity Reduction Factor

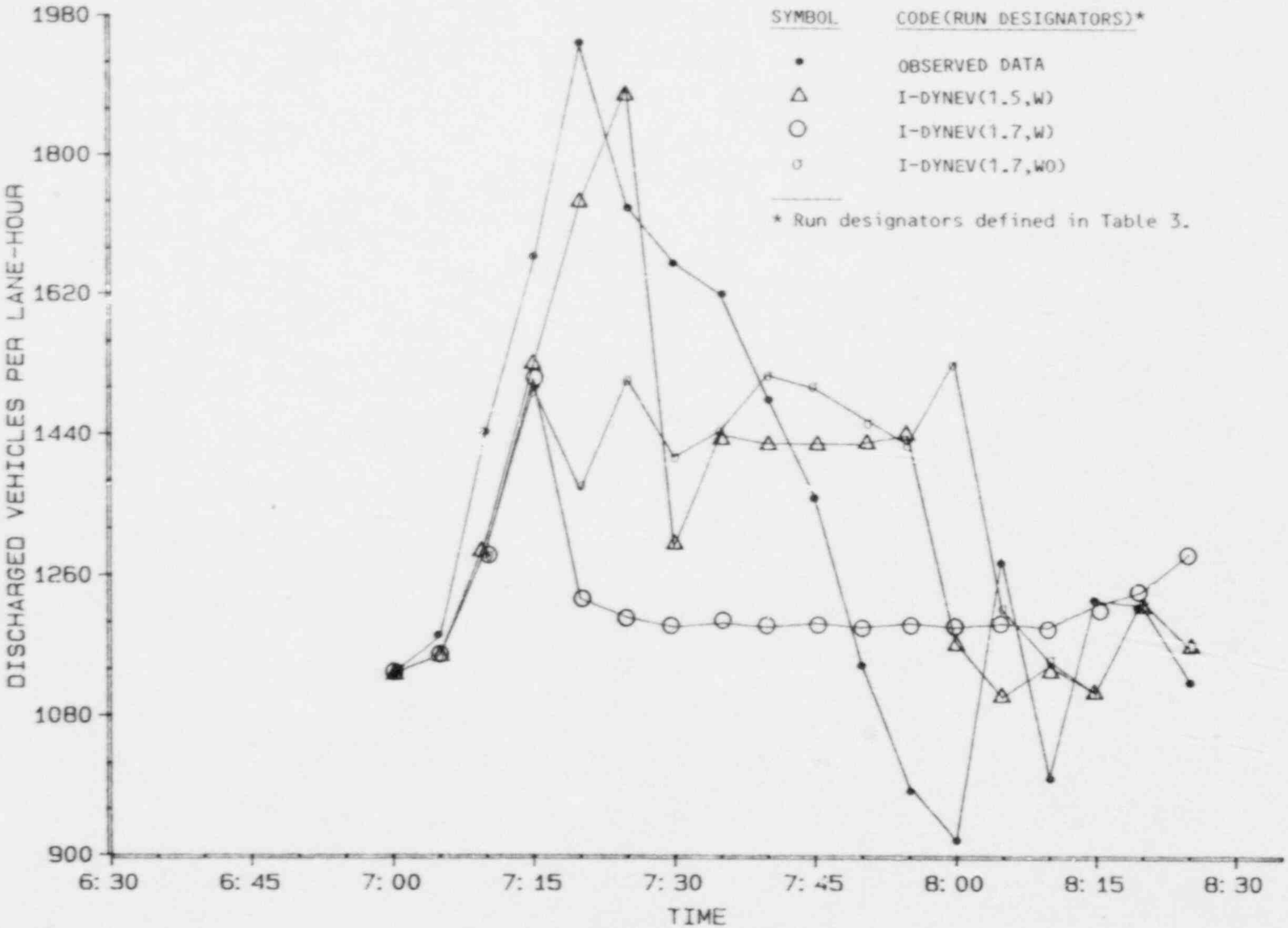


FIGURE 8. Observed and Predicted Discharge Rate of Vehicles From Segment 3 onto Segment 5

Vehicles Exiting the Network

The rate at which vehicles exit the transportation network as a function of time is a critical parameter describing traffic conditions during an evacuation. The simulated rates at which vehicles exited the network as a function of time for the I-DYNEV runs are presented together with the observed data in Figures 9a and 9b. Figure 9a includes I-DYNEV simulations for three vehicle discharge headway values (1.5, 1.7, and 1.8 sec), all with the capacity reduction factor. Figure 9b includes three runs designed to provide improved results. Each represents a change in either the vehicle discharge headway or a modification to the I-DYNEV code to make the capacity reduction factor a user input.

The I-DYNEV run using a 1.7-sec discharge headway with the capacity reduction factor simulated significantly fewer vehicles exiting the network than indicated by the observed traffic data. The number of exiting vehicles was underestimated because of the 15% capacity reduction during congested conditions. The I-DYNEV run using a 1.5-sec headway with the capacity reduction factor simulated a greater number of vehicles exiting the network than indicated by the observed traffic data. As previously described, using a 1.5-sec headway in an effort to compensate for the model's capacity reduction factor results in the network capacity being overestimated by 15% prior to the onset of congested conditions. These results suggest that it is inappropriate to adjust discharge headway to compensate for the capacity reduction factor.

The I-DYNEV run using the 1.7-sec discharge headway without the capacity reduction factor produced fair agreement with the observed data for vehicles exiting the network. Although the simulation does not reflect the detailed variations, the general trends are followed. Based on the rate of vehicles exiting the network, the 1.7-sec discharge headway without the capacity reduction factor is the only input scheme that adequately simulates the observed data. Consequently, the capacity reduction factor, which decreases capacity by 15% when congested conditions occur, is not appropriate for the network observed. As indicated earlier, the data set used had contained no evidence of a congestion-induced capacity reduction, making the use of a capacity reduction factor inappropriate.

Graphing and reviewing the data on the cumulative number of vehicles exiting the network provides a second perspective for analyzing the adequacy of I-DYNEV's simulation. Figures 10a and 10b illustrate the cumulative number of vehicles discharged from Segment 5 and, therefore, exiting the network. The graphs indicate that the simulation using a 1.7-sec headway with the capacity reduction factor significantly underestimates the cumulative number of vehicles exiting as a function of time. The graph also indicates that the simulation using the 1.5-sec headway with the capacity congestion factor overestimates the number of exiting vehicles until nearly the end of the observation period when traffic demand is less than capacity. Of the runs made, the I-DYNEV simulation using a 1.7-sec headway without the capacity reduction factor provides output that is most consistent with the observed data.

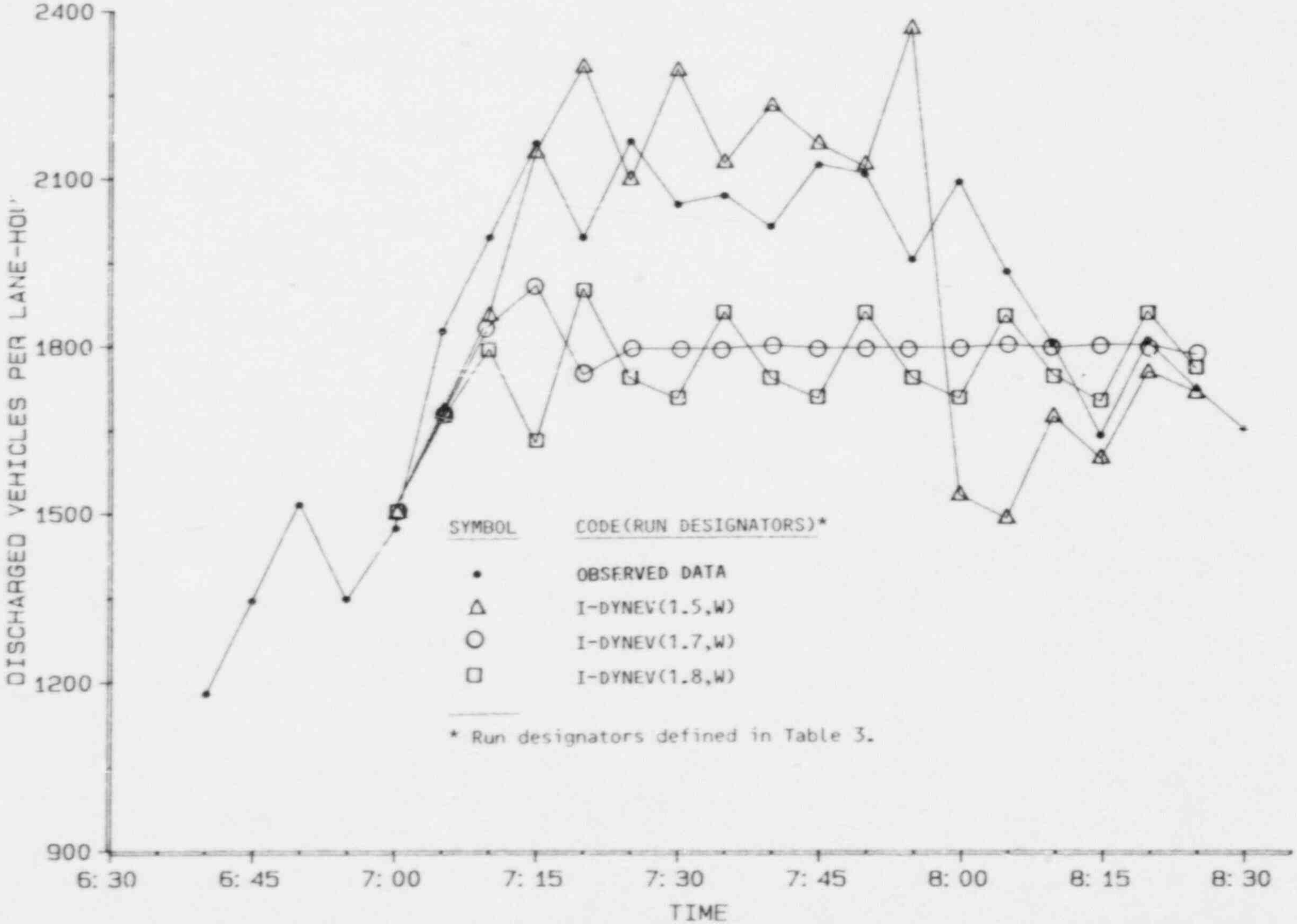


FIGURE 9a. Observed and Predicted Discharge Rate of Vehicles Exiting the Network, With Capacity Reduction Factor

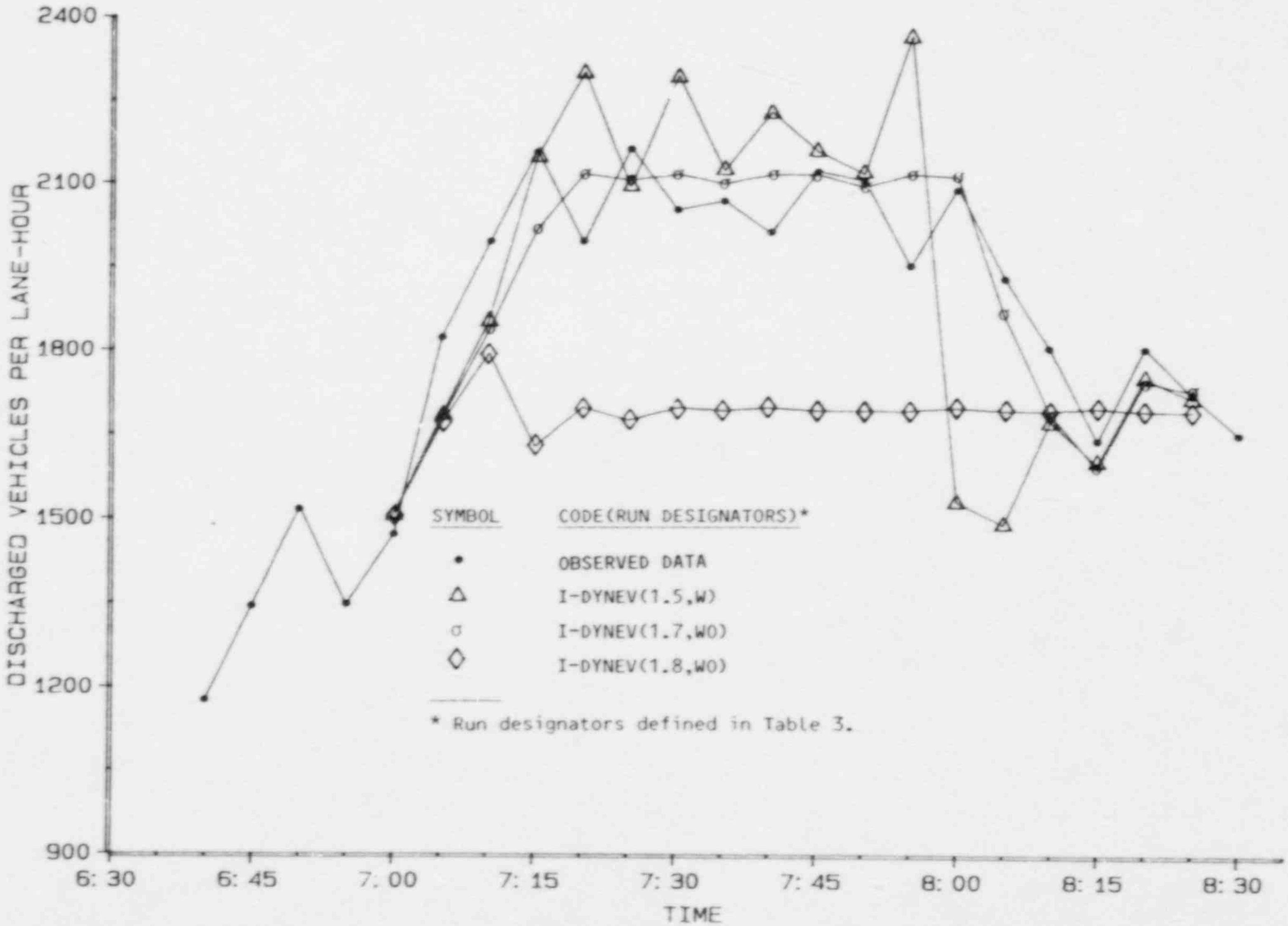


FIGURE 9b. Observed and Predicted Discharge Rate of Vehicles Exiting the Network, Without Capacity Reduction Factor

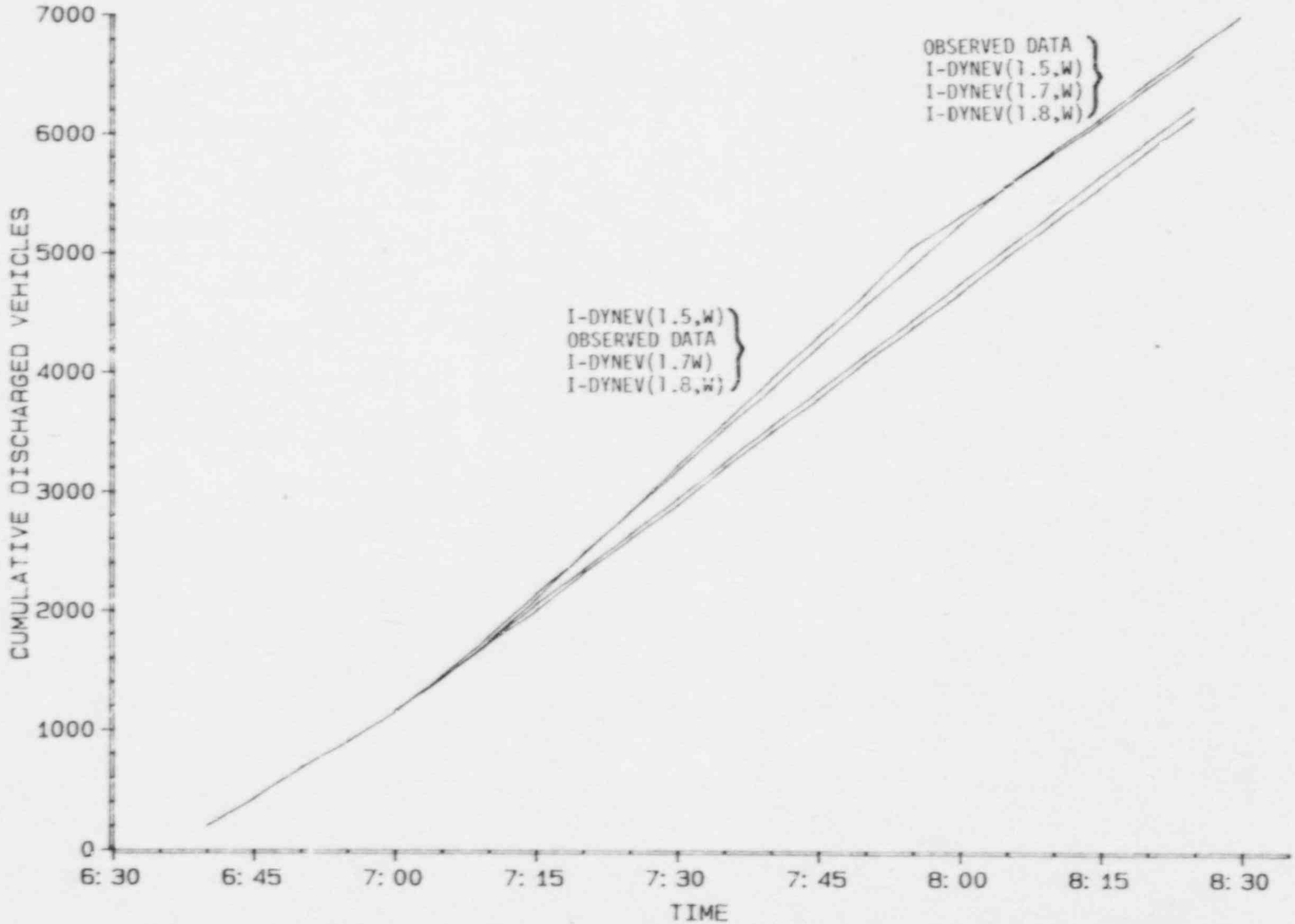


FIGURE 10a. Observed and Predicted Cumulative Number of Vehicles Exiting the Network, With Capacity Reduction Factor

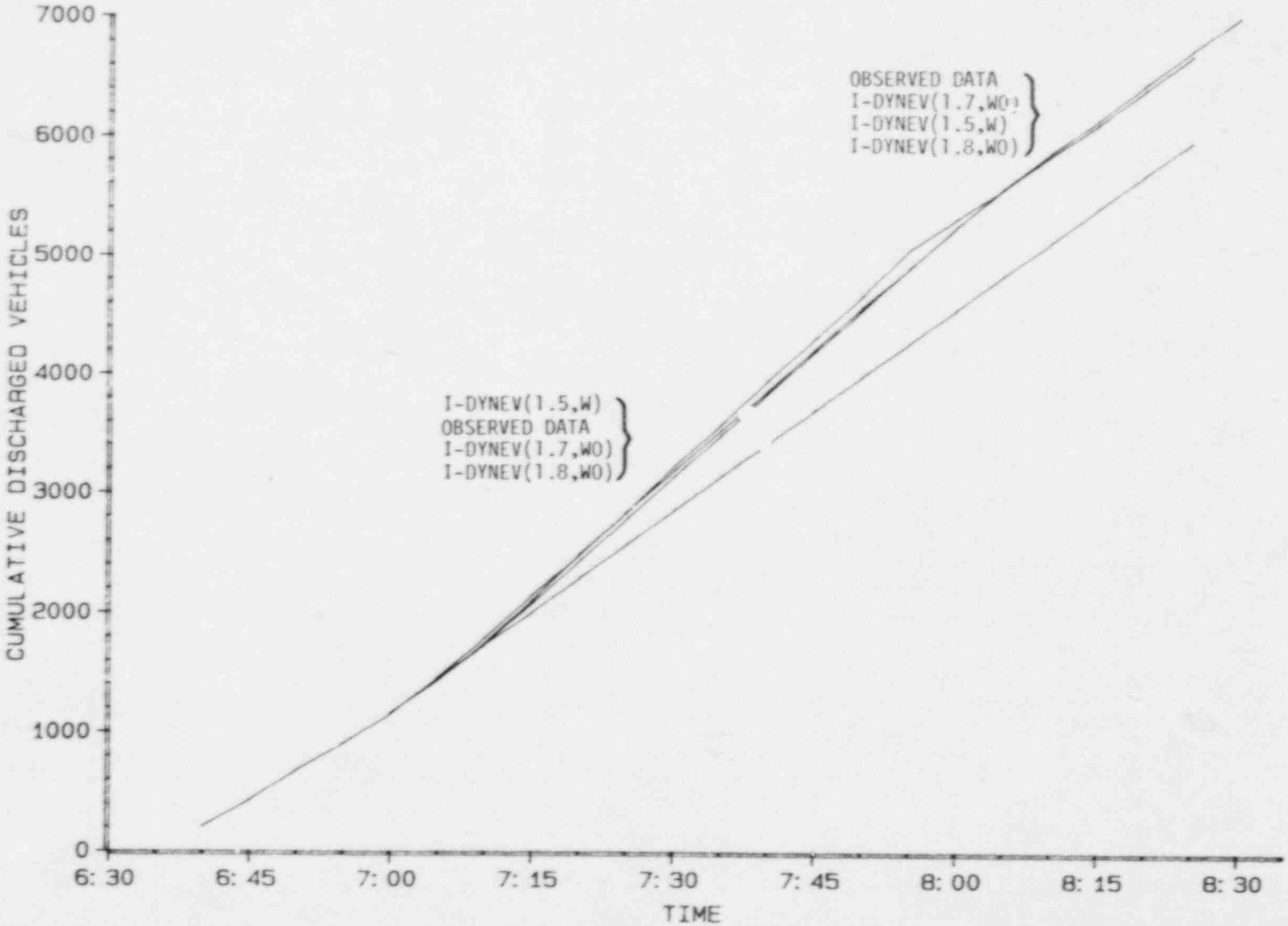


FIGURE 10b. Observed and Predicted Cumulative Number of Vehicles Exiting the Network, Without Capacity Reduction Factor

Average Speed

The average speed of the vehicles from the beginning of the study section to the end was calculated using the I-DYNEV output of cumulative vehicle-miles and average segment speed. I-DYNEV runs included those using a 1.7-sec discharge headway with the capacity reduction factor, a 1.5-sec discharge headway with the capacity reduction factor, and a 1.7-sec discharge headway without the capacity reduction factor. The average speeds of the vehicles along the network as a function of time as predicted by I-DYNEV are illustrated in Figure 11, together with the observed data.

As is evident from Figure 11, all of the curves, except for the I-DYNEV simulation using a 1.7-sec headway with the capacity reduction factor, follow the general trends of the observed data. The I-DYNEV simulation using a 1.7-sec headway with the capacity reduction factor appears to adequately depict the observed data through the peak period of congestion, but does not simulate the end of congestion. Instead, the curve shows a continued decrease the average speed until the end of the study period when a slight increase begins.

COMPARISON WITH OTHER MODELS

The I-DYNEV results were compared to the results calculated using other traffic simulation models to provide a perspective of the model's accuracy of simulation. The other simulation models were FREQ7 and CLEAR. The FREQ7 computer code is a traffic simulation model developed by the University of California at Berkeley. The code was developed to simulate traffic conditions on urban freeways. The CLEAR computer code was developed by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission expressly for the purpose of calculating evacuation time estimates. Each code was compared to I-DYNEV and the observed data for the three measures of model effectiveness reviewed previously.

The I-DYNEV simulation selected for comparison with the other two codes is the one that uses a 1.7-sec headway without the capacity congestion factor. Based on the results of the rate of vehicles exiting the system, this was the choice that appeared to best reflect the observed data. It should be noted, however, that the change of the capacity reduction factor represents a modification to the I-DYNEV code in that it is not presently an input parameter.

Discharge from Segments

A comparison of the estimated discharge rate of vehicles simulated by I-DYNEV, FREQ7, and CLEAR, together with the observed data is presented in Figures 12 through 15. The figures include the discharge of vehicles from Segment 1 onto 3, Segment 2 onto 3, Segment 4 onto 5, and Segment 3 onto 5.

The I-DYNEV simulation compares favorably with the other codes, as well as the observed data in Figures 12 through 14. In Figure 15, which reflects the discharge rate of vehicles from Segment 3 onto 5, neither I-DYNEV nor FREQ7 appear to depict the specific observed variations.

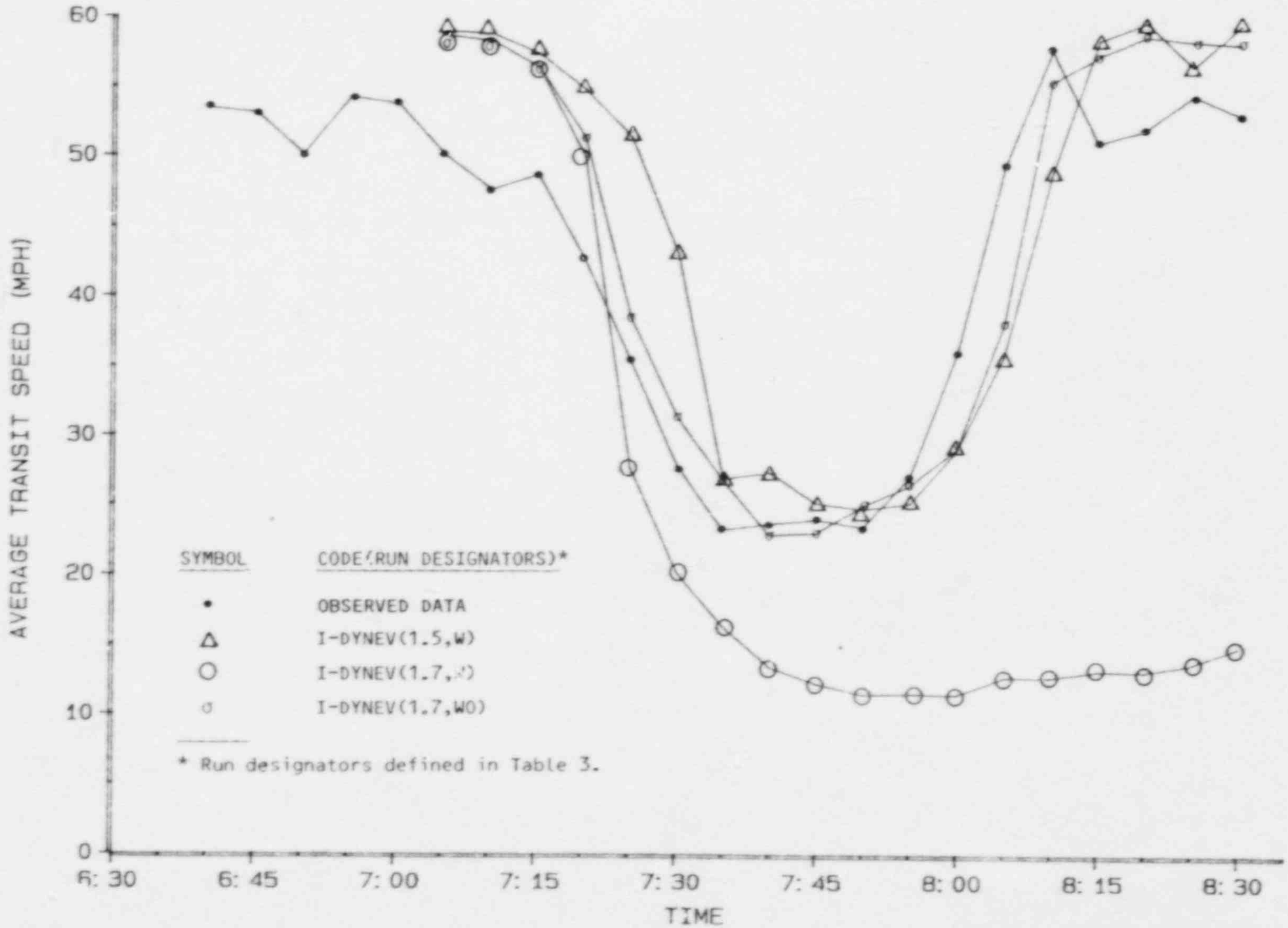


FIGURE 11. Observed and Predicted Average Transit Speed Along Segments 1, 3, and 5

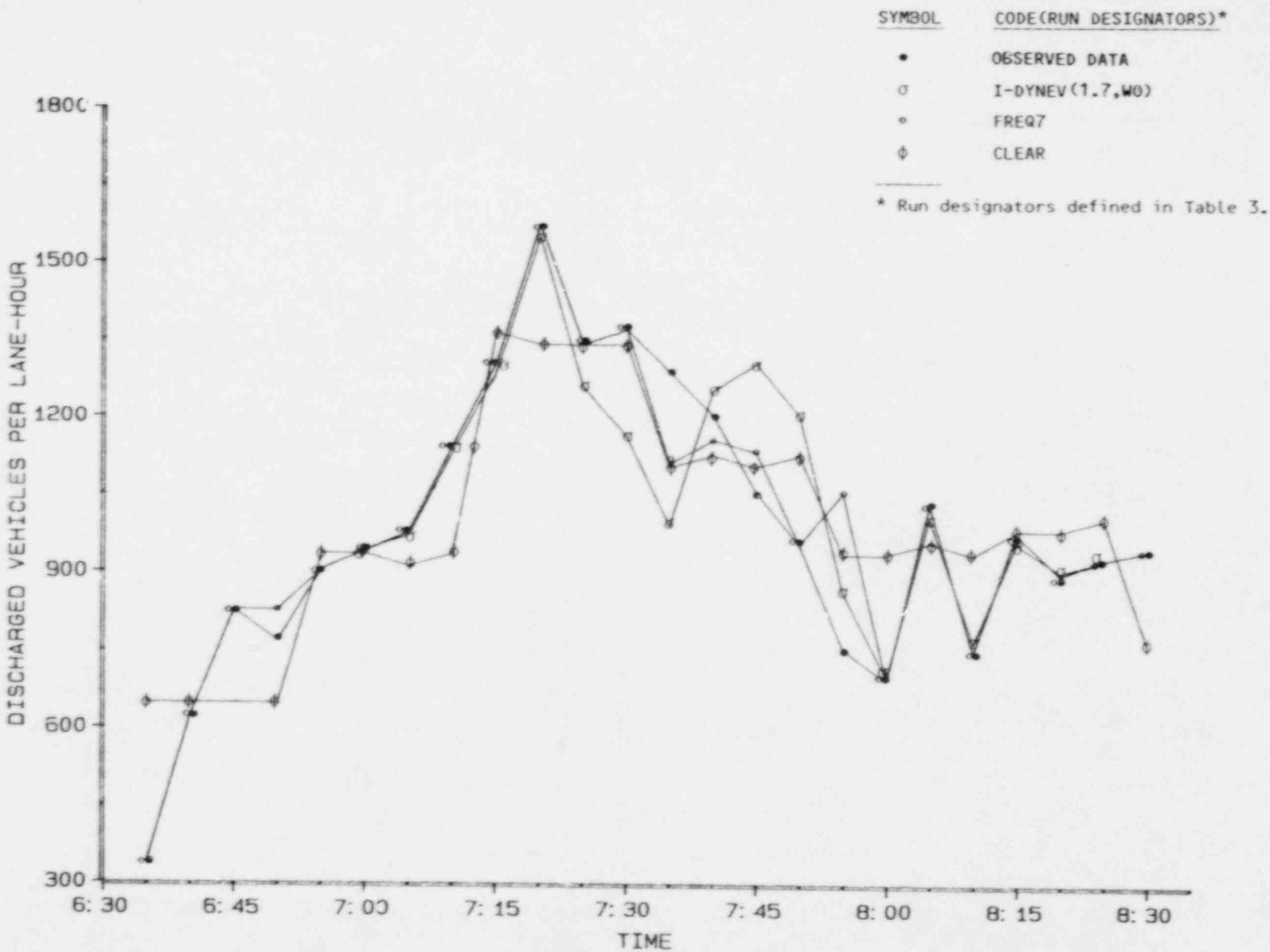


FIGURE 12. Observed Discharge Rate of Vehicles From Segment 1 onto Segment 3 and Predicted Values from I-DYNEV, FREQ7, and CLEAR

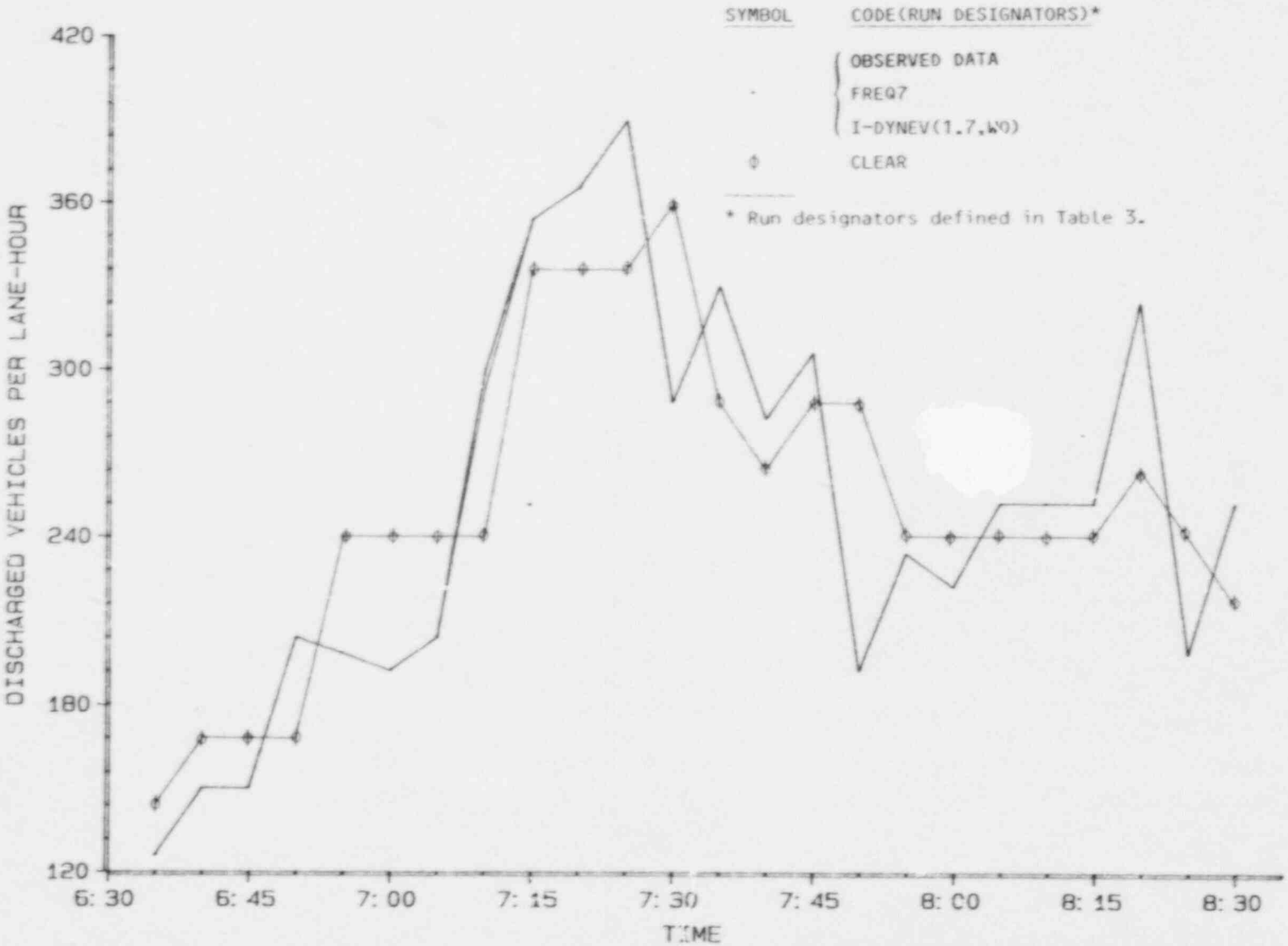


FIGURE 13. Observed Discharge Rate of Vehicles From Segment 2 onto Segment 3 and Predicted Values From I-DYNEV, FREQ7, and CLEAR

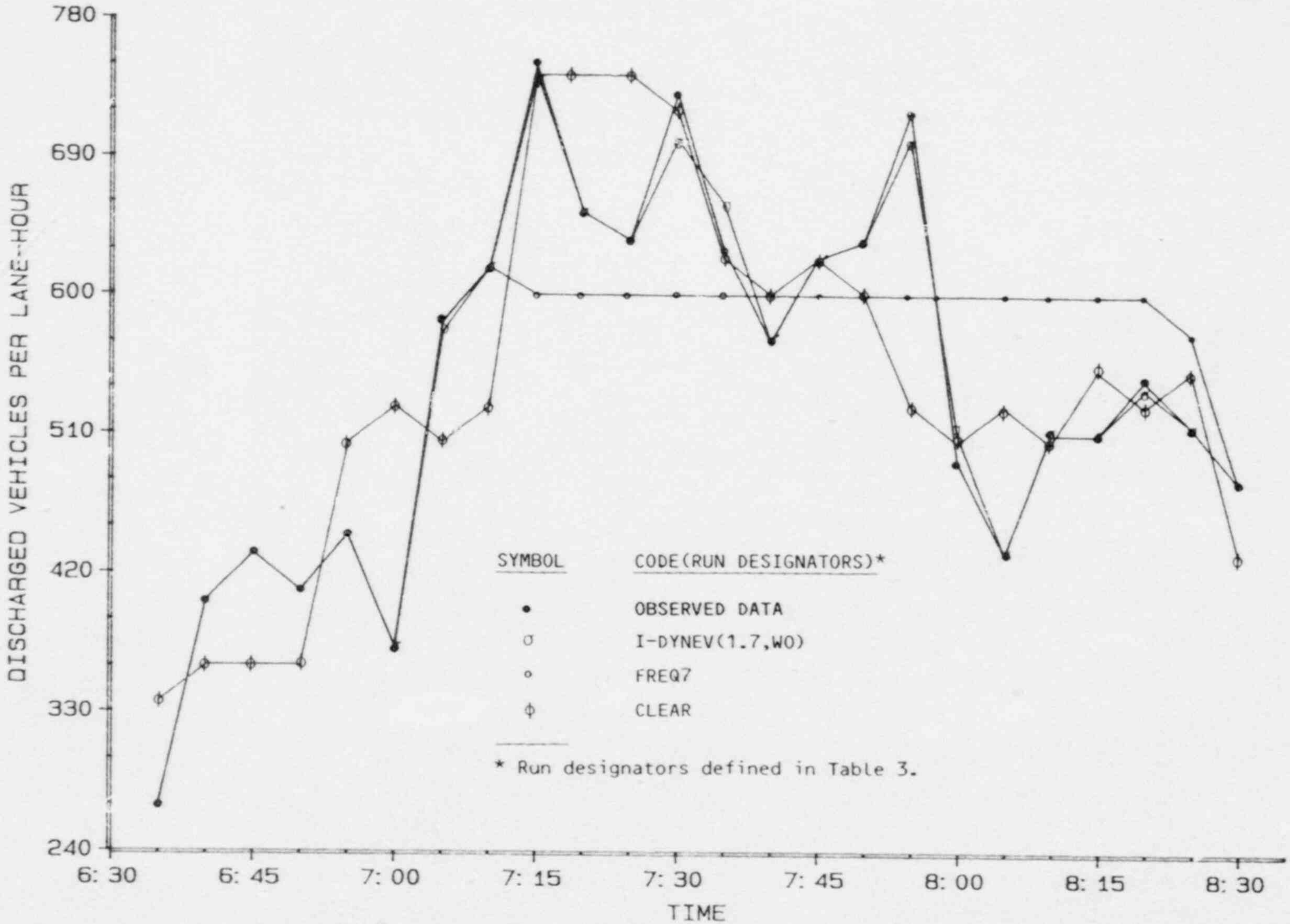


FIGURE 14. Observed Discharge Rate of Vehicles From Segment 4 onto Segment 5 and Predicted Values From I-DYNEV, FREQ7, and CLEAR

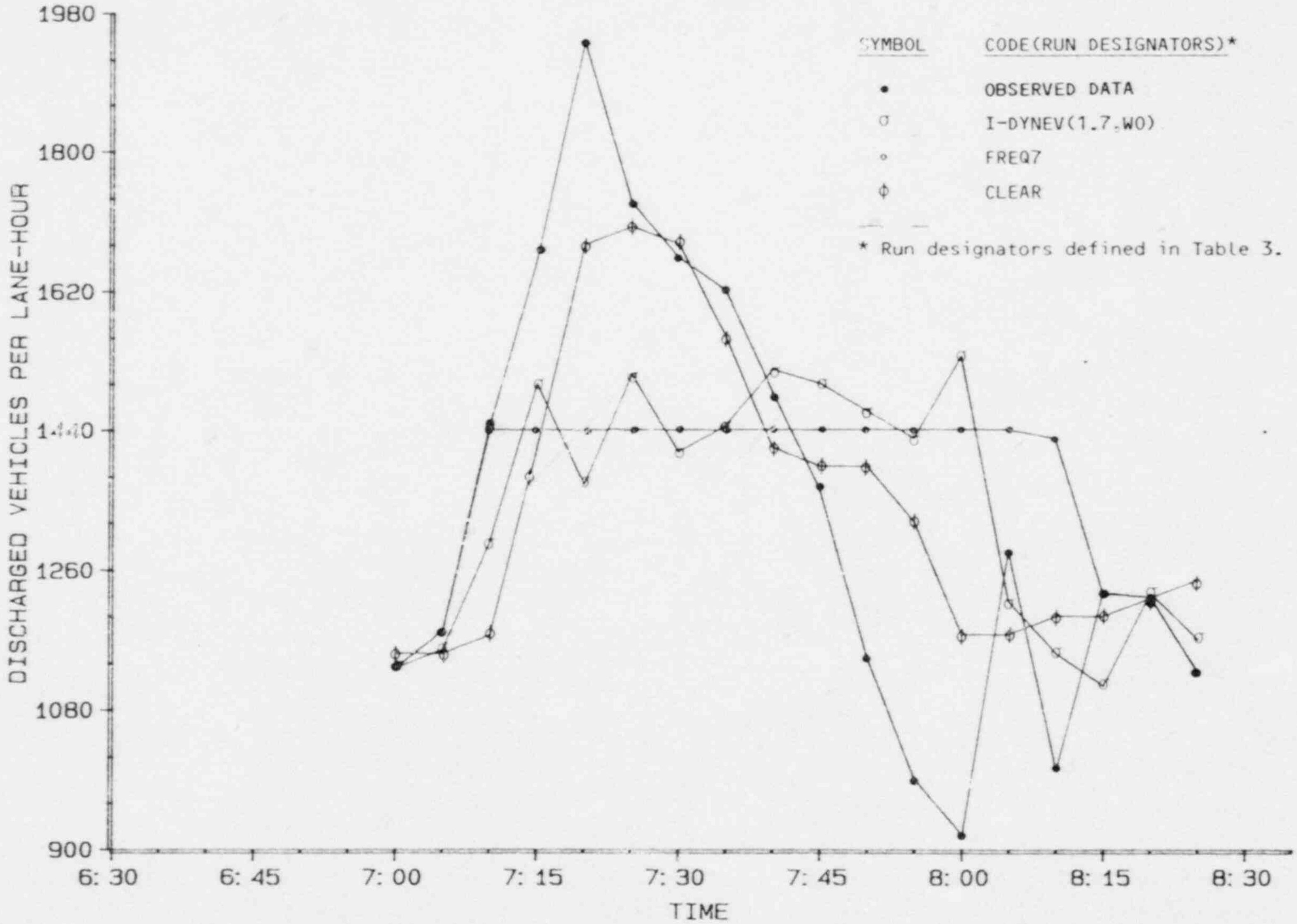


FIGURE 15. Observed Discharge Rate From Segment 3 onto Segment 5 and Predicted Values From I-DYNEV, FREQ7, and CLEAR

Vehicles Exiting the Network

The I-DYNEV run using the 1.7-sec discharge headway without the capacity reduction factor adequately predicted the rate of vehicles exiting the transportation network. Accurate simulation of this critical aspect of traffic flow is especially important for estimating evacuation. The results of simulations using I-DYNEV, FREQ7, and CLEAR are presented along with the observed data in Figure 16. The cumulative number of vehicles discharged from the network as a function of time is presented for the same simulations in Figure 17. As illustrated, all three simulations appear to accurately depict the traffic conditions. The I-DYNEV simulation appears to be more accurate than the simulations by the other codes.

Average Speed

The I-DYNEV run, using the 1.7-sec discharge headway without the capacity congestion factor, adequately simulated the observed average speed of vehicles moving through the transportation network. Accurate simulation of this aspect of traffic flow reflects an adequate representation of congested conditions. The results of simulations using I-DYNEV, FREQ7, and CLEAR are presented with the observed data in Figure 18. As shown, all three simulations appear to accurately represent the traffic conditions. The I-DYNEV simulation appears to be more accurate than the simulations by the other codes.

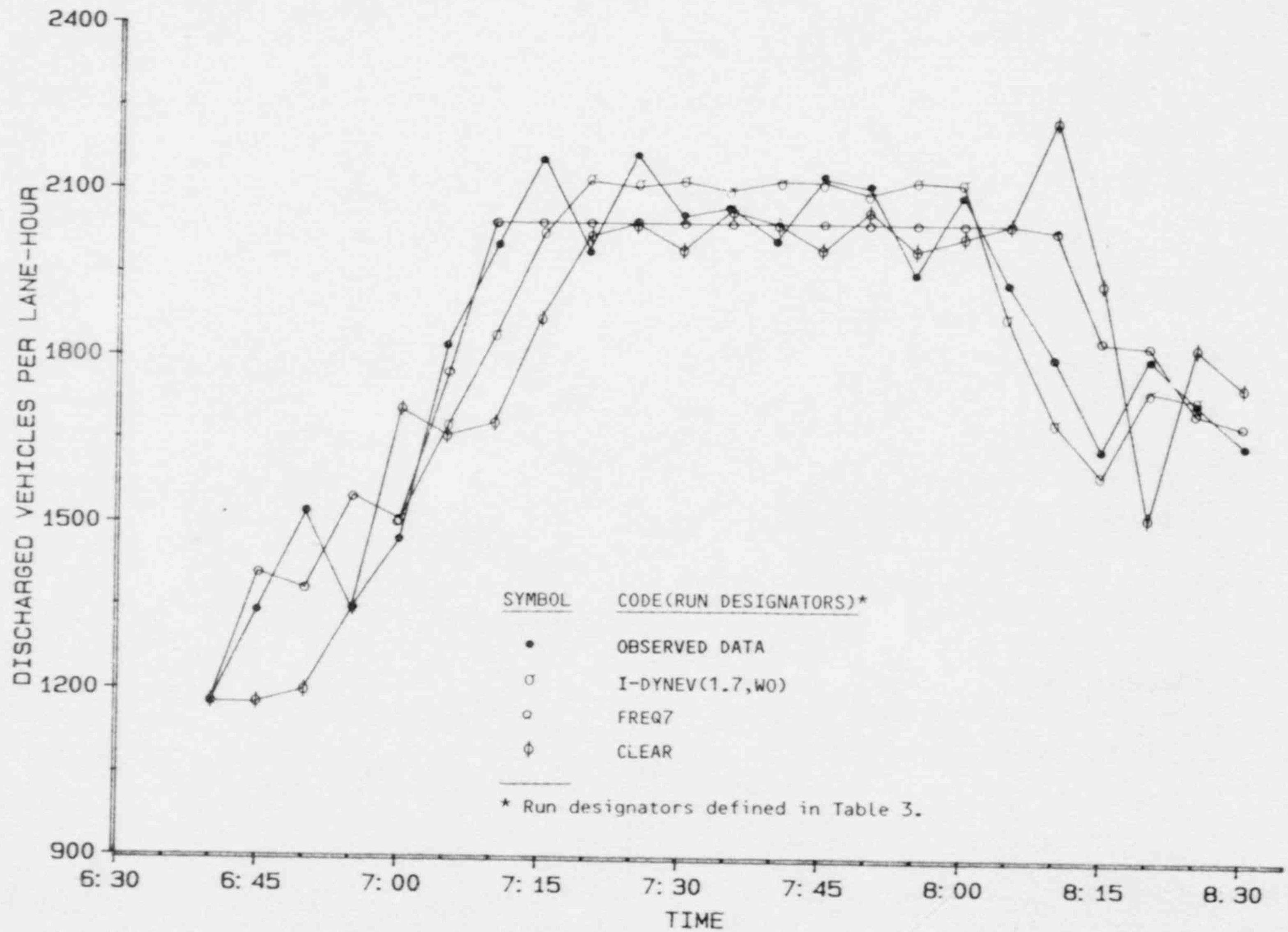


FIGURE 16. Observed Vehicles Exiting the Network and Predicted Values From I-DYNEV, FREQ7, and CLEAR

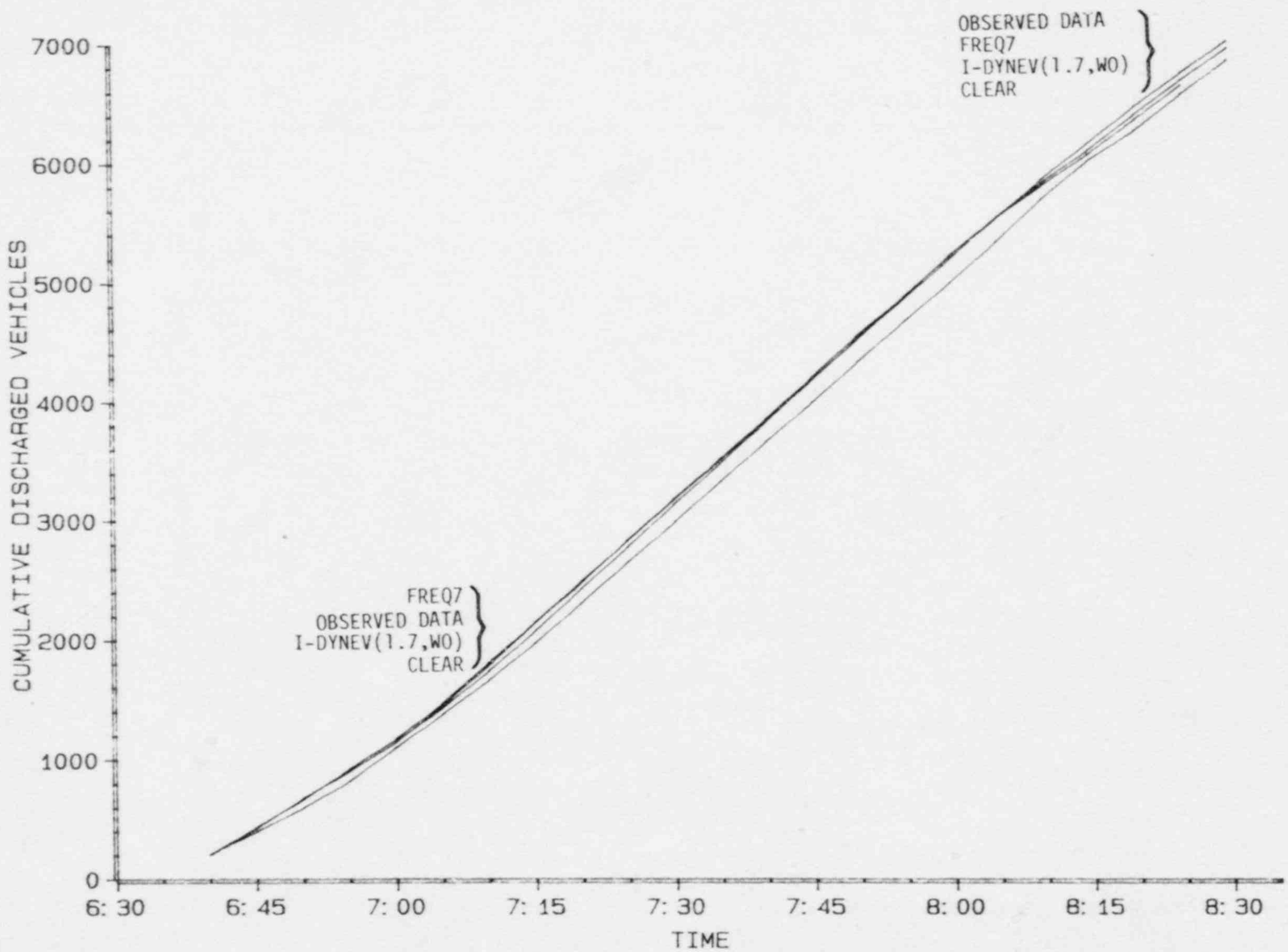


FIGURE 17. Observed Cumulative Number of Vehicles Exiting the Network and Predicted Values From I-DYNEV, FREQ7, and CLEAR

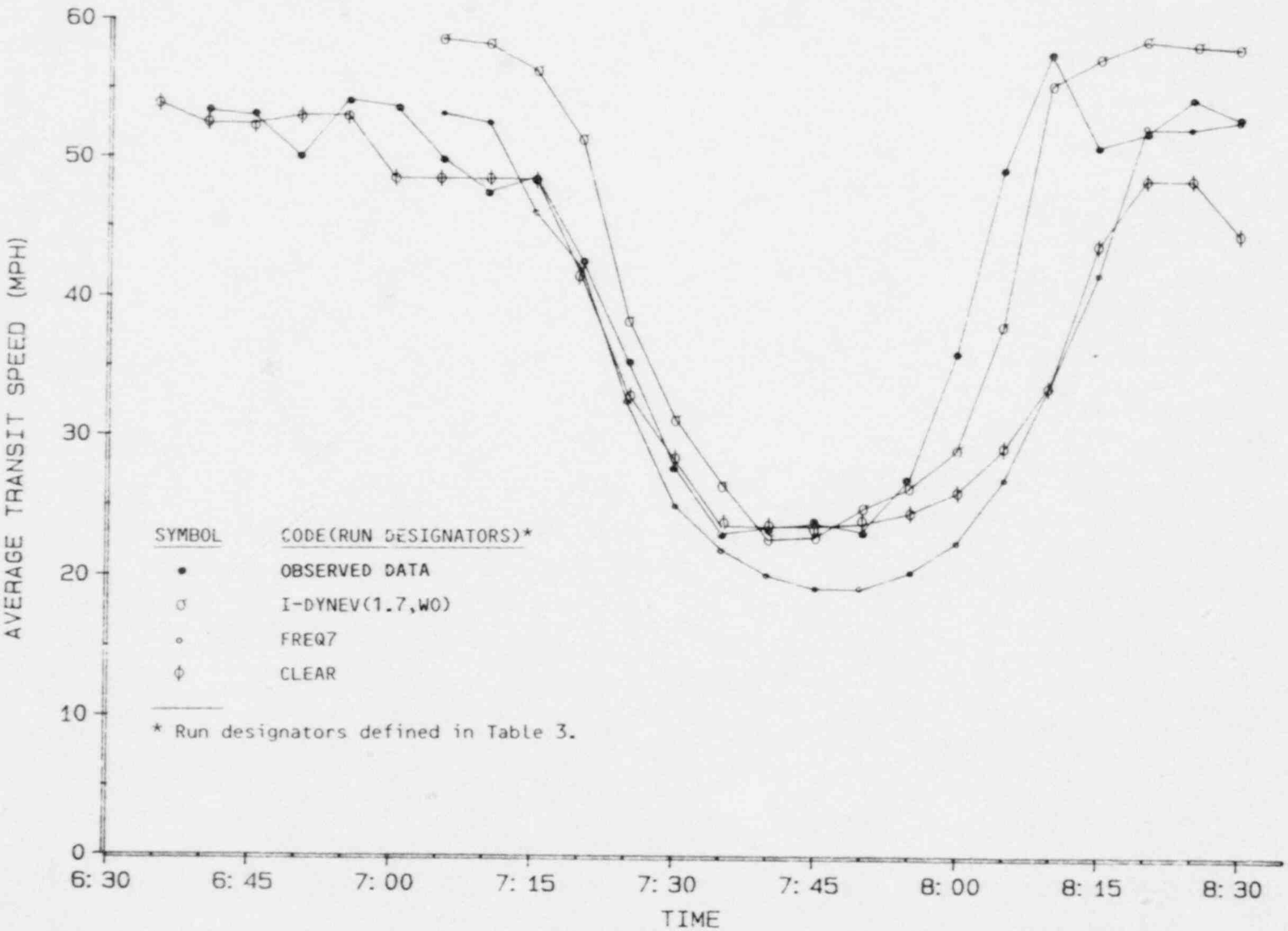


FIGURE 18. Observed Average Transit Speed Among Segments 1, 3, and 5 and Predicted Values From I-DYNEV, FREQ7, and CLEAR

CONCLUSIONS

The I-DYNEV code was not able to adequately represent the test data set until the capacity reduction factor was changed from an imbedded parameter to a user input. The appropriateness of congestion-induced capacity reduction is the subject of differing professional opinions. However, the data set used in this study could only be reasonably represented by not using the capacity reduction factor, suggesting that it is inappropriate to have its value inbedded in the I-DYNEV model. With the capacity reduction factor set to 1 (no congestion-induced capacity reduction), I-DYNEV produces results that are reasonably consistent with the observed data on a congested freeway. Further research is warranted into the effects of congestion on the capacity of highway networks in order to determine when a capacity reduction factor is appropriate.

BIBLIOGRAPHY

Urbanik II, T., M. P. Moeller and K. Barnes. 1987. The Sensitivity of Evacuation Time Estimates to Changes in Input Parameters for the I-DYNEV Computer Code. NUREG/CR-4874, PNL-6172, Pacific Northwest Laboratory, Richland, Washington.

Urbanik, T., A. E. Desrosiers, M. K. Lindell and C. R. Schuller. 1980. Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones. NUREG/CR-1745, BHARC-401/80-017. Battelle Human Affairs Research Center, Seattle, Washington.

U.S. Nuclear Regulatory Commission. 1980. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Nuclear Power Plants. NUREG-0654, FEMA-REP-1, Washington, D.C.

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13. ABSTRACT (200 words or less)

This report compares observed vehicle movement on a highway network during periods of peak commuter traffic with a simulation of the traffic flow made with the I-DYNEV computer model. The purpose of the comparison is to determine if the model can accurately simulate the patterns of vehicular movement and delay during congested commuter traffic.

The results indicate that the I-DYNEV model adequately simulates the patterns of vehicular movement and delay associated with an evacuation, provided that the model's capacity reduction factor is an input parameter. The current I-DYNEV model automatically reduces capacity by 15% of input capacity to account for congestion-induced losses in capacity. Because the study roadway did not have any capacity reduction due to congestion, the model underestimated capacity during congestion. Therefore the use of a capacity reduction factor should be a decision made by the analyst, not the model. When I-DYNEV was used with a capacity reduction factor appropriate to the data set used (i.e., no reduction in capacity), I-DYNEV produced reasonable results.

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