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16. Abstract

Two local responsive control tactics were evaluated on a five-entrance-ramp subsystem of the southbound direction of the Dan Ryan Expressway in Chicago.

Two local responsive ramp control tactics were evaluated. One (existing) tactic was based on a universal (typical to Chicago expressways) volume-occupancy relationship with metering rates changing every 20 seconds based on one minute moving average occupancy values updated every 20 seconds. The other tactics (developed) was based on a moving average of five minute occupancy values updated every minute.

No conclusive evidence as to the superiority of the developed tactic over the existing one is presented. This was possibly due to difficulties in sampling procedures.

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Traffic Operations Research

Evaluation of Two Isolated Responsive Ramp Control Tactics

by
James A. Budrick

With Appendix A: On Forecasting Freeway Volumes on Occupancies

by
Moshe Levin
and
Yen Der Tsao

Final Report
on

IHR-006 Testing and Evaluating Ramp Control Strategies

Project Conducted under Sponsorship of

STATE OF ILLINOIS
in Cooperation With
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

August, 1982

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CHAPTER I

INTRODUCTION

Freeway ramp control has been in operation for over twenty years during which time various control theories and models were developed offering ever increasing level of sophistication.

As the level of sophistication of the implemented control usually lags the level of sophistication of the related "state of the art" a proper question to ask is whether or not the freeway users are at a significant loss due to the above gap, or once a simple form of control has been implemented any increased level of control will have marginal cost greater than the marginal benefit.

This study tackled only a small part of the above issue. It attempted to evaluate two local responsive control tactics on a five-entrance-ramp subsystem of the southbound direction of the Dan Ryan Expressway in Chicago. The two tactics differed in their level of sophistication thus in the costs involved. Specifically, the evaluated tactics were:

1. The current tactic used in Chicago, where metering rates are changed every twenty-seconds based upon one general relationship between the metering rates and occupancy values. The actual rates used were derived from the 95th percentile volume versus occupancy curve (where each occupancy value is related to a distribution of traffic volume), as dictated by the minimum metering rate and maximum volume point on the curve (1).
2. Newly developed tactic, where metering rates are changed every minute based upon a relation between metering rates and occupancy levels developed for each individual controlled

ramp. The basis for this was the division of the volume versus occupancy curve into six "Levels of Service" zones related to the quality of traffic flow on the freeways (3). The range of occupancies representing Levels of Service D and E are further divided into sub-ranges representing the available metering rates.

The specific objective of this study was to compare two control tactics related to the isolated-responsive ramp control strategy as to their effect on traffic flow within:

1. A controlled section of freeway.
2. A freeway section upstream of the control section which is influenced by the control section.
3. A frontage road section along the controlled section.

CHAPTER II

THE STUDY SITE

Development and testing of such ramp control tactics required a study site under full electronic surveillance.

The site selected for this study was a portion of the southbound Dan Ryan Expressway between 65th and 95th streets, four and one-half miles in length, four lanes wide and under full surveillance and control. This section include five entrance ramps, equipped with ramp control signal devices, and six exit ramps. Traffic volumes in this area during the study peak hours ranged from 4,800 to 7,800 vehicles-per-hour (7,800 vph being the capacity) on the freeway itself and 300 to 900 vehicles-per-hour on the entrance ramps. There was also a two lane frontage road (Wentworth Avenue) that paralleled both the study site and a portion of the freeway immediately upstream of the study site, called the influenced section. This frontage road had a capacity of approximately 1,500 vehicles-per-hour and was an excellent alternate route for vehicles diverting from the freeway. The influenced section was determined to be between 45th and 65th streets on the southbound Dan Ryan Expressway. It was three miles in length, five lanes (three express and two local lanes) with three entrance and five exit ramps under full surveillance. However, the entrance ramps in this section were not equipped with control signal devices. (See Figure 1 for detail of both the study site and influenced section.) Both sections of the freeway were monitored for changes in traffic flow and any changes occurring within the influenced section were most likely due to traffic flow changes in the downstream study site.

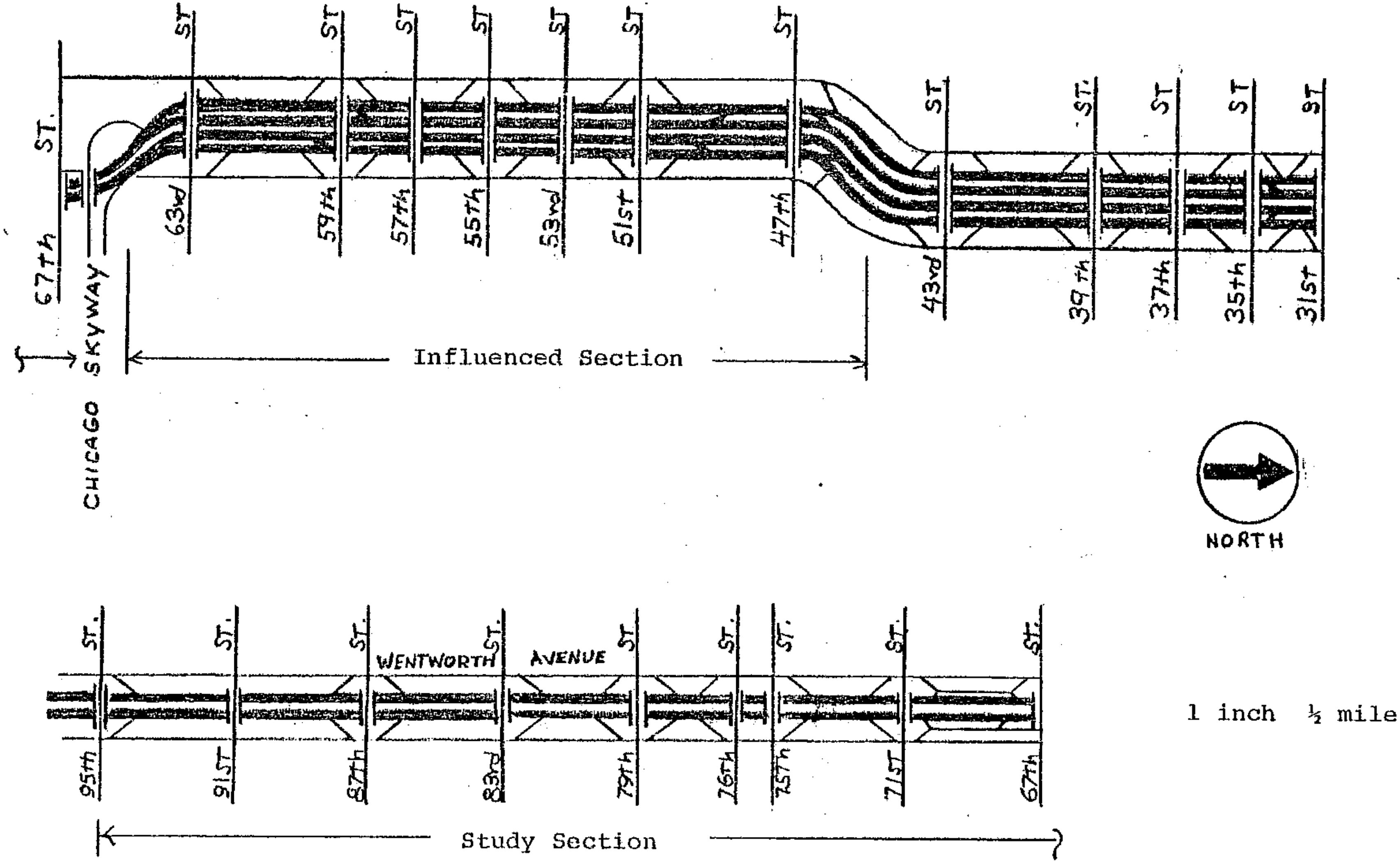

Figure 5: Southbound Dan Ryan Expressway Study Area

CHAPTER III

DEVELOPMENT OF CONTROL TACTICS

The Current Tactic

The current tactic was based on a generalized (typical to Chicago expressways) volume-occupancy relationship with metering rates changing every 20 seconds based on one minute moving average occupancy values updated every 20 seconds.

The generalized volume-occupancy relationship is shown in Figure 2. The controlling metering rates that correspond to the occupancy ranges are given in Table 1. A certain rate was effected when its threshold (the lower value of the related occupancy range) was measured by the central computer.

Two entrance ramps (67th and 71st Streets) were set in a manual fixed-time metering rate (eight and ten v.p.m., respectively) at the control center between 4:30 and 5:30 PM. This was done to take care of large queues waiting at these ramps and causing problems on the local street system. A full description of the current control tactic and other ramp control related matters can be found in Reference (1).

Table 1. Occupancy Ranges for Current Tactics

Metering Rate	Occupancy Range
1 = 12 v.p.m.	0 - 20%
2 = 10 v.p.m.	20 - 22.5%
3 = 8 v.p.m.	22.5 - 25%
4 = 6 v.p.m.	25 - 27.5%
5 = 4 v.p.m.	greater than 27.5%

The Newly Developed Control Tactic

The development of this tactic involved the following steps:

1. Determining the occupancy-volume relationship at each merging area.

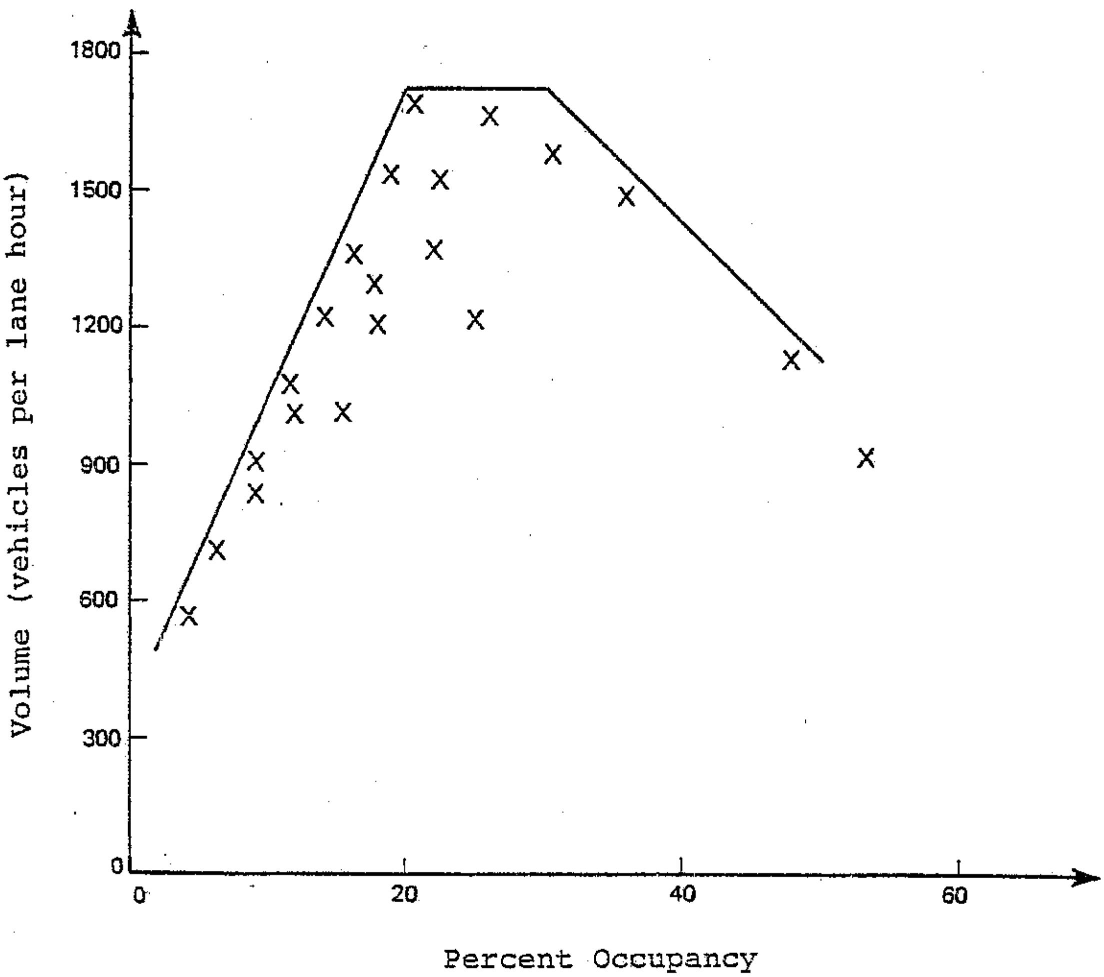

Figure 2: Volume Versus Occupancy Curve Developed in Chicago

2. Determining the control thresholds for changes in the metering rates.

3. Determining the frequency of the control changes.

The occupancy-volume relationship at each ramp was developed assuming a linear relationship between speed and occupancy as supported by the scattergram of speed vs. occupancy shown in Appendix B. The linear relationship assumed was:

$$u = u_f(1- \frac{\phi}{\phi_j})$$

where:

u = speed in mph

u_f = "free speed", speed at nearly 0% occupancy, in mph.

ϕ = occupancy in %

ϕ_j = "jam occupancy" at very low speed, in mph.

The above linear relationship follows the linear relationship between speed and density (3) where density was replaced by occupancy.

The parabolic relationship between volume and occupancy could be expressed as:

$$q = c_1\phi\ u_f(1- \frac{\phi}{\phi_j})$$

where:

q = volume in vph

c_1 = a conversion factor of occupancy to density

and the remaining variables are as defined before.

Table 5. Occupancy Ranges for New Tactics

Entrance Ramp	Rate 1 Occ. Limit	Rate 2 Occ. Limit	Rate 3 Occ. Limit	Rate 4 Occ. Limit	Rate 5 Occ. Limit
67th Street	0 - 17%	17 - 21%	21 - 25%	25 - 29%	>29%
71st Street	0 - 16%	16 - 22%	22 - 28%	28 - 34%	>34%
76th Street	0 - 17%	17 - 23%	23 - 29%	29 - 34%	>34%
79th Street	0 - 15%	15 - 22%	22 - 29%	29 - 36%	>36%
87th Street	0 - 17%	17 - 21%	21 - 25%	25 - 29%	>29%

CHAPTER IV

EVALUATION OF CONTROL TACTICS

Evaluation of the two control tactics took place over an eight week period (four weeks for each tactic) during the months of September and October, 1978. The data for this evaluation was collected in three ways:

1. Using the Illinois Department of Transportations Traffic System Center (TSC) computer to collect data from the surveillance detectors located throughout the study area;
2. Using pneumatic tube traffic counters to collect frontage road traffic volumes; and
3. Using the Illinois Department of Transportations helicopter to collect ramp queue data.

From the eight weeks of data collected, approximately four weeks (two weeks for each tactic) of data was actually used for the evaluation. The reason for this was that the incident free rush-dry period was selected for the evaluation. That is the weather had to be ideal (e.g. clear and dry) and no traffic conflicts could be present along any section of roadway where data was being collected (i.e. no accidents or vehicles blocking any lanes).

Data Collection Procedures

Data collected from the Traffic Systems Center (TSC) computer was done using a two part computer program. The first part was used to collect real-time data from the surveillance detectors located along the expressway and the second part was to store that data on a disk file and punch it directly onto cards in a specific format. The data was collected on a daily basis for each five-minute time interval during the P.M. peak hours (2:00 p.m. till 7:00 p.m.). Finally, as stated before, the queue data was collected using the Illinois Department of Transportations helicopter. These data was collected for two hour sample period (3:00 p.m. till 5:00 p.m.) within the same peak period.

Measures of Effectiveness

The measures of effectiveness that were chosen for this evaluation should give a good indication of the type of traffic loading (volume, density, etc.) and system performance (total travel, total travel time, system speed, etc.) that each tactic attains. These measures of effectiveness are as follows:

1. Total Travel Time (vehicle - hours)

   This is the total elapsed time that it takes all vehicles to travel from one specified point to another under existing traffic conditions. This parameter is calculated as follows:

   $$\frac{\text{Mainline Detector Distances (Mi.)}}{\text{Speed (M.P.H.)}} \times \text{Mainline Volumes} \times \text{No. of Lanes}$$

2. Minute Miles of Congestion (miles)

   This is the number of congested (over 30% occupancy) miles per minute.

3. Input/Output (vehicles)

   This is the number of vehicles that enter and exit a given section of freeway. This parameter is calculated as follows:

   Beginning Count Station Volume + Entrance Ramp Volumes - Exit Ramp Volumes.

4. Total Travel (vehicle - miles)

   This is the number of miles of freeway travelled by the total number of vehicles using that facility in a given time interval. This parameter is calculated as follows:

   (Beginning Count Station Volume X Center Line Distance to End of Section) + (Entrance Ramp Volumes X Distance to End to

Section) - (Exit Ramp Volumes X Distance to End of Section).

5. System Speed (miles-per-hour)

   This is the average speed that a specific section of roadway is operating at. This parameter is calculated as follows:

$$\frac{\text{Total Travel (Vehicle - Miles)}}{\text{Total Travel Time (Vehicle - Hours)}}$$

6. Frontage Road Volumes (vehicles-per-hour)

   This is the number of vehicles using the frontage road during a specified hour of the day. This parameter is taken directly from the volume counts received by the pneumatic traffic counters.

7. Entrance Ramp Volumes (vehicles-per-hour)

   This is the number of vehicles that enter the expressway by way of the entrance ramps within the study section.

8. Average Vehicle Delay at Each Entrance Ramp Between 3:00 p.m. and 5:00 p.m. (minutes)

   This is the average time a vehicle would wait in a queue at the entrance ramp before entering the freeway. This parameter is calculated as follows:

$$\frac{\text{Total Travel Time for the Queue}}{\text{Number of Entering Vehicles}}$$

9. Violations (vehicles-per-hour)

   This is the number of vehicles violating the entrance ramp signal.

CHAPTER V

SUMMARY OF ANALYSES AND RESULTS

This chapter displays the results of all the data collected for the evaluation of the two control tactics. First the data collected from the freeway detectors by way of the Traffic Systems Center (TSC) computer is found in Tables 6 and 7. Table 6 shows the results obtained from the "influenced section" of the southbound Dan Ryan Expressway (45th to 65th Streets). Each measure of effectiveness in broken down by hour within the control period (2:00 p.m. till 7:00 p.m.). For example: 1500 would represent the hour between 2:00 and 3:00 p.m.; 1600 the hour between 3:00 and 4:00 p.m. and so on ... The numbers shown in the "average" row is actually the average of all the data in the sample. The means and standard deviations were all found by using the "SPSS (Statical Package for the Social Sciences) Breakdown Program" (5). A test of significance between the means was performed using a T-Test. The 0.05 level of significance was chosen for the test of hypothesis. This test was done only on the "average" data.

Tables 8, 9, and 10 represent the data collected from the entrance ramps within the "study site". This data was also obtained by way of the TSC computer and detectors. Table 8 shows the entrance ramp volumes; Table 9 shows the number of violations at the entrance ramp signals, while Table 10 shows percent violations. The SPSS Breakdown Program was again used to determine the means and standard deviations and the "average" row represents the average of all the data in the sample. For this case the test of significance between the means was performed using a Z test.

Tables 11 and 12 show the results of the data collected from the frontage road (Wentworth Avenue). Table 11 gives the frontage road volumes broken down by hour (just as before) except in this case the "total" row represents

Table 6. Comparison of Total Travel Time, Minute Miles of Congestion, Input - Output Volumes, Total Travel, and System Speed Within the Influenced Section During the Control Period

		Current Tactics		Proposed Tactics			
M.O.E.	Time	Mean	Std. Dev.	Mean	Std. Dev.	%Diff.	Signif.?
Total Travel Time (Veh-Hrs.)	1500	503.0	14.7	543.0	55.8	+ 8.0%	
	1600	1105.6	60.0	1101.6	93.4	- 0.4%	
	1700	1331.7	79.5	1313.0	52.4	- 1.4%	
	1800	1291.6	165.3	1228.0	64.2	- 4.9%	
	1900	597.3	85.7	754.8	97.8	+26.4%	
	Average	965.9	365.2	988.1	305.3	+ 2.4%	No
Minute Miles (Miles) Congestion	1500	10.5	5.4	21.5	11.4	+105.0%	
	1600	176.3	11.7	184.9	26.4	+ 4.9%	
	1700	259.7	12.1	258.8	11.3	- 0.4%	
	1800	237.6	46.8	231.6	21.5	- 2.5%	
	1900	31.5	16.6	71.9	27.8	+128.3%	
	Average	143.1	107.4	153.7	95.3	+ 7.4%	No
Input Output (vph)	1500	6989.7	408.3	6728.3	193.1	- 3.7%	
	1600	6962.0	263.4	6333.3	326.4	- 9.0%	
	1700	5135.7	410.0	4855.7	281.7	- 5.6%	
	1800	4940.0	642.8	4679.0	341.6	- 5.3%	
	1900	5977.6	330.8	5344.0	294.9	-10.6%	
	Average	6001.0	959.2	5588.1	866.1	- 6.9%	Yes
Total Travel (Veh-Miles)	1500	21694.7	922.4	21560.0	707.4	- 0.6%	
	1600	22705.6	701.5	21306.4	1163.3	- 6.2%	
	1700	17070.8	1131.4	16684.7	834.4	- 2.3%	
	1800	16610.0	1772.7	16348.3	1125.5	- 1.6%	
	1900	19195.0	536.3	18256.7	751.2	- 4.9%	
	Average	19455.2	2669.7	18831.2	2419.4	- 3.2%	No
System Speed (mph)	1500	43.9	1.6	40.5	4.2	- 7.7%	
	1600	21.3	2.1	20.3	3.0	- 4.7%	
	1700	13.0	1.6	12.8	0.9	- 1.5%	
	1800	13.4	3.1	13.4	1.5	0.0%	
	1900	35.7	4.6	26.1	4.4	-26.9%	
	Average	25.4	12.8	22.6	10.8	-11.0%	No

Sample Size: n=35

Table 7. Comparison of Total Travel Time, Minute Miles of Congestion, Input - Output Volumes, Total Travel, and System Speed Within the Study Section During the Control Period

		Current Tactics		Proposed Tactics			
M.O.E.	Time	Mean	Std. Dev.	Mean	Std. Dev.	%Diff.	Signif.?
Total Travel Time (Veh-Hrs.)	1500	485.9	15.7	495.7	14.7	+ 2.0%	
	1600	644.7	23.9	633.8	29.2	- 1.7%	
	1700	754.7	76.9	737.4	51.4	- 2.3%	
	1800	707.0	50.2	715.5	30.4	+ 1.2%	
	1900	562.9	56.7	629.0	55.4	+11.7%	
	Average	631.0	108.9	642.3	93.8	+ 1.8%	No
Minute Miles (Miles)	1500	0.9	1.2	3.1	5.5	+244.0%	
	1600	13.2	5.2	11.8	5.4	-11.6%	
	1700	56.9	39.1	45.8	18.4	-19.5%	
	1800	52.7	24.6	43.2	16.4	-18.0%	
	1900	7.1	7.7	15.8	10.6	+122.0%	
	Average	26.2	31.2	23.9	21.1	- 8.8%	No
Input Output (vph)	1500	3066.6	220.6	3299.6	404.1	+ 7.6%	
	1600	3526.9	195.8	3819.7	490.3	+ 8.3%	
	1700	3933,3	238.8	4184.6	418.2	+ 6.4%	
	1800	3661.9	73.5	3835.4	384.6	+ 4.7%	
	1900	3272.7	209.9	3480.0	494.1	+ 6.3%	
	Average	3492.3	357.2	3722.1	514.9	+ 6.6%	Yes
Total Travel (veh-Miles)	1500	16343.0	601.5	16689.1	512.9	+ 2.1%	
	1600	18104.3	503.8	18392.2	606.1	+ 1.6%	
	1700	18206.9	907.9	18454.6	460.0	+ 1.4%	
	1800	17363.1	250.5	17344.6	881.0	- 0.1%	
	1900	16930.3	510.2	16794.4	848.4	- 0.8%	
	Average	17389.5	907.1	17535.0	1002.8	+ 0.8%	No
System Speed (mph)	1500	33.8	1.9	33.9	1.2	+ 0.3%	
	1600	28.4	2.0	29.1	2.0	+ 2.5%	
	1700	24.7	2.9	25.3	1.9	+ 2.4%	
	1800	24.9	1.8	24.4	1.8	- 2.0%	
	1900	30.8	3.1	27.2	3.0	-11.7%	
	Average	28.5	4.2	28.0	4.0	- 1.7%	No

sample size: n = 35

Table 8. Comparison of Entrance Ramp Volumes Within the Study Section During the Control Period

		Current Tactics		Proposed Tactics			
Location	Time (hr.)	Mean (vph)	Std. Dev. (vph)	Mean (vph)	Std. Dev. (vph)	Diff. (%)	Signif.?
67th St. Entrance Ramp	1500	545.4	132.0	536.7	122.6	- 1.6%	
	1600	585.6	105.1	556.1	112.9	- 5.0%	
	1700	568.8	81.2	473.1	110.8	-16.8%	
	1800	550.0	65.3	473.0	109.5	-14.0%	
	1900	536.0	110.9	509.4	124.9	- 5.0%	
	Average	557.2	102.5	509.8	119.1	- 8.5%	Yes
71st St. Entrance Ramp	1500	424.2	89.9	364.5	79.9	-14.1%	
	1600	428.8	61.6	435.3	60.9	+ 1.5%	
	1700	552.2	101.0	395.9	67.6	-28.3%	
	1800	525.6	88.7	391.1	75.8	-25.6%	
	1900	445.2	97.0	406.0	84.4	- 8.8%	
	Average	475.2	102.9	404.6	75.6	-14.8%	Yes
76th St. Entrance Ramp	1500	373.2	79.4	367.7	74.7	- 1.5%	
	1600	463.4	75.8	472.1	88.1	+ 1.8%	
	1700	467.8	89.4	544.7	119.3	+16.4%	
	1800	458.8	99.9	528.7	121.0	+15.3%	
	1900	422.0	107.1	453.6	84.6	+ 7.5%	
	Average	437.0	97.3	473.2	117.1	+ 8.3%	Yes
79th St. Entrance Ramp	1500	271.4	60.3	286.9	63.3	+ 5.7%	
	1600	323.2	61.2	327.1	65.7	+ 1.1%	
	1700	429.2	114.7	487.3	108.9	+13.5%	
	1800	374.4	82.1	438.8	92.8	+17.2%	
	1900	332.0	88.9	349.7	82.0	+ 5.4%	
	Average	346.0	98.8	377.7	111.7	+ 9.2%	Yes
87th St. Entrance Ramp	1500	511.4	83.7	506.0	79.1	- 1.1%	
	1600	588.8	102.7	583.1	83.1	- 0.2%	
	1700	537.6	139.9	547.4	115.1	+ 1.9%	
	1800	532.6	120.7	492.4	167.8	- 7.5%	
	1900	552.2	130.0	529.6	119.6	- 4.1%	
	Average	538.5	117.5	531.8	120.9	- 1.2%	No

sample size: n = 420

Table 9. Comparison of the Signal Violation Rate Within the Study Section During the Control Period

Location	Time (hr.)	Current Tactics Mean (vph)	Current Tactics Std. Dev. (vph)	Proposed Tactics Mean (vph)	Proposed Tactics Std. Dev. (vph)	Diff. (%)	Signif.
	1500	4.2	10.8	4.4	10.2	+ 4.8%	
67th St.	1600	21.4	17.7	22.1	18.7	+ 3.3%	
Entrance	1700	17.6	19.1	18.9	17.3	+ 7.4%	
Ramp	1800	18.8	14.1	19.5	17.6	+ 3.7%	
	1900	10.8	16.4	21.3	17.0	+97.2%	
	Average	14.6	16.9	17.3	17.6	+18.0%	Yes
	1500	6.6	16.2			-	
71st St.	1600	39.2	29.8	Data		-	
Entrance	1700	23.4	20.3	Not		-	
Ramp	1800	26.4	21.4	Available		-	
	1900	20.0	24.7			-	
	Average	23.1	25.1			-	?
	1500	5.0	14.2	7.9	16.4	+58.0%	
76th St.	1600	20.0	23.5	24.1	19.0	+20.5%	
Entrance	1700	25.0	20.2	20.3	26.8	-18.8%	
Ramp	1800	30.2	25.0	21.4	20.0	-29.1%	
	1900	12.4	19.9	20.9	19.6	+68.5%	
	Average	18.5	22.6	18.9	19.2	+ 2.2%	No
	1500	4.0	11.2	19.6	25.8	+390.%	
79th St.	1600	22.8	24.8	34.6	20.7	+50.9%	
Entrance	1700	34.6	29.3	33.3	25.2	- 3.8%	
Ramp	1800	31.2	25.5	32.2	23.0	+ 3.2%	
	1900	13.0	18.9	30.4	22.3	+134.%	
	Average	21.1	25.4	30.0	23.4	+42.0%	Yes
	1500	12.0	21.1	16.9	27.8	+40.8%	
87th St.	1600	51.4	51.3	51.9	37.4	+ 1.0%	
Entrance	1700	89.6	58.6	86.8	53.4	- 3.1%	
Ramp	1800	89.6	61.2	77.5	43.3	-13.5%	
	1900	41.4	49.7	59.6	53.8	+24.2%	
	Average	56.8	58.3	58.5	50.3	+ 3.0%	No

sample size: n = 420

Table 10. Comparison of Percent Signal Violation of Ramps

Location	Time	Current Tactics %Viol.	Proposed Tactics %Viol.
67th St. Entrance Ramp	1500	0.7%	0.8%
	1600	3.7%	4.0%
	1700	3.1%	4.0%
	1800	3.4%	4.1%
	1900	2.0%	4.2%
	Average	2.6%	3.4%
71st St. Entrance Ramp	1500	1.8%	-
	1600	4.3%	-
	1700	5.3%	-
	1800	6.6%	-
	1900	4.7%	-
	Average	4.2%	-
76th St. Entrance Ramp	1500	1.3%	2.1%
	1600	4.3%	5.1%
	1700	5.3%	3.7%
	1800	6.6%	4.0%
	1900	2.9%	4.6%
	Average	4.2%	4.0%
79th St. Entrance Ramp	1500	1.5%	6.8%
	1600	7.1%	10.6%
	1700	8.1%	6.8%
	1800	8.3%	7.3%
	1900	3.9%	8.7%
	Average	6.1%	7.9%
87th St. Entrance Ramp	1500	2.3%	3.3%
	1600	8.7%	8.9%
	1700	16.7%	15.9%
	1800	16.8%	15.7%
	1900	7.5%	11.3%
	Average	10.5%	11.0%

Table 11. Comparison of Frontage Road Volumes During the Control Period

		Current Tactics		Proposed Tactics			
Location	Time	Mean	Std. Dev.	Mean	Std. Dev.	Diff.	Signif.?
	(hr.)	(vph)	(vph)	(vph)	(vph)	(%)	
67th St.	1500	129	16	157	25	+22%	
	1600	278	33	401	79	+44%	
	1700	468	33	601	76	+28%	
	1800	481	34	711	69	+48%	
	1900	225	41	355	83	+58%	
	Total	1581	80	2225	268	+41%	Yes
71st St.	1500	224	19	260	37	+16%	
	1600	545	29	637	181	+17%	
	1700	748	35	1024	176	+37%	
	1800	765	45	1160	128	+52%	
	1900	396	56	589	83	+49%	
	Total	2678	53	3670	527	+37%	Yes
76th St.	1500	216	10	221	15	+ 2%	
	1600	459	20	457	79	-.4%	
	1700	752	51	782	65	+ 4%	
	1800	790	81	865	41	+ 9%	
	1900	406	76	465	63	+15%	
	Total	2623	159	2790	151	+ 6%	Yes
79th St.	1500	283	23	293	26	+ 4%	
	1600	469	41	510	68	+ 9%	
	1700	749	81	802	68	+ 7%	
	1800	776	42	892	64	+15%	
	1900	460	56	555	67	+21%	
	Total	2737	185	3052	104	+12%	Yes
87th St.	1500	294	35	280	22	- 5%	
	1600	492	28	474	21	- 8%	
	1700	716	104	692	66	- 3%	
	1800	645	73	670	114	+ 4%	
	1900	414	49	496	87	+20%	
	Total	2561	163	2612	149	+ 2%	No

Sample Size: n=20

Table 12. Comparison of Vehicle Delay at Entrance Ramps During the Control Period

		Current Tactics		Proposed Tactics				
Location	Time	Mean Delay (min.)	Std. Dev.	Mean Delay (min.)	Std. Dev.	Diff. (min.)	%Diff.	Sig. ?
67th St. Entrance Ramp	3-4pm	1.0	0.2	1.3	0.5	+0.3 min	+30%	Yes
	4-5pm	1.8	0.3	2.5	0.2	+0.7 min	+11%	Yes
	3-5pm	1.4	0.2	1.8	0.4	+0.4 min	+29%	Yes
71st St. Entrance Ramp	3-4pm	0.9	0.3	1.1	0.5	+0.2 min	+22%	No
	4-5pm	1.0	0.3	2.3	0.4	+1.3 min	+40%	Yes
	3-5pm	1.0	0.3	1.7	0.5	+0.7 min	+70%	Yes
76th St. Entrance Ramp	3-4pm	0.5	0.2	0.6	0.1	+0.1 min	+20%	Yes
	4-5pm	1.2	0.1	0.8	0.2	-0.4 min	-33%	Yes
	3-5pm	0.8	0.2	0.7	0.2	-0.1 min	-13%	No
79th St. Entrance Ramp	3-4pm	0.3	0.1	0.4	0.1	+0.1 min	+25%	Yes
	4-5pm	0.6	0.2	0.5	0.2	-0.1 min	-17%	No
	3-5pm	0.5	0.1	0.5	0.1	0.0 min	0%	No
87th St. Entrance Ramp	3-4pm	0.7	0.3	0.5	0.1	-0.2 min	-29%	Yes
	4-5pm	1.4	0.4	1.4	1.0	0.0 min	0%	No
	3-5pm	1.0	0.4	0.9	0.5	-0.1 min	-10%	No

Sample Size: n=20

the total of the five hour control period between 2:00 and 7:00 p.m. for all the days on which data was collected. Then, Table 11 shows the results of data obtained from the aerial survey of queues. This is the average delay per vehicles for each of the sampled hours (3:00 to 4:00 p.m. and 4:00 to 5:00 p.m.). The means and standard deviations for each of these Tables were calculated manually. A test of significance was performed only on the frontage road volume data (using a T-Test) because the sample size for the queue data was not large enough for the test.

Table 13 presents the summary statistics of the M.O.Es for the study and influence areas.

CHAPTER VI

OBSERVATIONS AND RECOMMENDATIONS

Based on the data collected and analysis conducted in the course of this research the following observations are made:

1. For both the study section and influenced section, no significant difference was found between the two tactics for total travel time, minute miles of congestion, total travel or system speed.
2. The 67th and 71st Street entrance ramps experienced a significant decrease in volume, while at the same time 76th and 79th Street entrance ramps experienced a significant increase. Obviously, the removal of the "queue override" used in the current tactics to 67th and 71st Streets was a significant factor, overweighting the more liberal metering rates of the newly developed tactics at these locations. On the other hand, the increase in volumes on the two downstream ramps could also indicate that drivers were willing to divert.
3. An apparent increase was seen in delays to vehicles waiting in queues at 67th and 71st Street (an average of 0.4 minutes and 0.7 minutes respectively) entrance ramps. This again might be due to the "queue override" removal.
4. The total increase in traffic volume on all the frontage road sections far offsets the possible increase due to diversion from the metered ramp, thus emphasizing the disparity of the data days.

The following recommendations are made:

1. Any further studies made of this type should incorporate data collection of intersections adjacent to the freeway and individual entrance and exit points so as to present a more accurate picture of the effects each tactic has on traffic flow.
2. A further refinement of the "Level of Service" concept as related to metering rate thresholds should be undertaken.
3. A more efficient "queue override" logic should be incorporated within the control tactics.
4. A more accurate or reporesentative model relating volume and occupancy, which would consider the fluctuations of volume for certain values of occupancy should be developed.
5. A cost analysis should be made to evaluate the ratio of marginal cost to marginal benefit of the newly developed tactic.

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APPENDIX A

ON FORECASTING FREEWAY VOLUMES AND OCCUPANCIES

INTRODUCTION

The efficiency of an adaptive traffic control system strongly depends on its ability to accurately forecast traffic flow so that appropriate real-time control tactics could be implemented to meet changes in traffic behavior.

Appropriate time intervals for real-time control could vary from 20 seconds to 5 minutes in the case of freeway control and could even be longer in the case of arterial control. Obviously, the shorter the forecasting interval the more adaptive is the control system. However, a short forecasting interval does not guarantee an accurate forecasting as it could vary for different forecasting intervals and forecasted parameters. It is desirable, therefore, to investigate the accuracy of forecasting certain control parameters utilizing various forecasting intervals and relate this accuracy to the effectiveness of a control system.

This research utilizes a Box-Jenkins ARIMA forecasting model (1) to investigate the accuracy of forecasting traffic occupancies and volumes at two freeway locations, one on the "express" lanes and the other on the "local" lanes of the northbound Dan Ryan Expressway in Chicago, Illinois. This location was different than the original study section. The "express" section represented by a single detector station was of the "straight pipe" type with no truck traffic allowed. The "local" section, also represented by a single detection station, was subject to 30-40 percent truck traffic and merging entrance ramp traffic 165 m. (500 ft.) downstream of the detector station.

Occupancy and volume data were collected for 20-second, 40-second, and 1-minute intervals during the morning rush.

Objectives

The specific objectives of this study were to:

1. Investigate the applicability of the Box-Jenkins ARIMA

models to forecasting traffic occupancies and volumes.

2. Determine the optimal forecasting interval as analyzed by the developed models.
3. Investigate the difference in the stochastic nature of the flow in lanes with different geometric and flow characteristics.

THE BOX-JENKINS MODELS

The general model capable of presenting a wide class of non-stationary time series is the AutoRegressive Integrated Moving Average process of order (p, d, q), abbreviated ARIMA (p, d, q), which is:

$$\Phi_p (B) \nabla^d Z_t = \Theta_q (B) E_t$$

where:

$$\Phi_p (B) = 1 - \phi_1 B - \phi_2 B^2 - \ldots - \phi_p B^p$$ ——

the autoregressive operator.

$$\Theta_q (B) = 1 - \theta_1 B - \theta_2 B^2 - \ldots - \theta_q B^q$$ ——

the moving average operator.

$\nabla^d Z_t$ = the dth differencing of time series $\{Z_t\}$

E_t = white noise; $E_t = N(0, \sigma^2)$.

ϕ_i and θ_i estimated parameters

Z_t = Observation at time t

Thus, the model represents the dth difference of the original series as a process containing p autoregressive and q moving average parameters.

Other important parameters in the time series analysis are the autocorrelation and partial autocorrelation functions.

The development of the ARIMA (p, d, q) model is a three phase iterative procedure including the following:

1. Identification.
2. Estimation.
3. Diagnostic checking.

DATA ANALYSIS

Development of Models

The model identification procedure was conducted utilizing computer programs developed for such a purpose (2). The values for the p, d, and q parameters of the ARIMA (p, d, q) models were determined by the cut-off and decay patterns of the autocorrelation (ACF) and partial autocorrelation (PACF) functions.

The models investigated were of the ARIMA (p, d, q) type with the following p, d, q values: (1, 1, 1), (0, 1, 1), (1, 0, 1), and (0, 1, 0) which is the forecasting model presently used by I.D.O.T. Traffic Systems Center. In this model, the forecast of the next period is the average of the preceding three periods. The ARIMA (0, 1, 1) model was found to be the statistically most significant (at 95% L.O.S.) for both the occupancy and volume data.

An efficiency index, E, that quantifies the forecasting improvement realized by using a more complicated ARIMA model (0, 1, 1) over the presently used model (0, 1, 0).

The Efficiency Index is defined as:

$$E = \frac{RSS(0, 1, 1)}{RSS(0, 1, 0)} * 100\%$$

where:

RSS(0, 1, 1) = the Residual Sum of Squares for ARIMA (0, 1, 1).

RSS(0, 1, 0) = the Residual Sum of Squares for ARIMA (0, 1, 0).

According to the analysis, the improvement in forecasting ranged between 40% and 50%.

The Optimal Forecasting Interval

The level of adaptiveness of a control system depend, in a major part, on the accuracy of forecasting the control parameters. This research evaluates the forecasting efficiency of the 20-second, 40-second, and 1-minute intervals.

In order to evaluate such efficiency, there was a need to define a certain measure of forecasting accuracy which would relate the forecast to the real data at any point in time. Since it was impossible to obtain a continuous curve of occupancy as a function of time, the 20-second occupancy data were used as the basis for comparison.

The forecasting efficiency D was defined as:

$$D = \Sigma |Z_t - Y_t|$$

where:

Y_t = 20-second occupancy at time t

Z_t = ARIMA occupancy forecast at time t

The D values were calculated for the 20-second, 40-second, and 1-minute forecasts, as shown in Table A-1. According to this analysis, the 1-minute forecasts yielded the least D value.

Occupancy Versus Volume Forecasts

A desirable control parameter is one that whenever measured yields a one to one relationship with an element of a set of control decisions. In traffic control the occupancy parameter is such a parameter. Different ranges of occupancy are related to different metering rates in the case of freeway control.

TABLE A-1

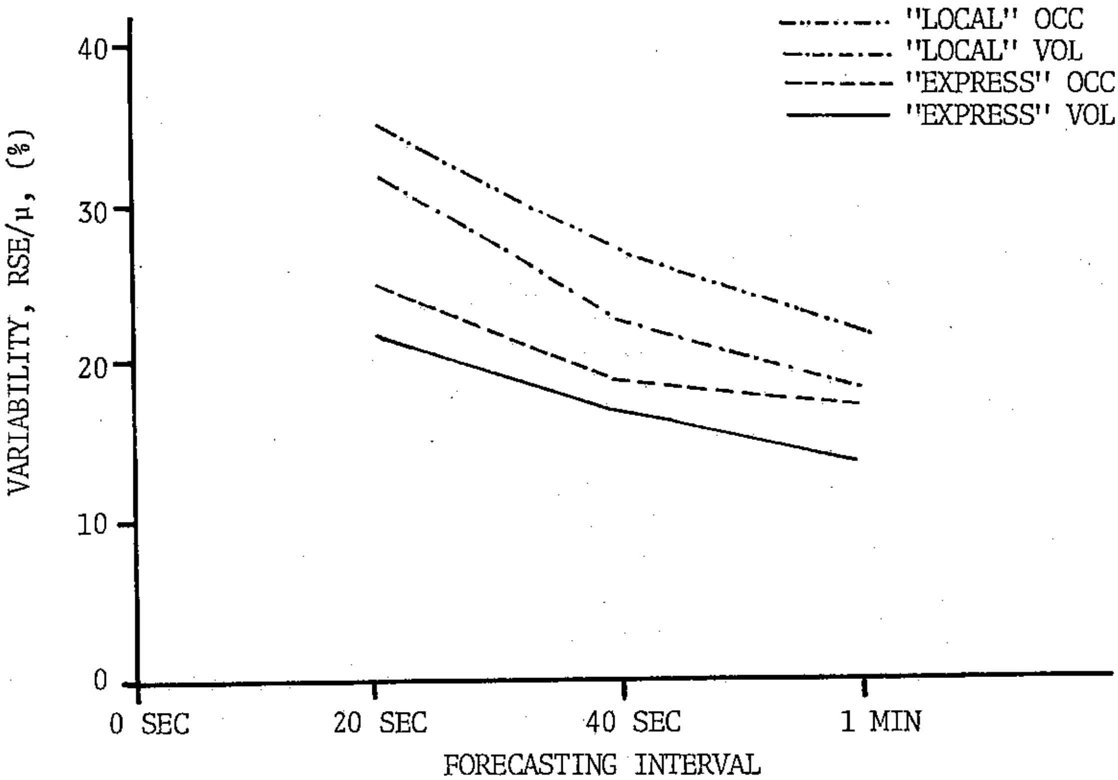
D-VALUES FOR OCCUPANCY FORECASTING INTERVALS

Location	20-Second	40-Second	1-Minute
Express	683.24	678.42	635.25
Local	1285.16	1217.13	1078.27

The volume parameter, on the other hand, does not provide one to one relationship with the control decision set. This is due to the fact that the same volume level could be related to two different traffic situations.

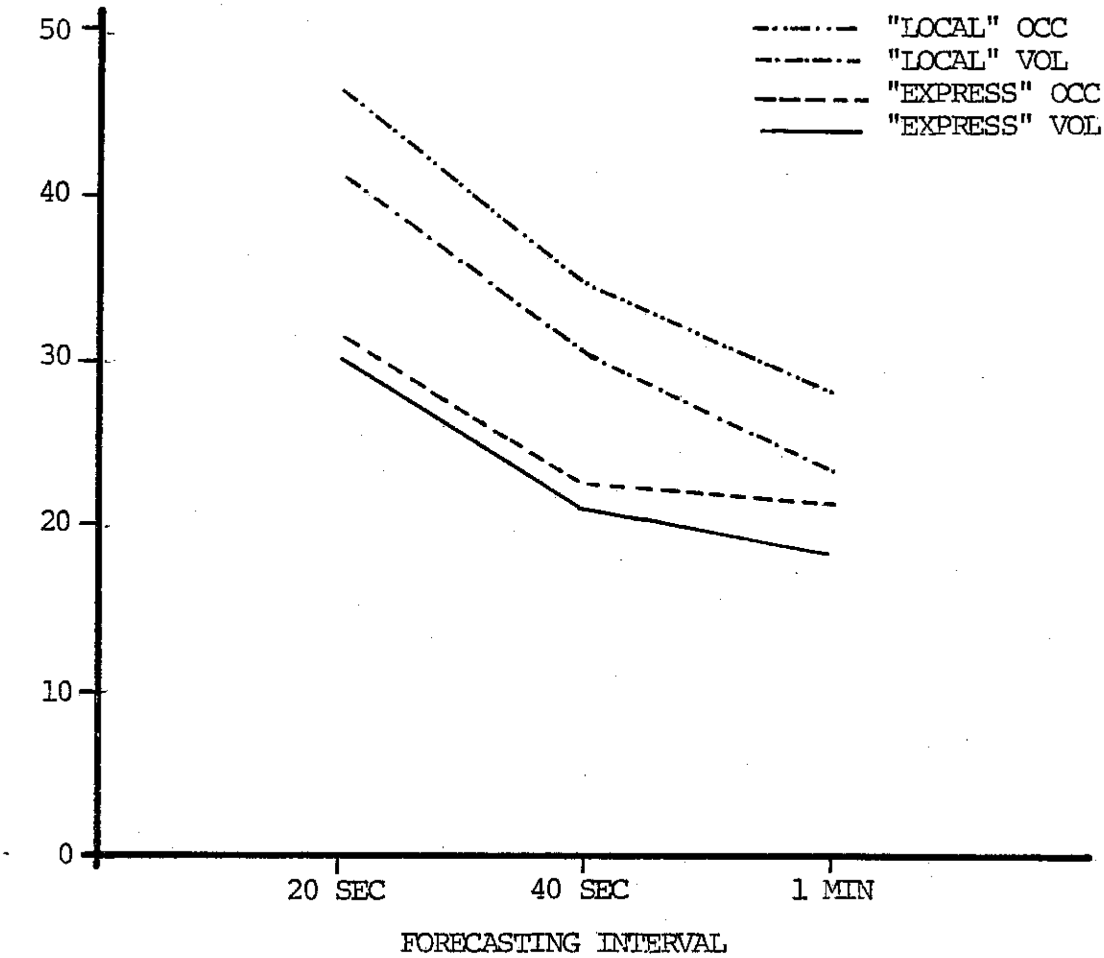
When a volume-occupancy relationship is plotted for a certain location, the scattergram obtained could yield a regression relationship or any other one to one relationship between volume and occupancy. Based on this relationship, metering rates are assigned to ranges of occupancy. The weakness of this method is that in many cases, the occupancy measured is related to volume levels that could allow higher rates than those determined by the one to one volume-occupancy relationship. The above suggest that freeway control tactics should incorporate occupancy and volume forecasts.

The above suggestion is further substantiated by analyzing the relative variability of the ARIMA forecasting models. The variability of the models, (RSE/μ), is defined by the relationship between the Residual Square Error and the observations mean. Figures A-1, A-2, A-3, and A-4 present the variability values for the various forecasting intervals for the "local" and "express" lanes, for the ARIMA (0, 1, 1) and ARIMA (0, 1, 0) models, respectively. From these figures it is realized that, for both models, the variability of volume is smaller than that of occupancy, and the variability of the two parameters is less for the "express" lanes than for the "local" lanes. Also, the variability of the forecasted parameters in the ARIMA (0, 1, 1) is smaller than in the ARIMA (0, 1, 0), as expected. Explanation of the differences in the variabilities of occupancy and volume could be attributed to the fact that the length of a vehicle has an effect on occupancy and not on volume. This explanation is further substantiated by the fact that the difference in the variability of occupancy and volume is more significant on the "local" lanes, where traffic mixture is significant (30% - 40% truck), than on the "express" lanes where trucks are not allowed. The differences in variability as shown



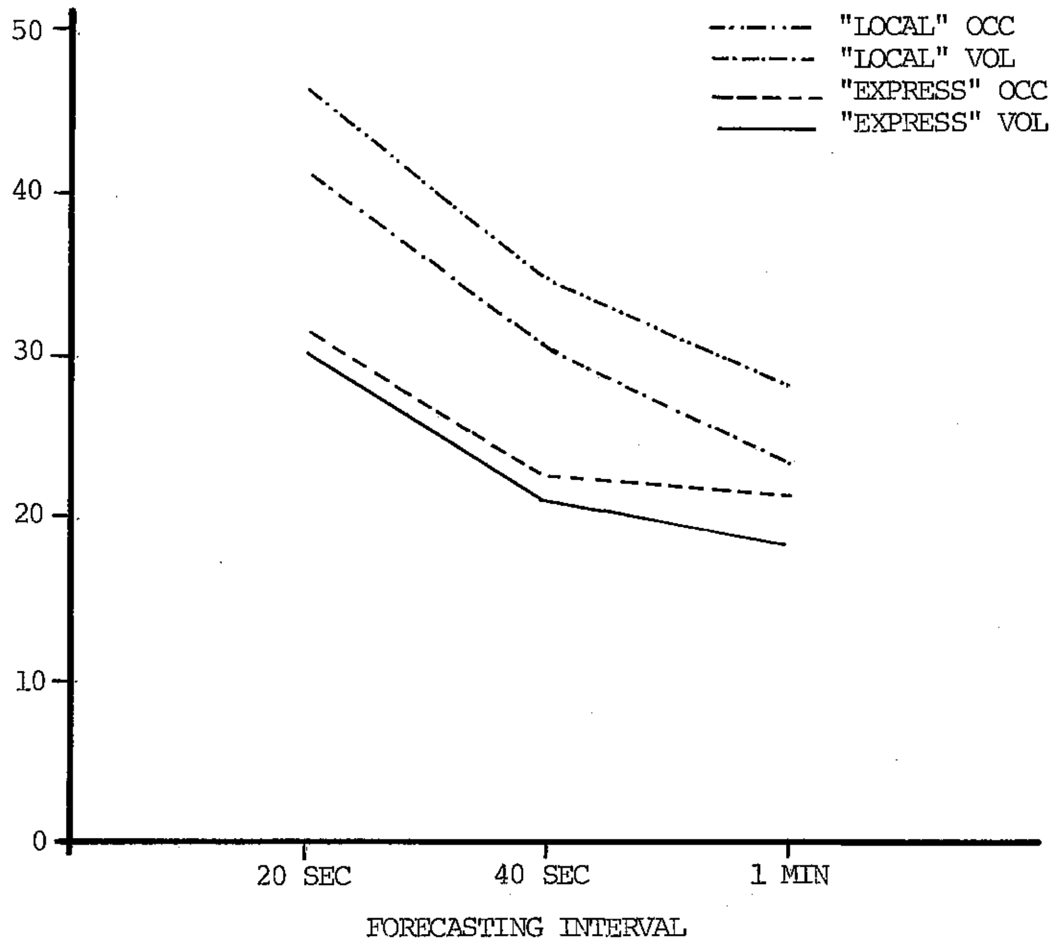
RELATIVE VARIABILITY OF FORECASTING, ARIMA (0, 1, 1)

FIGURE A-1



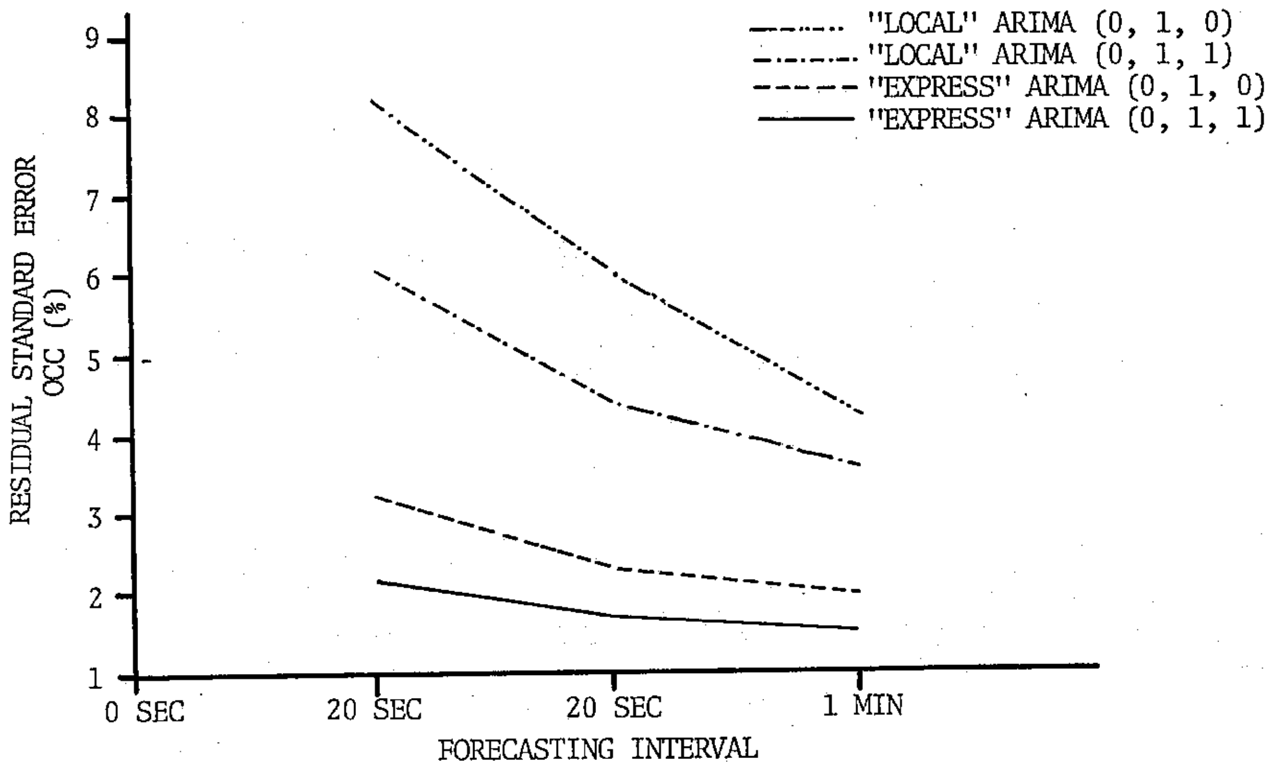
RELATIVE VARIABILITY OF FORECASTING, ARIMA (0, 1, 0)

FIGURE A-2



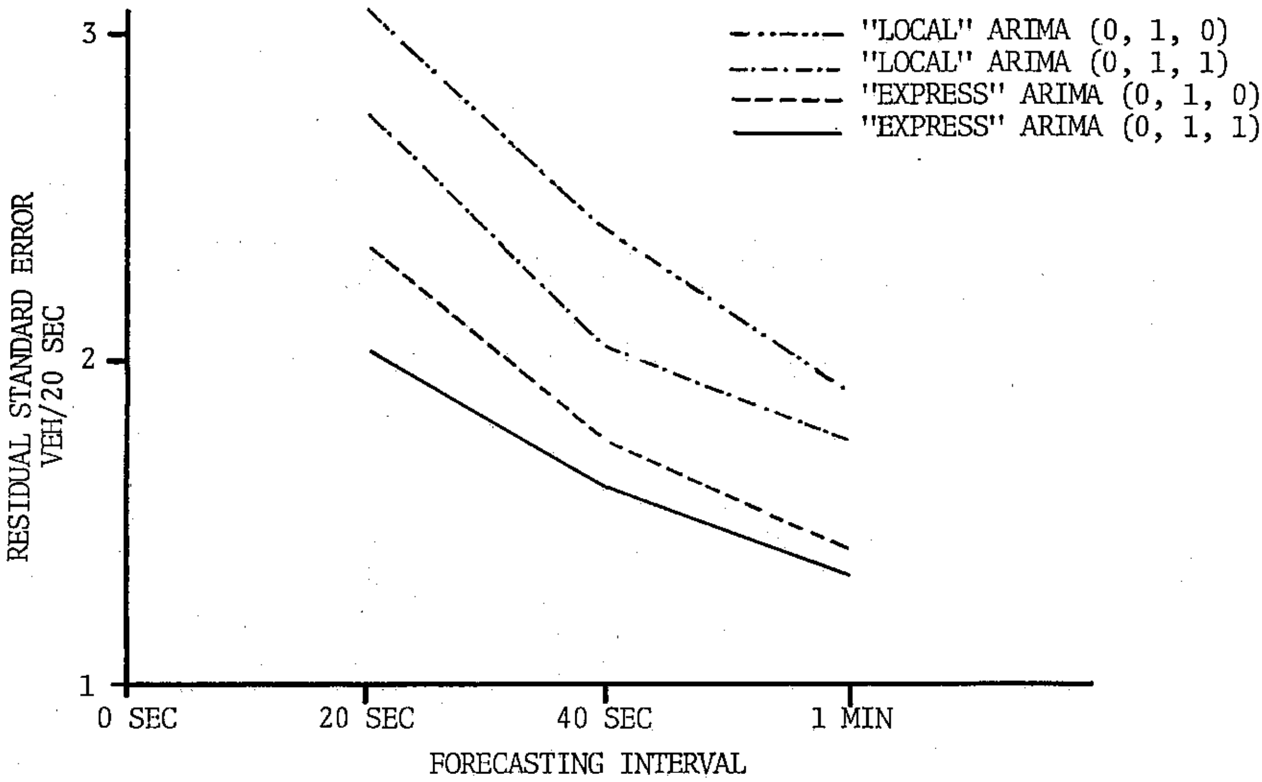
RELATIVE VARIABILITY OF FORECASTING, ARIMA (0, 1, 0)

FIGURE A-2



RESIDUAL STANDARD ERROR OF OCCUPANCY

FIGURE A-3



RESIDUAL STANDARD ERROR OF VOLUME

FIGURE A-4

in Figures A-3 and A-4 suggest that the effects of traffic composition and geometric features (entrance ramp 500' downstream of the detector station on the "locals") might offset the improvement in forecasting due to the introduction of a more sophisticated model. The above suggest that because of its lower variability, volume could be considered in the adaptive traffic control process.

OBSERVATIONS AND RECOMMENDATIONS

In general, the forecast of the dependent traffic parameter may be defined as the sum of a trend forecast and a fluctuation forecast. The trend forecast usually utilize a smoothing technique and the fluctuation forecast involves correlation. When the correlation of the data is weak, the contribution of the fluctuation forecast will be also small and the trend forecast will dominate as found in the case of forecasting freeway occupancy and volume.

The simple forecasting model ARIMA (0, 1, 1) was found to perform better than the model ARIMA (0, 1, 0) presently used by I.D.O.T. Traffic Systems Center.

As indicated by the D-Value analysis, the 1-minute sampling interval was found to be the most optimal forecasting interval among those investigated (20-sec., 40-sec., 1-min). However, due to the dominance of the trend forecast in the 1-minute forecast, it is suggested that a 5-minute moving average could effectively represent the 1-minute forecast.

With the existing detector system setup on Chicago expressways, the measured control parameters are volume and occupancy. Volume was found to be a stabler parameter as shown in Figures A-1 and A-2 and thus more accurately forecasted. However, volume is not unique from control decision point of view.

Based on this study, it is recommended that:

1. A comparison between the accuracy of the 1-minute ARIMA models

forecasts of occupancy and volume and the accuracy of the 5-minute moving average updated every minute of the above parameters should be conducted.

2. A study of freeway control efficiency based on the ARIMA (0, 1, 0) model for 20-second occupancy forecasting intervals, as presently used in Chicago, the ARIMA (1, 1, 0) model for 1-minute forecasting intervals, and the 5-minute moving average updated every minute should be conducted.
3. Incident detection models utilizing the Box-Jenkins time series analysis should be developed.
4. Freeway control algorithms involving both occupancy and volumes should be developed.

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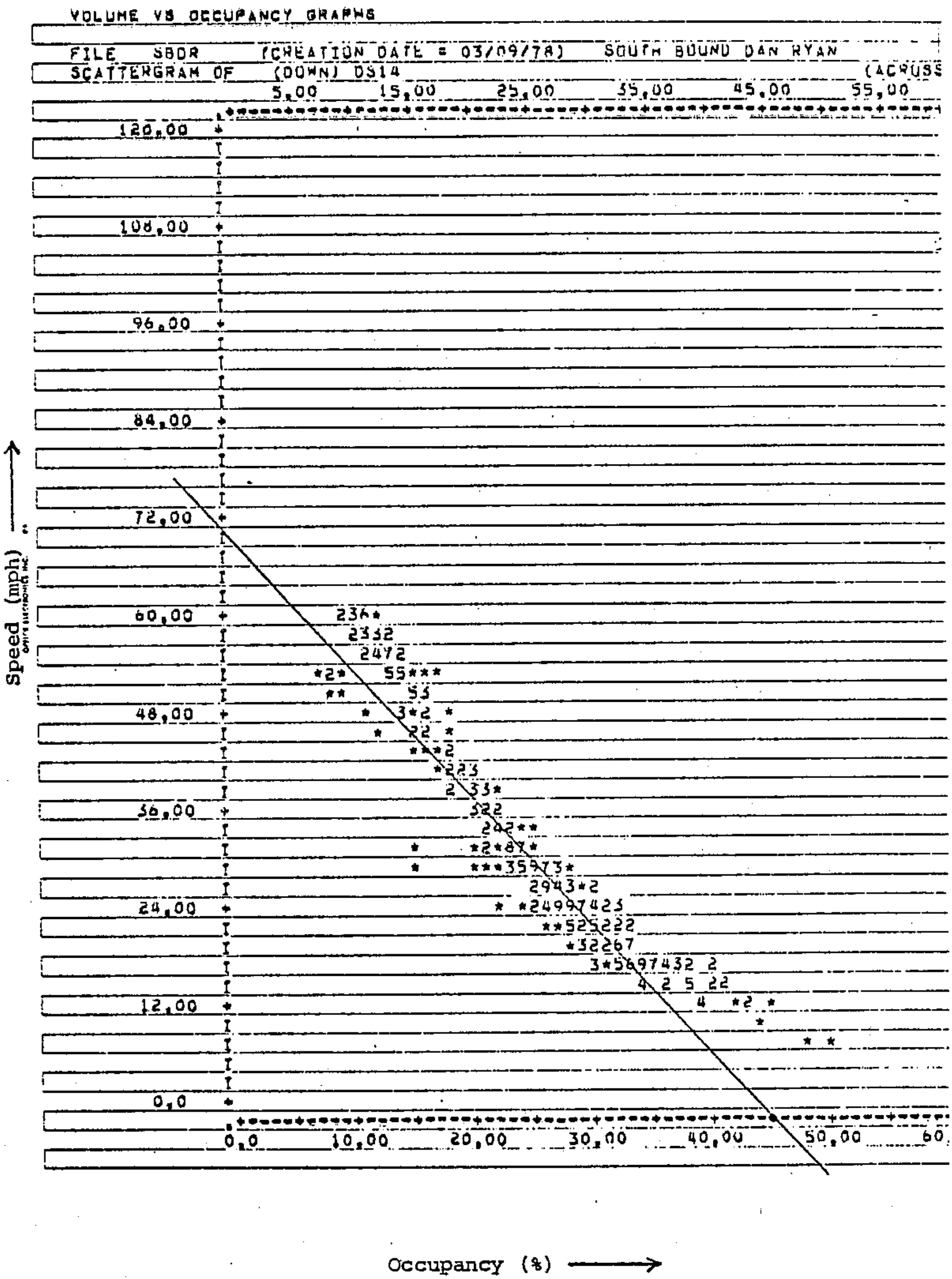
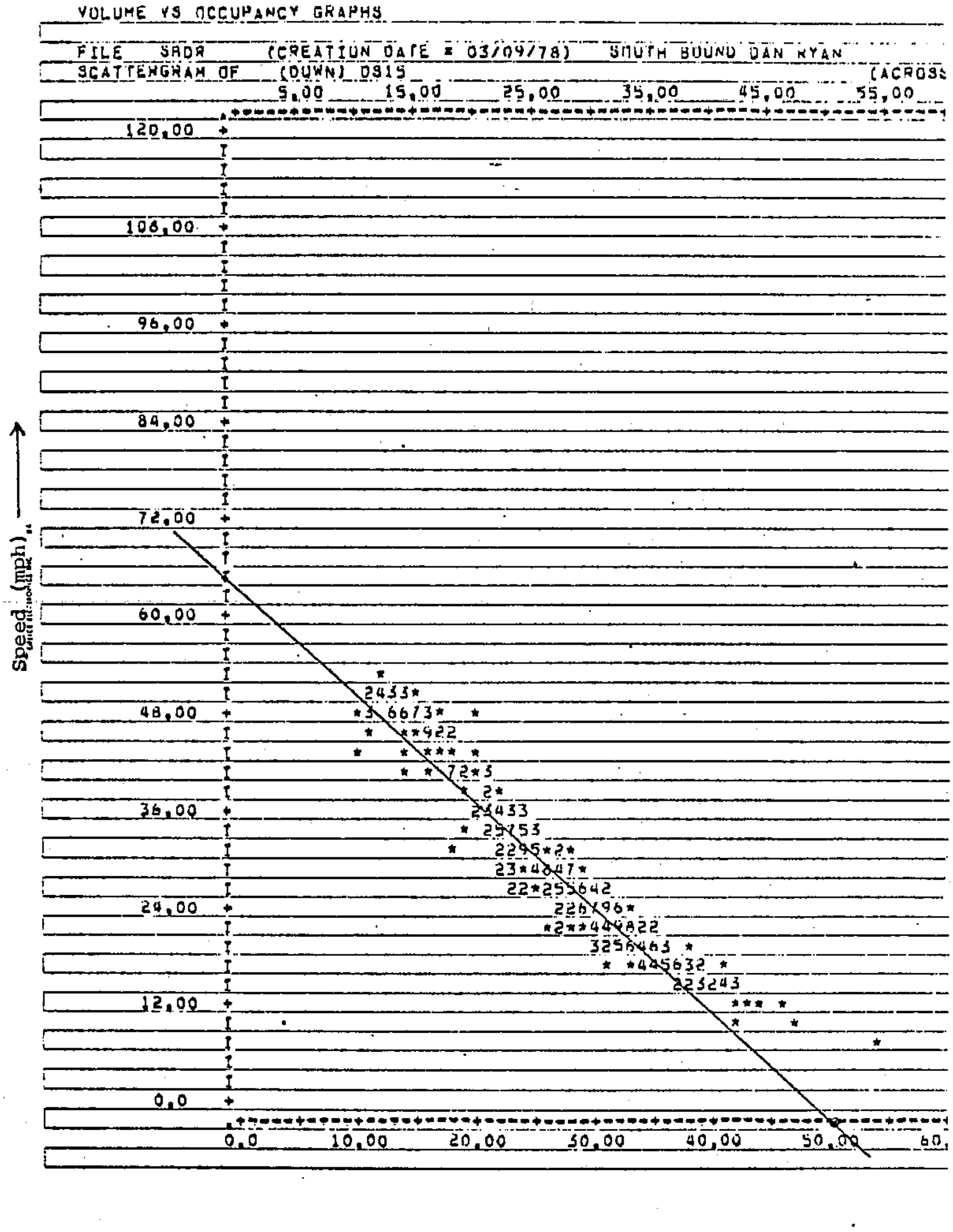
APPENDIX B

GRAPHS OF SPEED VERSUS OCCUPANCY AND VOLUME VERSUS OCCUPANCY

GRAPHS OF SPEED VERSUS OCCUPANCY AND VOLUME VERSUS OCCUPANCY

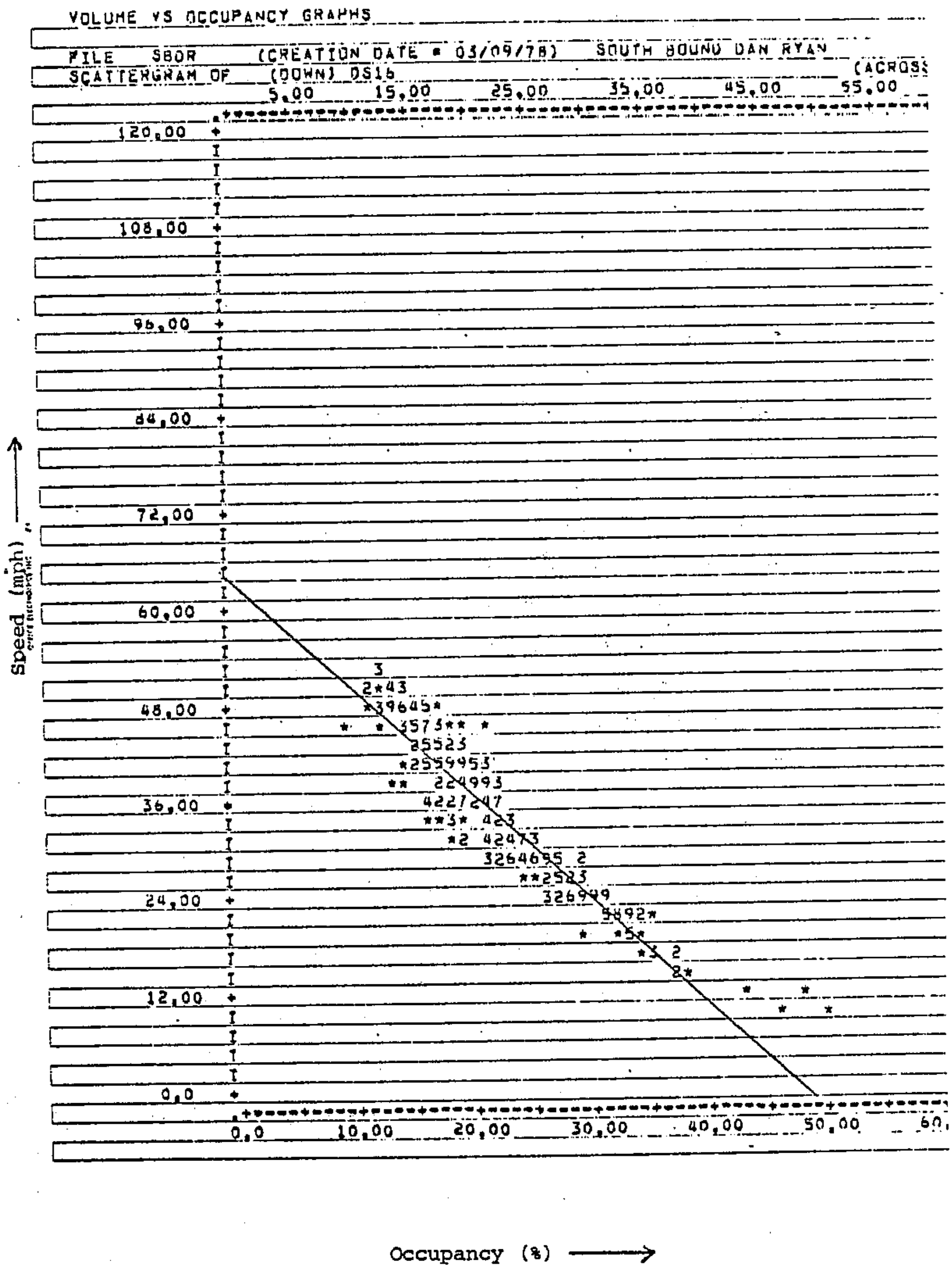


Speed Versus Occupancy at 67th Street

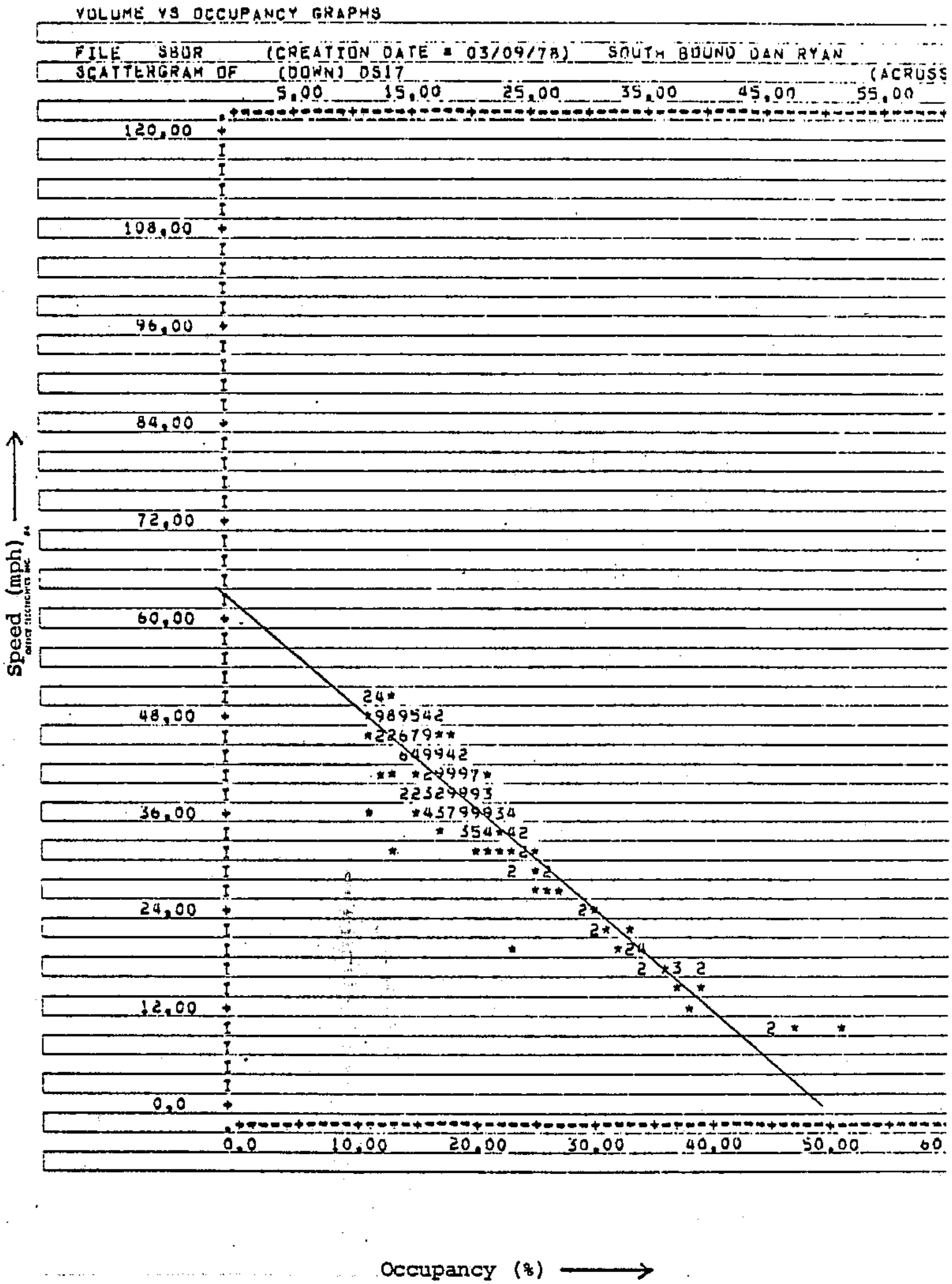


Occupancy (%) ⟶

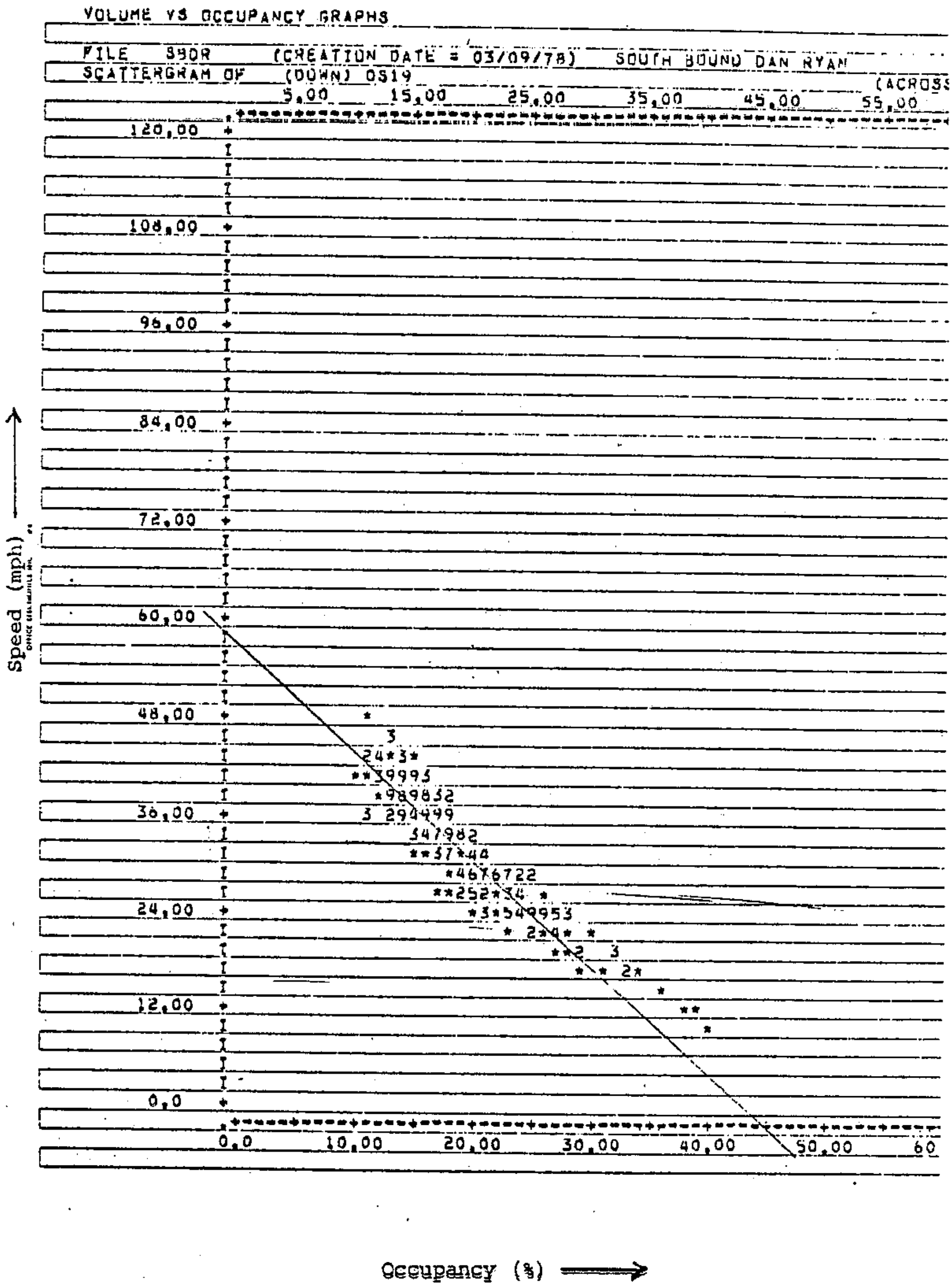
Speed Versus Occupancy at 71st Street



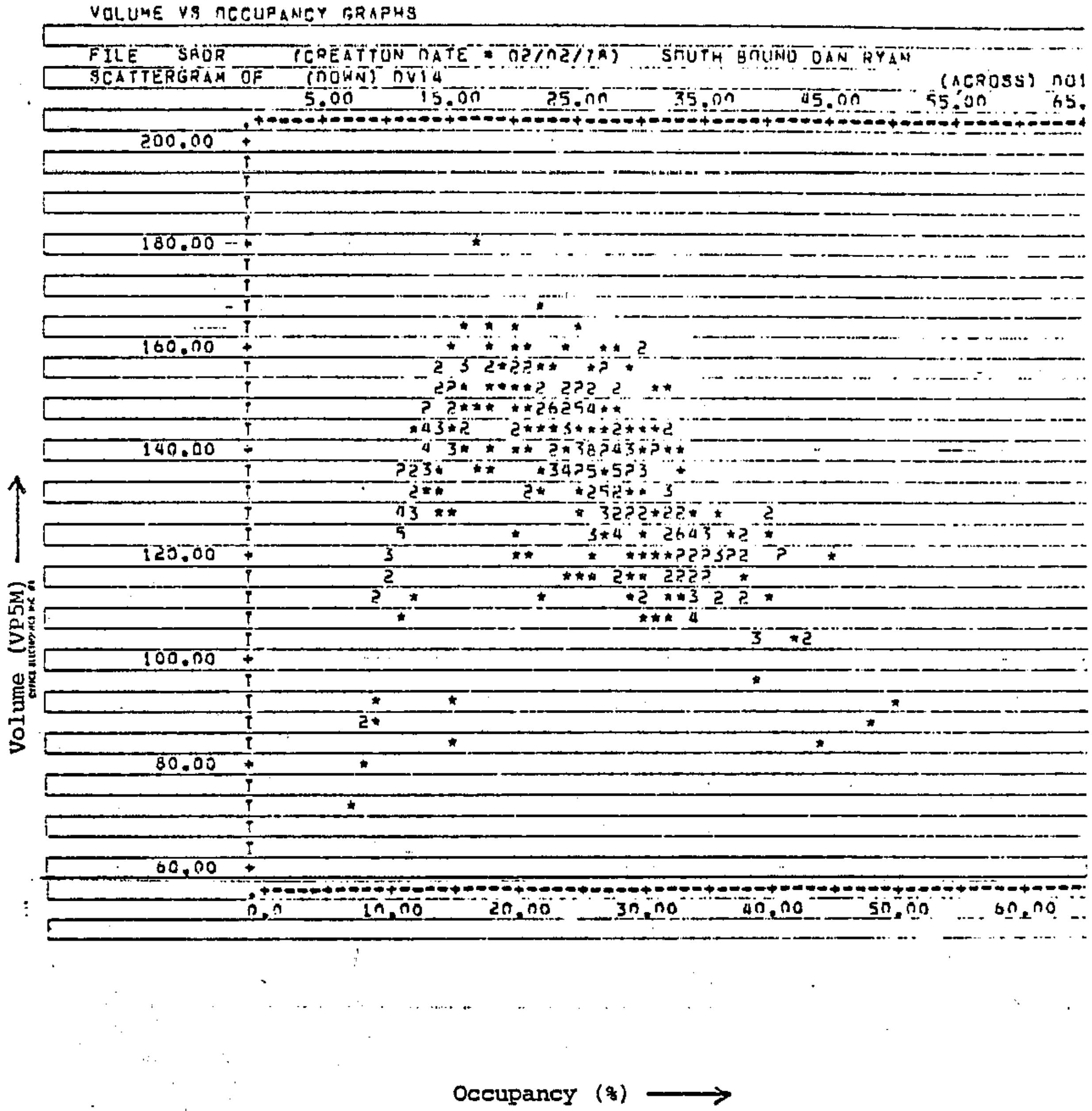
Speed Versus Occupancy at 76th Street



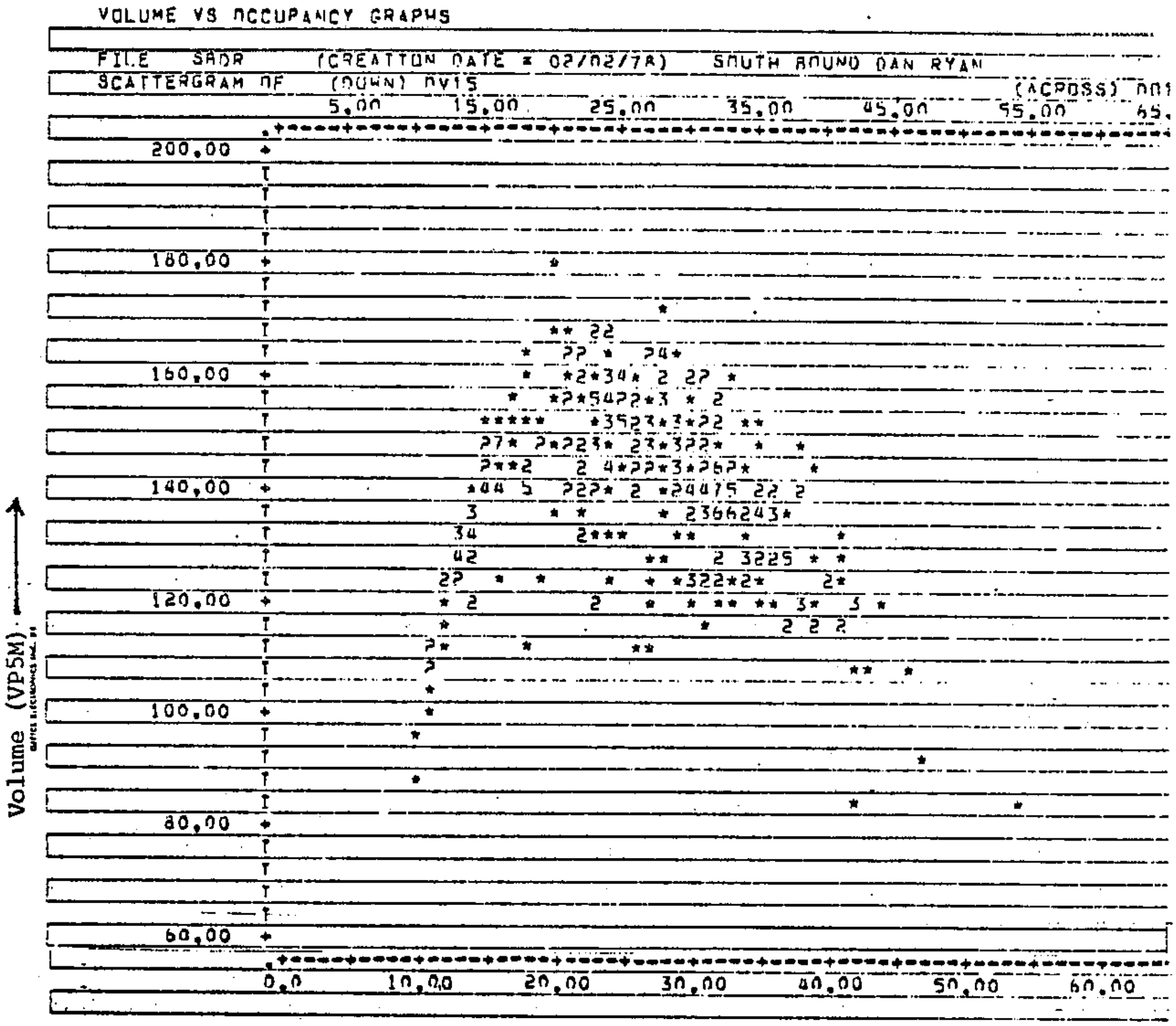
Speed Versus Occupancy at 79th Street



Speed Versus Occupancy at 87th Street

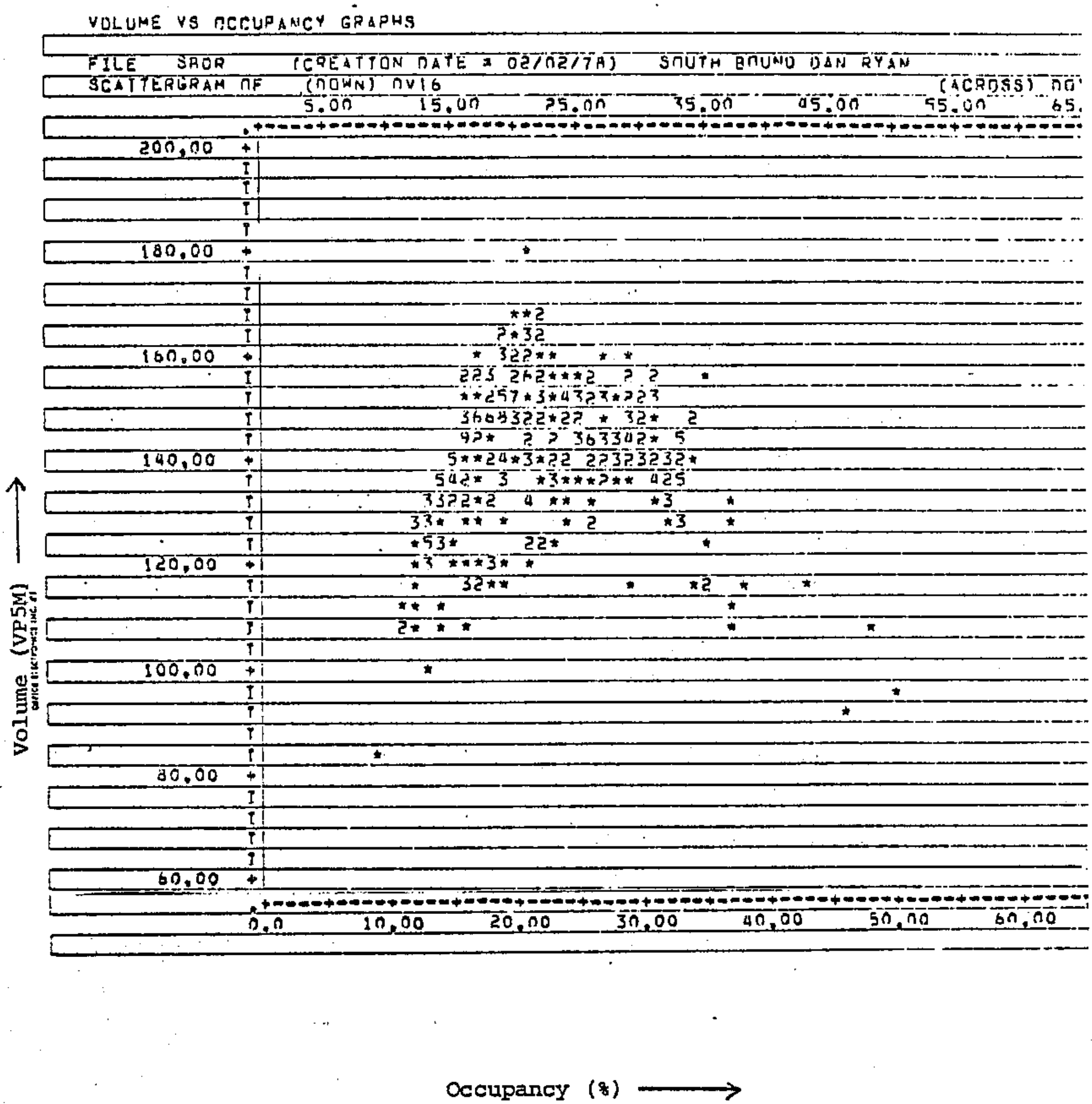


Volume Versus Occupancy at 67th Street

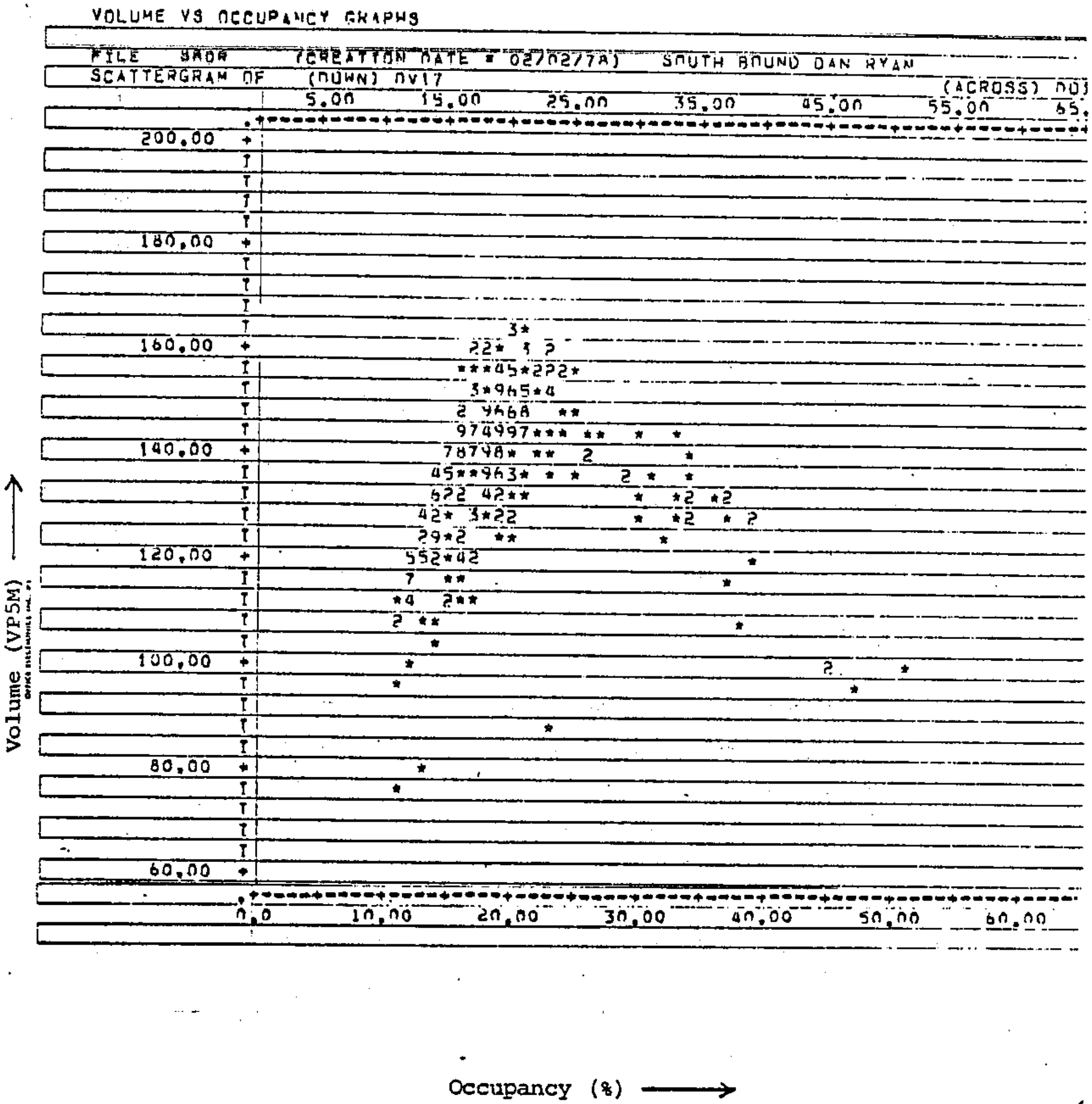


Occupancy (%)

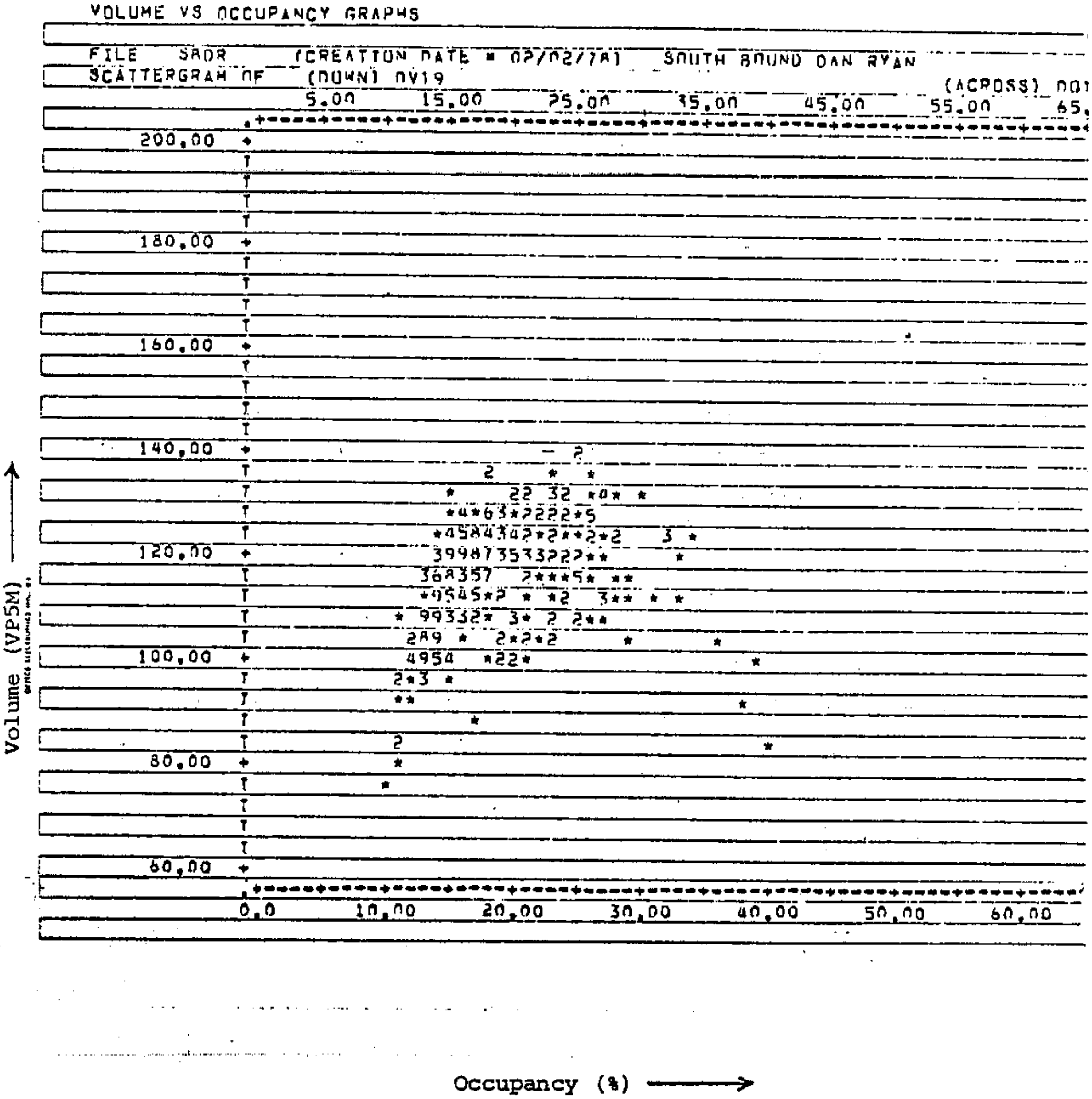
Volume Versus Occupancy at 71st Street



Volume Versus Occupancy at 76th Street



Volume Versus Occupancy at 79th Street



Volume Versus Occupancy at 87th Street