Evaluation of Ramp Meter Effectiveness for Wisconsin Freeways, A Milwaukee Case Study: Part 2, Ramp Metering Effect on Traffic Operations and Crashes

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Final Report

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16. Abstract

The purpose of the research is to determine the benefits of ramp meters in the Milwaukee area freeway system, to determine underlying relationships that permit evaluation of new ramp meters or ramp meter systems elsewhere, and to develop a coherent framework for performing evaluation of ramp meter effectiveness on a whole system. Part 2 concentrates on the traffic operations effect six new ramp meters had on the 14-mile long corridor where six ramp meters were already operational. A crash rate comparison was performed between the periods the corridor operated without and with the six new ramp meters. Metered on-ramp queue length and delay information is presented in Appendix A; details of the operation of a metered on-ramp as well as mainline speed occupancy and volume information in the vicinity of the ramp are presented in Appendix B.

Average corridor speeds improved when the new ramp meters were operational. Vehicle-hours of travel were lower during the more congested afternoon peak period. It is suggested that fine-tuning of ramp metering parameters is very likely to result in additional benefits for the corridor.

Crash rates during ramp metering hours were lower by 13% with the new ramp meters operational.

17. Key Words	18. Distribution Statement
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Appendix B

Wisconsin Avenue Ramp Meter Operation,
Afternoon Peak Period (4:00 pm to 5:30 pm)
Wednesday, February 9, 2000.

Introduction

The present Appendix provides detailed information on the operation of the Wisconsin Avenue ramp meter during the afternoon peak period (4:00 pm to 5:30 pm) on Wednesday, February 9, 2000. Information presented herein was compiled from data collected through pavement-embedded loop detectors on the ramp and the adjacent mainline lanes.

The Wisconsin Avenue ramp was chosen for this detailed presentation, because a complete set of traffic data was available at this location during the study period; the location coincides with cutline #6 for which additional information is presented elsewhere in the report.

Ramp metering settings for the presented period are shown in **Table B-1** below.

Table B-1. PM Peak Period Ramp Metering Settings-Wisconsin Avenue Ramp

Interval Times

Rate	1	2	3	4	5	6
Green	2.5	2.5	2.5	2.5	2.5	2.5
Yellow	0.0	0.0	0.0	0.0	0.0	0.0
Red	2.5	3.0	3.4	3.8	4.5	6.0

Thresholds

Rate	1	2	3	4	5	6
Volume	1700	1800	1900	2050	2150	2250
Occupancy	19	21	24	27	30	33
Speed	55	50	45	40	35	30
Ramp Occupancy	50	40	35	30	25	20

Time Of Day(TOD)

Time	
15:00	Must/May
15:15	Traffic Responsive Min Plan 1
15:15	Most Restrictive
18:00	Must/May
18:15	Non-Metering

According to information presented in **Table B-1**, under the "*Interval Times*" section of the table, six metering Rates (Rates 1-6) were pre-programmed for the Wisconsin Avenue ramp. All six metering rates allowed for 2.5 seconds of Green; no Yellow indication was present; rates differed in Red interval durations. Rate 1 was the least restrictive, with 2.5 seconds of Red; rate 6 was the most restrictive with 6.0 seconds of Red.

Table B-2 presents ramp metering plan selection information, extracted from the Milwaukee FTMS MONITOR program "Field Equipment Software Reference Manual," prepared by JHK & Associates in 1994. The "TOD[1]" Plan Selection was in effect during the analyzed period ("*Plan Selection"* choice #3).

Under this **Table B-2** choice, afternoon peak ramp metering operation was operational during the hours indicated in the *"Time Of Day (TOD)"* part of **Table B-1**. Explanations of terms are provided below.

15:00 Must/May Explanation: No ramp metering was in effect before 3:00 pm. Ramp metering started at 3:00 pm, if traffic conditions met any of the preset ramp metering controller thresholds (see explanations below) in **Table B-1**.

15:15 Responsive Min Plan 1 Explanation: Metering rate 1 (the least restrictive rate, with a Red duration of 2.5 seconds) would be in effect at this time if traffic did not meet any of the thresholds for a more restrictive metering rate (even if metering rate 1 thresholds were not met).

15:15 Most Restrictive Explanation: Metering rate selection was based on the Volume, Occupancy, or Speed threshold that required the most restrictive rate (longer red interval duration). However, all of these thresholds would be overridden, if queue occupancy values were high enough to dictate a less restrictive metering rate, so the ramp queue could be dissipated before it spilled into an adjacent arterial.

18:00 Must/May Explanation: If traffic conditions met any of the thresholds at 6:00 pm, ramp metering would have continued, otherwise it would have terminated at this time.

18:15 Non-Metering Explanation: Ramp metering would have been turned off at 6:15 pm, regardless of traffic conditions.

Metering rate choice depended on four ramp metering inputs: mainline volume, occupancy and speed, and ramp queue occupancy values indicated under the "*Thresholds*" part of **Table B-1**. Volume, occupancy and speed summary information was received from mainline pavement-embedded detectors; ramp queue occupancy information was received from detectors embedded on the ramp.

[1] TOD: Time of Day

Table B-2. Ramp Metering Plan Selection Information.

PLAN SELECTION LEGEND

Plan Selection	
0	All Plan Selection Levels Inhibited
1	Manual Plan Selection
2	Central Plan Selection
3	TOD Plan Selection

Plan Request	
0	No Plan Selection
1 - 6	Fixed Ramp Metering Plan
7	Non-Metering
9	Must/May Meter, Ramp Metering Plan 1
10	Must/May Meter, Traffic Responsive Ramp Metering Plan
11 - 16	Traffic Responsive Ramp Metering Plan, Minimum Plan

Current Plan	
1 - 6	Ramp Metering Plan
7	Non-Metering

Current Mode *	
17	Select Most Restrictive Plan Based on Volume, Occupancy and Vehicle Speed
18	Select Least Restrictive Plan Based on Volume, Occupancy and Vehicle Speed
19	Select Plan Based on Volume
20	Select Plan Based on Occupancy
21	Select Plan Based on Vehicle Speed

* Note: Current Mode is set to reflect Plan Selection mode.

Plan Reason	
0	No Plan Selection
1	Queue Failure
2	Fixed Plan
3	Fixed Plan, Queue Override
4	Holiday/Exception Day
5	Clock Failure
6	Traffic Responsive, Minimum Plan
7	Traffic Responsive, Most Restrictive, Volume
8	Traffic Responsive, Most Restrictive, Occupancy
9	Traffic Responsive, Most Restrictive, Vehicle Speed
10	Traffic Responsive, Least Restrictive, Volume
11	Traffic Responsive, Least Restrictive, Occupancy
12	Traffic Responsive, Least Restrictive, Vehicle Speed
13	Traffic Responsive, Volume
14	Traffic Responsive, Occupancy
15	Traffic Responsive, Vehicle Speed
16	Traffic Responsive, Queue Override

Current Interval	
0	No Interval (Non-Metering)
1	Metering Initial delay
2	Metering Green Delay
3	Metering Yellow Delay
4	Red
5	Red Extension
6	Red Rest
7	Red Countdown
8	Green
9	Yellow

Metering rate choice example
For example, if detected traffic conditions were between the values shown for Rates 2 and 3, say, volume 1850 vph, occupancy 22%, speed 49 mph, ramp queue override 37%, then ramp metering rate 2 would have been chosen (Green 2.5 sec., Red 3.0 sec.) If all other values remained the same, but speed was 42 mph, which was between the thresholds for rates 3 and 4, rate 3 would have been chosen, the most restrictive rate that the specific traffic conditions warranted. If all other values in the original example remained the same, but the ramp queue occupancy value was 43%, ramp metering rate 1 would have been chosen; ramp occupancy was programmed to override mainline input demands for more restrictive metering rates.

Description of Appendix figures
Figures B-1 through **B-8** in this Appendix are intended to provide a detailed view into the operation of the Wisconsin Avenue ramp on Wednesday, February 9, 2000, between 4:00 pm and 5:30 pm. These figures use the same time axis; they can be superimposed on one-another in order to provide insights into which thresholds were met at specific times, why a certain metering rate was chosen, and how metering rates affected ramp queue length.

Figures B-3 through **B-6** are based on 20-second mainline speed, volume and occupancy data that were averaged using a moving average of six observations (two minutes); **Figure B-6** represents 20-second ramp occupancy observations. Thresholds for each metering rate are marked on each of these graphs for easy reference.

Speed-volume and speed-occupancy graphs (**Figures B-9** and **B-10**) are provided for each quarter hour during this peak period. Similar graphs (**Figures B-11** and **B-12**) are provided for prevailing weekday afternoon peak conditions at this location based on information collected at the same location during all data collection days: February 1, 2, and 3 (week 1), February 8, 9, and 10 (week 2) March 14, 15, and 16 (week 3), and March 21, 22, and 23 (week 4).

A matrix graph (**Figure B-13)** relating volume, speed and occupancy at this location is provided to establish the relationship between all three traffic parameters. Each of the three distinct graphs on the matrix is presented separately on a larger scale for easier reference (**Figures B-14** through **B-16**).

Except for graphs indicating that they are based on two-minute average data, all other information is based on data collected every 20-seconds.

Description of ramp operation
The Wisconsin Avenue ramp queue length is shown in **Figure B-1** (the shaded area represents veh-min of delay). Maximum recorded queue length was 15 vehicles; there were many instances during the peak period that queue lengths were 12 or more vehicles. A characteristic see-saw pattern emerged throughout the peak period, when periods of longer queues were followed by periods of much shorter queues (1 or 2 vehicles-long).

The most persistent presence of long queues was observed approximately between 16:35 and 16:45.

The reason for choosing a certain ramp metering rate during a specific time can be seen in **Figure B-2**. For example, between 16:00 and 16:05, when the "most restrictive" plan was in effect (see **Table B-1**), plan reason #7 (see y-axis) controlled the metering rate. Plan reason #7 corresponds to the entry "Traffic Responsive, Most Restrictive, Volume" in **Table B-2**, indicating that mainline traffic volume was the first ramp metering input that crossed the threshold corresponding to the most restrictive metering rate.

Speeds during this period were 48-50 mph (**Figure B-3**) corresponding to ramp metering rate 2, volumes crossed into metering rates 3 and 4 (**Figure B-4**), mainline occupancies were well below 19% (**Figure B-5**) required for rate 1, and ramp occupancy did not exceed 25% (**Figure B-6**), thus queue override was not called for. The most restrictive metering rate was therefore dictated by mainline traffic volumes. The metering rate in effect at any time is shown in **Figure B-7**—rates 3 and 4 were in effect during these five minutes.

At approximately 16:05, ramp queue length increased to 12 vehicles (**Figure B-1**) within a short period of time, thus ramp occupancy increased as well. **Figure B-2** indicates that between 16:05 and 16:08, plan reason #16 controlled the metering rate ("Traffic Responsive, Queue Override" in **Table B-2**). Indeed, ramp occupancy exceeded 70% (**Figure B-6**), overriding all other inputs, and setting the least restrictive metering rate 1 (see **Figure B-7**) in order to dissipate the ramp queue.

Figure B-8 provides a detailed presentation of metering rates based solely on ramp occupancy. These rates governed only during the time periods that they were less restrictive than the rates demanded by mainline metering inputs.

Although mainline speed and occupancy did not change much during these three minutes, mainline volumes would have demanded rate 5 during this interval, had it not been for ramp queue occupancies overriding this demand and setting rate 1 instead. Thus, more vehicles were released onto the freeway (due to the queue override) at a time when the freeway could handle fewer vehicles because a heavy traffic volume was present.

Ramp operation summary
The most frequent reason for metering rate selection was mainline traffic volume (reason #7 **Table B-2**), which occurred 16 times, for a total of 45 minutes (see **Figure B-2**). Ramp queue override (reason # 16) occurred 14 times during the peak period, for a total 36 minutes. Mainline speed (reason #9) decided metering rate on four occasions for a total of 5 minutes, minimum plan values (reason #8) occurred five times for a total of 2 minutes; and mainline occupancy (reason #11) on one occasion for a total of 2 min.

Table B-3 summarizes how long each metering rate remained in effect when any of the most commonly used plan reasons (mainline volume, ramp queue override and mainline speed) was present. For example, when queue override was the plan reason, metering rate 1 was in effect for a total of 27.7 minutes, metering rate was in effect for 4.3 min., etc.

Table B-3. Reason for Metering Rate Selection and Metering Rate Duration (minutes)

Plan Reason	Current Plan						
	1	2	3	4	5	6	Total
Mainline Volume	0.0	6.0	21.3	14.7	3.3	0.0	45.3
Queue Override	27.7	4.3	2.3	1.3	0.3	0.0	36.0
Mainline Speed	0.0	0.0	0.0	2.7	1.7	0.7	5.0

Traffic characteristics in the vicinity of the ramp
Figures B-9 and **B-10** present mainline speed-volume and speed-occupancy relationships during the analyzed afternoon peak period. Forty-five observations, representing a 20-second interval each are plotted in each 15-minute chart.[2] The Figures indicate that speeds remained above 50 mph, and occupancies did not exceed 22% between 16:00 and 17:00; congestion was present for much of the last 30 minutes.

Figures B-11 through **B-16** present similar information at the same location, based on the 12 afternoon peak periods of the study data collection days. This information is intended to provide a background of traffic conditions at the analyzed location, for comparisons with the afternoon peak period of February 9, 2000, and fine-tuning ramp metering parameters.

Figures B-11 and **B-12** indicate that it was not uncommon for the mainline to be congested during any given quarter of an hour of the afternoon peak period. Congestion often was even more pronounced than during the February 9 afternoon peak, with lower speeds and higher occupancies.

Figure B-13 presents all two-way relationships between mainline volume, speed and occupancy. The peak period volume-speed relation is presented in **Figure B-14**, occupancy-speed in **Figure B-15** and occupancy-volume in **Figure B-16**.

Observations about the February 9, 2000 pm peak period
Overall, much wider ranges of mainline volume, speed and occupancy occurred near the Wisconsin Avenue ramp during the twelve field data collection dates, than the corresponding ranges measured during the February 9 afternoon peak (**Figures B-11** and **B-12**). Congestion was present quite frequently, throughout the afternoon peak period.[3] The most congested part of the afternoon peak was between 16:45 and 17:30.

When mainline volume controlled metering rate, metering rates 3-5 were implemented early-on, rates 2-3 between 16:18 and 16:37, and rates 3-5 later during the peak period.

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[2] As expected, a wider variability is present among 20-sec observations than among 2-min averaged observations in **Figures B-3** through **B-6**. For example occupancy values exceeding 40% are present-averaged values do not exceed 24%.
[3] These graphs are based on 20-second data, thus each 15-minute graph is based on 540 observations. Darker parts of the graphs indicate the most frequently occurring values.

Ramp queues built very fast and ramp occupancy values rose sharply very often. These ramp occupancy values exceeded 40%, thus the fastest metering rate 1 was set (green 2.5 sec, red 2.5 sec) during 75% of the duration of ramp metering under queue override control. Under this metering rate, queues dissipated quickly and ramp metering control returned to the volume, speed or occupancy thresholds.

All abrupt changes (changes that skip two or more metering rates) to metering rate 1 during the peak period were the result of queue override taking effect (**Figure B-7**). Unfortunately, queue override most often occurred during periods that mainline volume, occupancy or speed thresholds would have demanded more restrictive metering rates. For example, between 16:37 and 16:47, when a queue override was in effect, mainline volumes would have set a metering rate 4 or 5 (**Figure B-4**).

Ramp queues could build up very fast. In one instance, a 14-vehicle queue built up at 16:13:20, within 20 seconds. This corresponded to an arrival rate of one vehicle every 1.4 seconds (this arrival rate is too fast to be realistic—some rounding error is involved due to sampling at discrete time intervals). The arrival rate of one vehicle every 2 seconds that occurred at 16:17:20, when a queue of 10 vehicles occurred within the next 20 seconds is within reason.

The fastest queue dissipation rate was one vehicle every five seconds (metering rate 1) and the slowest one vehicle every 8.5 sec (metering rate 6). Thus, if a sustained arrival rate of one vehicle every two seconds occurred at any time during the metered period, ramp queue spillover could not have been avoided.

If no ramp queue spillover into adjacent surface streets is to be allowed, queue override must remain in effect, allowing a less restrictive metering rate when the ramp is about to overflow. If, during the same time period, mainline congestion warrants more restrictive metering rates, a compromise must be found between these competing ramp metering goals. A reasonable compromise would be to attempt to precisely manage ramp queue length, avoiding ramp spillover, but also avoiding complete ramp queue dissipation. If this compromise is successfully met, the "valleys" of **Figure B-1** will not reach queue lengths of zero vehicles when mainline volumes require more restrictive metering rates, but will remain at values of, for example 5 or 6 vehicles (thus the shaded part of **Figure B-1** will cover a larger portion of the Figure). This task is quite challenging and perhaps not worth pursuing for the following reasons:

1. Overall, ramp queue delay during the afternoon peak was 4.9% of all freeway delay during the before period, and 7.6% during the after period. The proposed change in ramp metering strategy is likely to affect a very small percentage of ramp delay, representing a negligible percentage of total delay. Labor (and perhaps additional hardware) costs to achieve the proposed strategy may not be justified.
2. The arrival rates of one vehicle every 1.4-2.0 seconds, observed on a couple of occasions following periods when no vehicles were present on the ramp were much higher than the fastest ramp metering rate of one vehicle every 5 seconds.

> Thus, the possibility of ramp overflow would increase if ramp queues were intentionally not allowed to completely dissipate and such an arrival rate were to materialize.

The benefit of spacing out on-ramp vehicle platoons is reaped regardless of how often metering rate 1 is used. However, if mainline congestion is very high when the least restrictive metering rate is set, a number of vehicles released from the stop line would be clustered at the merge area.

Figure B-1. Ramp Delay & Queue Length Wisconsin Ave. 2/9/2000

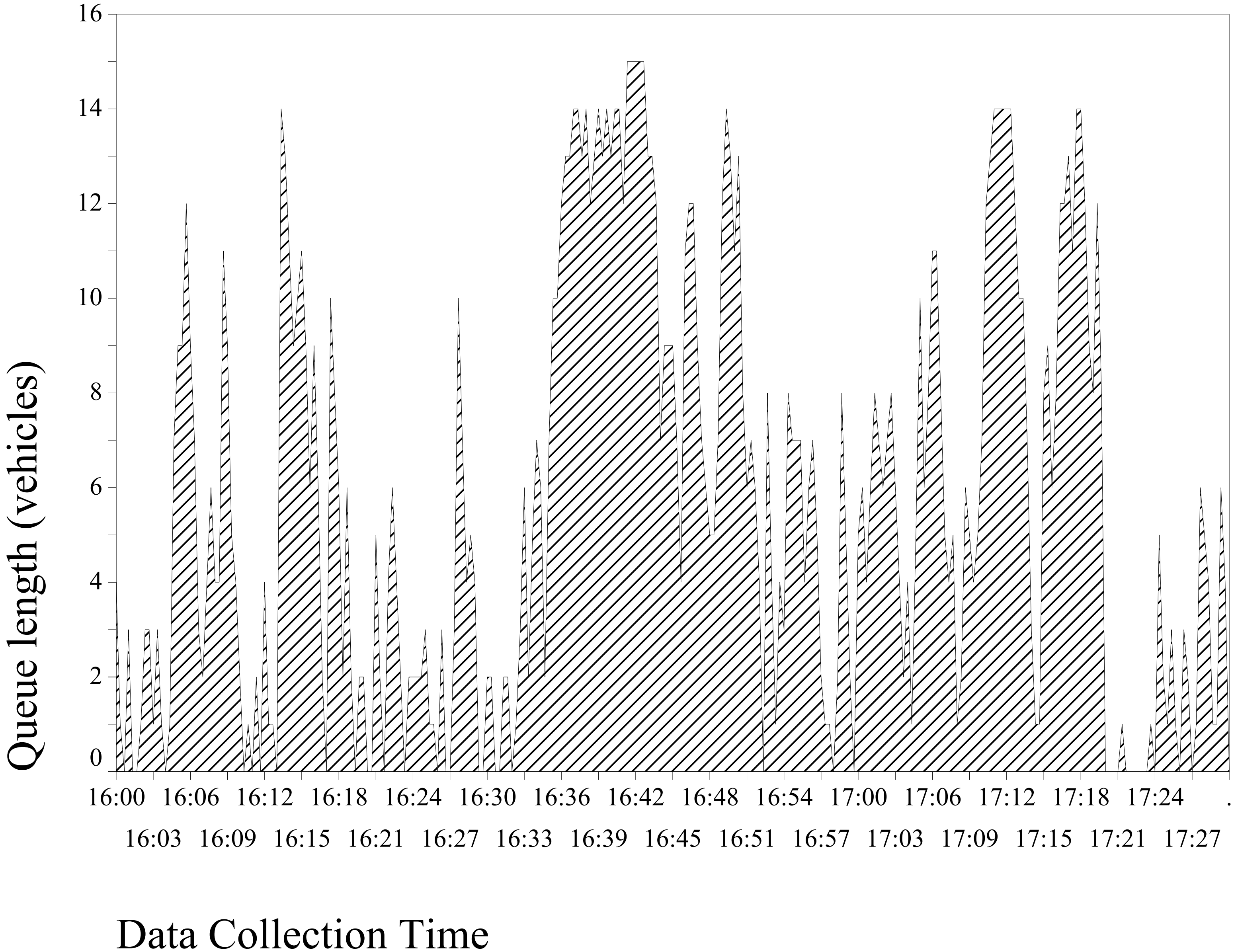


Figure B-2. Reason for Setting Metering Rate

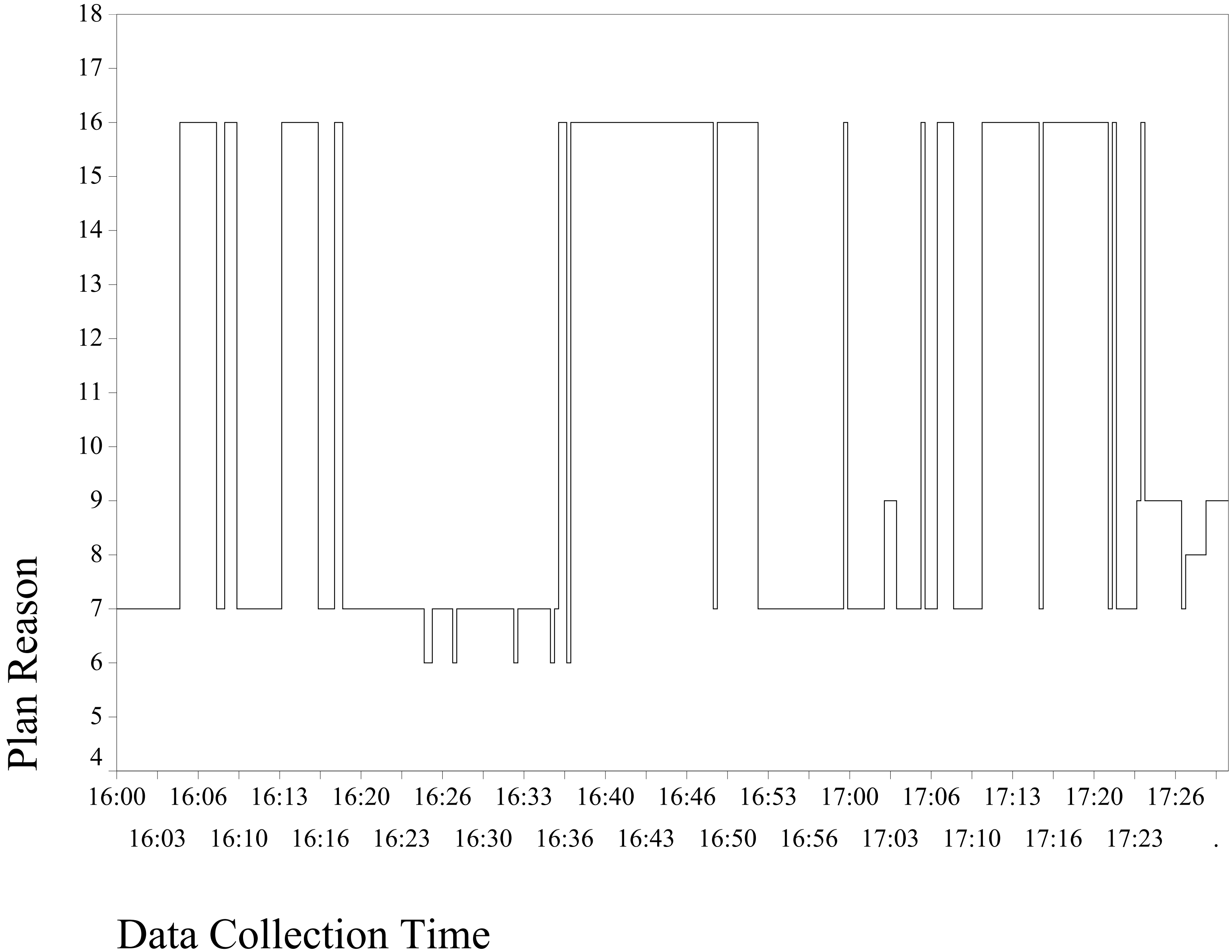


Figure B-3. Mainline Speed.

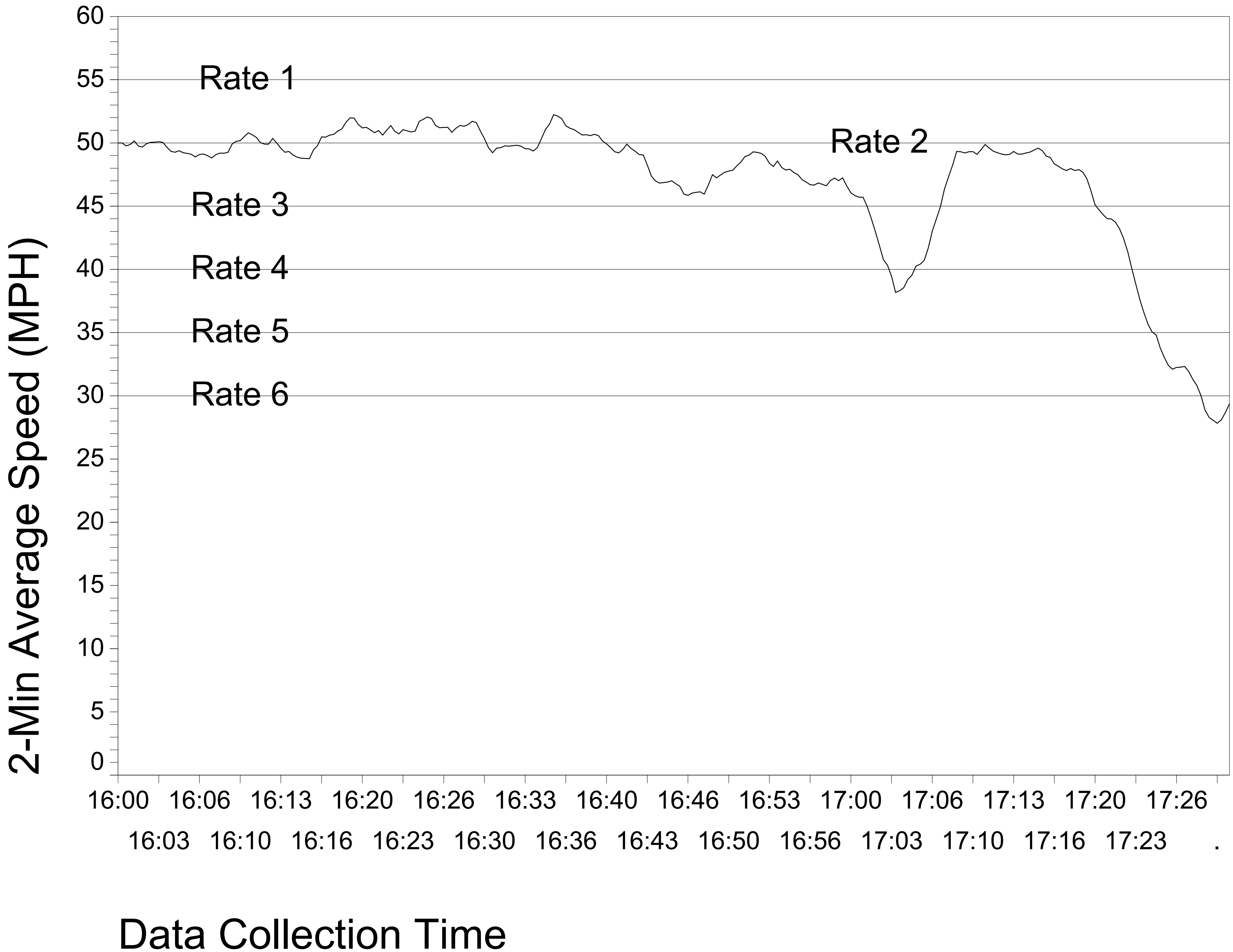
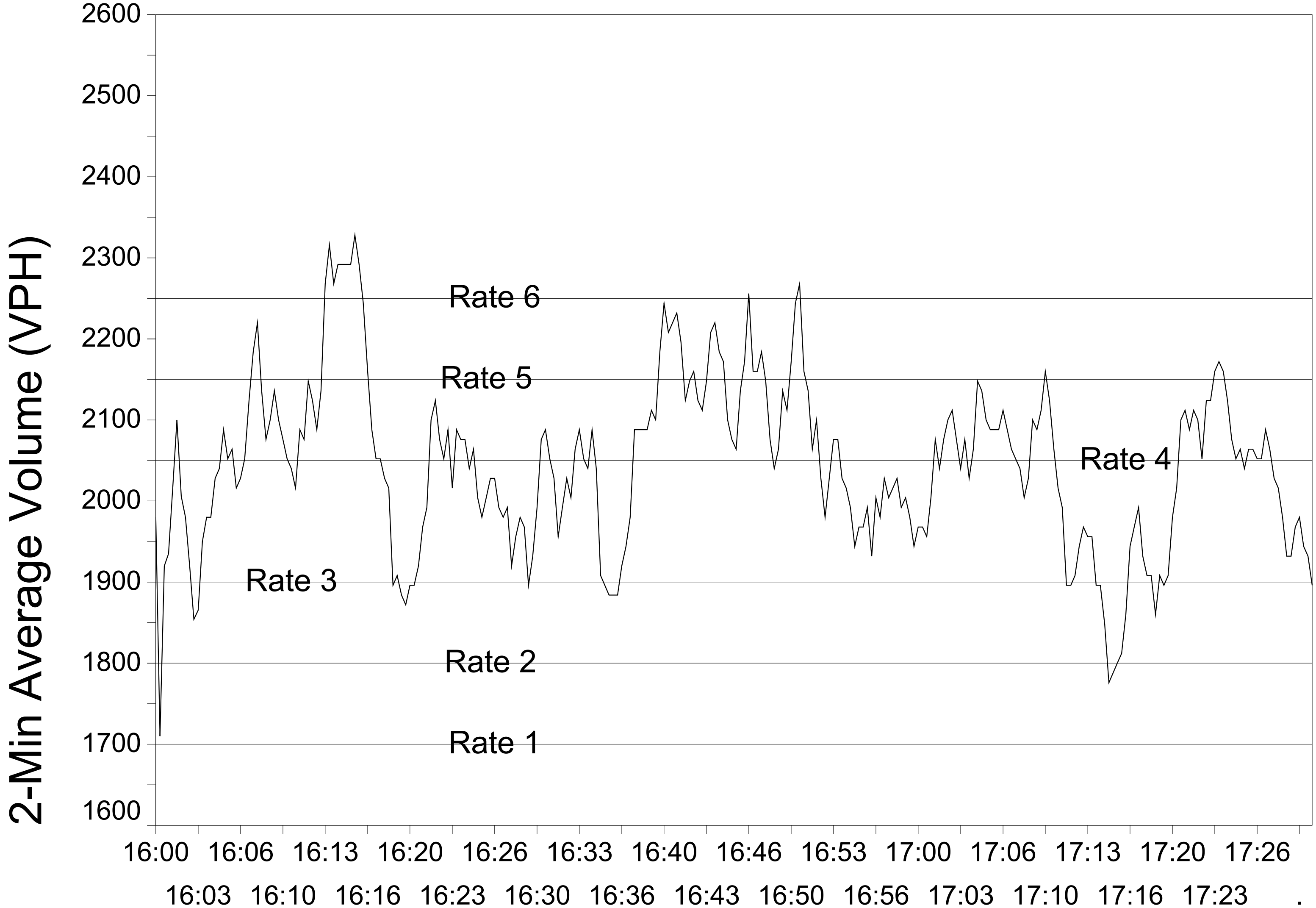


Figure B-4. Mainline Lane Volume.



Data Collection Time

Figure B-5. Mainline Lane Occupancy.

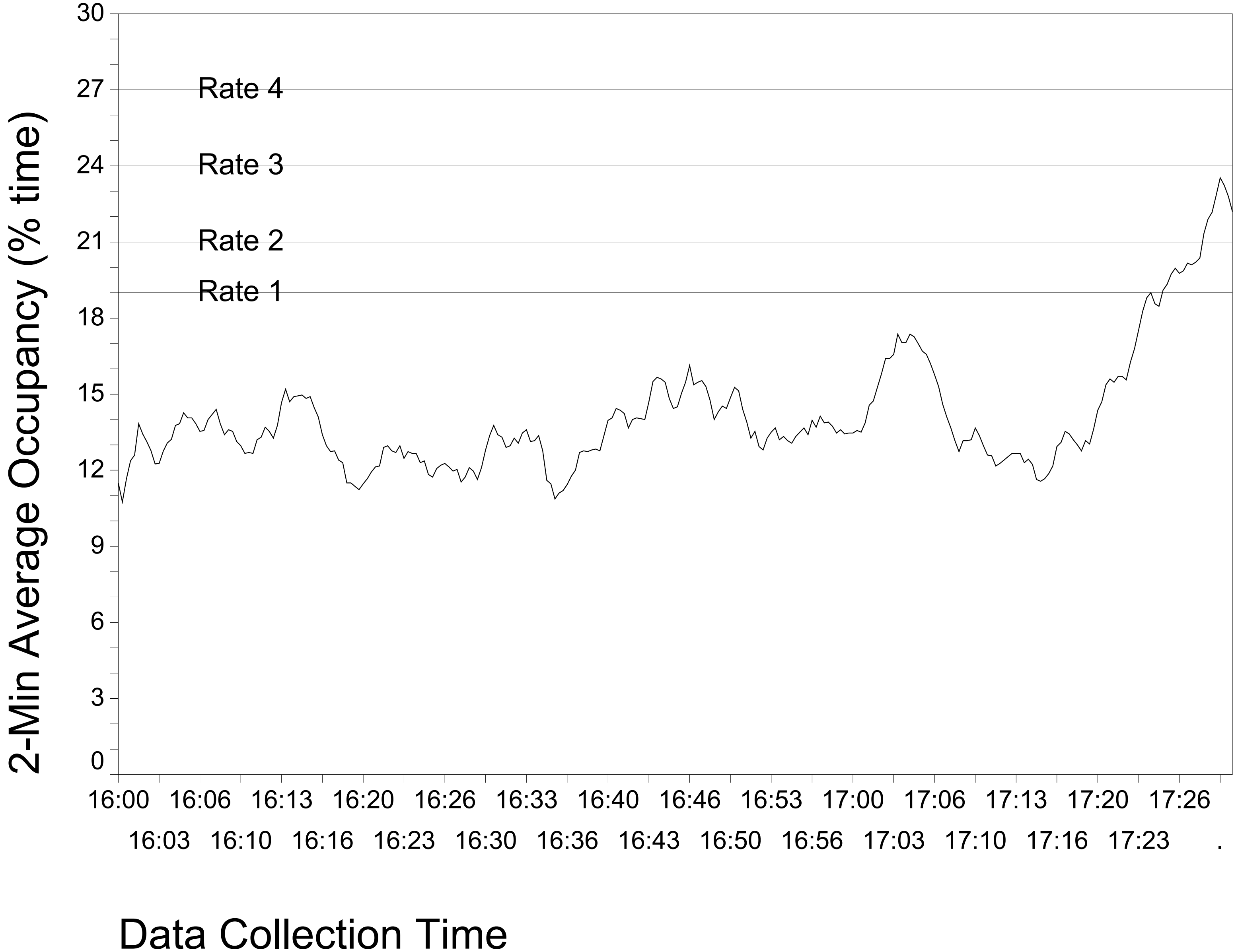


Figure B-6. Ramp Occupancy.

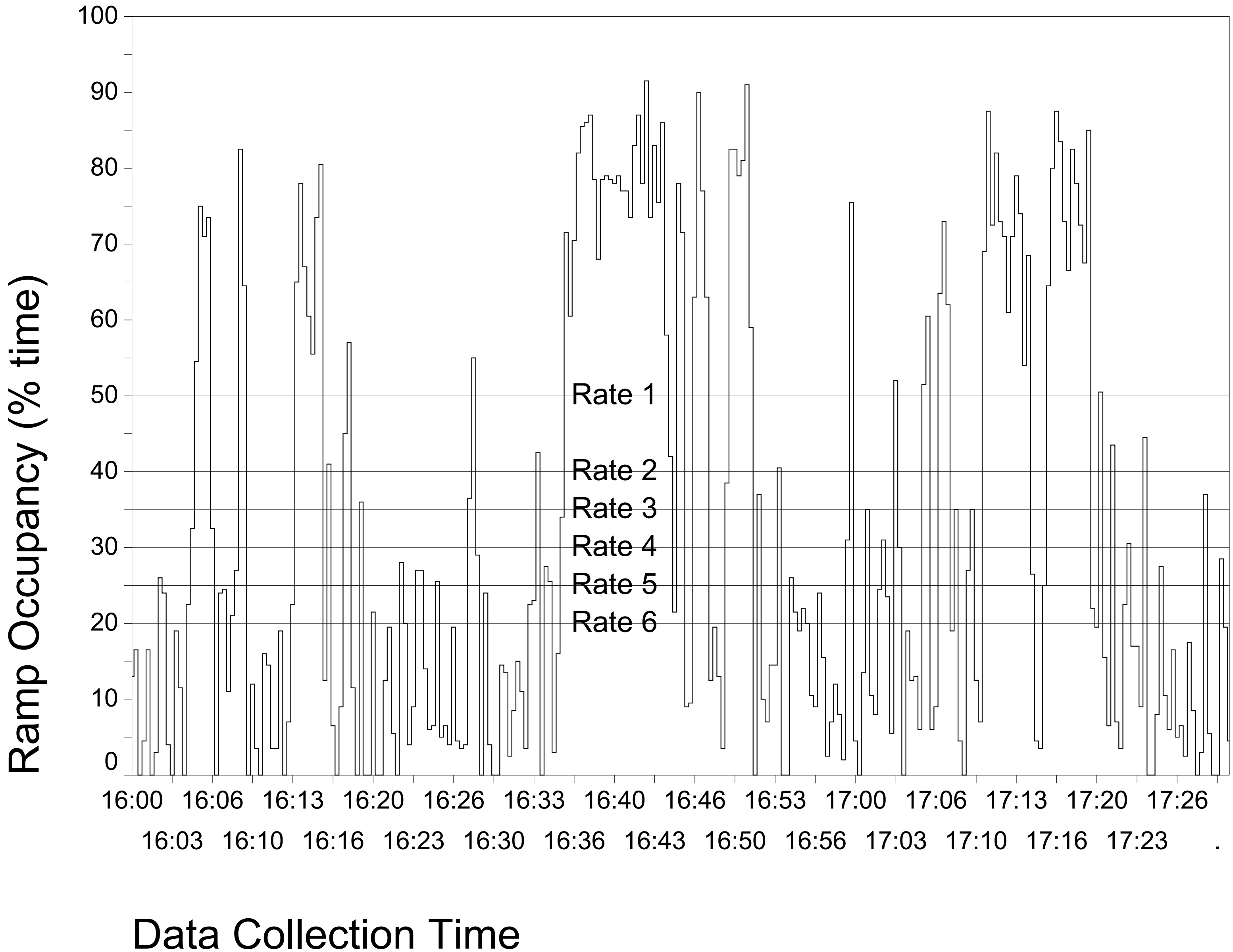


Figure B-7. Chosen Metering Rate.

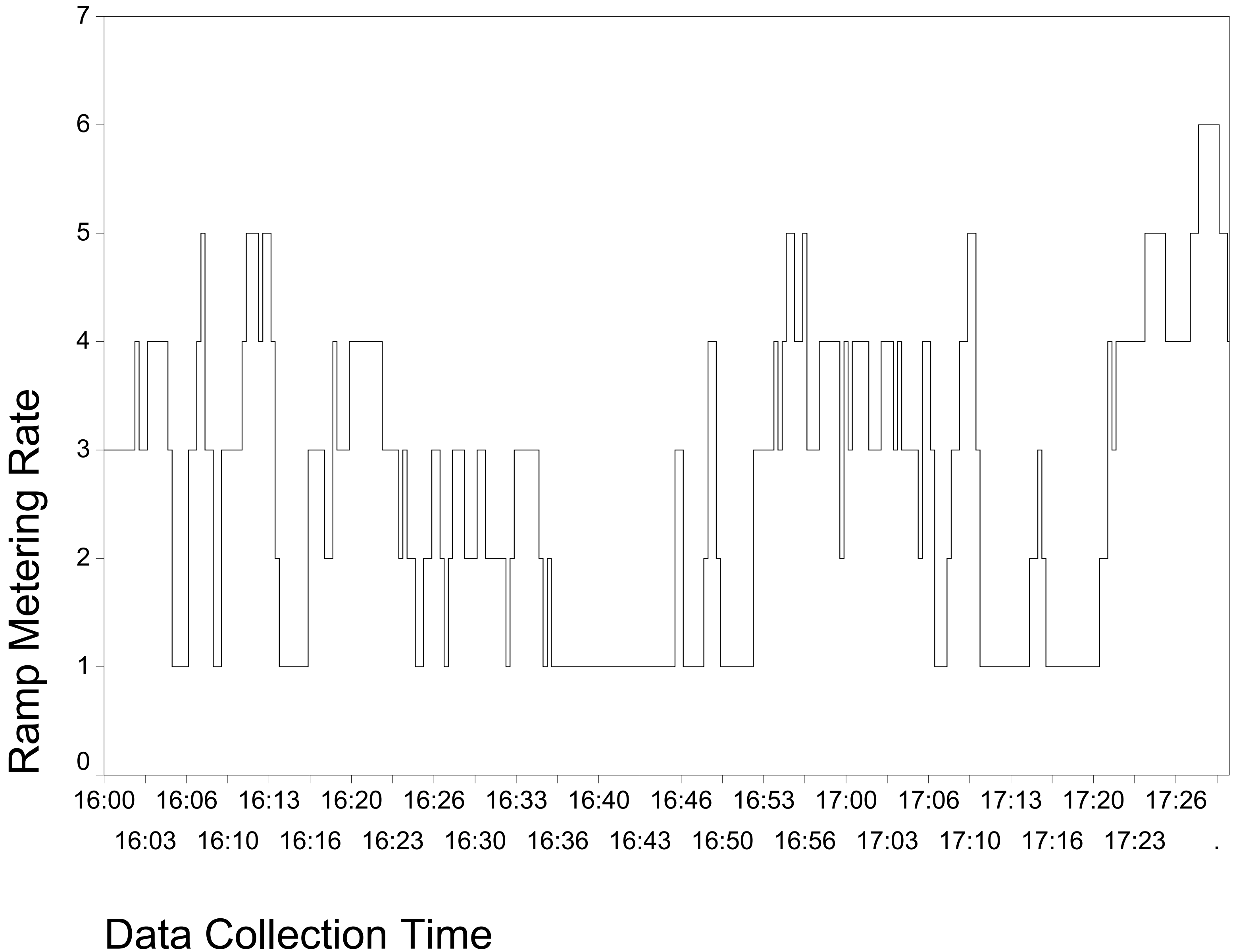
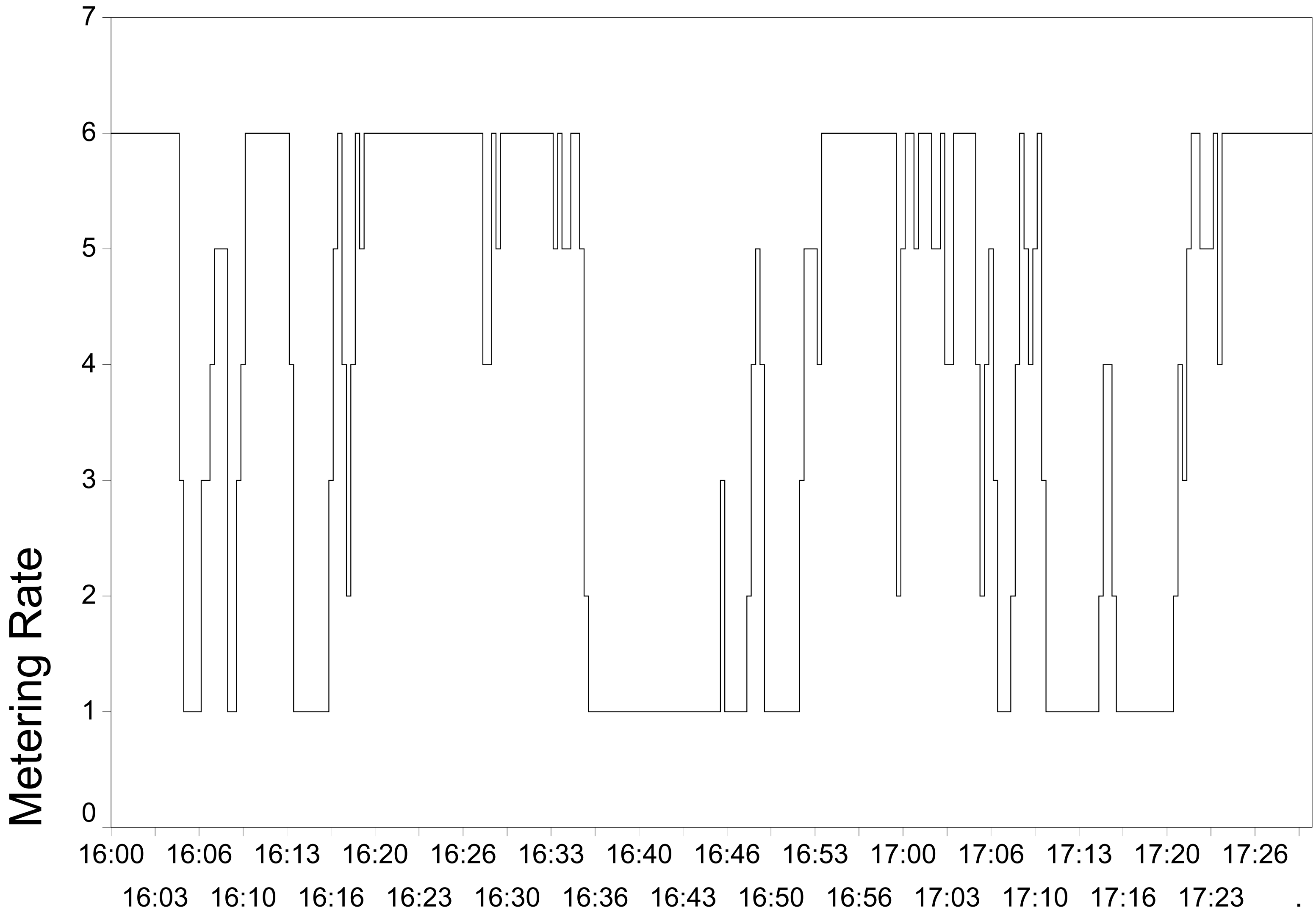


Figure B-8. Metering Rates Based on Ramp Occupancy.



Data Collection Time

Figure B-9. Mainline Speed-Volume Feb 9, 2000.

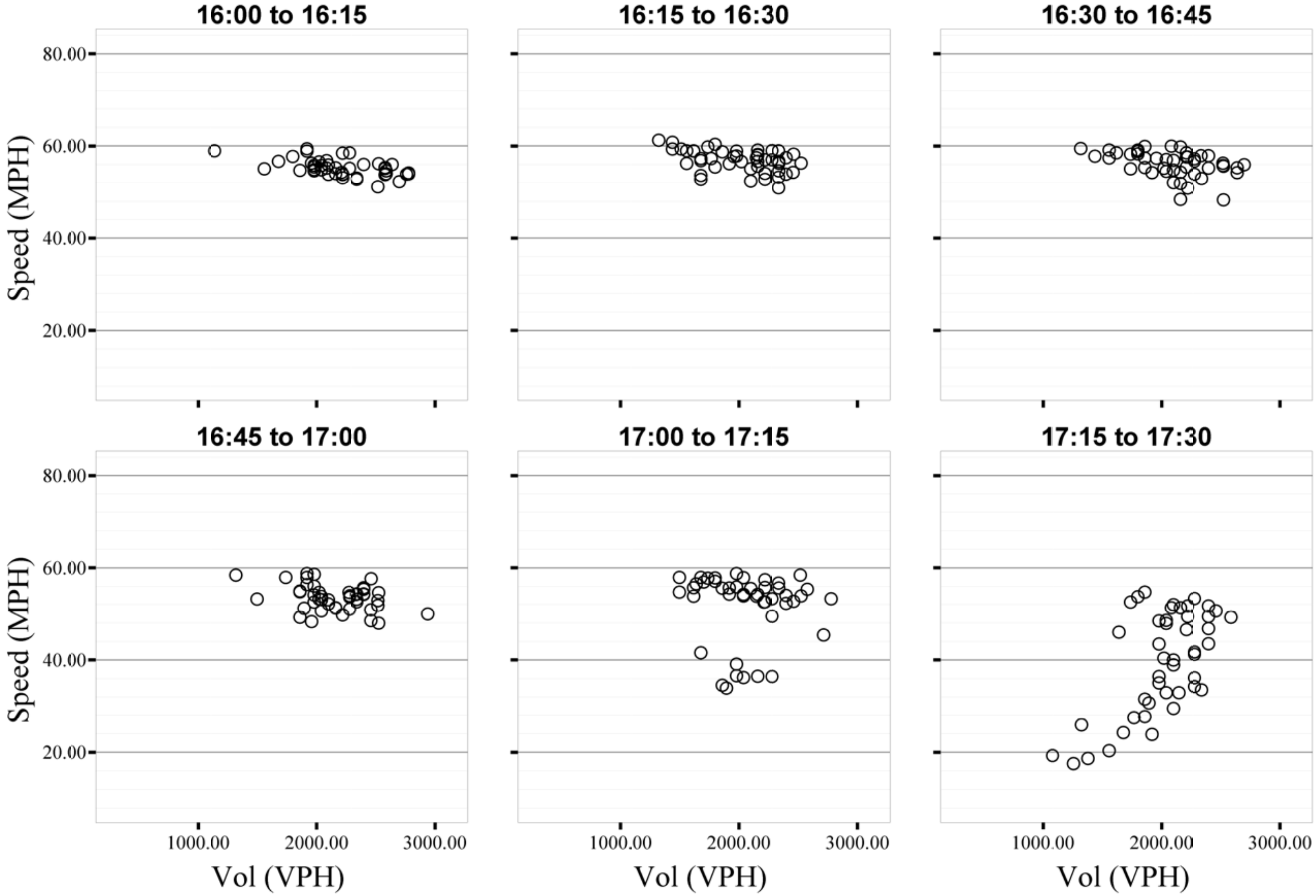


Figure B-10. Mainline Speed-Volume Feb 9, 2000.

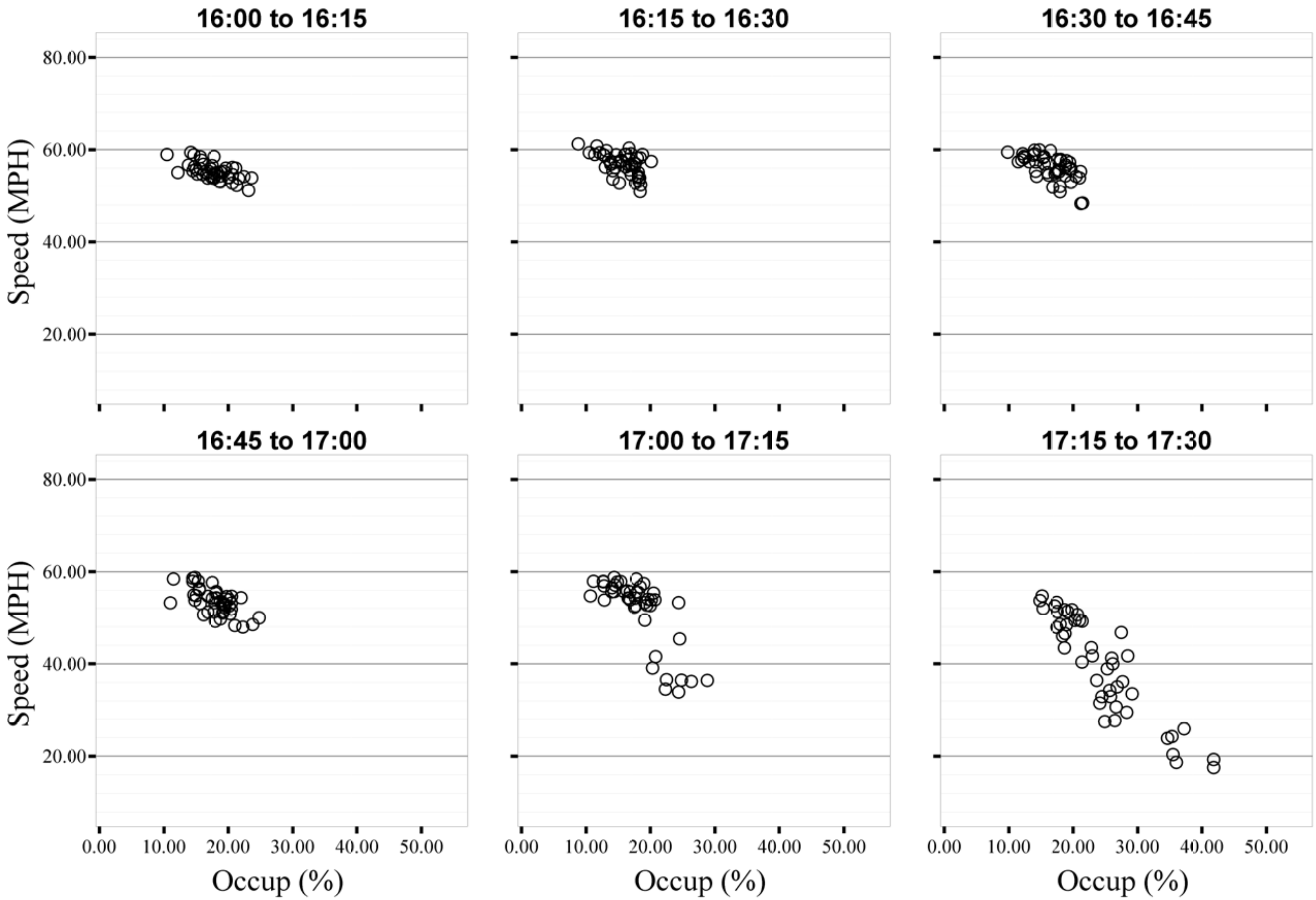


Figure B-11. Mainline Speed-Volume All Days.

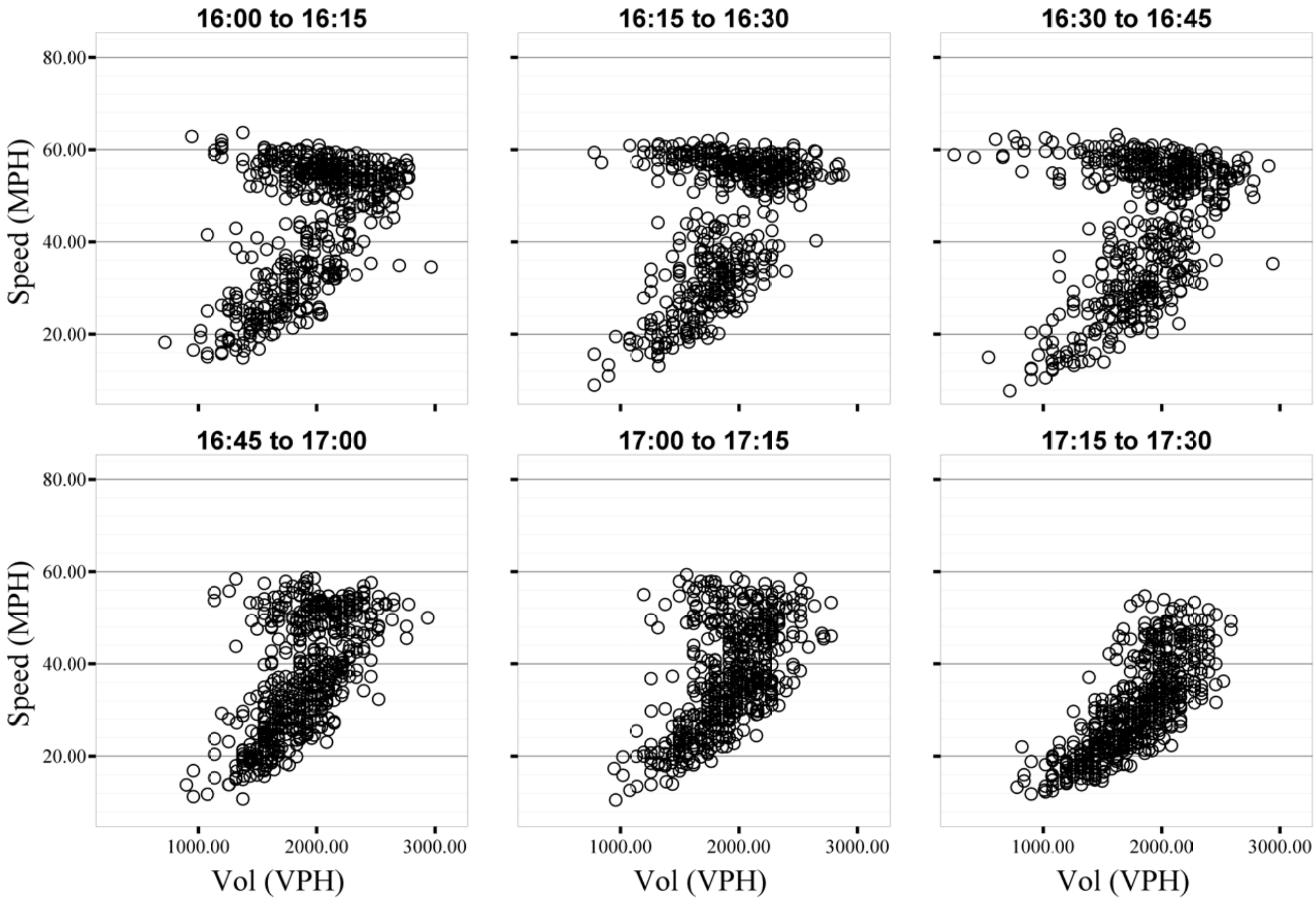


Figure B-12. Mainline Speed-Volume All Days.

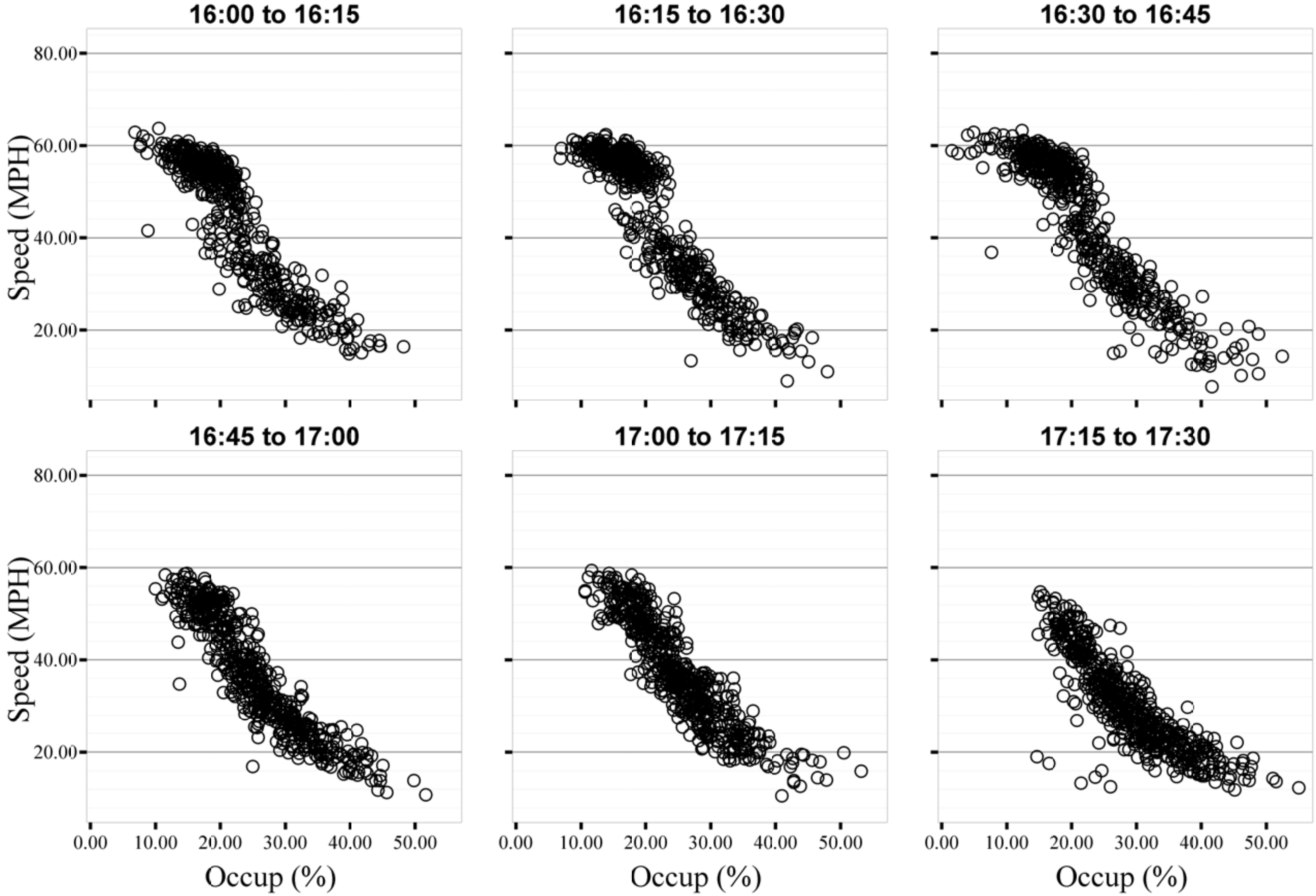


Figure B-13. Mainline Occupancy, Speed and Volume

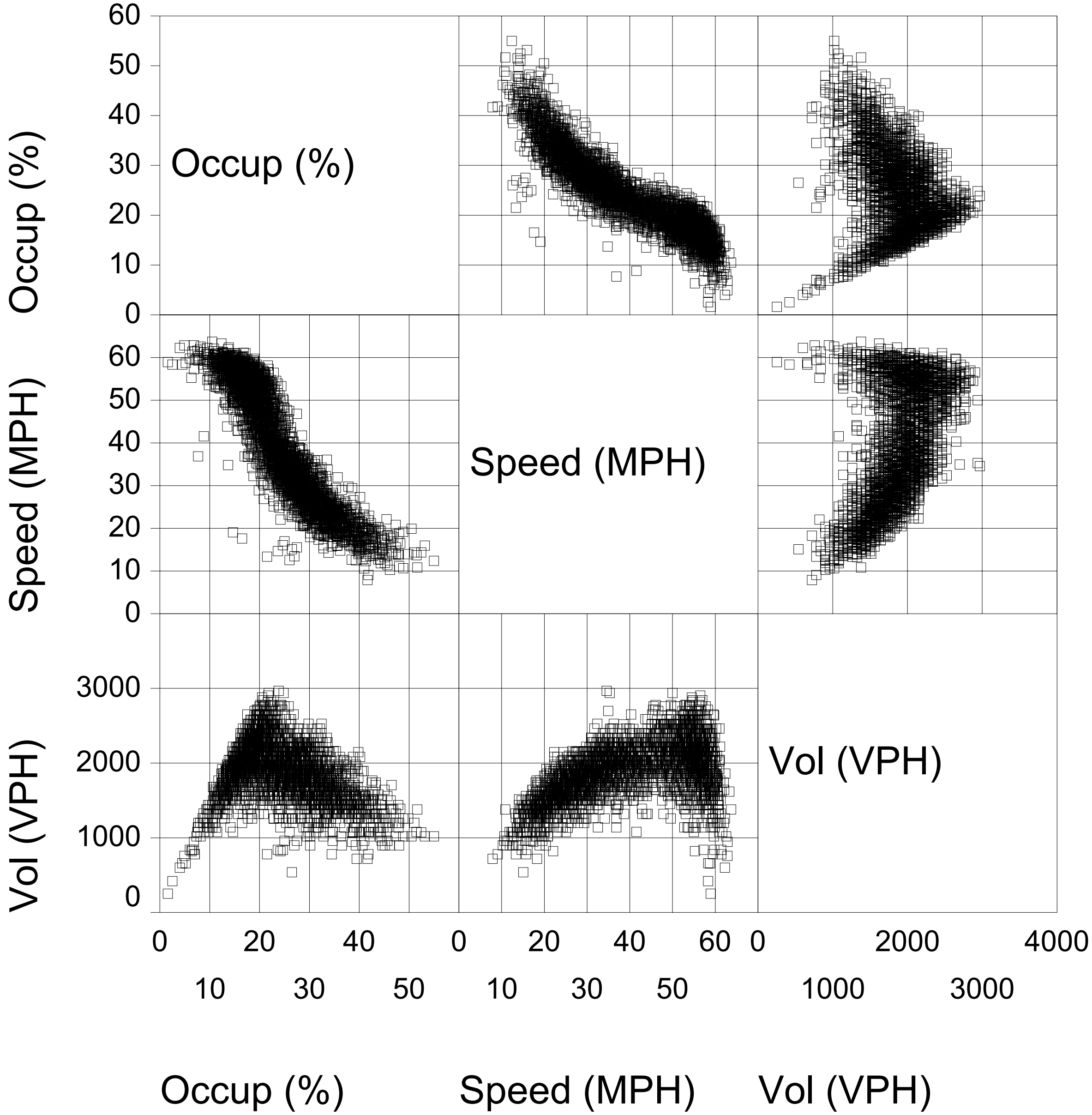


Figure B-14. Mainline Speed and Volume.

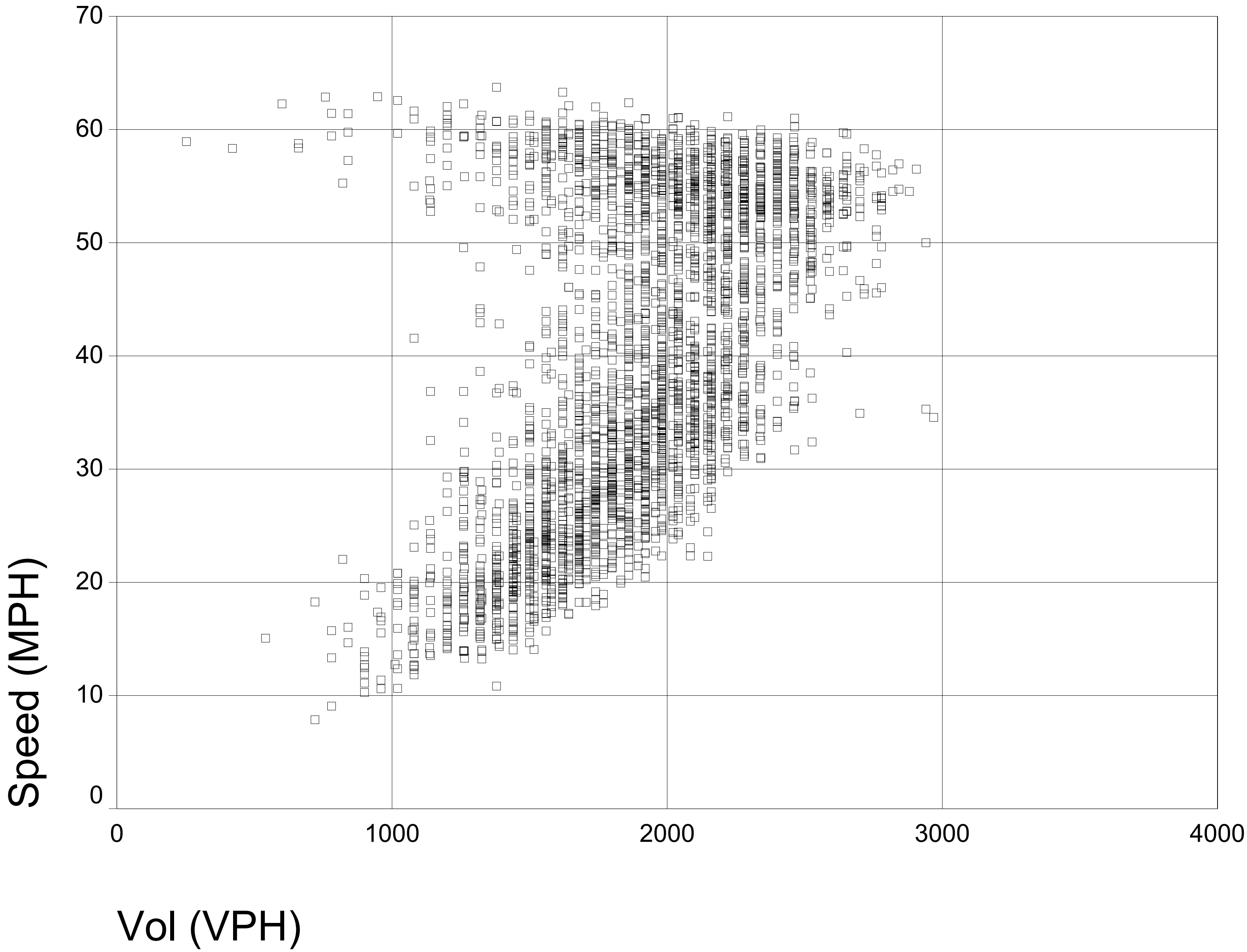
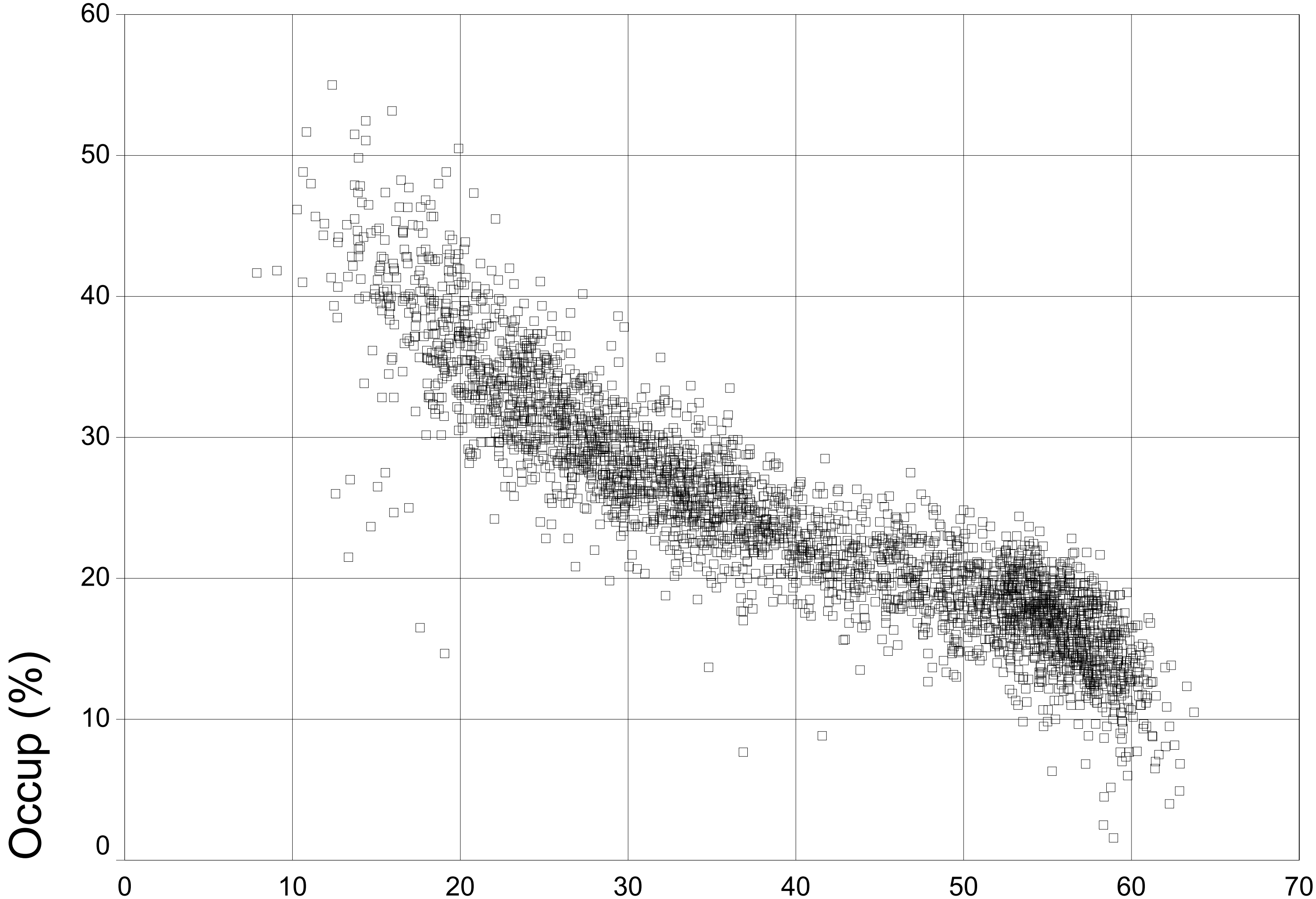


Figure B-15. Mainline Occupancy and Speed.



Speed (MPH)

Figure B-16. Mainline Occupancy and Volume.