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Berkeley Highway Laboratory Project: Final Report

Dolf May, Randall Cayford
Lannon Leiman, Greg Merritt

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FINAL REPORT

OF

BERKELEY HIGHWAY LABORATORY PROJECT

Authored by:

Dolf May
Randall Cayford
Lannon Leiman
Greg Merritt

Submitted by

PATH Program
Institute of Transportation Studies
University of California
Berkeley, California

Prepared for

California PATH Program
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BHL Traffic Detector Analysis, Consolidation of BHL Detector System at CCIT, and Development of Portable Detector Diagnostic Tool

Acknowledgment

The BHL team members would like to acknowledge the support given by Caltrans during this past year and particularly to a number of Caltrans staff members in District 04 and Headquarters who have participated in project advisory meetings, and provided advice and guidance throughout the life of the project.

The I-80 freeway detectors within the study section of the BHL detector project have been installed and are maintained by Caltrans. Caltrans has cooperated by permitting the detector signals to be transmitted to the Berkeley campus for research prior to their being forwarded to District 04 as part of their district-wide detector system. Caltrans District 04 staff members have made field visits when the research team has suspected field equipment problems and have made adjustments when necessary.

The following Caltrans staff persons have participated in project advisory meetings, and provided advice and guidance during the life of the project.
They include:

Rodrigo Acda	Kai Leung
Vic Barbarick	Adrian Levy
Alan Chow	Joe Palen
Sean Coughlin	Charles Price
Jim Durkee	Ron Slade
Ray Duschane	Martha Styer
Hector Garcia	Bill Wald
Lester Lee	

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Abstract

This document is the final report for the 2004-2005 Berkeley Highway Laboratory (BHL) Project that is part of the University of California's PATH program and supported by the California Department of Transportation (Caltrans). The primary objectives of this project have been to operate, maintain, enhance, and conduct research on the Berkeley Highway Laboratory (BHL) detector system. The project consists of following seven major tasks.

Task 1, Macroscopic Freeway Traffic Performance Measures
Task 2, Assessment and Improvements of Detector Diagnostics
Task 3, Installation and Testing of New BHL System at CCIT,
Task 4, Maintaining and Operating the BHL Detector System,
Task 5, Preliminary Design of Portable Detector Diagnostic Tool,
Task 6, Progress Reports and Advisory Meetings
Task 7, Preparation and Submission of Final Project Report

Key Words: Data communications, Detectors, Evaluation techniques, Freeways, High occupancy vehicle lanes, Real-time information, Traffic flow, Traffic surveillance, Vehicle detectors

Executive Summary

This one year research project extended from February 2004 through February 2005 and included seven major tasks. The highlights of each of the tasks are contained in the following paragraphs followed by specific accomplishments.

Task 1, Macroscopic Freeway Traffic Performance Measures, included the assessment of individual lane and directional roadway performance, the evaluation of HOV lane performance, a comparison of single-detector and dual-detector speed estimates, a methodology for substituting for missing data, and the development of macroscopic detector diagnostics. Specific accomplishments included:

- Individual lane flow-occupancy-speed relationships have been defined,
- Flow-occupancy-speed relationships between lanes have been identified,
- Estimation procedures for HOV lane speeds with and without congestion in the adjacent mixed-flow lanes have been developed,
- Estimating lane speeds from single detectors have been found to be not significantly different from estimating lane speeds from dual detectors,
- Algorithms have been formulated for estimating missing detector data from data obtained from other freeway lanes, and
- Procedures for detector diagnostics based on macroscopic flow relationships have been developed.

Task 2, Assessment and Improvements of Detector Diagnostics, included the testing and refinement of nine detector diagnostic tests. Specific accomplishments included:

- Improved parameter settings for detector diagnostic tests
- Continuous on-line implementation of the refined nine detector diagnostic tests.
- Immediately available test results for monitoring detector performance,
- Permanent record of previous detector diagnostic test results,
- Graphically presentations of 24-hour summaries of test results, and
- Identification of detectors providing acceptable data and those providing unacceptable data

Task 3, Installation and Testing of New BHL System at CCIT, was part of a long term goal to consolidate the ITS testbeds and data collection efforts in a single location. Some of the code in the software modules was cleaned up, the backend database was changed, and the software functions were consolidated onto fewer, higher powered computers.

Task 4, Maintaining and Operating the BHL Detector System, included the day-to-day operation of data collection and processing. Several modes of failure were encountered during the course of the project, and each problem was addressed. Archived all standard raw, processed, and diagnostic data sets off-site.

Task 5, Preliminary Design of Portable Detector Diagnostic Tool included an examination of how the BHL diagnostic suite could be applied in the field by installation and maintenance technicians to evaluate and trouble shoot loop detector installations. The functionality of the proposed tool is described in this report.

Task 6, Progress Reports and Advisory Meetings, included the submission of PATH progress reports each quarter and sponsoring three advisory meetings with Caltrans staff during the life of the project. This provided for a close working relationship between the project team and the Caltrans sponsors.

Task 7, Preparation and Submission of Final Project Report, resulted in the preparation and distribution of a draft final report, soliciting and obtaining review comments from Caltrans staff, and incorporated suggestions and distributing this final report. This resulted in a comprehensive final report that was responsive to the comments by Caltrans sponsors.

BHL data was distributed to other researchers doing independent work in traffic studies or data analysis. In each case, data was shared with the approval of Caltrans.

While not a specific project Task, the BHL Web site was revised and updated during the course of this project. These changes, including the display of additional diagnostics, are described in Chapter 10.

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1. Introduction

This final report is presented in two parts. This is due to the way the research was undertaken on the project and the distribution of a major progress report in August 2004 at the midpoint of the project.

The first part covers the initial research undertaken on Tasks 1 and 2 dealing with macroscopic analysis and detector diagnostics. Except for minor corrections, this first part was presented at the August 2004 advisory meeting and made available to project advisors at that time.

The second part of this final report covers final research undertaken on Tasks 1 and 2 as well as all research undertaken on the other project tasks.

While only minor further research was undertaken on Task 1, significant additional work was undertaken in fine tuning and finalizing the detector diagnostics as part of Task 2. All research undertaken on the remaining tasks during the entire duration of the project is covered in Part 2.

PART 1 – PROJECT PROGRESS REPORT

Part 1 is a progress report of accomplishments and future plans for two tasks of the PATH Program's Berkeley Highway Laboratory (BHL) Detector Project as of September 2004:

Task 1 Analysis of Macroscopic Freeway Traffic Performance Measures
Task 2 Assessment and Possible Improvements of Detector Diagnostics

This Part begins with this introductory chapter and ends with a summary chapter. The three main chapters of this Part (chapters 2, 3, and 4) are briefly introduced in the following three paragraphs.

Chapter 2 describes the most recent results and assessment of the current nine microscopic detector diagnostics for three of the BHL stations and identifies future directions for improvements. The three stations selected were stations 5W, 4W, and 8W. The detectors at Stations 5W and 4W are examples of the best and most consistent detectors in the BHL detector system. While on the other hand, some of the detectors at Station 8W are examples of detectors that were found to be the most questionable due to not providing any data or providing questionable data.

Chapter 3 is devoted to macroscopic freeway traffic performance measures for Station 5W. As mentioned in the previous paragraph, the detectors at Station 5W are examples of the best and most consistent detectors in the BHL detector system. All detectors provided data and positive results were obtained from most of the detector diagnostic tests. Analyses included individual lane performance, directional roadway performance, HOV lane performance, comparison of single-detector and dual-detector estimates of freeway lane speeds, methodology for handling missing detector data, and possible macroscopic detector diagnostics.

Chapter 4 is devoted to analysis of macroscopic freeway traffic performance measures and to further detector diagnostic investigations for Station 8W. As mentioned in an earlier paragraph, some of the detectors at Station 8W are examples of detectors that were found to be the most questionable due to not providing any data or providing questionable data. Two detectors did not provide any data and negative results were obtained in a number of the detector diagnostic tests. Further analysis of detector diagnostic test results for Station 8W is included in this chapter.

2. ASSESSMENT AND POSSIBLE IMPROVEMENTS OF DETECTOR DIAGNOSTICS

The first step on the BHL Detector Project's Task 2 "Assessment and Possible Improvements in Detector Diagnostics" was to assemble a comprehensive database including vehicle transition data, 30-second macroscopic data, system diagnostics results, detector diagnostics results, freeway incident reports, and weather data. Data was assembled for Tuesdays, Wednesdays, and Thursdays during the month of March. The data set for Tuesday, March 2nd was selected for this initial assessment because of the quality of detector data, the positive results from system and detector diagnostics, the occurrence of few freeway incidents (and no major ones), and good weather conditions.

This initial assessment of detector diagnostics was limited to stations 4, 5, and 8 in the westbound direction. The data for other directional stations will be undertaken as project time and resources permit.

Stations 4 and 5 in the westbound direction were selected because they appeared to have the highest quality data, all detectors appeared to provide data continuously for the entire study period, and were located on the longest freeway section between ramps. Stations 4 and 5 are located between the University Avenue on-ramp and the Ashby Avenue off-ramp in the direction toward Oakland and San Francisco. Station 4 is located just downstream of the University Avenue on-ramp while Station 5 is located just upstream of the Ashby Avenue off-ramp. A freeway lane is not added at the University on-ramp nor is a lane dropped at the Ashby off-ramp, and the entire upstream and downstream section is a level, straight, directional five-lane freeway. The median lane, lane 1, is a part-time concurrent HOV lane operating between 5 and 10 AM and between 3 and 7 PM.

Station 8 in the westbound direction was selected because it has the most complicated geometrics, does not always provide data continuously for the study period, and has more diagnostic test failures than any other station. It is located between the Powell Street off-ramp and the Powell Street on-ramp. There are six lanes at this station with the median lane, Lane 1, serving as a part-time HOV lane to San Francisco. Lane 2, the lane next to the median lane, serves as a part-time concurrent HOV lane to the Oakland area. The remaining four lanes are general-use lanes. The HOV Lane 1 begins just a short distance upstream of Station 8W and the HOV Lane 2 becomes a general-use lane just a short distance downstream of Station 8W. Any one of the three directional freeways in the downstream interchange may cause congestion to back into the Station 8W location during peak periods.

The results from the set of nine diagnostic tests applied to upstream and downstream detectors in each lane at each of the three stations were continuously recorded and the 24-hour data for Tuesday, March 2nd was analyzed in considerable detail. These results are presented in three sets of six illustrations: Illustrations 2.1 to 2.6, 2.7 to 2.12, and 2.13 to 2.18 for Stations 5W, 4W, and 8W respectively. Note that lane 1 is the median lane (part-time HOV lane; 5-10 AM and 3-7 PM) while lane 5 is the shoulder lane at Stations 5W and 4W and lane 6 is the shoulder lane at Station 8W. Generic software programs have been developed to generate such illustrations semiautomatically so that other stations in other directions could be analyzed in a similar manner in the future expeditiously.

The vertical scale on the first five illustrations in each set denotes the nine detector diagnostic results with information provided for each upstream and downstream detector in a particular lane. The upstream and downstream detectors in lane 6 at Station 8W did not provided any data (in fact have not been providing data for some time) and hence only five illustrations were prepared for this station (lanes 1 through 5). The horizontal scale in the illustrations is time from midnight to midnight on Tuesday, March 2nd. Light black lines and dashes indicate when the particular detector passed the diagnostic test while heavy black lines and dashes indicate when the particular detector failed the diagnostic test. Note that Test 5 uses data from both of the dual detectors in the test so only one positive or negative response results.

In order to more clearly see the pattern of the diagnostic test results and to evaluate the strengths and weaknesses of each test, a summary of results is included in the final illustration in each set (Illustrations 2.6, 2.12, and 2.18 for Stations 5W, 4W, and 8W respectively). The nine diagnostic tests are shown as horizontal rows for each of the detectors and the last six vertical columns provide diagnostic test results for six traffic periods of the day representing different traffic flow intensities. This summary table permitted studying the influence of traffic flow levels on diagnostic test results. A series of numbers (a-b-c-d-e) is shown in each cell of the table. The set of numbers in each cell represents the approximate number of diagnostic test failures in each of the five lanes (data for the sixth lane at Station 8W was not available) of the freeway during each of the six periods of the day. For example in Illustration 2.6 that presents the results for Station 5W, the cell entry “1-1-0-0-1” for the period of time 0000-0400 under low flow conditions with the dynamic maximum off-time test applied to the upstream detector is shown. The detectors in lanes 1, 2, and 5 each had one test failure while the detector in lanes 3 and 4 had no test failures.

The remaining portions of this chapter will include a description of each diagnostic test, an initial assessment of each detector diagnostic test for the three directional stations, and suggestions for improving each detector diagnostic. The concluding section is the chapter summary.

2.1 Task 1 Activity

The activity diagnostic test determines whether the detector signal has changed states in a 15-minute period. If the detector signal has not changed states in a 15 minute period, a test failure is recorded. Otherwise, it passes. The activity test results and assessment for each of the three directional stations will be presented in the following portions of this section of the chapter.

2.1.1 Station 5W Results and Assessment

Review of Illustrations 2.1 through 2.6 provides evidence that the signal from every detector at Station 5W has changed states over every 15-minutes throughout the 24-hour study period. Therefore there are no test failures.

Detector diagnostic results for a second day (March 4, 2004) were reviewed and were similar to the March 2, 2004 results, there were no test failures.

It should be kept in mind that there is no assurance from this test that the detector data is good but only that data is being received and recorded. It also should be noted that other detectors at other stations do fail this test which provides reassurance about the diagnostic test.

2.1.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are identical to those for the previously described Station 5W.
Review of Illustrations 2.7 through 2.12 provides evidence that the signal from every detector has changed states over every 15-minutes throughout the 24-hour study period. Therefore there are no test failures.

2.1.3 Station 8W Results and Assessment

Except for the two non-functioning detectors in lane 6 and the upstream detector in lane 2 between 1100 and 1130 and also between 1145 and 1215, the diagnostic test results for Station 8W are similar to those for the previously described Stations 5W and 4W. Illustrations 2.13 through 2.18 provide figures and a table of the results of this test for Station 8W.

Detector diagnostic results for a second day (March 4, 2004) were reviewed and they were similar to the March 2, 2004 results. There were no test failures in lanes 1, 3, 4, and 5 but some test failures in lane 2 (between 1115 and 1200, and also from 1745 to 1815) and continuous test failures in lane 6.

It should be kept in mind that there is no assurance from this test that the detector data is good but only that data is being received and recorded.

2.1.4 Possible Improvements in the Activity Test

No improvements are suggested for the Activity Test. The threshold value of 15 minutes appears to be appropriate. The Activity Test is considered to be one of the more important diagnostic tests.

The activity test's primary purpose is to flag completely dead loops. The BHL has several loops that have been non-operational since the beginning of the project. A 15-minute test interval may appear long but it was chosen so as to avoid false negative diagnostic results in the early morning hours under extremely low flow conditions. Review of 5-minute flows during the night at a number of detectors indicated that while there was one ten-minute period of time without a vehicle at one detector, there were no 15-minute periods without a vehicle at those detectors that were operational during other times of the day. This suggested that the 15-minute threshold value appeared to be appropriate. Occasional passing of this test for a loop detector with a known dead loop is a clear indicator of crosstalk within the detector cards where a signal on one card triggers a signal in a neighboring card.

Further study was undertaken of the upstream detector in lane 2 of station 8W just before noon on March 2, 2004 and before noon and in the late afternoon on March 4, 2004. This intermittent failure seemed to be a valid loop or detector card failure and it is suggested that Caltrans determine whether it is a loop or detector card failure. Caltrans has been informed that the two detectors in lane 6 at Station 8W are not providing any detector signals and have not been doing so for quite sometime.

2.2 Test 2 Minimum On-Time

The minimum on-time diagnostic test is applied to each consecutive set of 100 vehicle pulses provided by the detector. If 5% or more of the vehicle pulses have duration times less than 8/60 seconds, the detector fails this diagnostic test.

2.2.1 Station 5W Results and Assessment

Review of Illustrations 2.1 through 2.6 shows that only the pair of detectors (upstream and downstream) in lane 1 (median part-time HOV lane) do not pass this test in moderate to heavy traffic flow conditions (0400 to 1500 and 1800 to 2400). These detectors only fail this test a few times during these selected time periods. They pass this test under both light and congested conditions.

It should be noted that the test is not performed very often (one or two times) from 0000 to 0400 in lane 1 because that lane's traffic flow level is very low. On the other hand, the test is conducted more frequently in the other four lanes because of higher traffic flow levels and all of their detectors always pass this test.

Closer inspection of Illustration 2.1 (lane 1) provides a remarkable coincidence between the heavy dash lines (test failures) and the start and ending times of HOV lane restrictions (5:30 AM, 9 to 10 AM, and 7 PM). It also can be noted that both the upstream and downstream detectors have almost identical patterns of test failures. These test failures may be due to vehicles moving into and/or out of the HOV lane and their time duration over the detector does not correspond to the full length of the vehicle.
Detector diagnostic results for a second day (March 4, 2004) were reviewed and they were similar to the March 2, 2004 results. There were no test failures in lanes 2, 3, 4, and 5 but there were a few test failures in lane 1at the time of the beginning and ending of HOV lane operations similar to the August 02 test results.

Considering that this test is likely to have been conducted at least a 100 times per day in lane 1 and several hundred times a day in each of the other lanes, the test failure rate is relatively small.

2.2.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are similar to those for the previously described Station 5W but with a few more test failures recorded.

Review of Illustrations 2.7 through 2.12 shows that only the pair of detectors (upstream and downstream) in lane 1 (median part-time HOV lane) fail this test in moderate to congested traffic flow conditions. These detectors only fail this test one to four times during these selected time periods. They pass this test under light conditions.

The pattern of diagnostic test failures between upstream and downstream detectors in lane 1 is similar. While many of the test failures occurred at the beginning and ending of the morning and afternoon HOV lane use restricted time periods, a few occurred during the HOV lane use restricted time periods.

2.2.3 Station 8W Results and Assessment

The results of the minimum on-time diagnostic test for Station 8W were quite different from the results obtained from Stations 5W and 4W with many test failures in each of the lanes. The pattern and intensity of test failures varied between lanes and therefore the results for each lane will be described separately in the following paragraphs. Illustrations 2.13 through 2.18 provide figures and a table of the results of this test for Station 8W.

Lane 1 diagnostic test failures were only slightly higher than those for Stations 5W and 4W in this lane. Most of the test failures occurred from 0800 to 1000 under heavy traffic flow conditions. Unlike the results of the other two stations, test failures did not seem to occur with the start and ending time of HOV lane restricted use.

Lane 2 diagnostic test failures were very large for the upstream detector and relatively small for the downstream detector. The test failures for the upstream detector were almost continuous from 0600 to 1100 and from 1700 to 2300. On the other hand, the test failures for the downstream detector were relatively small and scattered throughout the day without any particular pattern.

Lane 3 diagnostic test failures were relatively high and the patterns of failures for the upstream and downstream detectors were similar. The test failures were scattered throughout the day without any particular pattern.

Lane 4 diagnostic test failures were exceedingly high with almost continuous failures from 0400 to 1600 and from 1800 to 2400. Both upstream and downstream detectors had similar patterns of test failures.

Lane 5 diagnostic test failures were similar to the results reported in the previous paragraph for lane 4. The test failures were exceedingly high with almost continuous failures from 0500 to 1600 and from 1800 to 2300. Both upstream and downstream detectors had similar patterns of test failures.

Lane 6 diagnostic tests all failed due to lack of any data being provided by the upstream and downstream detectors.

Higher lane changes are expected at this location than at stations 5W and 4W, and thereby may contribute to additional test failures. However, the pattern and intensity of test failures in lane 2 (upstream detector only), lane 4 (both detectors), lane 5 (both detectors), and lane 6 (both detectors) raise additional questions.

Ben Coifman of Ohio State University recently provided a copy of his research report dealing with experimentation of detector cards at Station 8W. With this information, it is suggested that Caltrans inspect the controller and with particular attention focused on the detectors identified in the previous paragraph. The concern is that the on-times are extremely small.

2.2.4 Possible Improvements in the Minimum On-Time Test

The minimum on-time test has proven useful in detecting certain failures. Reoccurring failure of this test is a good indicator of the card having been set to pulse mode. In pulse mode the detector card generates a short, set width pulse for every car. The pulse is around 6/60 seconds to 7/60 seconds that causes the card to fail the minimum on-time test. Extreme cases of sensitivity tuning error can also be detected by this test, though several of the other tests are more directly focused on testing card sensitivity.

For Station 5W, the distribution of on-times for the upstream and downstream lane 1 (median lane) detectors for every 100 vehicle samples during the beginning and ending times of HOV operations was analyzed. This analysis confirmed that in fact the detector data did not pass this diagnostic test during short periods of time due to more than 5% of the 100-vehicle samples having on-times less than 8/60 seconds. The cause(s) of this phenomenon is unknown. This presented a dilemma. For on the one hand, detectors in all other lanes at Stations 5W and 4W always passed this test and detectors in lane 1 at Stations 5W and 4W always passed this test except for these short periods of time. On the other hand there were a few test failures in lane 1 during these selected periods of time. It was decided not to decrease the threshold value of 8/60 seconds until other stations had also been investigated.

For Station 8W, much more study is needed of its performance with the Minimum On-Time Test. The comparison of video recording simultaneously with collecting detector data in lane 1 during the start and/or end period of HOV operations could be very effective in determining the cause(s) for these limited test failures. This will be covered later in Chapter 4.

2.3 Test 3 Maximum On-Time

The maximum on-time diagnostic test is applied to each consecutive set of 100 vehicle pulses provided by the detector. If 5% or more of the vehicle pulses have duration times greater than 600/60 seconds, the detector fails this diagnostic test.

2.3.1 Station 5W Results and Assessment

Review of Illustrations 2.1 through 2.6 provides evidence that all detectors throughout the 24-hour study period passed this test. This may indicate that the threshold value of 600/60 seconds may not be restrictive enough and that the value should be reduced.

Detector diagnostic results for a second day (March 4, 2004) were reviewed and were similar to the March 2, 2004 results, there were no test failures.

2.3.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are identical to those for the previously described Station 5W.

Review of Illustrations 2.7 through 2.12 provides evidence that all detectors throughout the 24-hour study period passed this test. This is likely to indicate that the threshold value of 600/60 seconds may not be restrictive enough and that the value should be reduced.

2.3.3 Station 8W Results and Assessment

The diagnostic test results for Station 8W are almost identical to those for the previously described Stations 5W and 4W.

Review of Illustrations 2.13 through 2.18 provides evidence that all detectors throughout the 24-hour study period passed this test except for one test failure. The test failure was for the upstream detector in lane 2 at about 1130. This is likely to indicate that the threshold value of 600/60 seconds may not be restrictive enough and that consideration should be given to reducing this value.

2.3.4 Possible Improvements in the Maximum On-Time Test

Failure of the maximum on-time test would generally indicate a detector card has locked in an on state. This has not happened with any of the detectors in the BHL, however. The Activity Test would also be an alert to this problem. There have been false negatives in the maximum on-time test in a couple of isolated situations where a vehicle has actually stopped over a loop for more than 600 seconds due to accidents.

A unique situation occurred in lane 3 between 1500 and 1600 on July 13, 2004 when a major incident occurred just downstream of Station 5 and the distributions of on-times were analyzed. A major incident just downstream of a detector is expected to result in the highest on-times. Further study was also made of individual vehicle on-times during normal congested periods of time. Based on this study it is suggested that the maximum on-time threshold value be reduced from 600/60 seconds to 400/60 seconds. This test is expected to rarely fail but when it does it may be due to detector failure or more likely, to extremely heavy congestion due to downstream major incidents. There were no failures of this test by any detector at Stations 5W and 4W on March 2 and 4, 2004 and only one test failure in one lane in Station 8W.

For Station 8W, a check should be made of the single failure at 1130 with the upstream detector in Lane 2. This will be discussed further in the later Chapter 4.

2.4 Test 4 Mode On-Time

The mode on-time diagnostic test is applied to each consecutive set of 1000 vehicle pulses during free-flow traffic conditions only (speeds over 50 mph) and the mode value of the on-times is calculated. Thus this test is limited to free-flow conditions only (speeds over 50 mph). If the calculated mode value is between 10.5/60 seconds and 15.5/60 seconds, the detector passes this diagnostic test. Otherwise it fails.

2.4.1 Station 5W Results and Assessment

Review of Illustrations 2.1 through 2.6 indicates that there were about thirteen test failures that occurred during medium to fairly heavy flow conditions. All detectors in the various lanes had at least one failure and in almost all cases, the pattern of failures of the upstream and downstream detectors in each lane was identical. It is important to observe that the failures all occurred between 8 and 11 AM and usually between 8 and 10 AM. However it is not clear whether the failures were due to mode on-times below or above the threshold values.

Detector diagnostic results for a second day (March 4, 2004) were reviewed and were similar to the March 2, 2004 results. There were fewer test failures (only four in the set of five lanes) and they all occurred at about 1030.

There are four issues to consider. First, why do the failures occur? Second, Can the sample size of 1000 be reduced? Third, it would be desirable to record if a test failure is due to the calculated modal value is less or greater than the acceptable threshold range. Finally, should the test be limited to uncongested flow conditions (speeds over 50 mph)?

2.4.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are essentially identical to those for the previously described Station 5W.

Review of Illustrations 2.7 through 2.12 indicates that there were about nine test failures that occurred during medium to heavy flow conditions. All detectors in the various lanes had at least one failure and in almost all cases the pattern of failures of the upstream and downstream detectors in each lane were identical. It is important to observe that the failures all occurred between 9 and 11 AM. However it is not clear whether the failures were due to mode on-times below or above the threshold values.

2.4.3 Station 8W Results and Assessment

Although the number of failures of this diagnostic test was moderate, they were significantly higher than for the other two stations discussed previously. It also should be remembered that this test is only conducted for every 1000 vehicles and so the number of tests conducted is much smaller than for the other tests.

Illustrations 2.13 through 2.18 provide figures and a table of the results of this test for Station 8W. Since the pattern between lanes and between detectors within lanes is different, the test results for each lane will be described in the following paragraphs.

Lane 1 had only one test failure and it was with the downstream detector at about 0830. This was about the same level of intensity at Stations 5W and 4W for Lane 1.

Lane 2 had only one test failure in the downstream detector but the upstream detector had about one-half of the test fail from 0700 to 1100 and 1800 to 2300. Recall that there were problems with the upstream detector in lane 2 with the minimum on-time diagnostic test also.

Lane 3 had a modest number of test failures but it is significant to observe that all tests failed for both the upstream and downstream detector between 0700 and 1000 under heavy flow conditions.

Lane 4 only had one test failure with the upstream detector but the downstream detector failed all tests between 0530 to 1200 and 1800 to 2000.

Lane 5 only had two test failures with each of its detectors but there patterns of test failures were different. They primarily occurred during heavy flow conditions between 0800 and 1000.

Lane 6 diagnostic tests all failed due to lack of any data being provided by the upstream and downstream detectors.

Particular attention needs to be given to the upstream detector in lane 2 and the downstream detector in lane 4. The mode test is a two-sided test and it is not clear whether the calculated mode is lower or higher than the acceptable range.

2.4.4 Possible Improvements in the Mode On-Time Test

The mode on-time test is a test of detector sensitivity tuning and of crosstalk between cards. The underlying principle is that the majority of vehicles passing over the loop are passenger cars that are generally all close to the same length. The similarity in length generates a very sharp peak in the on-time distribution graph for a loop detector of about 14/60ths of a second. Failure of this test, during free-flow conditions, may indicate the sensitivity of the loop is incorrect which will cause the peak of the distribution to shift up or down outside of the test range. Failure may also indicate that the detector card is picking up signals from neighboring cards which result in significant numbers of pulses with either too short or too long an on-time. This shows up in the on-time distribution graph as a secondary spike to one side or the other of the main peak and triggers failure of the mode on-time test.

The test is dependent on the calculation of the current speed, which, in the current implementation, is estimated from a single loop. In situations where the traffic is varying around the threshold free-flow speed of 50 mph, the mode on-time test may fail as some cars are not detected as moving at slower speeds and so are interpreted as having overly long on-times. An unusually large percentage of trucks may also cause a false negative diagnostic result.

Further study was undertaken of the mode on-time test for Station 5W. The results of this further study suggest that the threshold values be changed to 9.5/60 seconds and 16.5/60 seconds, the test not be limited to speeds over 50 mph, and the sample size be reduced to 100 vehicles.

For Station 8W, further study is required and will be addressed later in Chapter 4.

2.5 Test 5 Dual Detector On-Time Difference

The dual detector on-time difference diagnostic test is applied to each consecutive set of 1000 vehicle pulses during free-flow conditions (speeds over 50 mph) and the mean difference between upstream and downstream on-times is calculated. If 5% or more of the on-time differences of 1000 vehicles are not between +/- 3.5/60 seconds, the pair of detectors fails this diagnostic test.

2.5.1 Station 5W Results and Assessment

Review of Illustrations 2.1 through 2.6 indicates that all pairs of detectors pass this test during free-flow conditions. The test is currently not applied during congested periods of time; 3 to 6 PM.

Detector diagnostic results for a second day (March 4, 2004) were reviewed and similar to the March 2, 2004 results, there were no test failures.

There are four issues to consider. First, should the threshold values of +/- 3.5/60 seconds be reduced? Second, can the sample size of 1000 be reduced? Third, should the dual detector on-time difference diagnostic test be extended to the peak period? And fourth, whether the calculated value is higher or lower than the threshold range.

2.5.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are identical to those for the previously described Station 5W.

Review of Illustrations 2.7 through 2.12 indicates that all pairs of detectors pass this test during free-flow conditions. The test is currently not applied during congested periods of time when speeds are less than 50 mph.

2.5.3 Station 8W Results and Assessment

While there were no test failures in the detectors located at Stations 5W and 4W, there were serious test failures in lanes 2 and 4 at Station 8W. Illustrations 2.13 through 2.18 provide figures and a table of the results of this test for Station 8W.

The pair of detectors in lane 2 never passed the diagnostic test while the pair of detectors in lane 4 only passed the test in about one-half of the cases (usually in higher flow situations). The dual on-time difference test is a two-sided test and it is not clear whether the calculated on-time difference is lower or higher than the acceptable range. It should also be remembered that this test depends on the successful performance of both upstream and downstream detectors.

2.5.4 Possible Improvements in the Dual On-Time Difference Test

The dual on-time difference test is primarily a test of sensitivity tuning. Failure of this test usually indicates that the sensitivity of the two loops is significantly different. The test will also fail if one of the two detector cards is in pulse mode. Other tests must be looked at to see which of the two loops is faulty. Successful passing of this test does not necessarily mean the two loops are tuned correctly. They may both be out of tune by similar amounts. While this test does depend on the detection of free-flow conditions by evaluating the speed of each vehicle, it is not as sensitive as the other speed dependent tests. The dual loop test uses a different method to calculate speed that is based on the travel time between the two loops. This method is considerably more accurate than speed estimation using a single loop, particularly in situations where the speeds are varying quickly.

For Station 5W, further research was undertaken of the distribution of dual detector on-time differences since there were no test failures at Stations 5W and 4W. These distributions were obtained for different lanes during varying traffic flow levels including congested periods using a sample size of 100 vehicles. The results indicated that the threshold value range could be reduced from +/- 3.5/60 seconds to +/- 2.5/60 seconds and the sample size reduced from 1000 to 100 vehicles but the test should continue to be limited to uncongested flow conditions (speeds over 50 mph).

For Station 8W, further study is required and will be addressed later in Chapter 4.

2.6 Test 6 Dynamic Minimum On-Time

The dynamic minimum on-time diagnostic test is similar to the minimum on-time diagnostic test (earlier Test 2) except that the threshold value of 8/60 seconds varies with calculated traffic speed. The test fails if 5% or more of the on-times in a sample of 100 vehicles are less than the calculated minimum acceptable on-time threshold value. The equation for the minimum acceptable on-time threshold value is:

Min on-time (1/60 secs) = [(vl + dl)/(sp)][3600/88]
Where:
vl = average vehicle length (assumed 14 feet)
dl = detector zone length (assumed 6 feet)
sp = calculated average speed (mph)

The parameter for the vehicle length represents the detected length of the vehicle. The length seen by the detector is shorter than the manufacturer’s measured length since the detector reacts to the metal frame of the vehicle not the leading and trailing edge. Further studies indicated that the majority of passenger vehicles have a detector length of approximately 14 feet.

2.6.1 Station 5W Results and Assessment

Review of Illustrations 2.1 through 2.6 indicates that all detectors throughout the entire 24-hour period continuously passed this diagnostic test. This may indicate that the diagnostic test is not stringent enough and the equation for the threshold value needs to be re-visited. Two factors need to be considered; the estimated traffic speed and the function feature. The estimated traffic speed calculation has been checked and found to compare favorably with detector speed predictions.

Detector diagnostic results for a second day (March 4, 2004) were reviewed and were similar to the March 2, 2004 results, there were no test failures.

The earlier detector diagnostic test 2, minimum on-time diagnostic test failed in lane 1 (HOV lane) for short periods of time such as at about 5:30 AM, 9 to 10 AM, and 7 PM while Test 6 did not ever fail. Therefore it would be desirable to compare the two test results in more detail for periods of time just before, during, and after the Test 2 diagnostic test failures.

2.6.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are identical to those for the previously described Station 5W.

Review of Illustrations 2.7 through 2.12 indicates that all pairs of detectors pass this test during free-flow conditions.

2.6.3 Station 8W Results and Assessment

The diagnostic test results for Station 8W are identical to those for the previously described Stations 5W and 4W.

Review of Illustrations 2.13 through 2.18 indicates that all pairs of detectors pass this test during free-flow conditions.

2.6.4 Possible Improvements in the Dynamic Minimum On-Time Test

The dynamic minimum on-time test is intended to detect when the sensitivity of the detector card is set too low. As there have been extremely few false negatives with this test, the threshold value is likely set too low. A second area of concern is in the calculation of speed from a single loop. Comparison of the single loop speed estimation and the more accurate, dual loop speed measurement shows that, for correctly working loops, the single loop speed estimation is reasonably accurate. However. Further examination of the performance of the single loop speed estimation algorithm with mistuned loops needs to be done (see other portions of this report in Chapters 3 and 4).

For Station 5W, the earlier Test 2, minimum on-time diagnostic test, failed in lane 1 (HOV lane) for short periods of time such as at about 5:30 AM, 9 to 10 AM, and 7 PM while Test 6 did not

ever fail. The dynamic nature of Test 6 makes it less sensitive to very fast or very slow vehicles. A short car or motorcycle traveling 75 mph will be noted as a failure for the minimum on-time. Since Test 6 adjusts the expected on-time based on speed, it will correctly pass a series of fast vehicles or short vehicles where Test 2, the minimum on-time test, will fail.
Since essentially all detectors at the three stations passed this diagnostic test, further study should be undertaken of the equation for the threshold value. Consideration should be given to tighten this test and this will be discussed later in Chapter 4.

2.7 Test 7 Dynamic Maximum On-Time

The dynamic maximum on-time diagnostic test is similar to the maximum on-time diagnostic test (earlier Test 3) except that the threshold value of 600/60 seconds varies with the calculated traffic speed and whether the lane is designated as a truck-use lane or not. The test fails if 10% or more of the on-times in a sample of 100 vehicles are greater than the calculated maximum acceptable on-time threshold value. The equations for threshold value as a function of estimated traffic speed for predominant passenger vehicle lanes and for the anticipated truck-use lane (lane 5) are:

Max on-time (1/60 secs) = [(vl + dl)/(sp)][3600/88]

Where vl +dl is assumed to be 30 feet for predominant passenger vehicle lanes and 66 feet for other lanes

vl = vehicle length (assumed to be 24 feet for predominant passenger vehicle lanes and 60 feet for truck use lanes)
dl = detector zone length (assumed 6 feet)
sp = calculated average speed (mph)

<u>2.7.1 Station 5W Results and Assessment</u>

Review of Illustrations 2.1 through 2.6 indicates that except for lane 1 (HOV lane), there are a significant number of times the detectors fail this test particularly in lanes 3 and 4. It is significant to note that the upstream and downstream detectors in a particular lane give almost identical test results. The test results for each lane will be presented separately in the next paragraphs.

The diagnostic test applied to the two detectors in lane 1 gives identical results and no test failures were recorded for the entire 24-hour period. It would appear that a lane that is essentially a passenger vehicle-use lane would normally pass this diagnostic test. In fact consideration could be given to lowering the threshold value for freeway lanes carrying predominant passenger vehicles only. However the March 4, 2004 data indicated that there were two test failures at about 0800 and about three test failures between 1500 and 1600.

The diagnostic test applied to the two detectors in lane 2 gives identical results. While no diagnostic test failures were noted during free-flow conditions, there were many test failures during the afternoon congested period between 1500 and 1800. This lane is considered to be a predominant passenger vehicle lane and the test failures occurring only during the afternoon congested period suggests that attention should be given to the calculated speeds that influence the threshold value. The March 4, 2004 data indicated many test failures in both the morning and afternoon peak periods.

The test results for the diagnostic test applied to the two detectors in lane 5 will be discussed next because of the insights obtained from this lane which will be helpful in better understanding the test results for lanes 3 and 4. Recall that this was designated as a truck-use lane and had its own threshold equation. The two detectors in lane five gave almost identical results with no test failures under modest to congested flow (0530 to 0130) and some test failures during very low flow conditions (0130 to 0530). One suspects that during these early morning low-flow periods of time that there is a higher percent of longer vehicles in this lane and perhaps higher speeds. The results for March 2, 2004 were almost identical; test failures from about 0130 to 0500. Further research into these two issues will be important not only for lane 5 but as will be discussed in the next paragraph, important for lanes 3 and 4.

The test results for the diagnostic test applied to the two detectors in lanes 3 and 4 gave almost identical results. There were many test failures with both detectors throughout the 24-hour period except for the early evening hours (1800 to 2000). The test results for March 4, 2004 were very similar with some test failures. It does appear that the percent of trucks in lanes 3 and 4 is higher than originally expected and likely should be using the threshold equation applied to lane 5. Treating lanes 3 and 4 with the same threshold equation as used for lane 5 should result in lanes 3 and 4 giving similar results as now obtained for lane 5. However the test failures described in the previous paragraph and the suggested research for lane 5 is also applicable to lanes 3 and 4.

2.7.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are essentially identical to those for the previously described Station 5W.

Review of Illustrations 2.7 through 2.12 indicates that except for lane 1 (HOV lane), there are a significant number of times the detectors fail this test particularly in lanes 3 and 4. It is significant to note that the upstream and downstream detectors in a particular lane give almost identical test results.

2.7.3 Station 8W Results and Assessment

The results of the dynamic maximum on-time diagnostic test were quite different from the results obtained from Stations 5W and 4W with many test failures in most of the lanes. The pattern and intensity of test failures varied between lanes and therefore the results for each lane will be described separately in the following paragraphs. Illustrations 2.13 through 2.18 provide figures and a table of the results of this test for Station 8W.

Lane 1 diagnostic test failures were only slightly higher than those for the other two stations in this lane. There were two test failures in the upstream and downstream detectors between 1600 and 1700.

Lane 2 diagnostic test failures were relatively large for the upstream detector and there were no failures with the downstream detector. The test failures for the upstream detector occurred primarily between 1100 to 1200 and 1730 to 1830.

Lane 3 diagnostic test failures were relatively modest and the pattern of failures for the upstream and downstream detectors was similar. Almost all failures occurred between 1600 and 1900 under congested flow conditions.

Lane 4 diagnostic test failures were exceedingly high with almost continuous failures from 0000 to 1900. Both upstream and downstream detectors had similar patterns of test failures. These failures may be due to a higher percentage of trucks in this lane than expected and consideration should be given to reclassifying this lane as a truck-use lane.

Lane 5 diagnostic test failures were almost as severe as the results reported in the previous paragraph for lane 4. The test failures were exceedingly high with almost continuous failures from 0000 to 0500 and from 1000 to 1800. Both upstream and downstream detectors had similar patterns of test failures. These failures may be due to a higher percentage of trucks in this lane than expected and consideration should be given to reclassifying this lane as a truck-use lane.

Lane 6 diagnostic tests all failed due to lack of any data being provided by the upstream and downstream detectors.

2.7.4 Possible Improvements in the Dynamic Maximum On-Time Test

The dynamic maximum on-time test was intended to detect conditions where the detector cards are set with too high a sensitivity. The almost continuous failure of this test in mixed flow lanes under moderate to high flow makes interpretation of the test results problematic. Several hypotheses are being investigated to try to understand the results of this test. The BHL data provides information on the lengths of all vehicles passing over the loops by comparing the upstream and the downstream actuations. A possible cause of test failure is that trucks along this corridor are generally longer than the assumed truck length of 60 feet. Examination of the distribution of actual lengths should help determine if this is the cause of the test’s suboptimal performance. Designating several of the outer lanes as truck lanes, instead of just the outermost, would probably eliminate most of the failures in lanes 3 and 4 but raises the question of how to determine when a lane is mixed flow use and when it is not. The threshold for a mixed use lane is much looser than for a passenger car only lane so designating more lanes than necessary as mixed use lanes might miss loop failures that might otherwise be detected.

A study of the distribution of vehicle lengths revealed that there are a very large number of passenger vehicles in the range of 12 to 18 feet. The dynamic maximum on-time test essentially measures the percentage of on-times for vehicles lying beyond the trailing edge of this bulge in the length distribution. If the detector is too sensitive, the peak will shift to the right and the test will fail. The parameter length of 24 feet was selected as representing the upper end of the majority of passenger vehicles. This further analysis suggests that this parameter should be lowered to 18 feet.

For truck-use lanes, the vehicle length parameter appears to be too high. The distribution of truck lengths shows a small peak in the length distribution between 54 feet and 74 feet. The test parameter of 60 feet for trucks appear to be much too short and a more reasonable value would be approximately 74 feet. As discussed below, the overly short expected truck length resulted in many test failures in truck-use lanes.

2.8 Test 8 Minimum Off-Time

The minimum off-time diagnostic test is applied to both detectors in each lane and if 5% or more of the off-times in a sample of 100 vehicles are less than 25/60 seconds, the detector fails this test.

2.8.1 Station 5W Results and Assessment

Similar to other test results, the upstream and downstream detectors essentially had similar patterns of test failures and passes.   Review of Illustrations 2.1 through 2.6 indicates that while all detectors pass this test during the early morning low-flow period of time (0000-0500), all detectors did frequently fail the diagnostic test during other periods of the day.

Lanes 2 and 5 had the highest number of test failures while lane 3 had the lowest number of test failures. The March 4, 2004 test results were similar will the highest number of test failures in Lanes 1, 2, and 4 and the lowest in Lane 3.

2.8.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are essentially identical to those for the previously described Station 5W.

Similar to other test results, the upstream and downstream detectors essentially had similar patterns of test failures and passes.   While all detectors pass this test during the late evening (1800 to 2400) and early morning low-flow period of time (0000-0400), all detectors did occasionally fail the diagnostic test during other periods of the day. Review of Illustrations 2.7 through 2.12 confirms the previous observations.
Frequency of test failures was pretty well distributed between lanes with lanes one and four having a slightly higher number and lane 3 the lowest.

2.8.3 Station 8W Results and Assessment

The results of the dynamic minimum off-time diagnostic test were quite different from the results obtained from Stations 5W and 4W with many test failures with the detectors in lanes 2 through 5. The pattern and intensity of test failures varied between lanes and therefore the results for each lane will be described separately in the following paragraphs. Illustrations 2.13 through 2.18 provide figures and a table of the results of this test for Station 8W.

Lane 1 diagnostic test failures were rare and actually smaller than with the other two stations in this lane. There were two test failures in the upstream and downstream detectors that occurred at about 0700 and at about 1300.

Lane 2 diagnostic test failures were relatively high for both detectors in this lane. The test failures generally occurred from 0800 to 1500, however continuous test failures in the upstream detector were recorded from 1730 to 1830 (which was also true for Test 7 with this upstream detector).

Lane 3 diagnostic test failures were exceeding high and the patterns of failures for the upstream and downstream detectors were similar. Almost all failures occurred between 0500 and 1600. The least failures occurred during low flow situations.

Lane 4 diagnostic test failures were exceedingly high with almost continuous failures from 0400 to 2300. Both upstream and downstream detectors had similar patterns of test failures. The downstream detector passed this test less frequently than the upstream detector.

Lane 5 diagnostic test failures were almost as severe as the results reported in the previous paragraph for lane 4. The test failures were exceedingly high with almost continuous failures from 0500 to 2200. Both upstream and downstream detectors had similar patterns of test failures. The downstream detector passed this test less frequently than the upstream detector.

Lane 6 diagnostic tests all failed due to lack of any data being provided by the upstream and downstream detectors.

2.8.4 Possible Improvements in the Minimum Off-Time Test

The minimum off-time test will fail under a variety of loop detector error conditions. A failure may indicate the loop is triggering separately for the cab of a truck and the trailer. Under heavily congested conditions, the test will fail if the loop sensitivity is too high. The primary concern with this test is the lowering of the threshold to 25/60ths of a second. This is an extremely small gap time between vehicles. Further work is being done to assess whether the traffic in this corridor is unusually closely spaced or whether the test has implementation problems. A companion video study might also be helpful in the further study of minimum off-time distributions.

Ben Coifman of Ohio State University recently submitted a research report to Caltrans on his experimentation with detector cards at Station 8W. With this information, it is suggested that Caltrans inspect the controller and with particular attention focused on the detectors in lanes 3, 4, and 5. The concern is that the off-times are extremely small.

Because of the quality of data from the detectors at Station 5W, off-time distributions for each detector in each lane under varying traffic flow intensities were obtained. Particular attention was given to off-times less than 25/60 seconds. The results of this investigation confirmed that some vehicles on I-80 were traveling at very small time gaps between vehicles. Detailed analyzed suggested that the threshold value would have to be lowered from 25/60 seconds to 20/60 seconds for detectors to pass this test almost all of the time.

A simultaneous video record of one of the lanes at Station 8W with the detector pulse data (such as lane 3) might confirm these very short off-times and under what circumstances that they occur.

2.9 Test 9 Dynamic Maximum Off-Time

The dynamic maximum off-time diagnostic test is applied to both detectors in each lane and threshold value for this test is calculated as being three times the measured average time headway.

If 5% or more of the off-times in a sample of 100 vehicles are greater than the threshold value, the test is recorded as a failure. The equation for the threshold value is:

Max off-time (1/60 secs) = (t)(Tbar)(60)

Where:
t = 3 (representing 3 standard deviations)
Tbar = average time headway (seconds per vehicle)
60 = conversion from seconds to 1/60 secs

2.9.1 Station 5W Results and Assessment

Review of Illustrations 2.1 through 2.6 indicates that upstream and downstream detectors had similar patterns of test failures. The unique result was that lane 1 (HOV lane) had many more failures than the sum of all other lanes. Test failures were particularly noted in the evening from 1800 to 2400 in lane 1 (HOV lane). Detectors in lanes 3 and 4 always passed this diagnostic test.

The March 4, 2004 results were generally similar to the March 2, 2003 results with the highest number of test failures in Lane 1 and no test failures in Lane 4.

2.9.2 Station 4W Results and Assessment

The diagnostic test results for Station 4W are essentially identical to those for the previously described Station 5W.

Review of Illustrations 2.7 through 2.12 indicates that upstream and downstream detectors had similar patterns of test failures. The unique result was that lane 1 (HOV lane) had almost all of the test failures. Test failures were particular noted during the middle of the day (1000 to 1500) and in the evening from 1800 to 2400 in lane 1 (HOV lane). Detectors in lanes 3 always passed this diagnostic test.

2.9.3 Station 8W Results and Assessment

The test failures of the dynamic maximum off-time diagnostic test were higher than for Stations 5W and 4W. Illustrations 2.13 through 2.18 provide figures and a table of the results of this test for Station 8W.

Lane 1 diagnostic test failures were higher than other lanes at this station and at about the same level as lane 1 at the other two stations. Both upstream and downstream detectors failed in about one-half of the tests and had a similar pattern of test failures. It was unclear why this test failed so many times during periods of time of the HOV lane use restrictions particularly during the afternoon peak period.

The other lanes had more failures than similar lanes at other stations but about half as many as lane 1 at this station. Most of the test failures occurred between 1800 and 0400 under low to moderate flow levels. The pattern of test failures between upstream and downstream detectors was not consistent.

2.9.4 Possible Improvements in the Dynamic Maximum Off-Time Test

The dynamic maximum off-time test is a reasonable test for intermittent loop failures. The test will fail whenever there are several unusually long gaps between vehicles. It dynamically adjusts for the flow level so that as the flow falls, the expected gap between vehicles increases. An intermittent loop failure will violate this gap timing. The only systemic failures appear to be related to low flow conditions in HOV lanes. A possible explanation of this is that traffic in the HOV lane may exhibit platooning behavior that violates the underlying test assumptions. A series of closely spaced vehicles will generate a relatively small set of average time headway values such that next following vehicle some distance behind may be interpreted as a loop failure.

Because of the good quality of data from the detectors at Station 5W, the relationship between the calculated threshold value and the 5% measured off-time value will be investigated for each detector in each lane. The results of this investigation are likely to lead to a modification in the equation of the threshold value.

Further investigations will be required for Station 8W and these results will be presented later in Chapter 4.

2.10 Summary

The detectors at Stations 5W and 4W always provided data for the diagnostic tests and generally performed very well in the detector diagnostic tests. The detectors at Station 8W did not all provide data for the diagnostic tests and generally did not perform very well in these tests.

Because the detectors at Station 8W did not perform well based upon the detector diagnostics, further investigations and discussion of the performance of these detectors will be covered in the later Chapter 4 when the macroscopic freeway traffic performance results are provided for Station 8W.

The detector diagnostic test results for Stations 5W and 4W are summarized in the following paragraphs.

The Activity Test provided good results and no improvements are suggested.

The Minimum On-Time Test performed well except at the beginning and ending of HOV operations in Lane 1. Further studies suggested no change in the test procedures.

The Maximum On-Time Test was successfully passed by all detectors. Further studies suggested reducing the threshold value from 600/60 seconds to 400/60 seconds.

The Mode On-Time Test was successfully passed by all detectors with few exceptions. Further study results suggest that the threshold values be changed to 9.5/60 seconds and 16.5/60 seconds, not limit the test to speeds over 50 mph, and the sample size be reduced to 100 vehicles.

The Dual Detector On-Time Difference Test was successfully passed by all detectors. Further studies suggested that the threshold range be changed from +/- 3.5/60 seconds to +/- 2.5/60 seconds and the sample size be reduced to 100 vehicles but the test should continue to be limited to uncongested flow conditions (speeds over 50 mph).

The Dynamic Minimum On-Time Test was successfully passed by all detectors. Further study is underway to compare these results with the non-dynamic minimum on-time test and to determine if the equation for the threshold value should be modified to tighten this test.

The Dynamic Maximum On-Time Test was successfully passed only by detectors in lane 1. There was a significant number of test failures by detectors in other lanes. Further study was undertaken of passenger vehicle and truck length distributions. These results suggest changing the test parameter for passenger vehicles from 24 to 18 feet and for trucks from 60 to 74 feet.

The Minimum Off-Time Test frequently failed in almost all situations except under very low flow conditions. Further studies were undertaken of off-time distributions with particular attention given to off-times less than 25/60 seconds. Because of the extremely close spacing of vehicles, it is suggested that the threshold value be changed from 25/60 seconds to 20/60 seconds.

The Dynamic Maximum Off-Time Test often failed when applied to the detectors in the various lanes. Further study is underway to determine the relationship between the calculated threshold value and the 5% measured off-time value.

3. ANALYSIS OF MACROSCOPIC FREEWAY TRAFFIC PERFORMANCE MEASURES – STATION 5W

The first step on the BHL Detector Project's Task 1 "Analysis of Macroscopic Freeway Traffic Performance Measures" was to assemble a comprehensive data base including vehicle transition data, 30-second macroscopic data, system diagnostic results, detector diagnostic results, freeway incident reports, and weather data. Data was assembled for Tuesdays, Wednesdays, and Thursdays during the month of March 2004. The data set for Thursday, March 4th and the initial assessment of macroscopic performance measures for Station 5W were selected. The criteria used were the quality of the detector data, the positive results from the system and detector diagnostics, the occurrence of only a few minor freeway incidents in the area, and good weather conditions.

A map of the I-80 freeway study section showing the locations of the eight detector stations is presented in Illustration 3-1. Each detector station includes an array of detectors in each direction of travel with each array consisting of a pair of detectors in each lane. Each directional station consists of five lanes except for station 8 that has six lanes in each direction. Stations 4W and 5W are westbound detector stations located between the University on-ramp and the Ashby off-ramp along a straight and level section of the freeway slightly more than one mile in length. This is the direction toward Oakland and San Francisco. Station 4W is just downstream of the University on-ramp while station 5W is just upstream of the Ashby on-ramp. Station 5W was selected for the initial assessment of macroscopic freeway traffic performance measures.

The scope of this initial assessment includes the following macroscopic freeway traffic performance investigations:

- Assemble and assess March 2004 comprehensive database
- Develop software for processing BHL detector data for macroscopic freeway traffic performance analysis
- Assessment of individual lane traffic performance measures
- Assessment of directional roadway traffic performance measures
- Assessment of median lane (referred to hereafter as lane 1) traffic performance measures during hours of HOV operations and hours of mixed-flow operations
- Comparison of single-detector and dual-detector estimates of freeway lane speeds
- Development of methodology for substituting for missing data when detector(s) have failed
- Development of macroscopic detector diagnostics for individual lanes having single-detector and dual-detectors

3.1 Assemble and Assess March 2004 Comprehensive Database

The BHL data collection system calculates 30-second aggregate data that is continually recorded and then archived. The 30-second data for March 2, 2004 and March 4, 2004 was assembled and evaluated for completeness. It was determined that the March 2nd 30-second data had a period of time for which data was not recorded, but that the March 4th data was without any obvious gaps.

Therefore it was decided to use the March 4th data for assessment of macroscopic freeway traffic performance.

The 30-second summary data over 24 hours consists of 25,920 rows of data: 1 row for each of the 2880 30-second time periods for each of nine stations (station 8 is divided into an Eastbound station and a Westbound station). The data set has 53 columns. There are 5 columns of data for each of the 5 Eastbound lanes and 5 columns of data for each of the 5 Westbound lanes for stations 1-7 for a total of 50 columns. Stations 8W and 8E have 5 columns of data for each of their 6 lanes for a total of only 30 columns of data. There are three additional columns in the 30-second summary data set: the epoch time in milliseconds, expressed as elapsed time since midnight (beginning of the calendar day) GMT on January 1, 1970; the station number, and the date and time in PST.

The 30-second summary data is recorded in files of 4 hours duration for all stations so the first task was to import all six files into a spreadsheet program (JMP) and then sort it by station. The data for individual stations was then exported to Excel files and because the Westbound direction was chosen for analysis, the columns for Eastbound traffic were removed.

3.2 Develop Software for Processing BHL Detector Data for Macroscopic Freeway Traffic Performance Analysis

An Excel macro was developed to calculate 5-minute aggregate data for the Excel files that were created for each of the directional stations as described in the previous section. The code for this macro can be found in Appendix B. Code was developed so that if 30-second were missing, the appropriate rows would still be used to calculate the 5-minute aggregate data.

The 5-minute aggregate Excel macro was applied to each of the directional station Excel 30-second summary data files. The 5-minute aggregate data so produced consists of 288 rows, one for each 5 minute time period during the 24 hour day.

Before mapping the 5-minute aggregate data, the epoch time in milliseconds was converted to a 24-hour time from 0.000 to 23.917. These time values became a new column that could be used for plotting.

The first plots that were made revealed four points that appeared “suspicious” in that they were well outside the pattern of the other 284 points in all plots independent of the variables being plotted. It was determined that no data was received from the freeway for 152 seconds during the 5-minute period beginning at 16.583 hours and for 66 seconds during the 5-minute period beginning at 16.667 hours. This interruption of data transmission from the freeway resulted in missing 30-second summary data and thus incorrect 5-minuate aggregate data. In addition the 30-second data was not recorded for a 7.5 minutes period that spanned the 5-minute data points at 16.417 and at 16.50. Thus these two points were also incorrect. Based on the fact that all four of these “suspicious” points were incorrect due to technical problems in the data collection system, it was decided to remove them from the analysis.

3.3 Assessment of Individual Lane Traffic Performance Measures

The traffic performance measures of individual lanes will be assessed in terms of flow-percent occupancy relationships, speed-percent occupancy relationships, and speed-flow relationships. The following sections contain the assessment for individual lanes.

3.3.1 Lane 1 (Median Lane)

The median lane, hereafter referred to as lane 1, is a part-time HOV lane. Only vehicles with 3 or more persons can legally use this lane during the weekday morning (5 to 10 AM) and weekday afternoon peak periods (3 to 7 PM). It should be noted that while the lane adjacent to the median lane is lightly congested during the morning peak periods, the adjacent lane is heavily congested during the afternoon peak period. As will be presented later, the performance of the adjacent lane has a significant impact upon the performance in the median lane particularly during the afternoon HOV operations.

The flow rate (vehicles per hour per lane) versus the lane percent occupancy (%) relationship is displayed in Illustration 3.2. The flow rate is shown on the vertical scale while the percent occupancy is shown on the horizontal scale. Each point on the illustration represents a five-minute period of time and there are a total of 284 data points displayed (12 data points per hour for 24 hours) minus the four data points previously discussed.

Except for a cluster of unique data points (flow rates of 800 to 1400 vehicles per hour with percent occupancies of 6 to 15%), the relationship represents a typical freeway lane. The significance of this unique set of data points will be discussed later but essentially all of these data points were for the afternoon peak period from 3 to 7 PM when the median lane was designated for HOV vehicle use only and the adjacent lane was heavily congested.

The typical relationship can be subdivided into three parts: free-flow, near-capacity flow, and congested-flow. Free-flow operations occur when the percent occupancy is less than about 12% with flow rates increasing almost linearly from very low flow to almost capacity flow. Near-capacity conditions occur with percent occupancies between about 12% up to about 20 percent and flow rates on the order of 2000 vehicles per hour or slightly higher. Congested-flow conditions occur with percent occupancies over 20% and flows less than 2000 vehicles per hour.

Illustration 3.3 displays the same 284 data points but this time as an average speed (miles per hour) versus percent occupancy (%) relationship. Again there is the same unique cluster of data points (speeds from 65 to 35 mph and percent occupancies from 5% to 15%). Otherwise the relationship is a very tight relationship with most data points lying within +/- 5 mph of the central value. Note that maximum 5-minute average speeds are on the order of 73 to 83 mph and the highest observed 5-minute percent occupancies were about 35%.

The final illustration for lane 1 is of the average speed-flow rate relationship as presented in Illustration 3.4. As before the same 284 data points are included in this illustration. The unique cluster of data points also occurs in this illustration (flow rates of 750 to 1300 vph with average speeds of 65 to 35 mph). Data points under free-flow conditions can be clearly seen almost as a linear function from speeds of 75-83 mph under very low flow conditions to speeds of about 65 mph under flow rates of 2000 vph. Near-capacity conditions occur at speeds of 40 to 65 mph and lane densities of 30 to 50 vehicles per mile (density can be calculated as the ratio of flow divided by speed). Data points observed during congested-flow conditions occur at flows less than 2000 vph and speeds less than 40 mph.

3.3.2 Lane 2

The data points for lane 2 are arranged in a flow rate-percent occupancy relationship format in Illustration 3.5. The data points in the free-flow range are relatively tight and linear in the 0% to 12% range. Flows over 2000 vph are observed at percent occupancies between 12 and 22% with a single maximum 5-minute flow rate of slightly over 2500 vph. The data points in the congested-flow conditions are more scattered with percent occupancies ranging from 22% to a high of 44%. Note that the unique cluster of data points identified earlier for the median lane (lane 1) does not appear in the data points for this lane.

The data points for lane 2 are arranged in an average speed-percent occupancy relationship format in Illustration 3.6. The data points in the free-flow range are relatively tight with speeds ranging from 75 to 65 mph with associated percent occupancies from 0% to 12%. The near-capacity data points are almost linear in the 12% to 22% with speeds between 65 to 45 mph. The data points observed under the congested-flow conditions are more scattered with percent occupancies ranging from about 22 percent to 44 percent and speeds less than 45 mph.

The data points for lane 2 are arranged in an average speed-flow rate relationship format in Illustration 3.7. The data points in the free-flow range are relatively tight and linear with average speeds ranging from 75 to 65 mph and flows increasing to over 2000 vph. The near-capacity data points occur at speeds between 65 to 45 mph and many 5-minute flows occur over 2000 vph with the highest flow being over 2500 vph. The data points observed during the congested-flow conditions are slightly more scattered with speeds observed lower than 45 mph and flows less than 2100 vph.

3.3.3 Lane 3

The data points for lane 3 are arranged in a flow rate-percent occupancy relationship format in Illustration 3.8. The data points in the free-flow range are relatively tight and linear in the 0% to 14% range. Flows over 1800 vph are observed at percent occupancies between 14 and 20% with a maximum 5-minute flow rate of about 1900 vph. The data points in the congested-flow conditions are more scattered with percent occupancies ranging from 20% to a high of 47%.

The data points for lane 3 are arranged in an average speed-percent occupancy relationship format in Illustration 3.9. The data points in the free-flow range are relatively tight with speeds ranging from 73 to 60 mph with associated percent occupancies from 0% to 14%. The near-capacity data points are almost linear in the 14% to 20% with speeds between 60 to 40 mph. The data points observed under the congested-flow conditions are more scattered with percent occupancies ranging from about 20 percent to 47 percent and speeds less than 40 mph.

The data points for lane 3 are arranged in an average speed-flow rate relationship format in Illustration 3.10. The data points in the free-flow range are relatively tight and linear with average speeds ranging from 73 to about 60 mph and flows increasing to over 1800 vph. The near-capacity data points occur at speeds between 60 to 40 mph and with some 5-minute flows occur over 1800 vph with the highest flow being about 1900 vph. The data points observed during the congested-flow conditions are slightly more scattered with speeds observed lower than 40 mph and flows less than 1800 vph.

3.3.4 Lane 4

The data points for lane 4 are arranged in a flow rate-percent occupancy relationship format in Illustration 3.11. The data points in the free-flow range are relatively tight in the 0% to 13% range. Flows over 1800 vph are observed at percent occupancies between 13 and 20% with a maximum 5-minute flow rate of about 2100 vph. The data points in the congested-flow conditions are more scattered with percent occupancies ranging from 20% to a high of 37%.

The data points for lane 4 are arranged in an average speed-percent occupancy relationship format in Illustration 3.12. The data points in the free-flow range are relatively tight with speeds ranging from 71 to 60 mph with associated percent occupancies from 0% to 13%. The near-capacity data points are almost linear in the 13% to 20% with speeds between 60 to 35 mph. The data points observed under the congested-flow conditions have percent occupancies ranging from about 20 percent to 37 percent and speeds less than 35 mph.

The data points for lane 4 are arranged in an average speed-flow rate relationship format in Illustration 3.13. The data points in the free-flow range are relatively tight and linear with average speeds ranging from 71 to about 60 mph and flows increasing to 1800 vph. The near-capacity data points occur at speeds between 60 to 35 mph and with some 5-minute flows occurring over 1800 vph with the highest flow being about 2100 vph. The data points observed during the congested-flow conditions are slightly more scattered with speeds observed lower than 35 mph and flows less than 1800 vph.

3.3.5 Lane 5

The data points for lane 5 are arranged in a flow rate-percent occupancy relationship format in Illustration 3.14. The data points in the free-flow range are relatively tight in the 0% to 16% range. Flows over 1900 vph are observed at percent occupancies between 16 and 25% with a maximum 5-minute flow rate of about 2100 vph. The data points in the congested-flow conditions are more scattered with percent occupancies ranging from 25% to a high of 34%.

The data points for lane 5 are arranged in an average speed-percent occupancy relationship format in Illustration 3.15. The data points in the free-flow range have speeds ranging from 71 to 50 mph with associated percent occupancies from 0% to 16%. The near-capacity data points are almost linear in the 16% to 25% with speeds between 50 to 35 mph. The data points observed under the congested-flow conditions have percent occupancies ranging from about 25 percent to 34 percent and speeds less than 35 mph.

The data points for lane 5 are arranged in an average speed-flow rate relationship format in Illustration 3.16. The data points in the free-flow range from average speeds of 71 to about 50 mph and flows increasing to 1900 vph. The near-capacity data points occur at speeds between 50 to 35 mph and with some 5-minute flows occurring over 1900 vph with the highest flow being about 2100 vph. The data points observed during the congested-flow conditions are slightly more scattered with speeds observed lower than 35 mph and flows less than 1900 vph.

3.3.6 Assessment

A tabular summary of the individual lane traffic performance measures is provided in Illustration 3.17. The ranges of flow rates, percent occupancies, and average speeds for each of the five lanes are provided for free-flow, near-capacity flow, and congested-flow conditions.

Under free-flow conditions, the maximum average speed decreased from lane 1 to lane 5 (83, 75, 73, 71, to 71 mph respectively). The maximum lane percent occupancy under free-flow conditions generally increased from lane 1 to lane 5 (12%, 12%, 14%, 13%, to 16% respectively).

The near-capacity conditions are the most interesting to observe. The maximum lane flow rates varied from 1900 to 2600 vph and always were at least 1800 vph in each lane. The lower bound of lane percent occupancies varied from 12% to 16% while the upper bound of lane percent occupancies varied from 20% to 25%. The upper bound of lane average speed varied from 50 to 65 mph while the lower bound of lane average speed varied from 35 to 45 mph.

Under-congested flow conditions, the maximum lane percent occupancy varied between 34% to 47% while the minimum lane average speed varied between 8 and 20 mph. Flow rates as low as 700 vphpl were observed under heavy congested-flow conditions.

There were a few other interesting results from this initial assessment of individual lane macroscopic freeway traffic performance measures.

A unique set of data points were observed in lane 1 (the HOV lane) in all three of the relationship illustrations. These will be addressed later in Section 3.5 of this chapter.

There were four widely scattered data points observed in all lanes in all three of the relationship illustrations. They occurred under very low flow and speed conditions between about 1625 and 1645. Further study indicated that the entire BHL system did not receive detector data for several minutes during this period of time. These four 5-minute data points were removed from this analysis.

Under free-flow conditions, the three relationships are relatively well defined with increased flows having a greater impact in lowering speeds and increasing percent occupancies in the lanes closer to the right-shoulder.

Under near-capacity flow and congested-flow conditions, the average speed-flow rate relationships are not well-defined, the flow rate-percent occupancy relationships are moderately well-defined, and the average speed-percent occupancy relationships are well-defined (Illustrations 3.3, 3.6, 3.9, 3.12, and 3.15). These recognized patterns (particularly the speed-percent occupancy relationships) will be very helpful later in Sections 3.7 and 3.8 of this chapter in developing methods for substituting missing data and developing macroscopic detector diagnostics.

3.4 Assessment of Directional Roadway Traffic Performance Measures

The traffic performance measures for the individual lanes presented in the previous section have been combined (all five lanes) to provide directional roadway traffic performance measures. The results will be presented in the next few paragraphs followed by an assessment of these results.

3.4.1 Results

Illustration 3.18 presents the variation of 5-minute hourly flow rates by time of day for the entire directional roadway at Station 5W. The lowest flow rates were observed from 11:45 PM to 4:30 AM (less than 2000 vph) with the lowest 5-minute flow rate (324 vph) occurring between 2:00 and 2:05 AM. The highest flow rates (over 9000 vph) were observed from 6:10 AM until 7:15 AM with the highest 5-minute flow rate (10,032 vph) occurring between 6:15 and 6:20 AM. Surprising, the highest afternoon 5-minute flow rates only exceeded 8000 vph between 1 and 3 PM. Very few 5-minute periods during the afternoon peak period exceeded 7000 vph due to downstream bottlenecks that caused heavy congestion at station 5W. Note the unusual values entered for the 5-minute periods between 1625 and 1645 due to the absence of detector data for several minutes.

Illustration 3.19 presents the variation of 5-minute percent occupancies and average speeds by time of day for the entire directional roadway at Station 5W. Some interpretations from these two curves will be discussed in the following two paragraphs.

The lowest percent occupancies (less than 10%) were observed from 6:40 PM until 5:45 AM with the lowest 5-minute percent occupancy (0.5%) occurring between 2:00 and 2:05 AM. The highest percent occupancies (over 25%) occurred in the morning between 7:15 AM and 7:50 AM and in the afternoon between 2:40 PM and 5:30 PM. The highest individual 5-minute percent occupancy occurring in the morning peak period (31%) was between 7:30 and 7:35 AM and in the afternoon peak period (34%) was between 3:25 and 3:30 PM.

The highest average speeds (over 65 mph) were observed from 6:50 PM until 5:45 AM with the highest 5-minute average speed (73 mph) occurring between 11:50 and 11:55 PM. The lowest average speeds (less than 30 mph) occurred in the morning between 7:15 and 7:50 AM and in the afternoon between 2:40 PM and 5:55 PM. The lowest individual 5-minute average speed occurring in the morning peak period (21 mph) between 7:30 and 7:35 AM and in the afternoon peak period (18 mph) between 4:10 to 4:15 PM.

3.4.2 Assessment

The maximum observed five-minute flow rate at this station was 10,000 vph (an average of 2000 vphpl). It is likely that this station could maintain this flow rate for longer periods of time or even exceed this value if shock waves from downstream bottlenecks had not occurred.

It is of great significance to note that during the afternoon peak period when traffic demand is extremely high, the maximum observed five-minute flow rate at this station was only 7800 vph (an average of lane flow rate of 1560 vph). This indicates that when capacity flow at station 5W is needed most, the maximum five-minute flow rates were reduced from about 10,000 to 7800 vph, a loss of 2200 vph (22% loss); essentially one lane of maximum flow potential has been lost due to downstream bottleneck(s).

The average speed and percent occupancy plots versus time of day were very revealing. Some refer to this phenomenon as the 'speed-to-occupancy inversion' with speed and occupancy exhibiting mirror images. This again confirms the well-defined relationship between speed and occupancy. Both the average speed pattern and the percent occupancy pattern between about 0900 and 1100 indicate a continuing transition between congested-flow conditions and free-flow conditions. This is likely caused by intermittent shock waves passing through this station due to downstream bottleneck(s).

3.5 Assessment of HOV Median Lane Traffic Performance Measures

As described earlier in Section 3.3 in this chapter, there was a cluster of unique data points on the flow-occupancy, speed-occupancy, and speed-flow relationship illustrations for the median lane (lane 1). This lane is a part-time HOV lane that is reserved for HOV vehicles from 5 until 10 AM and from 3 to 7 PM on weekdays. During other hours of the day and also on weekends, this lane operates as a general-use lane. While the level of congestion in lanes 2-5 is not too heavy during the morning peak period, they are very congested during the afternoon peak period. It was suspected that the low speed operation in the lane adjacent to the median lane (lane 2) during the peak periods, particularly the afternoon peak period, reduced the expected speeds in lane 1.

One objective of this section in the chapter is to determine the reasons for these clusters of unique data points. A second objective is develop a better procedure for estimating lane 1 average speeds and percent occupancies during HOV lane operations (at least for the afternoon peak period) as influenced by congestion in the adjacent lane 2.

3.5.1 Further Assessment of Lane 1 Flow-Percent Occupancy Relationship

Illustration 3.20 is identical to the earlier Illustration 3.2 that is a plot of 5-minute date points on a flow rate-percent occupancy type of graph including 284 five-minute data points for the 24-hour period of time. The cluster of unique data points can be seen in the graph lying in a area between the vertex (0,0) and a flow of 1300 at a percent occupancy of about 15%.
Illustration 3.21 is identical to the previous Illustration 3.20 except the data points that are included are limited to non-HOV hours of operation. The data points are very consistent with

typical flow-percent occupancy relationships and do not include any data points in the unique data cluster.

Illustration 3.22 is identical to the previous Illustration 3.20 except the data points that are included are limited to HOV hours of operations. The data points for the morning peak period of HOV operations are depicted with one symbol and the data points for the afternoon peak period of HOV operations are depicted with a different symbol. While the data points for the morning peak period are similar to those for non-HOV operations periods of time, the data points for the afternoon peak period are very dissimilar to those for non-HOV lane operations periods of time.

For given flow levels in the HOV lane, the percent occupancy is several percent to 7-8 percent higher than expected with corresponding reduced flow levels up to 1000 vphpl.. Also recall that the slope of the line from the vertex up and to the right is a function of average speed with flatter slopes representing lower speeds. Thus for a given flow level in the HOV lane in the afternoon peak period when the adjacent lane is heavily congested, the percent occupancies are higher and the average speeds are lower than expected.

Based on this analysis, the flow conditions (congested or not congested) in the adjacent lane needs to be considered if percent occupancies are to be estimated in the HOV lane.

3.5.2 Further Assessment of Lane 1 Speed-Percent Occupancy Relationship

Illustration 3.23 is identical to the earlier Illustration 3.3 that is a plot of 5-minute date points on a average speed-percent occupancy type of graph including 284 five-minute data points for the 24-hour period of time. The cluster of unique data points can be seen in the graph lying in a line between an average speed of about 65 mph at a percent occupancy of 6% to an average speed of 40 mph at a percent occupancy of 16%.

Illustration 3.24 is identical to the previous Illustration 3.23 except the data points that are included are limited to non-HOV hours of operation. The data points are very consistent with typical flow rate-percent occupancy relationships and do not include any data points in the unique data cluster.

Illustration 3.25 is identical to the previous Illustration 3.24 except the data points that are included are limited to HOV hours of operations. The data points for the morning peak period of HOV operations are depicted with one symbol and the data points for the afternoon peak period of HOV operations are depicted with a different symbol. While the data points for the morning peak period are close to those for non-HOV operations periods of time, the data points for the afternoon peak period are very dissimilar to those for non-HOV lane operations periods of time.

For a given percent occupancy levels in the HOV lane, the average speed is zero to 20 mph less than expected. There is little difference between actual average speed and expected average speed when speeds in the HOV lane are high or when the percent occupancy is high. The largest differences occur at percent occupancy levels of 8% to 13%. Thus for a given percent occupancy level in the HOV lane in the afternoon peak period when the adjacent lane is heavily congested, the average speeds in the HOV lane are much lower than expected. Thus, special procedures need to be developed for improving the estimation of percent occupancies and average speeds in lane 1 during the afternoon peak period of HOV operation based on these results and whether the adjacent lane is congested.

At least three approaches could be considered. One would use the data as shown in the previous Illustration 3.25 for the morning and afternoon peak period. One could either develop a separate equation for the average speed-percent occupancy relationship for these special conditions (HOV lane operation and congested adjacent lane) or a correction factor to reduce the normal expected average speed (i.e.18 mph reduction in average speed under percent occupancy levels of 10%). Illustration contains a linear equation (solid line) for estimating lane 1 average speed as a function of the lane 2 average speed. The dashed line represents the situation when the average speed in lane 1 would be equal to the average speed in lane 2.

Another approach would be to develop a lane average speed relationship between the HOV lane and the adjacent lane. The data points depicting the relationship between lane 1 average speed and lane 2 average speed are shown in Illustration 3.26. Except for the four data points described earlier, the other data points are clustered along a line whose relationship suggests that the lane 1 average speed would approximately be equal to 32 mph plus 0.63 times the lane 2 average speed. This would result in the median HOV lane speed of about 32 mph when the adjacent lane is essentially stopped and a lane 1 speed about equal to the adjacent lane speed is 75 to 80 mph. The linear equation and the line representing the equation is shown on Illustration 3.26. The dashed line represents the situation when the average speed in lane 1 is equal to the average speed in lane 2.

A third method would be to estimate the percent occupancy based on the measured flow rate (using earlier Illustration 3.20) and then re-estimate the average speed based on the estimated percent occupancy (using earlier Illustration 3.23). Keep in mind that these three procedures would be limited to HOV lane operations when the adjacent lane is heavily congested.

3.5.3 Summary

Unique flow rate-average speed-percent occupancy relationships occur in lane 1 during the afternoon peak period when the lane is reserved for HOV vehicles and the adjacent lane is heavily congested. For given flow levels, percent occupancies are considerably higher and average speeds are considerable lower than general-use lanes (as much as 8 percent occupancy and 20 mph). Methodologies have been suggested for estimating traffic performance measures under such situations.

For those predicting the performance of HOV lanes on proposed new HOV facilities these results may be very important. In estimating the benefits to HOV users, these results may provide a more conservative but realistic estimate of the benefits of HOV lanes. It may also be of value in re-assessing the added benefits of some type of barrier separation between the HOV lane and the adjacent mixed-flow lane in the event of heavy congestion in the mixed-flow lanes.

3.6 Comparison of Single-Detector and Dual-Detector Estimates of Freeway Lane Speeds

The current BHL detector system permits the estimation of freeway lane speeds by employing dual-detectors and uses the elapsed time between passage of a vehicle between detectors at input. Other detector systems employing single-detectors estimate freeway lane speeds based on flow rate and percent occupancy relationships or percent occupancy relationships.

The BHL detector system permits the comparison of methods of estimating freeway lane speeds from dual-detectors and single-detectors. This research is important for two reasons. Obviously such study will provide information about the differences between methods. A more important objective of the study from the perspective of the BHL detector system is to determine the best method of estimating freeway lane speed when one of the two lane dual-detectors is not providing good data and a speed estimate is desired.
There are at least two methods for estimating freeway lane speed from a single presence-type detector. One method is to estimate speed from the average speed-percent occupancy relationship obtained from previous field measurements for the lane in question. Such relationships for individual lanes at Station 5W were depicted earlier in this chapter in Illustrations 3.3, 3.6, 3.9, 3.12, and 3.15. Curve equations for such relationships can be developed that permitted estimating the mean freeway lane speed as a function of percent occupancy.

Another method for estimating lane speed from a single presence-type detector is to estimate speed from the combination of flow rate and percent occupancy. Freeway lane speed can be calculated as the ratio of flow rate to density. Density can be estimated as a function of percent occupancy. Combining these two equations, speed can be estimated from flow rate and percent occupancy by the following equation (Reference 1).

$$\text{Speed} = \text{Flow}/[(52.8 * \%\ \text{Occ})/(Lv + Ld)]$$

Where Lv = average length of vehicle and
Ld = length of detector zone

It is necessary to calibrate the equation for the average vehicle length and detector zone length. The calibration effort is complicated by the fact that it is likely that average vehicle length may vary over time and vary particularly between lanes and stations.

The first of the two methods was applied to each of the five lanes at Station 5W and equations developed for the average speed-percent occupancy relationships for each lane. Then an analysis was made of the resulting predicted single-detector average speeds and the dual-detector measured average speeds. The results for each of the five lanes will be discussed first followed by a summary of the set of results.

3.6.1 Lane 1

Illustration 3.27 is similar to the earlier Illustration 3.3 with several added results. Curve fitting of the data points was undertaken and the curve is superimposed upon the data points and a single-regime equation is shown for the curve. The resulting R-square value was 0.90 and the mean error (the absolute mean difference between the measured average speed and the curve predicted speed) varied from 1.3 mph to 4.3 mph in five percent occupancy intervals from 0% to 35%. Note the cluster of data points below the curve in the 5% to 10% interval. These data points were obtained during the afternoon peak period when the lane adjacent to the HOV lane was heavily congested. This reduced the expected speed in the HOV lane during this period of time. Also visualize the shape pattern of the remaining data points. It is apparent that a two-regime (free-flow and congested-flow regimes) curve fit would better fit the data points but with the added complexity of having two equations and selecting a breakpoint between the two regimes. A two-regime curve fit was not pursued.

The comparison of results between estimating freeway lane speed using the elapsed time between dual-detectors (horizontal scale) and estimating freeway lane speed using percent occupancy from a single detector (vertical scale) is shown in Illustration 3.28. The results from the upstream detector and the downstream detector in each lane were so similar that only the upstream detector results are shown on the vertical scale.

Illustration 3.28 clearly shows the relatively close comparison between the two methods of estimating speed. The linear regression analysis for the data points is shown on the illustration as well as the linear curve (solid line). The R-square value was 0.90 and the overall mean error of the individual data points was 3.4 mph. The pair of dashed lines signifies potential errors of +/- 5 mph for reference purposes. Again the largest error discrepancies in the single-detector estimated average speeds for the median HOV lane was due to the adjacent lane being congested during the afternoon peak period. Note that under extremely low flow conditions, the single-detector estimated speed is a constant (77 mph)

3.6.2 Lane 2

Illustration 3.29 is similar to the earlier Illustration 3.6 with several added results. Curve fitting of the data points was undertaken and the curve is superimposed upon the data points and a single-regime equation is shown for the curve. The resulting R-square value was 0.97 and the absolute mean error varied from 1.6 mph to 4.4 mph in five-percent occupancy intervals from 0% to 45%. Visualize the shape pattern of the data points. It is apparent that a two-regime (free-flow and congested-flow regimes) curve fit would better fit the data points but with the added complexity of having two equations and selecting a breakpoint between the two regimes. A two-regime curve fit was not pursued.

The comparison of results between estimating freeway lane speed using the elapsed time between dual-detectors (horizontal scale) and estimating freeway lane speed using percent occupancy from a single detector (vertical scale) is shown in Illustration 3.30. The results from the upstream detector and the downstream detector in each lane were so similar that only the upstream detector results are shown on the vertical scale.

Illustration 3.30 clearly shows the relatively close comparison between the two methods of estimating speed. The linear regression analysis for the data points is shown on the illustration as well as the resulting linear curve (solid line). The resulting curve lies almost exactly along the line representing when the single detector speed estimate is exactly equal to the dual detector speed estimate line. The R-square value was 0.97 and the overall mean error of the individual data points was 2.7 mph. The pair of dashed lines signifies potential errors of +/- 5 mph for reference purposes. Note that under extremely low flow conditions, the single-detector estimated speed is constant (74 mph).

3.6.3 Lane 3

Illustration 3.31 is similar to the earlier Illustration 3.9 with several added results. Curve fitting of the data points was undertaken and the curve is superimposed upon the data points and a single-regime equation is shown for the curve. The resulting R-square value was 0.96 and the absolute mean error varied from 0.6 mph to 4.2 mph in five percent occupancy intervals from 0% to 45%. Visualize the shape pattern of the data points. It is apparent that a two-regime (free-flow and congested-flow regimes) curve fit would better fit the data points but with the added complexity of having two equations and selecting a breakpoint between the two regimes. A two-regime curve fit was not pursued.
The comparison of results between estimating freeway lane speed using the elapsed time between dual-detectors (horizontal scale) and estimating freeway lane speed using percent occupancy from a single detector (vertical scale) is shown in Illustration 3.32. The results from the upstream detector and the downstream detector in each lane were so similar that only the upstream detector results are shown on the vertical scale.

Illustration 3.32 clearly shows the relatively close comparison between the two methods of estimating speed. The linear regression analysis for the data points is shown on the illustration as well as the resulting linear curve (solid line). The R-square value was 0.96 and the overall mean error of the individual data points was 2.7 mph. The pair of dashed lines signifies potential errors of +/- 5 mph for reference purposes. Note that under extremely low flow conditions, the single-detector estimated speed is a constant (71 mph).

3.6.4 Lane 4

Illustration 3.33 is similar to the earlier Illustration 3.12 with several added results. Curve fitting of the data points was undertaken and the curve is superimposed upon the data points and a single-regime equation is shown for the curve. The resulting R-square value was 0.96 and the absolute mean error varied from 1.2 mph to 3.4 in five-percent occupancy intervals from 0% to 40%. Visualize the shape pattern of the data points. It is apparent that a two-regime (free-flow and congested-flow regimes) curve fit would better fit the data points but with the added complexity of having two equations and selecting a breakpoint between the two regimes. A two-regime curve fit was not pursued.

The comparison of results between estimating freeway lane speed using the elapsed time between dual-detectors (horizontal scale) and estimating freeway lane speed using percent occupancy from a single detector (vertical scale) is shown in Illustration 3.34. The results from the upstream detector and the downstream detector in each lane were so similar that only the upstream detector results are shown on the vertical scale.

Illustration 3.34 clearly shows the relatively close comparison between the two methods of estimating speed. The linear regression analysis for the data points is shown on the illustration as well as the fitted linear curve (solid line) that is it an almost perfect 45-degree angle. The R-square value was 0.96 and the overall mean error of the individual data points was 2.2 mph. The pair of dashed lines signifies potential errors of +/- 5 mph for reference purposes. Note that at extremely low flow conditions, the estimated single-detector speed is a constant (70 mph).

3.6.5 Lane 5

Illustration 3.35 is similar to the earlier Illustration 3.15 with several added results. Curve fitting of the data points was undertaken and the curve is superimposed upon the data points and a single-regime equation is shown for the curve. The resulting R-square value was 0.97 and the absolute mean error varied from 1.0 mph to 2.6 mph in five-percent occupancy intervals from 0% to 35%. Visualize the shape pattern of the data points. It is apparent that a two-regime (free-flow and congested-flow regimes) curve fit would better fit the data points but with the added complexity of having two equations and selecting a breakpoint between the two regimes. A two-regime curve fit was not pursued.

The comparison of results between estimating freeway lane speed using the elapsed time between dual-detectors (horizontal scale) and estimating freeway lane speed using percent occupancy from a single detector (vertical scale) is shown in Illustration 3.36. The results from the upstream detector and the downstream detector in each lane were so similar that only the upstream detector results are shown on the vertical scale.

Illustration 3.36 clearly shows the relatively close comparison between the two methods of estimating speed. The linear regression analysis for the data points is shown on the illustration as well as the resulting fitted linear curve (solid line). The R-square value was 0.97 and the overall mean error of the individual data points was 2.0 mph. The pair of dashed lines signifies potential errors of +/- 5 mph for reference purposes. Under extremely low flow conditions, the estimated single-detector average speed was a constant (67 mph).

3.6.6 Summary

The R-square values for the speed-percent occupancy curve for lanes 1, 2, 3, 4, and 5 were 0.90, 0.97, 0.96, 0.96, and 0.97 respectively. The R-square values for the single-detector estimated speed to the dual-detector estimated speed for lanes 1, 2, 3, 4, and 5 were 0.90, 0.97, 0.96, 0.96, and 0.97 respectively. The greatest difference of the speed-percent occupancy curves between lanes occurred under high speed-low percent occupancy conditions. The was due to differenting y-intercepts of 77, 74, 71, 70 and 67 mph in lanes 1, 2, 3, 4, and 5 respectively.

Summaries of the mean errors by 5% occupancy levels from 0% to 45% for each of the five lanes is shown in two tables contained in Illustration 3.37. The average values shown in the upper table are based on summing the individual error for each data point (including the sign of the error for each data point) and divided by the number of data points. The overall average errors for lanes 1, 2, 3, 4, and 5 were 0.5, 0.3, 0.4 0.3, and 0.3 respectively.

The average values shown in the lower table are based on summing the individual error for each data point (disregarding the sign of the error) divided by the number of data points and are labeled as absolute average errors. The absolute average errors for lanes 1, 2, 3, 4, and 5 were 3.4, 2.7, 2.7, 2.2, and 2.0 respectively. Minimum and maximum values of individual data points are also given in each table for each lane and for each 5% occupancy range. The largest maximum individual values occurred in the median HOV lane 1. The maximum individual value in all over lanes was 13.1 mph in lane 3.

In summary, The estimated speeds from single-detectors were very close to estimated speeds from dual-detectors. This close agreement was reassuring for those freeway surveillance systems having only single-detector systems. It also extremely important for dual-detector systems as a fall-back mode of operation for estimating average speed when one of the two dual-detectors in a lane has failed.

3.7 Development of Methodology for Substituting for Missing Detector Data

Individual detectors in freeway detector systems fail in providing good data from time to time. The objective of detector diagnostic procedures is to predict when individual detectors are providing good data. When a detector is not providing good data, it is important to have methodologies that would replace the ‘missing’ data with reasonably good estimates. The objective of this section of the chapter is to develop this methodology for replacing ‘missing data’ with reasonably good estimates.

The proposed methodology consists of four major steps as shown in Illustration 3.38. Step one is to determine whether the methodology needs to be applied, and if so, what portion of the methodology should be used.

3.7.1 One Detector Failure in a Lane

Step two provides a methodology for the situation when only one detector in a particular lane is predicted as not providing good data. Up to one detector in every lane can fail but not both detectors in any lane in order for the methodology to work. This methodology is based on the results presented in the previous section of this chapter. That is, the flow rate and percent occupancy from the detector that is predicted as providing good data is used for this lane’s performance measures, and speed is estimated based on the percent occupancy as described in the previous section of this chapter. The potential loss of accuracy due to this substituting of missing data was provided in the previous section of this chapter and is in the order of 2 to 3 mph on average.

3.7.2 Both Detectors Fail in One Lane Only

Step three provides a methodology for the situation when both of the dual-detectors in a single lane are predicted as not providing good data. This methodology is not applicable if both detectors in two or more lanes are predicted as not providing good data.

The Step three methodology is based on estimating the missing lane's percent occupancy on the average percent occupancy of the remaining freeway lanes. These relationships and equations for each of the individual five lanes for Station 5W are shown in Illustrations 3.39, 3.40, 3.41, 3.42, and 3.43. Thus the occupancy in any lane can be estimated based on the average occupancy in the remaining four lanes. Note the unique display of data points in Lane 1 due to the adjacent lane being heavily congested during the afternoon peak period when lane 1 is designated as a HOV lane. None of the other lanes exhibit this unique display. The R-square values for the linear equations for the five lanes (from the median lane to the shoulder lane) were 0.92 (0.91), 0.94, 0.95, 0.95, and 0.96.

Based on the estimated percent occupancy from Illustrations 3.39, 3.40, 3.41, 3.42, and 3.43, the lane flow rate and the average speed are estimated based on the relationships contained in earlier portions of this Chapter.
For example for lane 2, Illustration 3.5 would be used to estimate the flow rate while Illustration 3.29 and accompanying equation would be used to estimate the average lane speed. To simplify the methodology if a lower accuracy is acceptable, a more generic single flow rate-percent occupancy and average speed-percent occupancy relationships for all lanes could be developed; and possibly for all stations. Carrying this example further,

Lane 2 percent occupancy is estimated to be 10% based on the average of the other lanes percent occupancy being 8% (Illustration 3.40)
Lane 2 flow rate is estimated to be 1700 vphpl (Illustration 3.5)
Lane 2 average speed is estimated to be 65 mph (Illustration 3.29)

3.7.3 Both Detectors Fail in Two or More Lanes

The fourth and final step, Step 4, would address the situation when both detectors in two or more lanes are predicted not to provide good data. While a methodology has not been developed for this situation several alternatives, while not as attractive could be considered. One would be based on a methodology similar to Step 3 except the average percent occupancy would use data from adjacent lane(s) that have one or more detectors operational. Other approaches may include using adjacent upstream and downstream station detectors or time-of-day look-up tables.

3.7.4 Summary

In summary, methodological procedures have been developed for substituting for missing data whenever one of the two dual-detectors in a lane is not available and when both of the dual-detectors are not operational in one lane. More complicated and less accurate methodologies could be developed when additional detector failures were detected.

3.8 Development of Macroscopic Detector Diagnostics

The BHL detector system project has developed, implemented, and are currently continue to test microscopic detector diagnostics for single-detectors and dual-detectors lane stations. Prior to this present research, macroscopic detector diagnostics have not been considered for the BHL detector system. The purpose of this section of the chapter is to develop a set of macroscopic detector diagnostics that can be considered later for possible implementation. Two levels of macroscopic detector diagnostics are described in the following two sections.

3.8.1 Minimum and Maximum Limits

The obvious first macroscopic detector diagnostic level to be considered would be to establish minimum and maximum threshold limits for flow rates, percent occupancies, and average speeds. They could be global or disaggregated by lane and/or station, and even refined by time-of-day or by adjacent lane(s) observations.

The lower and upper range of 5-minute lane flow rates observed varied from 0 to 2544 vphpl. While zero flow rates were rare, they did occur in two 5-minute time periods in lane one. The previously implemented microscopic detector diagnostics included the ‘no activity’ diagnostic which would record a test failure if their were no pulse transitions in a 15-minute time interval. Thus the lower flow rate limit concern is fairly well covered by the existing diagnostic. An upper 5-minute flow rate limit on the order of 2600 to 3000 vphpl could enhance the set of diagnostics to identify unreasonably high flow rates.

The lower and upper range of 5-minute lane percent occupancies observed varied from 0% to 47%. The previously implemented ‘no-activity’ diagnostic fairly well covered the lower percent occupancy limit. Establishing an upper limit for 5-minute lane percent occupancies is more complicated. While the maximum observed percent occupancy was 47%, the presence of major incidents and/or unusual geometrics under heavy flow conditions on other days and at other locations could result in higher observed percent occupancies. For example, freeway surveillance projects often use a percent occupancy level on the order of 40% to denote incident and very unusual flow conditions. Though a rarity, percent occupancy could be observed as high as 100%. Perhaps the best check on the expected individual lane occupancy would be to use the relationships developed in Section 3.7 of this chapter in which lane percent occupancy is predicted on the basis of the average percent occupancy in the other freeway lanes (Illustrations 3.39 through 3.43). The microscopic diagnostic tests include a maximum on-time diagnostic test. This may be sufficient to monitor the very high percent occupancy situations.

The lower and upper range of 5-minute average speeds observed varied were 0 (no vehicles present) to 83 mph. The previously implemented ‘no-activity’ diagnostic fairly well covered the zero average speed condition. The lowest average speed observed with vehicles present was 8 mph. While the lowest average speed was 8 mph with vehicles present, the presence of major incidents and unusual geometrics under heavy flow conditions on other days and at other locations could result in lower observed average speeds. One approach would set the value at much lower level, such as 3 mph, and use it provided that the detector passed the ‘no activity’ test. The highest 5-minute average speed observed was 83 mph and for urban locations a upper threshold value of 99 mph seems reasonable.

3.8.2 Flow Relationships

The previous Section 3.3 provided individual lane flow rate-percent occupancy, average speed-percent occupancy, and average speed-flow rate relationships (Illustrations 3.2 through 3.16) for Station 5W. As an example, consider the relationships for lane 2 in the earlier illustrations.

Consider the flow rate-percent occupancy relationship shown in Illustration 3.5. Under free-flow conditions, if the detector(s) in lane 2 indicated a percent occupancy of 10%, the expected flow rate would be 1700 vphpl and at the 95% confidence level, the expected range in flow rate would be between 1400 to 2000 vphpl. Under congested-flow conditions, if the detector(s) indicated a percent occupancy of 30%, the expected flow rate would be 1400 vphpl and at the 95% confidence level, the expected range in flow rate would be between 1000 to 1800 vphpl.

Consider the average speed-percent occupancy relationship in Illustration 3.6 and 3.29. Under free-flow conditions, if the detector(s) in lane 2 indicated a percent occupancy of 10%, the expected average speed would be 65 mph and at the 95% confidence level, the expected range in average speed would be between 58 mph and 72 mph. Under congested-flow conditions, if the detector(s) indicated a percent occupancy of 30%, the expected average speed would be 21 mph and at the 95% confidence level, the expected range in average speed would be between 13 mph to 29 mph.

Consider the average speed-flow rate relationship in Illustration 3.7. This relationship is more difficult to use for diagnostics because of the dual-value of average speed for a given flow rate level and the wide range in flow rate for a given speed. For example, at a flow rate of 1500 vphpl, the expected average speed range could be on the order of 60 mph to 76 mph or on the order of 20 mph to 32 mph. An average speed of 70 mph could be observed under a wide range of flow levels, from 1 to 2000 vphpl. Hence it is suggested that the flow rate-percent occupancy and the average speed-percent occupancy relationships be the primary candidates for macroscopic relationship diagnostics.

In summary, the primary candidates for minimum and maximum limits of individual macroscopic flow characteristics are limited to maximum values for flow rates and average speeds. A maximum threshold flow rate of 3000 vphpl and a maximum threshold average speed of 99 mph are suggested.

The primary candidates for macroscopic flow relationships are the flow rate-percent occupancy and the average speed-percent occupancy relationships. A specific example can be provided using the average speed-percent occupancy relationship shown in Illustration 3.29. The procedure would be to enter the reported detector's percent occupancy (ie., 10%) into the equation, predicted the expected average speed (65 mph), set acceptable limits (ie.,+/- 10 mph), and if the predicted average speed was not within the range of 55 to 75 mph, the diagnostic test would record a failure.

3.9 Summary

Comprehensive data sets have been assembled and assessed for selected days during the month of March 2004 for all detectors in the BHL detector system. This chapter is based on the data obtained on Thursday, March 4, 2004 and the initial analysis is limited to Station 5W.

Software programs have been developed for processing BHL detector data for macroscopic freeway traffic performance measures. These software programs include storing 30-second data into spreadsheets and converting this data into 5-minute spreadsheets, automating the production of graphic plots of various traffic performance measures, and calculating equations including confidence limits for various traffic performance measure relationships.

The relationships between flow rates, average speeds, and percent occupancies were analyzed for each of the five lanes. These relationships included scatter data point plots. The maximum 5-minute average speed was 83 mph while the maximum 5-minute percent occupancy was 47%. Maximum lane flows varied from 1800 to 2600 vphpl and occurred at average speeds of 35 to 65 mph and percent occupancies of 12 to 25%. A unique subset of data points was observed in lane 1 during the afternoon peak period of HOV operations.

The traffic performance of the directional freeway at Station 5W was analyzed. The maximum 5-minute directional freeway flow was 10,000 vph and occurred during the morning peak period. The maximum 5-minute directional freeway flow in the afternoon peak period was always less than 8000 vph due to downstream recurring bottleneck conditions. The typical speed and occupancy inversion occurred during the morning peak period from 7 AM until almost 11 AM and during the afternoon peak period from 2 PM until 7 PM.

Special analysis was undertaken of lane 1 that operates as a HOV lane from 5 to 10 AM and 3 to 7 PM. Unique flow, speed, and percent occupancy relationships were observed during HOV operations particularly during the afternoon peak period. This was due to the congested slow speed conditions in the adjacent lane during the afternoon HOV operations and partly due to the lack of a barrier between the lanes. For a given flow level in the HOV lane (lane 1), HOV lane speeds were up to 20 mph lower than expected with percent occupancies up to 8% higher. It should be noted that the HOV lane benefits for HOV vehicles were less than expected.

Estimating average lane speeds based on the elapsed time between dual-detectors and the speed-occupancy relationship for a single detector were investigated and compared. There were little numerical differences between the two methods. This is encouraging information for single-detector systems and very helpful in developing methods for substituting for missing detector data in dual-detector systems.

A methodological structure was developed for substituting created data when some detector data was not available. The first level of the methodology was to create missing data when one of the two detectors in a dual-detector lane was not providing data. The second level of the methodology was to create missing data when both detectors in a single dual-detector lane were not providing data. The second level could only be applied if one or more detectors in the remaining lanes were providing acceptable data. Possible methods for handling situations with more extensive detector failures were briefly discussed and possible solution approaches identified.

Macroscopic detector diagnostics have been investigated that included determining minimum and maximum limits of flow parameters as well as establishing confidence limits on such relationships as the average speed-percent occupancy relationship. If time and resources permit, such macroscopic detector diagnostics could be added to the BHL system.

The current investigation of macroscopic flow data is limited to one day of field measurements (Thursday, March 4th) and to one of the 16 directional stations (Station 5W) within the BHL detector system. Future efforts could be directed toward applying the developed software programs to other portions of the assembled data set.

Analyses of the data for Station 5W for other days would confirm (or modify) the results reported in this chapter. Analyses of the data for other stations might lead to more generic methodologies for assessing individual lane traffic performances, directional roadway traffic performances, assessment of HOV operations, comparison of single-detector speed estimation and dual-detector speed measurement, substitution methodologies for missing detector data, and macroscopic detector diagnostics. Unfortunately because of limited resources and time, it may not be possible to do further research in this area.

On the positive side, Station 5W is considered to be a typical freeway site that is level and straight, and some distance away from ramps and geometric design changes. It also was one of the most reliable detector stations in that all detectors provided data and with few exceptions all detectors passed the nine diagnostic tests for the 24-hour period. The extensive analyses performed revealed only a few situations of questionable data points.

4. MACROSCOPIC FREEWAY TRAFFIC PERFORMANCE AND FURTHER ASSESSMENT OF DETECTOR DIAGNOSTIC TESTS – STATION 8W

This chapter is related to the previous two chapters but exclusively deals with Station 8W. Both macroscopic freeway traffic performance and further assessment of detector diagnostic tests are covered in this chapter but with concentration only on Station 8W. Recall from Chapter 2 that the detectors at Station 8W did not all provide data and they generally did not perform well in the detector diagnostic tests. Hence as the results of the macroscopic freeway traffic performance are presented, the results of the diagnostic tests will be presented first. In addition, the accuracy of estimating speed from the upstream and downstream detectors in each lane will provide further support for this analysis. The intend is to better understand the quality of the detector data at Station 8W and obtain insights in interpreting the flow-speed-percent occupancy relationships.

Station 8 in the westbound direction was selected for further analysis because it has the most complicated geometrics, does not always provide data continuously for the study period, and has more diagnostic test failures than any other station observed. It is located between the Powell Street off-ramp and the Powell Street on-ramp. A number of video cameras are located on the top of an adjacent tall apartment building in the near-vicinity of Station 8W. The possible use of these cameras in connection with this research will be discussed in this Chapter.

There are six lanes at this station with the median lane, Lane 1, serving as a part-time HOV lane to San Francisco. Lane 2, the lane next to the median lane, serves as a part-time concurrent HOV lane to the Oakland area. The remaining four lanes are mixed-flow lanes. The HOV Lane 1 begins just a short distance upstream of Station 8W and the HOV Lane 2 becomes a mixed-flow lane just a short distance downstream of Station 8W. Any one of the three directional freeways in the downstream interchange may cause congestion to back into the Station 8W location. Illustration 4.1 depicts the lane configuration in the vicinity of Station 8W.

The first six sections of this chapter will be devoted to assessing the performance of the upstream and downstream detectors in each of the six lanes individually. This assessment will be based on detector diagnostic results for two days of operation (March 2 and 4, 2004); on macroscopic flow, percent occupancy, and average speed relationships for March 4, 2004; and on estimating speeds from single-detector and dual-detectors for March 4, 2004. Both the upstream and downstream detectors in each lane are included in the evaluation. A summary of findings and suggested research are provided at the end of each of these six sections.

The next section in this chapter will present an assessment of directional roadway traffic performance for Station 8W. It should be noted that lane 6 provided no detector data and the data obtained from some detectors in other lanes are questionable. Therefore these results should be used with caution.

The final section of this chapter will provide a summary including suggestions for further research.

4.1 Assessment of Lane 1

Lane 1 is the lane next to the median and is a part-time HOV lane for vehicles carrying 3 or more vehicles during the morning (0500 to 1000) and the afternoon (1500-1900) weekday peak periods. During other time periods, this lane is a general-purpose lane. This lane is added to the freeway a short distance upstream of this station. Only traffic destined to San Francisco use this lane.

4.1.1 Detector Diagnostic Test Results

The detector diagnostic test results for March 2, 2004 presented earlier in Chapter 2 (Illustration 2.13) are presented in this discussion as Illustration 4.2. Since the macroscopic data analysis was undertaken for March 4, 2004, a similar illustration of detector diagnostic test results, Illustration 4.3, is included for March 4, 2004. This permits a comparison between diagnostic test results between two different days for the same station and also provides detector diagnostic test results for the same day as for the macroscopic flow relationships and speed estimates discussed next.

The detector diagnostic test results for the two days are almost identical. The upstream and downstream detectors also were in very close agreement. The detector diagnostic results for lane 1 at Station 8W were similar to the results in lane 1 for Stations 5W and 4W. There were no test failures in tests 1, 3, 4, 5, and 6; only a few test failures in tests 7 and 8; and a significant number of failures for tests 2 and 9. While the test failures of test 9 occurred throughout the daylight hours, the test failures in other lanes occurred only during the morning and afternoon peak periods. There were no test failures from 2300 to 0500. This lane provided one of the better lane data sets of Station 8W and always provided data from both detectors on both days.

4.1.2 Macroscopic Flow Relationships

The flow-percent occupancy relationships obtained from the upstream and downstream detectors in Lane 1 are presented in Illustrations 4.4 and 4. 5 with flow rate on the vertical scale and percent occupancy on the horizontal scale. Each data point represents a single 5-minute time period and there are a total of 288 data points. There are only two data points with percent occupancies over 16% and the highest 5-minute flow rate was 1800 vphpl. There are two streams of data points; one when the adjacent lane is congested (the lower stream) and the other when the adjacent lane is not congested.

The flow rate-percent occupancy scatter of data points for the upstream and downstream detectors are very similar. Note that the flow rates and percent occupancies are direct measurements from each of the detectors and the data from the two detectors are independent of one another. The fact that the scatter of data points in the two illustrations is almost identical provides some level of confidence in these two detectors.

The average speed-percent occupancy relationships from the upstream and downstream detectors in Lane 1 are shown in Illustrations 4.6 and 4.7 with average speed on the vertical scale and percent occupancy on the horizontal scale. The pattern is similar to the flow-percent occupancy relationship in that there are only two data points with occupancies over 16% and two streams of data points (the lower one when the adjacent lane is congested and the other when it is not congested). Highest speeds varied from about 72 to 82 mph.

The average speed-percent occupancy scatter of data points for the upstream and downstream detectors are very similar. While the average speed calculation is common to the two illustrations (taken from the elapsed time between detectors), the percent occupancies measures are independent of one another. The fact that the scatter of data points in the two illustrations is almost identical provides some level of confidence in these two detectors. An attempt was made to fit a curve to the data point scatter as noted in the illustration. However due to the effect of the adjacent lane congestion during the HOV afternoon peak period and the fact that almost all data points were taken during free-flow conditions in this lane (percent occupancies from 0% to 16%), the curve fit is poor. The data points for the HOV lane during the afternoon peak period generally lie about 10 to 20 mph lower than for other periods of the day.

The average speed-flow rate relationships from the upstream and downstream detectors in Lane 1 are depicted in Illustrations 4.8 and 4.9 with speed on the vertical scale and flow rate on the horizontal scale. The pattern is similar to the previous two relationships in terms of maximum speeds and flow rates as well as displaying two streams of data points (the lower one when the adjacent lane is congested and the other when it is not congested). The data points are more scattered than in the previous two relationships. The speed-percent occupancy scatter of data points for the upstream and downstream detectors are very similar. While the average speed calculation is common to the two illustrations (taken from the elapsed time between detectors), the percent occupancies measures are independent of one another. The fact that the scatter of data points in the two illustrations is almost identical provides some level of confidence in these two detectors.

4.1.3 Single-detector and Dual-detector Estimation of Freeway Lane Speeds

The average speed-percent occupancy relationships were shown earlier in Illustrations 4.6 and 4.7. Based on the fitted curves, average speed could be estimated as a function of percent occupancy from each of the detectors.

The five-minute data points of estimates of freeway lane speed based upon the individual upstream and downstream detectors (vertical scale) and the estimated freeway lane speed based on the dual-detector data (horizontal scale) are shown in Illustrations 4.10 and 4.11. A 45-degree imaginary line would indicate when the single-detector speed estimates are equal to the dual-detector speed estimates. A +5/-5 mph band around this 45-degree imaginary line can be used as a reference. However due to the effect of the adjacent lane congestion during the HOV afternoon peak period and the fact that almost all data points were taken during free-flow conditions in this lane (percent occupancies from 0% to 16%), the indicated relationship is poor.

4.1.4 Summary of Observations

Data was always available from both detectors for both days. The pattern of diagnostic test results was similar for both days and there was close agreement between the upstream and downstream detectors. Except for diagnostic tests 2 (minimum on-time) and test 9 (dynamic maximum off-time), there were few test failures. These results for lane 1 at Station 8W were similar to those obtained in lane 1 at Stations 5W and 4W.

The scatter of data points depicting flow-percent occupancy, speed-percent occupancy, and speed-flow relationships were not typical due to the influence of congestion in the adjacent lane during the HOV afternoon peak period and perhaps due to the unique geometrics at the site. The upstream and downstream detectors provided almost identical results. Except for two five-minute time intervals (percent occupancies of 25% and 27%), the highest percent occupancy was 16%. The maximum five-minute flow was 1800 vphpl and five-minute average speeds varied from 28 to 82 mph.

The scatter of data points in the average speed-percent occupancy relationships and the relationships from upstream and downstream single-detector estimates of speed and dual-detector estimates of speed were quite dispersed. This was due to the HOV afternoon peak period congestion in the adjacent lane and the fact that almost all data was obtained during free-flow conditions.

From the perspective of detector diagnostics results and the close agreement between the upstream and downstream detectors in estimating flow rates and percent occupancies, this lane provided one of the better data sets from Station's 8W six lanes. However the macroscopic flow relationships were not typical due to the HOV afternoon peak period congestion in the adjacent lane, the fact that almost all data was obtained during free-flow conditions, and the unique geometrics at this site.

4.2 Assessment of Lane 2

Lane 2 is a part-time HOV lane for vehicles carrying 3 or more vehicles during the morning (0500 to 1000) and the afternoon (1500-1900) peak periods. During other time periods, this lane may be used by any vehicle. HOV operations in this lane ends a short distance downstream of the station and becomes a normal mixed-flow lane. Only traffic destined to Oakland use this lane.

4.2.1 Detector Diagnostic Test Results

The detector diagnostic test results for March 2, 2004 presented earlier in Chapter 2 (Illustration 2.14) are presented in this discussion as Illustration 4.12. Since the macroscopic data analysis was undertaken for March 4, 2004, a similar illustration, Illustration 4.13 is included for March 4, 2004. This permits a comparison between diagnostic test results between two different days for the same station and also provides same-day data as presented later for the macroscopic flow relationships.

The detector diagnostic test results for the two days were very similar but the upstream detector results did not match the downstream detector results with the upstream detector having many more test failures. The upstream detector did not have any failures on tests 3 and 6; a few failures on test 1, and many failures on tests 2, 4, 5, 7, 8,and 9. The downstream detector did not have any failures on tests 1, 3, 4, and 6; a few failures on tests 2 and 7; and many failures on tests 5, 8, and 9. The detectors in lane 2 at Station 8W did not perform nearly as well as the detectors in lane 2 at Stations 5W and 4W based on the diagnostic test results.

Of particular concern was that test 5 (dual on-time difference test) always failed on both March 2 and 4. This indicates that the sensitivity settings for the two detectors were different and therefore it raises a question about the accuracy of the dual-detector speed estimates.

4.2.2 Macroscopic Flow Relationships

The flow rate-percent occupancy relationships for lane 2 for the upstream and downstream detectors are presented in Illustration 4.14 and 4.15 with flow rate on the vertical scale and percent occupancy on the horizontal scale. The data points depict a somewhat non-typical scatter of data points with unique data points with flow rates between 1000 and 1500 vphpl and percent occupancies between 10 and 20 percent. Also the data points are well scattered in the congested region and the two days are somewhat different. This may be due to the uniqueness of the HOV lane configuration and/or congestion in the adjacent lanes. The highest flow rates are on the order of 1900 vphpl at percent occupancies between 16 and 22%. The highest percent occupancies observed were in the mid-40's.

The average speed-percent occupancy relationships for lane 2 for the upstream and downstream detectors are shown in Illustrations 4.16 and 4.17 with average speed on the vertical scale and percent occupancy on the horizontal scale. The pattern of data points for the two days are different and both exhibit incorrect data at very low percent occupancies (speeds 0 to 60 mph) and on March 4 there are a number of data points with zero speeds at mid-range percent occupancy values. The congested-flow portion is not typical on March 4 and these results are questionable. An attempt was made to fit a curve to the data points for the two days of data but the results are questionable because of the apparent bad data.

The speed-flow relationships are depicted in Illustrations 4.18 and 4.19 with average speed on the vertical scale and flow rate on the horizontal scale. The pattern of data points for the two days are somewhat different but neither gave reasonable results. Again, there are data points indicating low flow rates combined with lower speeds than expected (0 to 60 mph) for both days while the data for March 4 also includes data points representing mid-range flow rate levels but with speeds of 0 mph. The maximum flow levels on March 2 are unreasonable and occur at lower than expected speeds.

4.2.3 Single-detector and Dual-detector Estimation of Freeway Lane Speeds

The average speed-percent occupancy relationships were shown earlier in Illustrations 4.16 and 4.17. Based on the fitted curves, average speed could be estimated as a function of percent occupancy from each of the detectors.

The five-minute data points of estimates of freeway lane speed based upon the individual upstream and downstream detectors (vertical scale) and the estimated freeway lane speed based on the dual-detector data (horizontal scale) are shown in Illustrations 4.20 and 4.21. A 45-degree imaginary line would indicate when the single-detector speed estimates are equal to the dual-detector speed estimates. A +5/-5 mph band around this 45-degree imaginary line can be used as a reference.

The resulting relationships for both days were poor as shown by the solid line in the two illustrations. There are certainly errors with the March 4 data on regard to the estimated speed from dual detectors (many zero speeds) and with the estimated speed from both single detectors in terms of estimating a constant speed of near 75 mph for many data points.

4.2.4 Summary of Observations

Data was always available from the downstream detector for both days and available from the upstream detector for both days except from about 1100 to 1200 and 1730 to 1830 on March 4. The upstream detector had many more test failures than the downstream detector. The many test failures of the detectors in this lane raise into question any expectation of reasonable results in the macroscopic flow analysis. Note that the dual-detectors on March 2 and on March 4 never passed the dual on-time difference test which raises into question the reliability of estimating average speeds based on elapsed time between these detectors.

Each of the three traffic performance relationships displayed some questionable characteristics for both the upstream and downstream detectors. They are most noticeable in the speed-flow relationship under low flow conditions where speeds less than 60 mph are observed and where high flow rates are observed at very low speeds (many at zero mph). Until the detectors are improved, reasonable flow, speed, and percent occupancy relationships can not be obtained.

The scatter of data points depicting the relationship from upstream and downstream detector estimates of speed and dual-detector estimates of speed showed are also unrealistic and the problem is with both the single-detector and dual-detector estimates of speed. Until the detectors are improved, further research on the comparison of single-detector and dual-detector estimates of speed can not be undertaken.

4.3 Assessment of Lane 3

Lane 3 is a mixed-flow lane for traffic with destinations primarily to Oakland and beyond.

The detector diagnostic test results for this lane will be first presented and discussed followed by a presentation and discussion of the macroscopic flow relationships and the comparison of single-detector and dual-detector estimates of average speeds.

4.3.1 Detector Diagnostic Test Results

The detector diagnostic test results for March 2, 2004 presented earlier in Chapter 2 (Illustration 2.15) are presented in this discussion as Illustration 4.22. Since the macroscopic data analysis was undertaken for March 4, 2004, a similar illustration, Illustration 4.23 is included for March 4, 2004. This permits a comparison between diagnostic test results between two different days for the same station and also provides same-day data as presented later for the macroscopic flow relationships.

The detector diagnostic test results for both the upstream and downstream detectors for the two days were in close agreement. Both the upstream and downstream detectors on both days had no failures on tests 1, 3, 5, and 6; had a few failures on tests 4 and 9; and had many failures on tests 2, 7, and 8. It was encouraging that test 5 (dual on-time difference test) never failed which provides some confidence in the dual-detector speed estimates to be discussed later. However the detectors in lane 3 at Station 8W did not perform as well as the detectors in lane 3 at Stations 5W and 4W based on the diagnostic test results.

4.3.2 Macroscopic Flow Relationships

The flow rate-percent occupancy relationships for the upstream and downstream detectors for lane 3 are presented in Illustrations 4.24 and 4.25 with flow on the vertical scale and percent occupancy on the horizontal scale. Each data point represents a single 5-minute time period and there are a total of 288 data points. The scatter of data points for the two detectors is very similar and very typical. Maximum flows on the order of 2300 vphpl at percent occupancies of about 18% occupancies were observed. Percent occupancy values slightly over 50% were observed. There were a few data points outside of the normal pattern of data points.

The average speed-percent occupancy relationships are shown in Illustrations 4.26 and 4.27 with speed on the vertical scale and percent occupancy on the horizontal scale. The scatter of data points is very similar for the two detectors and very typical. A curve was fitted to the two scatter diagrams and the equations, R-square values, and actual curves are shown on the illustrations. The R-square values were found to be 0.92 for both detectors and the two curves are almost identical. There is a percent occupancy gap between 19% and 23% separating free-flow conditions from congested-flow conditions. Maximum speeds between the mid-60’s to the mid-70’s were observed. These results were very encouraging.

The average speed-flow rate relationships are depicted in Illustrations 4.28 and 4.29 with speed on the vertical scale and flow rate on the horizontal scale. The pattern is similar to the previous two relationships in terms of maximum speeds and flow rates. The pattern of data points represents a typical freeway lane with a free-flow portion and a congested-flow portion, and the two detectors provided almost identical sets of data points.

4.3.3 Single-detector and Dual-detector Estimation of Freeway Lane Speeds

The five-minute data points of estimates of freeway lane speed based upon the individual upstream and downstream detectors (vertical scale) and the estimated freeway lane speed based on the dual-detector data (horizontal scale) are shown in Illustrations 4.30 and 4.31. A 45-degree line would indicate that the single-detector speed estimates are equal to the dual-detector speed estimate. Dashed lines representing +5/-5 mph from the 45-degree line have been added as a reference. A best-fit linear regression line has been added to the diagram, and the equation and resulting R-square values provided on the illustration. The R-square value for both detectors was found to be 0.86 and the linear regression equations are almost identical. There are a few data points in which the dual-detector estimate is relatively low while the singe-detector estimate is relatively high.

4.3.4 Summary of Observations

Data was always available from both detectors for both days. The pattern of diagnostic test results was similar for both days and there was close agreement between the upstream and downstream detectors. Except for diagnostic tests 2 (minimum on-time) and test 8 (minimum off-time), there were few test failures.

The scatter of data points depicting flow-percent occupancy, speed-percent occupancy, and speed-flow relationships were similar to typical such relationships, and the upstream and downstream detectors provide almost identical results. The highest percent occupancy was slightly over 50%. The maximum five-minute flow was 2300 vphpl which occurred at percent occupancies of 17% to 19%, and the five-minute average speed varied from 9 to 75 mph.

The scatter of data points and resulting best-fit linear regression curve depicting the relationship from upstream and downstream detector estimates of speed with dual-detector estimates of speed were in general agreement. There were a few unexplained data points. Most data points were within the +/- 5 mph band and with few exceptions, within the +/- 10 mph range. This lane provided one of the better data sets from Station's 8W six lanes.

4.4 Assessment of Lane 4

Lane 4 is a general-purpose lane for traffic that is going to either Oakland or San Francisco.

4.4.1 Detector Diagnostic Test Results

The detector diagnostic test results for March 2, 2004 presented earlier in Chapter 2 (Illustration 2.16) are presented in this discussion as Illustration 4.32. Since the macroscopic data analysis was undertaken for March 4, 2004, a similar illustration, Illustration 4.33 is included for March 4, 2004. This permits a comparison between diagnostic test results between two different days for the same station and also provides same-day data as presented later for the macroscopic flow relationships.

The detector diagnostic test results for the two days are almost identical and the upstream and downstream detectors have matching patterns of test failures. The detectors had no test failures on tests 1 (data always available), 3, and 6; a few on tests 4 and 9; and many on tests 2, 5, 7, and 8. Later analysis of data from the detectors in this lane should be viewed with caution including dual-detector speed estimates due to the number of test failures and particularly the frequent failure of test 5 (dual on-time difference test). The detectors in lane 4 at Station 8W did not perform nearly as well as the detectors in lane 4 at Stations 5W and 4W based on the diagnostic test results.

4.4.2 Macroscopic Flow Relationships

The flow rate-percent occupancy relationships for lane 4 are presented in Illustrations 4.34 and 4.35 with flow on the vertical scale and percent occupancy on the horizontal scale. Each data point represents a single 5-minute time period and there are a total of 288 data points. The pattern of data points represents a typical freeway lane under free-flow conditions (percent occupancies less than 15%) but with more scatter and difference between detector results in the congested-flow portion. Maximum flows on the order of 2300 vphpl at percent occupancies of about 19% occupancies were observed at the upstream detector and on the order of 2700 vphpl at percent occupancies of about 20 to 22%. These differences in maximum flows between the upstream and downstream detectors are of some concern. Percent occupancy values slightly over 50% were observed.

The average speed-percent occupancy relationships are shown in Illustrations 4.36 and 4.37 with speed on the vertical scale and percent occupancy on the horizontal scale. The scatter of data points is very similar for the two detectors and very typical. A curve was fitted to the two scatter diagrams and the equations, R-square values, and actual curves are shown on the illustrations. The R-square values were found to be 0.85 for both detectors and the two curves are almost identical. Maximum speeds between the mid-60's to the mid-70's were observed. These results were very encouraging.

The speed-flow relationships are depicted in Illustrations 4.38 and 4.39 with speed on the vertical scale and flow rate on the horizontal scale. The pattern is similar to the previous two relationships in terms of maximum speeds and flow rates. The pattern of data points represents a typical freeway lane with a free-flow portion and a congested-flow portion but with a little more scattering than normal. It is of interest to note that as long as speeds are above 50 mph, flow rates in excess of 2000 vphpl could be maintained.

Again, it can be observed that the maximum flow at the upstream detector is several hundred vehicles per hour per lane less than that reported by the downstream detector.

4.4.3 Single-detector and Dual-detector Estimation of Freeway Lane Speeds

The five-minute data points of estimates of freeway lane speed based upon the individual upstream and downstream detectors (vertical scale) and the estimated freeway lane speed based on the dual-detector data (horizontal scale) are shown in Illustrations 4.40 and 4.41. A 45-degree line would indicate that the single-detector speed estimates are equal to the dual-detector speed estimate. Dashed lines representing +5/-5 mph from the 45-degree line have been added as a reference. A best-fit linear regression line has been added to the diagram, and the equation and resulting R-square values provided on the illustration. The R-square value for both detectors was found to be 0.85 and the linear regression equations are almost identical. There are some data points in which the dual-detector estimate is relatively low while the singe-detector estimate is relatively high.

4.4.4 Summary

Data was always available from both detectors for both days. The pattern of diagnostic test results was similar for both days and there was close agreement between the upstream and downstream detectors. There were many failures in tests 2, 5, 7, and 8, and macroscopic flow analyses should be reviewed with caution particularly those involved with the dual-detector estimated speeds.

The scatter of data points depicting flow-percent occupancy, speed-percent occupancy, and speed-flow relationships were somewhat similar to typical relationships, and the upstream and downstream detectors provided almost identical results. The highest percent occupancy was slightly over 50%. The maximum five-minute flow was 2300 vphpl at the upstream detector and 2700 vphpl at the downstream detector which is of some concern. Five-minute average speed varied from 9 to 75 mph. The average speed-percent occupancy equation was found to have a reasonably good fit both visually and as a result of the R-square value.

The scatter of data points and resulting best-fit linear regression curve depicting the relationship from upstream and downstream detector estimates of speed with dual-detector estimates of speed were in general agreement. There were a few unexplained data points. Most data points were within the +/- 5 mph band and with few exceptions, within the +/- 10 mph range. This lane provided data which was not the best but not the worst at Station 8W.

4.5 Assessment of Lane 5

Lane 5 is a lane with traffic destined primarily to San Francisco.

The detector diagnostic test results for this lane will be first presented and discussed followed by a presentation and discussion of the macroscopic flow relationships.

4.5.1 Detector Diagnostic Test Results

The detector diagnostic test results for March 2, 2004 presented earlier in Chapter 2 (Illustration 2.17) are presented in this discussion as Illustration 4.42. Since the macroscopic data analysis was undertaken for March 4, 2004, a similar illustration, Illustration 4.43 is included for March 4, 2004. This permits a comparison between diagnostic test results between two different days for the same station and also provides same-day data as presented later for the macroscopic flow relationships.

The detector diagnostic test results for the two days are almost identical. The upstream and downstream detectors had similar performance. The two detectors had no test failures on tests 1 (data always available), 3, and 6; a few on tests 4, 5, and 9; and many on tests 2, 7, and 8. Later analysis of data from the detectors in this lane should be viewed with caution including dual-detector speed estimates because of Test 5 failures (dual on-time difference).

4.5.2 Macroscopic Flow Relationships

The flow-percent occupancy relationships for lane 5 are presented in Illustrations 4.44 and 4.45 with flow on the vertical scale and percent occupancy on the horizontal scale. Each data point represents a single 5-minute time period and there are a total of 288 data points. The pattern of data points represents a typical freeway lane with a free-flow portion and a congested-flow portion but there is more scattering in the data point pattern than expected particularly in the congested-flow portion. Maximum flows on the order of 2200 vphpl at percent occupancies of about 15% occupancies were observed. Percent occupancy values slightly over 50% were observed.

The average speed-percent occupancy relationships are shown in Illustrations 4.46 and 4.47 with speed on the vertical scale and percent occupancy on the horizontal scale. Except for a few scattered data points at low flow rates, the pattern of data points approximately represents a typical freeway lane with a free-flow portion and a congested-flow portion but with a little more scatter than expected in the free-flow portion. Maximum speeds between 60 and 70 mph were observed.

The average speed-flow rate relationships are depicted in Illustrations 4.48 and 4.49 with speed on the vertical scale and flow rate on the horizontal scale. The pattern is similar to the previous two relationships in terms of maximum speeds and flow rates. The pattern of data points approximately represents a typical freeway lane with a free-flow portion and a congested-flow portion but with considerable more scatter than normal. It is of interest to note that as long as speeds are above 50 mph, flow rates in excess of 1800 vphpl could be maintained up to 2200 or 2300 vphpl.

4.5.3 Single-detector and Dual-detector Estimation of Freeway Lane Speeds

The five-minute data points of estimates of freeway lane speed based upon the individual upstream and downstream detectors (vertical scale) and the estimated freeway lane speed based on the dual-detector data (horizontal scale) are shown in Illustration 4.50 and 4.51. The 45-degree line indicates when the single-detector speed estimates are equal to the dual-detector speed estimate. A +5/-5 mph band around this line is shaded and data points within the shaded area are considered acceptable. The fit is marginally good but with many data points also the +5/-5 mph band.

4.5.4 Summary

Data was always available from both detectors for both days. The pattern of diagnostic test results was similar for both days and there was close agreement between the upstream and downstream detectors. There were many failures in tests 2, 5, 7, and 8, and macroscopic flow analyses should be reviewed with caution particularly those involved with the dual-detector estimated speeds.

The scatter of data points depicting flow-percent occupancy, speed-percent occupancy, and speed-flow relationships were somewhat similar to typical relationships, and the upstream and downstream detectors provided almost identical results. The highest percent occupancy was slightly over 50%. The maximum five-minute flow was 2200 vphpl at the upstream detector and 2300 vphpl at the downstream detector which is of some concern. Five-minute average speed varied from 10 to 72 mph. The average speed-percent occupancy equation was found to have a reasonably good fit both visually and as a result of the R-square value.

The scatter of data points and resulting best-fit linear regression curve depicting the relationship from upstream and downstream detector estimates of speed with dual-detector estimates of speed were in general agreement. However there were a number of data points where the dual detector speed was predicted to be low but the single detector speed was predicted to be high. In addition, there were a few unexplained data points.

4.6 Assessment of Lane 6

Lane 6 is the right-shoulder lane with traffic destined almost exclusively to San Francisco.

No data was available from lane 6 from either the upstream or downstream detector. Therefore it was not possible to analysis the detector diagnostic test results (except for the no activity test) nor to determine the macroscopic flow relationships for the lane or compare single-detector and dual-detector speeds.

4.7 Assessment of Directional Roadway Traffic Performance Measures

The traffic performance measures for the individual lanes presented in the previous sections have been combined to provide directional roadway traffic performance measures. It should be kept in mind that no traffic data was available from lane 6 and data from some of the detectors in the other lanes are questionable.

Illustration 4.52 presents the variation of 5-minute hourly flow rates by time of day for five of the six lanes at Station 8W. The lowest flows are observed from 11:45 PM to 4:30 AM (less than 2000 vph) with the lowest 5-minute flow of about 400 vph occurring shortly after 1:00 AM and 2:00 PM. The highest flow rates on the order of 8800 vph occurred between 6:15 and 7:00 AM. The highest flows in the afternoon peak period were only on the order of 7000 vph. There were a few scattered data points between 1600 and 1700 but they were due to a few minutes in which no data was received from the detectors.

Illustration 4.53 depicts the variation of 5-minute average lane percent occupancies (left scale) and average speeds (right scale) by time of day for the combined five lanes of the six lane roadway at Station 8W. The percent occupancy daily pattern is what might be expected with values over 25% from 0700 to 0830 in the morning and from 1415 to 1845 in the afternoon. The average speed daily pattern appears typical for the peak periods with speeds less than 50 mph between 0700 to 0900 and from 1400 to 1900. However speeds less than 50 mph are reported during the earlier morning hours of 0100 to 0300.

For a number of reasons these results are questionable including that no data is available for lane 6 and data particularly from lanes 2, 4, and 5 is questionable. It is important to observe that the maximum flow reported during the afternoon peak period is on the order of 2000 vph less than during the morning peak period and yet the demand (and resulting congestion) is greatest in the afternoon peak period. This is due to downstream bottleneck(s) on one or more of the downstream freeways.

4.8 Summary

The diagnostic test failures of greatest concern were with detectors in lanes 2 through 5 at Station 8W with the minimum on-times (Test 2) and the minimum off-times (Test 8). The detectors in lane 6 have not provided data for sometime.

The minimum on-time test is recorded as failed if five percent or more of a 100-vehicle sample has on-times less than 8/60 seconds. A ten-foot long vehicle passing over a six-foot long detector at 80 mph would result in a on-time of approximately 8/60 seconds. Reducing the threshold value would decrease the number of test failures but such reduction does not seem reasonable. Reducing the threshold value too much would also decrease its effectiveness in identifying detectors set on pulse mode. Only the lane 1 detectors at Stations 5W and 4W failed this test and only in a few tests.

The minimum off-time test is recorded as failed if five percent or more of a 100-vehicle sample has off-times less than 25/60 seconds. Two vehicles traveling at 80 mph that have an off-time of 25/60 seconds would have a distance gap between them of about three-car lengths. Two vehicles traveling at 10 mph that have an off-time of 25/60 seconds would have a distance gap between them of about the length of the detector zone. Reducing the threshold value would decrease the number of test failures but such reduction does not seem reasonable. There were few test failures with the detectors at Stations 5W and 4W.

Two directions of further research appear promising. The first one would be for an on-site investigation to the cabinet of Station 8W and a careful inspection and testing of the detector cards and associated connections with the loops and the modem. A second one would be for a joint study using the video cameras simultaneously with the BHL detector data recording a selected lane at a selected period of time. These options will be discussed at the September 2004 Advisory Meeting

PART 2 - FINAL RESEARCH

The project's progress report that was distributed in September 2004 and presented at the second advisory meeting on September 9, 2004 at the Caltrans District 04 Office is contained in Part 1 of this final report and in Appendices A, B, and C. This progress report was exclusively devoted to early work on Tasks 1 and 2.

Part 2 of this final report contains the results of further research undertaken since September 2004 on Tasks 1 and 2 as well as all research undertaken on Tasks 3, 4, 5, 6, and 7. The next seven chapters are devoted to each of these seven tasks.

5. Analysis of Macroscopic Freeway Traffic Performance Measures (Task 1)

The research leading to the development of macroscopic detector diagnostics was included in Section 3.8 (see Part 1). Particular attention was given to developing diagnostics based upon individual lane flow rate-percent average occupancy relationships and some guidelines were provided. The reason for selecting this particular relationship is because they are both direct measurements from the detector and also because of their very strong relationship particularly under free-flow conditions.

A more detailed investigation was undertaken in this final research effort to provide a more definitive procedure based upon the relationship for lane 2 at Station 5W. The results are presented in Illustration 5.1.

The vertical scale is lane 2 flow rate (vphpl) and the horizontal scale is lane 2 average percent occupancy. The relationship is divided into a free-flow region (percent occupancy equal to or less than 12 percent and a congested-flow region (percent occupancy greater than 12 percent).

The flow-occupancy equation, R-square value, and standard error for the free-flow region is:

$$y = 162.7x + 43.232$$

R-square = 0.9949

Stnd Error = 40

This means that with 99% confidence, the actual flow should lie within +/- 120 vphpl of the expected value represented by the equation. The very high R-square value over 0.99 indicates a very strong relationship between the flow-occupancy relationship.

The flow-occupancy equation, R-square value, and standard error for the congested-flow region is:

$$y = -37.554x + 2532.3$$

R-square = 0.7758

Stnd Error = 140

This means that with 99% confidence, the actual flow should lie within +/- 420 vphpl of the expected value represented by the equation. The modest R-square value indicates the existence of a relationship but with a more disperse distribution than for the free-flow region.

Project time and resources did not permit expanding this analysis to other lanes nor to attempts to developing a more generalized lane approach.

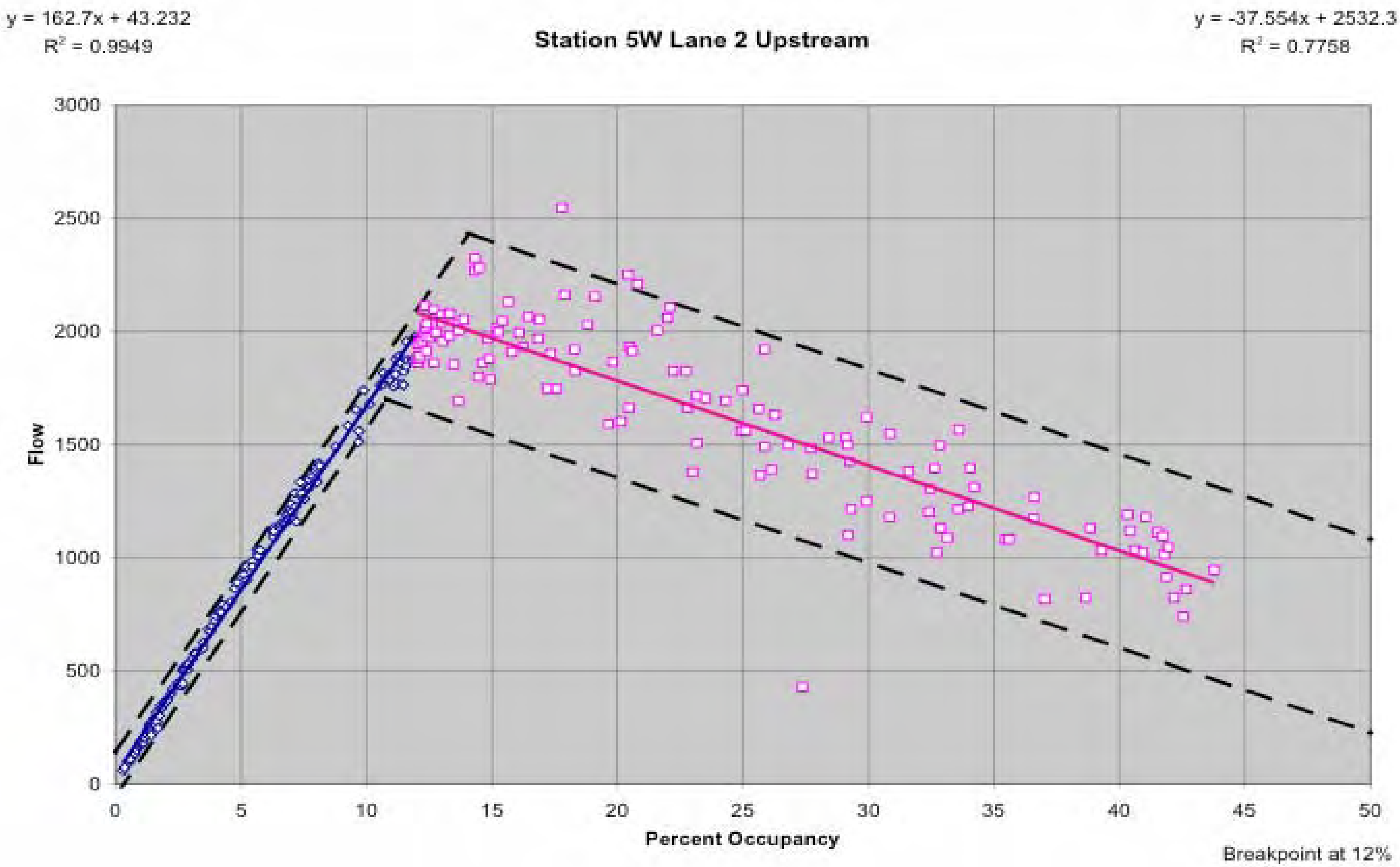

Figure 5.1 – Flow-Occupancy for Station 5W, Lane 2, Upstream Detector

6. Final Assessment and Final Improvements of Detector Diagnostics (Task 2)

A significant number of investigations were undertaken to modify and improve the performance of the nine detector diagnostic tests. These modifications consisted primarily of changing the threshold parameters and sample sizes. Some of the diagnostic tests appeared not to be sensitive enough and resulting in tests passing when in fact the performance of the detector was questionable. Some of the diagnostic tests were deemed to be too sensitive and resulting in tests failing when in fact the performance of the detector seemed to be acceptable. No changes were made in some diagnostic tests.

It was fortunate that all detectors at Stations 4W and 5W as well as detectors at Station 8W in lanes 1 and 3 gave the general impression of performing well. On the other hand, detectors in lanes 2, 4, and 5 at Station 8W gave the general impression of not performing very well. This resulted in a significant difference in test results for most of the detector diagnostics between these two sets of detectors that assisted in the modifications of the threshold parameter values.

The guideline used throughout the process of modifying the diagnostic threshold parameters was that (1) at least one or more of the detectors would be expected to pass a particular test (at least for a short period of time) and (2) at least one or more detectors would be expected to fail a particular test (at least for a short period of time). All detectors always passing (or failing) a particular diagnostic test indicated that the test was not sensitive enough (or too sensitive) and raised questions about the desirability of the particular diagnostic test.

This chapter is divided into nine sections with each section devoted to one of the nine detector diagnostics. Each section contains a description of the particular detector diagnostic, the initial test results and proposed modifications, and the final test results.

6.1 Test 1 Activity

The activity diagnostic test determines whether the detector signal has changed states in a 15-minute time period. If the detector signal has not changed states in a 15-minute period, a test failure is recorded. Otherwise, it passes.

The Activity test is considered to be one of the most important detector diagnostics and if this test fails, no data is available for performing the other diagnostic tests. The initial test results and proposed modifications are first discussed followed by a presentation of the final test results.

6.1.1 Initial Test Results and Proposed Modifications

All detectors at Stations 4W and 5W and nine of the twelve detectors at Station 8W passed this test. The detectors not passing this test were the upstream and downstream detectors in lane 6 throughout the day (which will not be discussed further in these tests) and the upstream detector in lane 2 during four 15-minute time periods in the middle of the day (See Appendix A).

Consideration was given to reducing the 15-minute threshold value in order to make the test more sensitive. Review of night-time five-minute traffic flows revealed that all BHL detectors had at least one vehicle passing within a ten minute period on March 2 and 4, 2004. However the time interval between passage of vehicles may be greater than ten minutes on other days and it was decided not to change the threshold value.

6.1.2 Final Test Results

Since the features of the test were unchanged, the final results are almost identical to the initial results. These results are shown in Appendix D.

6.2 Test 2 Minimum On-Time

The minimum on-time diagnostic test is applied to each consecutive set of 100 vehicle pulses provided by the detector. If 5% or more of the vehicle pulses have duration times less than 8/60 seconds, the detector fails this diagnostic test.

6.2.1 Initial Test Results and Proposed Modifications

Detectors at Station 4W and 5W in lanes 2, 3, 4, and 5 all passed this test. Detectors in lane 1 of Stations 4W and 5W and all detectors in Station 8W failed this test (See Appendix A).

Experiments were undertaken to reduce the threshold value of 8/60 seconds in order to make the test less sensitive. Reducing the threshold value to 7/60 seconds did not appreciably change the results and there was also the concern that one of the strengths of the test was to identify detectors operating in 'pulse' mode. Hence the threshold value was not changed.

6.2.2 Final Test Results

Since the features of the test were unchanged, the final results are identical to the initial results. These results are shown in Appendix D.

6.3 Test 3 Maximum On-Time

The maximum on-time diagnostic test was initially applied to each consecutive set of 100 vehicle pulses provided by the detector. If 5% or more of the vehicle pulses had duration times greater than 600/60 seconds, the detector failed this diagnostic test.

6.3.1 Initial Test Results and Proposed Modifications

All detectors at Stations 4W, 5W, and 8W passed this test except for the upstream detector in lane 2 at Station 8W (See Appendix A).

Experiments were undertaken to reduce the threshold value of 600/60 seconds in order to make the test more sensitive. Reducing the threshold value to 400/60 seconds appeared to provide the desirable results and was implemented.

6.3.2 Final Test Results

The change in the threshold value caused a few detectors to fail this test for short intervals of time (see Appendix D).

6.4 Test 4 Mode On-Time

The mode on-time diagnostic test is applied to each consecutive set of 1000 vehicle pulses during free-flow traffic conditions only (speeds over 50 mph) and the mode value of the on-times is calculated. Thus this test is limited to free-flow conditions only (speeds over 50 mph). If the calculated mode value is between 10.5/60 seconds and 15.5/60 seconds, the detector passes this diagnostic test. Otherwise it fails.

6.4.1 Initial Test Results and Proposed Modifications

Many detectors failed this test but for only one sample of 1000 vehicles during the day. These failures usually occurred at the beginning and ending of congested periods of time in which the 1000 vehicles included free-flow conditions and near-congested flow conditions (see Appendix A).

It was thought desirable to reduce the sample size to minimize the current problem and also to provide the test results at more frequent intervals and be compatible with the sample size of other tests. A number of experiments were conducted in which the sample size was reduced to 100, to extend the test to congested-flow conditions, and to adjust the threshold bandwidth.

The conclusion of these experiments was to reduce the sample size to 100 vehicles, continue to limit the test to free-flow conditions, and slightly increase the threshold bandwidth to between 10.5/60 seconds and 16.5/60 seconds.

6.4.2 Final Test Results

The final results indicated that the number of test failures at Stations 4W and 5W were mostly eliminated and that the number of test failures at Station 8W was generally increased (see Appendix D). In addition it was very advantageous to reduce the sample size to 100 vehicles.

6.5 Test 5 Dual Detector On-Time Difference

The dual detector on-time difference diagnostic test is applied to each consecutive set of 1000 vehicle pulses during free-flow conditions (speeds over 50 mph) and the mean difference between upstream and downstream on-times is calculated. If 5% or more of the on-time differences of 1000 vehicles are not between +/- 3.5/60 seconds, the pair of detectors fails this diagnostic test.

6.5.1 Initial Test Results and Proposed Improvements

The pair of detectors in all lanes at Stations 4W and 5W passed this test as well as in lanes 1 and 3 at Station 8W (see Appendix A).

It was thought desirable to reduce the sample size and thereby provide more frequent test results as well as being more compatible with other tests and also attempt to not limit the test to free-flow conditions. A number of experiments were conducted in which the sample size was reduced to 100, the test was extended to congested-flow conditions, and the threshold bandwidth was adjusted.

The conclusion of these experiments was to reduce the sample size to 100 vehicles, continue to limit the test to free-flow conditions, and slightly decrease the threshold bandwidth to +/- 2.5/60 seconds.

6.5.2 Final Test Results

The final test results were almost identical to the initial test results but now based upon a sample size of 100 vehicles (see Appendix D).

6.6 Test 6 Dynamic Minimum On-Time

The dynamic minimum on-time diagnostic test is similar to the minimum on-time diagnostic test (earlier Test 2) except that the threshold value of 8/60 seconds varies with calculated traffic speed. The test fails if 5% or more of the on-times in a sample of 100 vehicles are less than the calculated minimum acceptable on-time threshold value. The equation for the minimum acceptable on-time threshold value is:

$$\text{Min on-time (1/60 secs)} = [(vl + dl)/(sp)][3600/88]$$

Where:

vl = average vehicle length (assumed 14 feet)

dl = detector zone length (assumed 6 feet)

sp = calculated average speed (mph)

The parameter for the vehicle length represents the detected length of the vehicle. The length seen by the detector is shorter than the manufacturer's measured length since the detector reacts to the metal frame of the vehicle not the leading and trailing edge. Further studies indicated that the majority of passenger vehicles have a detector length of approximately 14 feet.

6.6.1 Initial Test Results and Proposed Modifications

All detectors at Stations 4W, 5W, and 8W passed this test (see Appendix A).

It was thought desirable to modify the parameters in this test to cause the test to be more sensitive. This test includes several parameters but the most promising one was changing the vehicle length. After a number of experiments, the vehicle length was changed to 16 feet.

6.6.2 Final Test Results

The final test results indicated that a few detectors failed for some short periods of time but overall most detectors passed the test most of the time (see Appendix D).

6.7 Test 7 Dynamic Maximum On-Time

The dynamic maximum on-time diagnostic test is similar to the maximum on-time diagnostic test (earlier Test 3) except that the threshold value of 600/60 seconds varies with the calculated traffic speed and whether the lane is designated as a truck-use lane or not. The test fails if 10% or more of the on-times in a sample of 100 vehicles are greater than the calculated maximum acceptable on-time threshold value. The equations for threshold value as a function of estimated traffic speed for predominant passenger vehicle lanes and for the anticipated truck-use lane (lane 5) are:

$$\text{Max on-time (1/60 secs)} = [(vl + dl)/(sp)][3600/88]$$

Where vl +dl is assumed to be 30 feet for predominant passenger vehicle lanes and 66 feet for other lanes

vl = vehicle length (assumed to be 24 feet for predominant passenger vehicle lanes and 60 feet for truck use lanes)
dl = detector zone length (assumed 6 feet)
sp = calculated average speed (mph)

6.7.1 Initial Test Results and Proposed Modifications

With few exceptions, almost all detectors failed this test and many of them failed it frequently (see Appendix A).

It was thought desirable to modify the parameters in this test to cause the test to be less sensitive. This test includes several parameters but the most promising one was changing the vehicle length. After a number of experiments, the vehicle length was changed to 22 feet. It was also necessary to increase the percent failure level from 10% to 25%.

6.7.2 Final Test Results

The final test results were that the number of failures was significantly reduced at all detectors at all stations. However there were still a few test failures at most stations for short periods of time (see Appendix D).

6.8 Test 8 Minimum Off-Time

The minimum off-time diagnostic test is applied to both detectors in each lane and if 5% or more of the off-times in a sample of 100 vehicles are less than 25/60 seconds, the detector fails this test.

6.8.1 Initial Test Results and Proposed Improvements

All detectors at Stations 4W, 5W, and 8W failed this test with only a few failures at individual detectors at Stations 4W and 5W while the individual detectors at Station 8W had many failures (see Appendix A).

Experiments were undertaken to reduce the threshold value of 25/60 seconds in order to make the test less sensitive. Reducing the threshold value to 20/60 seconds appeared to provide the desirable results and was implemented.

6.8.2 Final Test Results

There were rarely any detectors at Stations 4W or 5W that failed the test and if they did, they failed only a few times during the day. There was a reduction in the number of failures at the individual detectors at Station 8W but the number of failures were generally large except for lane 1 (see Appendix D).

6.9 Test 9 Dynamic Maximum Off-Time

The dynamic maximum off-time diagnostic test is applied to both detectors in each lane and threshold value for this test is calculated as being three times the measured average time headway.

If 5% or more of the off-times in a sample of 100 vehicles are greater than the threshold value, the test is recorded as a failure. The equation for the threshold value is:

Max off-time (1/60 secs) = (t)(Tbar)(60)

Where:
t = 3 (representing 3 standard deviations)
Tbar = average time headway (seconds per vehicle)
= conversion from seconds to 1/60 secs

6.9.1 Initial Test Results and Proposed Improvements

Most detectors at Stations 4W, 5W, and 8W had test failures with the largest number of test failures for individual detectors occurring in lane 1 at all three stations (see Appendix A).

Experiments were conducted by varying the ‘t’ variable in lane one in order to reduce the sensitivity of the test. The result was to propose that lane one’s ‘t’ value should be increased to 3.6. The ‘t’ value for the other lanes were kept at a 3.0.

6.9.2 Final Test Results

The final test results were that the number of test failures in lane one at Stations 4W, 5W, and 8W were significantly reduced and while, as expected, there was little or no changes in the test results for the other lanes (see Appendix D).

6.10 Summary

A summary of the initial and final detector diagnostic test failures for Tuesday March 2, 2004 are presented in Illustration 6.1. The horizontal rows represent each of the thirty-two detectors at Stations 4W, 5W, and 8W. The vertical columns represent the test failures for the nine diagnostic tests. The first number in each column represents the number of test failures with the initial diagnostic parameters while the second number in each column represents the number of test failures with the final diagnostic parameters. The results for each of the three stations are described in the following three paragraphs.

Station 4W detectors passed all diagnostic tests 1, 3, and 5 with both the initial and final diagnostic test parameters since they were essentially unchanged. The number of test failures in test 7, 8, and 9 were significantly reduced, were slightly reduced in tests 2 and 4, and were slightly increased in test 6 with the changes from the initial parameter settings to the final parameter settings. The maximum number of test failures with the final diagnostic test parameters was six 100-vehicle samples out of several hundreds of 100-vehicle sample tests in the twenty-four hour period.

The results for the detectors at Station 5W were almost identical with the results obtained with the detectors at Station 4W. These similar results between Stations 4W and 5W was very encouraging and gave some level of confidence in the robustness of the tests and the final parameter settings.

The results for the detectors at Station 8W indicated that changes in diagnostic test parameters had little effect on the number of test failures. Further, that the number of test failures at Station 8W was significantly larger than those for Stations 4W and 5W for all tests except tests 1, 3, and 6. The greatest concern with the detectors at Station 8W was the significant number of test failures with minimum on-times (test 2) and minimum off-times (test 8) for most of the detectors. Note that there was no detector activity from the two detectors in lane 6.

Further research would likely lead to further improvements in the detector diagnostics and the parameter values. However, the diagnostic test results clearly indicate that the detectors at Stations 4W and 5W are predicted to be operating in a satisfactory manner while most of the detectors at Station 8W are predicted not to be operating in a satisfactory manner.

Illustration 6.1 Initial and Final Detector Diagnostic Test Failures for Tuesday, March 2, 2004

STATION	LANE	LOOP	TEST 1		TEST 2		TEST 3		TEST 4		TEST 5		TEST 6		TEST 7		TEST 8		TEST 9	
4W	1	UP	0	0	7	5	0	0	1	1	0	0	0	1	0	0	9	0	25	3
4W	1	DOWN	0	0	10	6	0	0	0	0			0	3	0	0	8	0	25	3
4W	2	UP	0	0	0	0	0	0	1	0	0	0	0	2	12	0	5	0	2	3
4W	2	DOWN	0	0	0	0	0	0	1	0			0	1	8	0	4	0	2	4
4W	3	UP	0	0	0	0	0	0	1	0	0	0	0	0	>45	0	2	0	0	0
4W	3	DOWN	0	0	0	0	0	0	1	0			0	0	>45	1	3	0	0	0
4W	4	UP	0	0	0	0	0	0	1	0	0	0	0	0	>55	4	6	0	0	0
4W	4	DOWN	0	0	0	0	0	0	1	0			0	0	>55	5	4	0	1	0
4W	5	UP	0	0	0	0	0	0	1	0	0	0	0	0	6	2	4	0	1	1
4W	5	DOWN	0	0	0	0	0	0	1	0			0	0	7	2	4	0	0	2
5W	1	UP	0	0	6	6	0	0	1	1	0	0	0	3	0	0	6	0	25	1
5W	1	DOWN	0	0	3	8	0	0	0	1			0	1	0	0	2	0	25	2
5W	2	UP	0	0	0	0	0	0	2	0	0	0	0	1	9	0	11	0	2	1
5W	2	DOWN	0	0	0	0	0	0	2	0			0	3	10	0	10	0	2	1
5W	3	UP	0	0	0	0	0	0	1	0	0	0	0	0	>60	1	2	0	0	0
5W	3	DOWN	0	0	0	0	0	0	1	0			0	0	>60	1	1	0	0	0
5W	4	UP	0	0	0	0	0	0	1	0	0	0	0	0	>55	3	6	0	1	1
5W	4	DOWN	0	0	0	0	0	0	1	0			0	0	>55	3	8	1	1	3
5W	5	UP	0	0	0	0	0	0	2	0	0	0	0	0	7	2	6	0	0	3
5W	5	DOWN	0	0	0	0	0	0	2	0			0	0	5	1	5	0	2	4
8W	1	UP	0	0	11	12	0	0	0	0	0	0	0	0	2	0	2	0	20	1
8W	1	DOWN	0	0	10	10	0	0	1	0			0	0	2	0	2	0	24	2
8W	2	UP	4	4	50	50	1	1	10	>65	11	10	0	0	11	9	20	13	10	7
8W	2	DOWN	0	0	10	10	0	0	1	0			0	0	0	0	17	2	8	10
8W	3	UP	0	0	31	34	0	0	3	0	0	0	0	0	9	0	>60	15	4	4
8W	3	DOWN	0	0	45	45	0	0	3	0			0	0	10	0	>60	26	6	5
8W	4	UP	0	0	80	80	0	0	1	10	10	8	0	0	>70	13	>60	>80	8	4
8W	4	DOWN	0	0	80	80	0	0	10	>30			0	0	>70	22	>90	>95	8	5
8W	5	UP	0	0	80	80	0	0	2	2	4	8	0	0	0	0	>85	>65	8	5
8W	5	DOWN	0	0	80	80	0	0	2	19			0	0	2	3	>90	>80	9	7
8W	6	UP	*	*																
8W	6	DOWN	*	*																

* Detectors at station 8W lane 6 are dead

Figure 6.1 – Initial and Final Detector Diagnostic Test Failures for Tuesday, March 2, 2004

7. Installation and Testing of New BHL System At CCIT (Task 3)

The BHL Detector Project's Task 3, "Installation and testing of new BHL system at CCIT" was to upgrade the BHL data collection and analysis system to new hardware installed at CCIT (the California Center for Innovative Transportation). The new system was installed, tested and operations have been moved to CCIT (with the exception of the frame relay data line; see section 7.2). This task is part of a long term goal to consolidate the ITS testbeds and data collection efforts in a single location.

As part of setting up the new installation, various improvements and corrections were made to the BHL system. These included cleaning up some of the code in the software modules, switching the backend database used to store the data collected and produced by the BHL system, and consolidating all the software functions onto fewer, higher powered, computers.

7.1 The BHL System

The BHL loop detector system consists of 9 independent software modules that interact through a central database. Illustration 7.1 shows the components of the BHL software. The software is written in Java with all communications between components handled by JDBC calls to the database. The system monitor uses TCP/IP connections to individual software components to determine their status. The central database is currently MySQL version 4.18. The components of the BHL system are:

- Detector Stations
- Data Collection Server
- Database
- Summary Generator
- Vehicle Re-Identification and Travel Time Processor
- Diagnostic Processor
- Caltrans D4 Link Server
- System Monitor
- Data Archiver
- Web Server

Conceptually, the components of the BHL can be grouped into three categories. The detector stations, data collection server, and database form the raw data collection system. The summary generator, vehicle re-identification and travel time processor, diagnostic processor, system monitor, and database analyze the raw data and generate processed data such as travel times, aggregate measures, and status information. The Caltrans D4 link processor, data archiver, and web server support the different means of data distribution. Each of the individual components is described below.

7.1.1 Detector Stations

The BHL has 16 detector stations installed along I-80 in 9 controller cabinets. Each detector station consists of a set of inductive loops, 2 per lane spaced 20 feet apart center-to-center, for one side of the freeway. The loops are connected to a set of detector cards and a Model 170 controller installed in a cabinet by the side of the road. Eight of the cabinets have 2 detector stations, one for each side of the freeway while 2 cabinets have detectors for one side only. Each Caltrans cabinet has an Airlink Pinpoint CDPD modem attached to the serial port of the Model 170 controller. The controller runs the log_170 program which produces one data packet per second containing the loop detector transitions for the previous second. The format of the log_170 data is:

- 7 byte header containing a timestamp with the number of seconds since midnight
- 3 byte transition information for each observed change in loop state
- 2 byte checksum

The 7 byte header consists of 2 bytes of constant data and a 5 byte time value which is the number of seconds since midnight. This value is maintained internally by the controller and typically drifts by 1-2 seconds per day. One detector station drifts by approximately 20 seconds per day.

For every detected transition of the loop state either on or off, 3 bytes of data are generated. The data consists of a timestamp in 1/60ths of a second past the second contained in the data packet timestamp, the controller port number on which the transition was seen, and a Boolean value indicating the state (on or off) of the loop.

The checksum at the end of the controller data packet is a simple sum of all the bits in the packet and provides a validity check of the data packet used by the Data Collector. Should the data be corrupted during transmission over the CDPD network, the checksum value calculated off the received data packet will not match the checksum value stored in the data packet and the Data Collector will know the data is bad. While there are very few transmission errors, the check is important due to partial packets generated when the CDPD modem in the field is first turned on.

The CDPD modem detects the line return character at the end of each packet and sends a single UDP packet to the data collection server. UDP is a simple network transmission protocol that does not guarantee either that the data is received without errors or that the data is received at all. One packet is sent and there is no interaction with the receiving server. Monitoring of the BHL system indicates about 99.7% of the data packets are successfully received.

7.1.2 Data Collection Server

The data collection server handles all communication with the cabinets in the field and is responsible for collecting, checking and storing all the raw field data into the central database. The data collection server receives the UDP packet and adds a timestamp to it. The timestamp is the number of seconds since January 1, 1970 and is based on the arrival time of the packet combined with the controller clock's count of the number of seconds since midnight. The controller clocks drift slightly over time so the data collection server keeps track of that drift and ensures that each packet has a unique timestamp.

The data collection server checks the data packet with the included checksum generated by the controller to ensure that there was no change in the data during transmission. If the checksums don't match the packet is discarded. Valid packets are stored in the database in the FREEWAYDATA table.

Most of the cabinets in the BHL coverage area monitor loops on both sides of the freeway. Two cabinets, however, monitor a single side. To regularize the data for the remaining software components, the data collection server divides the transitions in each dual side controller packet into two packets each containing only the transitions for a single side. These new data packets are stored in the database in the RAWDATABYSIDE table. Most of the other software components use this table as the input data for their operations.

7.1.3 Database

The BHL system depends on a central database accessible to all software components. The database stores the raw data, processed data, and status information. The current implementation of the BHL software uses MySQL version 4.18 as the database.

7.1.4 Summary Generator

The summary generator reads the raw data packet from the central database and calculates the flow, occupancy and speed for the last 30 seconds. These parameters are calculated for both the upstream and downstream loops in each lane. The result is stored back in the database in the AVERAGE30SECOND table. In addition the summary generator produces a 5 min average across all lanes of flow, occupancy and speed that is stored in the AVERAGE5MIN table. The 5-minute values are used by the website to produce the history graphs.

7.1.5 Vehicle Re-identification and Travel Time Processor

The vehicle re-identification algorithm was developed using the unique high resolution data of the BHL system. The algorithm matches sequences of vehicles between two stations based on the sequence of vehicle lengths in each lane. Once a vehicle has been identified at both stations, the travel time between the stations can be calculated. The resulting travel times are stored back in the database in the TRAVELTIMESBYSIDE table.

7.1.6 Loop Diagnostics Processor

The diagnostics processor pulls the raw data from the database and runs a set of 17 tests on the data. The tests are described in detail in chapter 2 of this report and consist of the 9 tests described there plus 8 more longer term tests. The primary tests are run on sequences of 100 vehicles. The long term tests are the same tests, with the exception of the activity test, but run on sequences of 10,000 vehicles. For the I80 freeway in the BHL coverage area, the long term tests run slightly more often than once a day. For each test, the detector information, the result, pass or fail, the time of completion of the test, and the parameters of the test are stored in the database in two tables, DIAGNOSTICSTATUS and DIAGNOSTICHISTORY. The results in DIAGNOSTICSTATUS for that test for that detector are replaced each time the test is completed. The results are written the DIAGNOSTICHISTORY table only if the result changed since the last time the test was run.

7.1.7 Caltrans D4 Link Server

The D4 link server consists of two separate programs running on two machines, one on the UCB campus and one in D4, which work in tandem to feed data to the D4 TMC. The component at UCB pulls the most recent 30 second summary data from the database every 9 seconds and waits for a data request coming over a frame relay line connecting the UCB campus and Caltrans' offices in Oakland. The second program runs in the D4 TMC and requests data from the UCB link server also every 9 seconds. The D4 component also waits for requests from the TMC for data. These requests come in every 30 seconds. To the TMC, the BHL link server looks like the other data concentrators which poll the other detector cabinets in district 4.

7.1.8 System Monitor

The system monitor polls all the other components of the BHL system every two minutes. Each of the software components calculates its own status when polled and reports relevant information back to the system monitor. The system monitor tracks the status of each component over time and emails the BHL system operator whenever any component either fails or comes back online. In addition, the system monitor sends a data request to all the CDPD modems in the field every two minutes and waits for a response. This allows the system monitor to determine whether the CDPD modems are powered and have proper network connectivity. After the system monitor has polled all the components, it updates the status information in the database in the SYSTEMSTATUS table.

7.1.9 Data Archiver

The BHL data collection and analysis system generates approximately 3 gigabytes of data per month. As data collects in the database, database operation slows and the storage requirements grow. To minimize resource use, the data archiver software module copies data from the database and stores it in text files on the server hard drive. The data is then removed from the database. Only the last two days worth of raw data and summary data is left in the database. The disk files are archived to backup media regularly as described in chapter 6.

7.1.10 Web Server

The BHL website uses data from the various database tables to present information to both the BHL system operators and to the general public. The web pages are written as java server pages and are generated by Tomcat and Apache web software. The website is described in detail in chapter 10.

7.2 BHL Hardware

The BHL software runs on two computers. The main computer is a dual processor Xserve installed at CCIT. This machine holds the MySQL database, stores the archived data, and runs all the software except the D4 link server. The link server runs on a separate machine installed in McLaughlin Hall on the UCB campus. The link server is directly attached to a frame relay line at UCB that connects to Caltrans' Oakland building. Plans are underway to move the frame relay line into the CCIT server room. Frame relay is an outdated technology and is becoming difficult to get installed and expensive to run. Alternatives are being explored, however it is expected that the system will remain on frame relay. If a new line cannot be installed at CCIT, the existing line will be maintained. In this case, a second server will run the Caltrans D4 link server and pull the summary data from the CCIT BHL server to send to Caltans. If and when the new frame relay is installed, the link server will also run on the CCIT machine and all BHL software will be consolidated onto a single server.

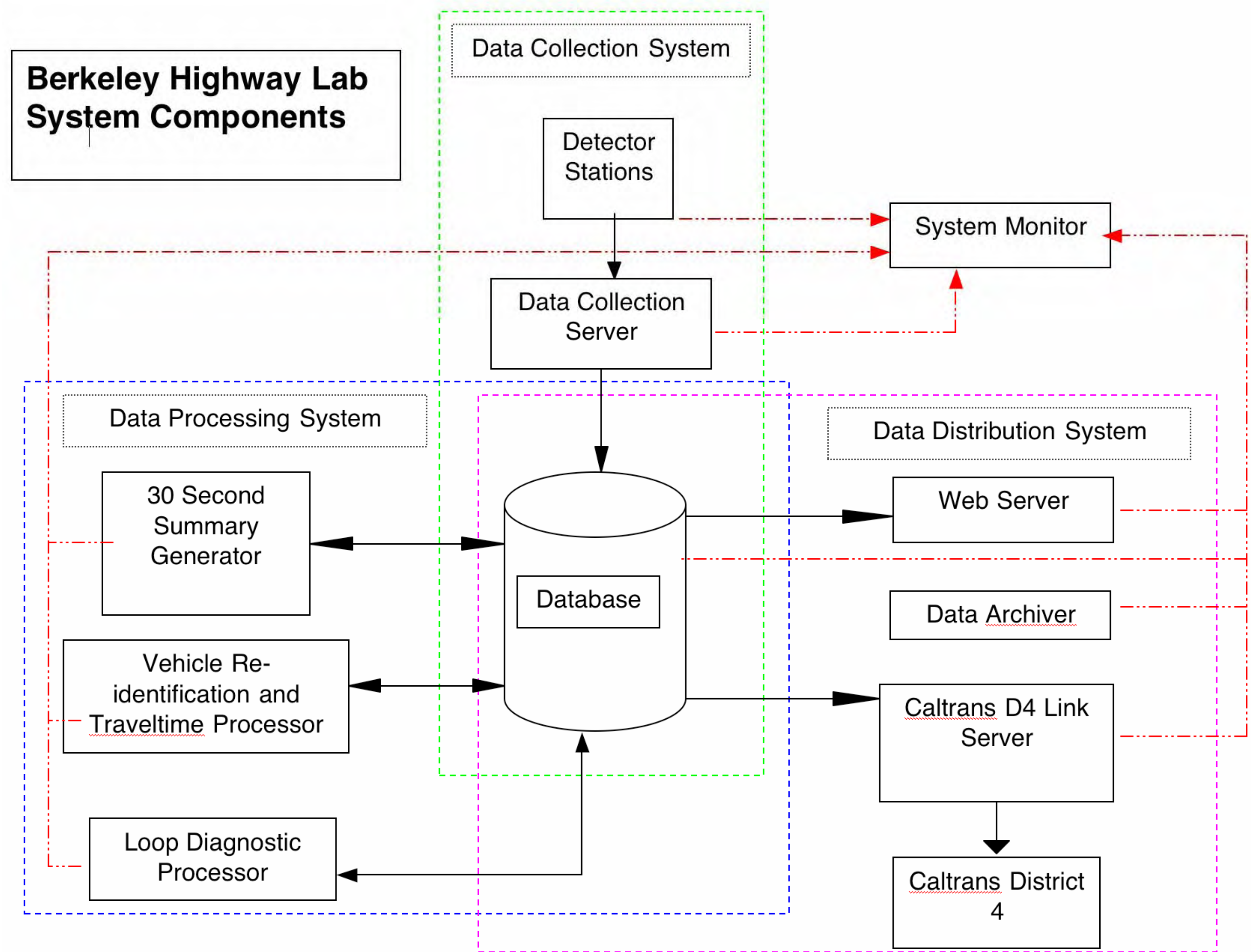

Figure 7.1 – BHL Software Components

8. Maintaining and Operating the BHL System (Task 4)

8.1 Monitoring for Failures and Outages

The Berkeley Highway Lab consists of many physical components, including network communications infrastructure and computer hardware and software. To capture as much data as possible, it is important to maintain full functionality of all of these components.

The core functions of the data collection and processing system are continuously monitored by an automated fault detection and notification system. When the status of a system component changes from a functional state to a failed state, or from a failed state to a functional state, an e-mail message is sent to project staff.

When error notification is received, project staff investigate the failure. By reviewing the Web-based system diagnostics (Figure 10-6) and directly or remotely accessing system components, an attempt is made to determine the nature of the problem. In cases where project staff can access and correct the appropriate components, this is done immediately. If the problem requires access by Caltrans, Verizon (wireless modem provider), or another party, the appropriate contacts are made to resolve the issue.

Regardless of the nature of the problem, Caltrans is informed in the event of any significant outage.

8.2 Operational Problems and Solutions

Several different categories of failure were encountered during the course of this project. Component failures of various types are described below.

<u>8.2.1 Field equipment – failures and errors</u>

- February 2004 – Controller at station 6 required a hard reset.
- May 2004 – Station 3 exhibited symptoms of controller lock-up; a Caltrans field visit was scheduled, but was cancelled since the controller returned to full functionality on its own.
- July 2004 – Station 2 exhibited complete outages of several outages on almost a daily basis, and only during daylight hours; a Caltrans field visit identified clogged cooling air flow to the equipment. Cabinet was service and operation returned to normal.
- December 2004 – Station 6 modem went off-line; wireless provider indicated no service issues. A Caltrans field visit identified a failed modem power supply, which was replaced. This outage is represented pictorially in Figure 8.1: the third vertical bar from the left in each plot represents Station 6; loss of data can be seen for December 9 through December 20.

8.2.2 Field equipment – configuration

- September 2004 – Station 8 cards were found to all be set to the same frequency, which caused excessive crosstalk. Caltrans personnel corrected the issue in the field.
- November 2004 – Continued poor data quality from stations 8 and 9 was attributed to an unreliable version of IST detector cards. Caltrans replaced cards with a newer version.

8.2.3 Wireless communications service

- March 2004 – All modems went off-line in a short period of time. While in conversation with Verizon over the issue, service returned to all modems. Verizon did not recognize the problem and did not have an explanation for the return to service.
- April 2004 – Multi-day Verizon outage of all modems. Problem reported repeatedly to Verion; service restored without explanation.
- September 2004 – All-modem outage due to Verizon. No confirmation of outage from Verizon, but service returned shortly after report of problem to Verion.

8.2.4 Data collection and processing system

- April 2004 – Recurring database corruption issues. New system that was being staged for CCIT move was brought on-line early so that old database could be removed from service.
- December 2004 – New server would freeze and reboot under heavy disk usage. An operating system update resolved the issue. This outage is represented pictorially in Figure 8.1: horizontal gaps in the daily data (representing no data collected) on several occasions in the period from December 1 through December 9 are due to these outages.

8.3 Data Archiving

As part of the hardware system upgrade, an additional computer was purchased to run daily off-site backups of the BHL data collection system. This second computer sits in McLaughlin Hall on the U.C. Berkeley campus, and has sufficient hard disk storage capacity to hold more than one full year of raw and processed data.

Each night, automated processes running on the backup computer connect to the data server at CCIT. All new data files that have been created on the CCIT server since the previous backup are copied to the machine in McLaughlin Hall. The process is not a literal mirror, as the automated processes will never remove files from the backup machine; it is only ever an additive process.

Long-term archiving of BHL data is handled by copying monthly data sets onto optical disks (CDs or DVDs). The following data sets are included in the archive:

- Raw, bitpacked detector data
- Sorted, bitpacked detector data

- Measured travel times
- 30 second aggregate by lane
- 5 minute aggregate by station
- Daily summary images
- Diagnostic data
- Individual vehicle data

Data file formats are described on the BHL Web site (Chapter 10) and in our previous report (May, 2004).

8.4 Data link to CalTrans District 04

Caltrans collects 30 second data from highway loop detectors statewide. The Berkeley Highway Lab, in addition to collecting 1/60 second data, generates 30 second data which is relayed to Caltrans and integrated into the statewide Caltrans IFS2 data collection system. For this data to reach Caltrans, the dedicated data communication line between the Berkeley campus and Caltrans District 4 must function, and 30 second data must be made continuously available over this link.

The data link that allows 30 second data to travel from the BHL system to Caltrans District 4 is supported by a frame relay connection. This is a virtual point-to-point link with robust error correction, and has performed very reliably during the course of the project.

A Caltrans server at the remote end of the frame relay connection continuously sends data requests to the BHL Caltrans D4 Link Server, which provides the 30 second data in response to each request. The BHL team monitors the Caltrans data requests and can inform Caltrans in the event that data is not being pulled from the Berkeley Highway Lab.

The frame relay data line between the Berkeley campus and District 4 is highly reliable; service on this line is estimated to exceed 99% availability.

The status link is monitored continuously as part of the BHL system diagnostics. Current status of the link is displayed on the BHL Web site, and link outages cause an automated e-mail warning to be sent to BHL team members.

8.5 Distribution of Loop Detector Data

Sharing the unique Berkeley Highway Lab data with other researchers allows others to conduct additional traffic research beyond the scope of this project. Some Berkeley Highway Lab data is publicly available via the BHL Web site; additional data is made available to other researchers upon request, and with the understanding that Caltrans will be apprised of all data sharing arrangements.

BHL data has been used by a number of researchers at several institutions. During the course of this project, these researchers have included:

- Vijay Kovvali of Cambridge Systematics, Inc., Oakland, CA requested BHL data to assist with work on the Federal Highway Administration's Next Generation Simulation (NGSIM) program.
- Emerson Murphy-Hill, a computer science graduate student at Portland State University, received BHL data to assist with the development of data streaming systems.
- Andrei Boitor, a student working with Petros Ioannou at the University of Southern California's Center for Advanced Transportation Technologies, is using BHL data to calibrate a traffic simulator.

As long as the lab continues to operate with a scope similar to the current project, BHL data available will be made available to other researchers on a case-by-case basis and with the approval of Caltrans. The BHL research team will continue to evaluate with Caltrans the importance of the project and announcing the availability of data sets.

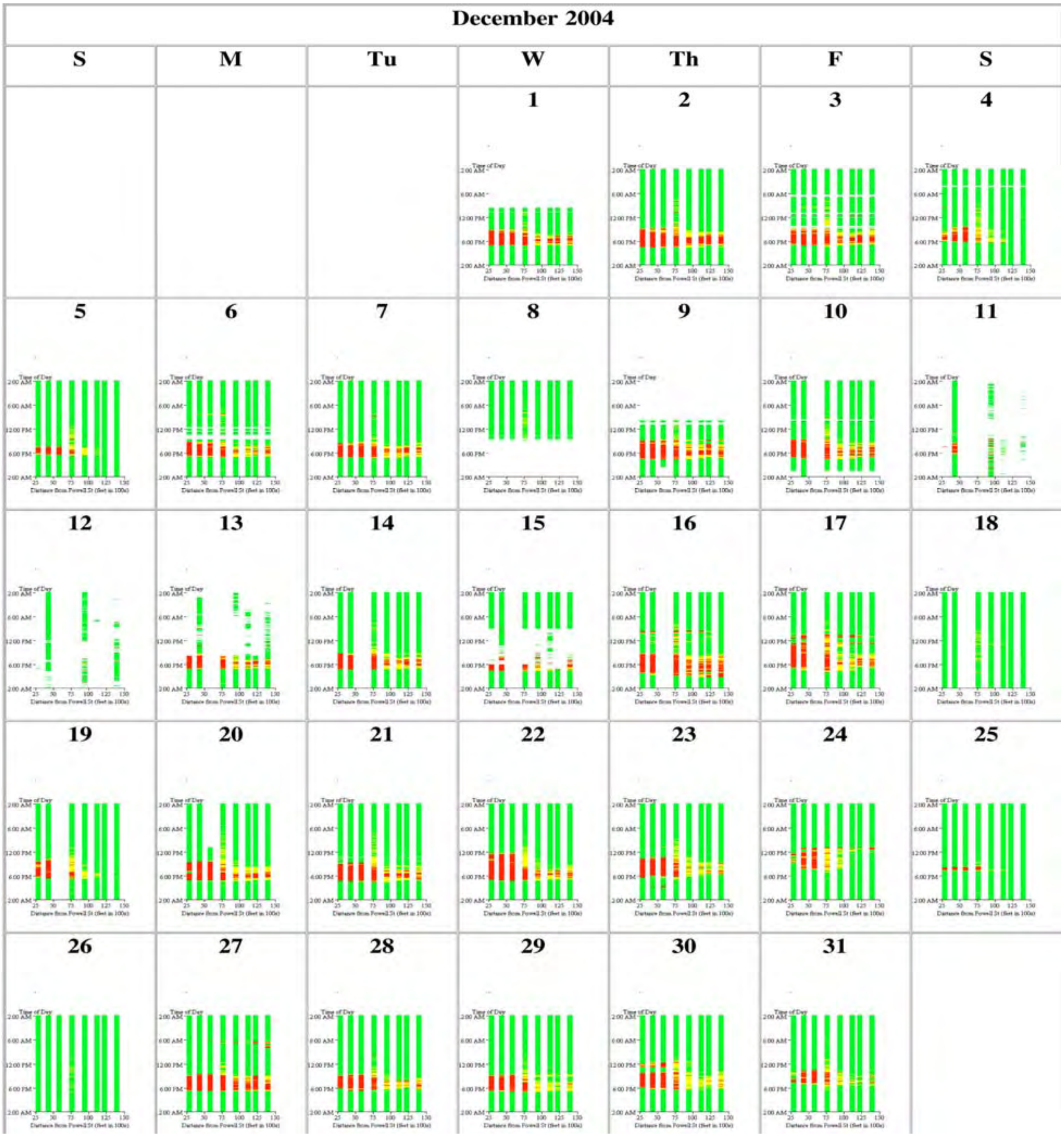

Figure 8.1 – Eastbound Density Contour Maps for December, 2004.

Each density contour map displays congestions levels for one direction of travel at all 8 stations for a full day. System outages discussed in sections 8.2.1. and 8.2.4. are revealed in these plots.

9. Preliminary Design Of Portable Detector Diagnostic Tool (Task 5)

The BHL Detector Project's Task 5, "Preliminary Design of a Portable Diagnostics Tool" was to examine how the BHL diagnostic suite could be applied in the field by installation and maintenance technicians to evaluate and troubleshoot loop detector installations.

9.1 Common Error Conditions

There are a variety of installation mistakes and operational failures that can occur in loop detector systems. The first prerequisite in designing a diagnostic tool is to determine what is being tested for. The BHL loop detector collection system has been operating for over 8 years and has encountered a variety of errors. There are several classes of known errors in loop detectors. Among them are:

- Wiring errors
- Card errors
- Sensitivity errors

In addition to problems due to faulty wiring or defective components, there are number of additional problems which result in data of questionable quality. These include:

- Cabinet configuration errors
- Sensitivity settings on the detector cards
- Cross-talk between neighboring cards

The diagnostics developed in the BHL are primarily concerned with detecting data quality problems though they can also help with finding wiring and installation errors.

<u>9.1.1 Wiring Errors</u>

There are a number of possible wiring errors. The BHL system was implemented at a pre-existing location where the loop connections had already been in operation for some time. Very few wiring errors have been found in the BHL. A new installation would be more likely to encounter mistakes or failures in the wiring, however. There are several types of wiring errors, some of which can be detected by examining the controller output data and some which cannot. Possible wiring errors that may be identifiable are:

- Open or broken loops
- Loops with incorrect impedance
- Bad connections
- Intermittent loop failures – ie shorting due to moisture, vibration, etc.
- Loop matched to wrong lane
- Upstream and downstream loops switched

9.1.2 Card Errors

Assuming that there are no wiring errors and the physical loops are in correct operating condition, there are a number of card problems that can occur. The cards can fail and produce no data at all. Most detector cards have a presence test mode (pulse mode) where they simply register a single, fixed width detection pulse whenever a vehicle is detected. This will generate correct flow counts but incorrect occupancy and speed data. A major problem with most detector cards is crosstalk. This is the phenomenon where a vehicle detected by one card causes a phantom pulse on another card. Detector cards operate on different frequencies but can be mis-set to the same frequency, which causes crosstalk. Electrical noise of various sorts can also cause crosstalk.

9.1.3 Sensitivity Errors

Even for correctly wired loops, there are card settings that can result in errors or questionable data. Most detector cards have a sensitivity setting that adjusts the threshold at which the cards signal the presence or absence of a vehicle. When set too low, vehicles may fail to be detected at all. More commonly, the detector will not trigger until more of the vehicle is on the loop and will turn off earlier than appropriate when the vehicle starts to leave the loop. This will change the duration of the on time pulse resulting in incorrect occupancy and speed calculations. Similarly, setting the sensitivity too high will cause too long an on time pulse, which will also cause incorrect values for occupancy and speed. In addition, a too high sensitivity may cause the detector card to pick up vehicles in adjacent lanes.

9.2 Testing Sequence

The detector diagnostics developed as part of the Berkeley Highway Laboratory are primarily concerned with testing the quality of data. Many of the possible loop detector errors involve earlier stages in the data flow from the roadway to the TMC. Figure 9.1 shows a sequence of diagnostic tests. Checking operation at each stage ensures that the necessary data (with adequate correctness) are available at subsequent stages.

9.2.1 Activity Testing

The first stage in testing a loop installation is determining that data is actually coming from the loops. The BHL activity test can be used to test that transitions are arriving at the model 170 controller. A screen similar to Figure 9.2 is suggested to show the status of each detector loop. If a loop is shown as not producing data, there are several troubleshooting steps that should be done to isolate the problem. First, the light on the card should be checked. If the detector card does not signal the presence of vehicles, either the card, the wiring connection, or some part of the loop are bad. If the card does show activity, the lane to port mapping used by the controller and the portable diagnostic tool is probably incorrect.

9.2.2 Port to Lane Mapping

The second step in the testing sequence is to check the lane to port mappings of the loops and the detector cards. This includes both which lanes are the loops in and, for dual loop installations, which order are the upstream and downstream loops in. While a version of the BHL activity test with immediate feedback about each transition could be used for this, a simpler method is to use the lights built into the detector cards. The log170 controller program used in the BHL adds a 1 second, or greater, delay between when the vehicle passes the loop and when the loop data becomes available within a testing tool. This makes a direct comparison between the observed vehicle stream on the freeway and the diagnostic test results slightly problematic. The most straightforward way to check the lane to loop signal matching is to observe the traffic stream and compare the passage of a vehicle in a particular lane over the approximate location of the loop with the flashing light on the detector card. This will likely require two technicians. Once the card has been identified which matches a particular lane and lane position (upstream or downstream) the controller lane to port mappings can be tested by pulling the card briefly and checking that the activity test fails for the expected loop. To facilitate this test, the activity test should be modified to run on a very short time interval, around 5 seconds. The time interval is a configuration parameter in the existing activity test.

Ensuring that the loops are in the correct order can be done with a check of the dual loop speed calculation. The testing tool should display the calculated speeds for each vehicle in a lane. When the loops are correct, the speed will match approximately the technician's estimate of speed on the freeway. If the loops are in reversed order or mismatched across different lanes, the calculated speeds are very far off the correct speeds.

9.2.3 BHL Diagnostic Testing

Once the basic operation of the loops and the lane to port mappings have been confirmed, the BHL derived diagnostics can be applied. The BHL diagnostics suite can determine correct operation of several aspects of loop operation. The recently developed macro-diagnostics can determine that flows and occupancies are correctly related. Failure in the relationship between flow and occupancy indicates a tuning problem. The micro-diagnostic tests can determine whether the sensitivity of the loops is set correctly, whether the card is in pulse mode rather than sense mode, and whether the card is picking up signals from neighboring loops and cards (crosstalk).

Testing would be best done when traffic is heavy but still in free-flow. This allows the tests that depend on numbers of cars to run most quickly. Free-flow conditions allow the running of the mode on-time and dual loop difference tests that are good tests for sensitivity testing. The diagnostic tests use a 100 vehicle sample size which requires 5 to 10 minutes of traffic under moderate conditions.

9.3 Testing Hardware

The proposed hardware components of the portable diagnostic tool are shown in Figure 9.2. The diagnostic software runs on a portable computing device such as a laptop or a Personal Digital Assistant (PDA). The requirements are that the computer have a serial port and be capable of running Java. Many PDAs can meet these requirements and would make the diagnostic tool very low cost, on the order of $200 each. Using a low cost computing device would allow placing them in multiple cabinets simultaneously or for longer periods of time which would improve the testing procedures. A standard laptop could be used as well which has advantages in terms of display screens and better input capabilities.

The diagnostic test suite analyzes the high resolution, 60 Hz data that the model 170 controller is capable of generating. It is likely that most controllers in the field would not be set to produce this data which presents a problem for testing particularly for controllers which are in use, as opposed to initial testing on newly installed detectors. While it would be possible to set the model 170 controller in the field to produce high resolution data by swapping the controller module, this would take the controller out of commission for the duration of the test.

A better solution is to install a passive tap between the detector cards and the controller that feeds the loop information to a separate emulated controller that produces the necessary 60 Hz data packets. Caltrans has developed such a system already which could be used in the field as part of a diagnostic tool with no additional development. A significant advantage of this approach is that the controller continues to operate undisturbed while the testing is being done.

9.4 Diagnostic Tool Interface

While the interface for the diagnostic tool will vary depending on the computing platform chosen, most of the elements would be the same or similar for any. At the start of testing, some basic configuration needs to be entered. The required information is the port to loop mapping information for the detectors at that station. Additional information would be desirable such as the station number, testing technician, time of day, and so forth, which would be stored along with the test results and saved to a machine in the TMC. Figure 9.3 shows a possible input screen for the initial information.

After the diagnostic tool has been configured for the particular detector station, the diagnostics can be run. As a basic first test of correct operation, the testing tool could generate standard macroscopic measures as shown in Figure 9.4. The macroscopic measures provide an easy way to tell whether the configuration is likely correct and which detectors are having severe problems. An experienced field technician can tell whether the flow and speed values are in approximately the correct range of values. In addition, several macroscopic relationships have been identified which could serve as diagnostic tests such as the relationship between flow and occupancy discussed in chapter 2.

After the macroscopic measures are displayed, the microscopic diagnostic tests used in the Berkeley Highway Laboratory would be run. While there are many possible displays for the outcomes of the diagnostics, at least three would be desirable: a summary of detector status, the diagnostic test results, and the on-time pulse width distribution. Possible displays are shown in illustrations 9.5, 9.6, and 9.7.

The primary result screen would be a summary screen such as shown in Figure 9.5. This would show either a passing status message for the detector or, if problems were detected, an indicator of the nature of the problem. This would be linked to context sensitive follow-up screen listing possible causes and solutions to the identified problems.

At any point, more detail about the diagnostic results could be displayed as shown in Figure 9.6. The results screen is similar to the current BHL website results screen. It shows the results of the current 9 diagnostic tests (8 for single loop installations) and would include additional tests as they are developed. This screen is intended for the technician to get a better sense of what contributed to the conclusions about the health of the detector shown in the summary screen.

The lengths of the on-time pulses have been found to be very informative when examining the operation of a loop detector. The final diagnostic screen would show the distribution of the on-times for a particular detector. The shape of the distribution curve can tell the technician whether there are problems with cross-talk or with tuning. While the software should be able to determine tuning problems, severe crosstalk causes similar diagnostic failures, Looking at the distribution curve and comparing it to the expected curve would help the field technician determine the correct fix for any problems. Figure 9.7 shows an on-time distribution for a detector with severe cross-talk. The peak of the distribution is around 14/60ths of a second which is expected based on free flow speeds and average vehicle lengths. However, the secondary peak around 5/60ths of a second is caused by partially detected pulses picked up from one or more neighboring detector cards. Figure 9.8 shows the expected distribution with a single large peak around 14/60ths of a second and very few small length on-times.

9.5 Summary

A portable diagnostic tool based on the BHL detector diagnostic tests could be used to establish correct operation of new loop detector installations and to troubleshoot data quality issues with existing installations. For new installations, the model 170 controller can be set to run the log170 program and the testing tool can be directly fed off the output of the controller. For existing installations, a passive tap on the output from the detector cards and the Caltrans developed log170 emulator box can be used to provide data to the testing tool without disturbing the data flow to the TMC.

The diagnostic tests developed for the BHL can help diagnose tuning problems, loop to port mapping or wiring problems, crosstalk problems, incorrect sensitivity settings, and detector card errors. The required hardware is relatively inexpensive and easily available which would allow flexibility in how the testing tool was used. It could be used in the field for brief periods under the direct control of a technician or it could be left in the cabinet for longer periods of time allowing longer term testing of the loop detectors.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 9.1 – Diagnostic Testing Sequence

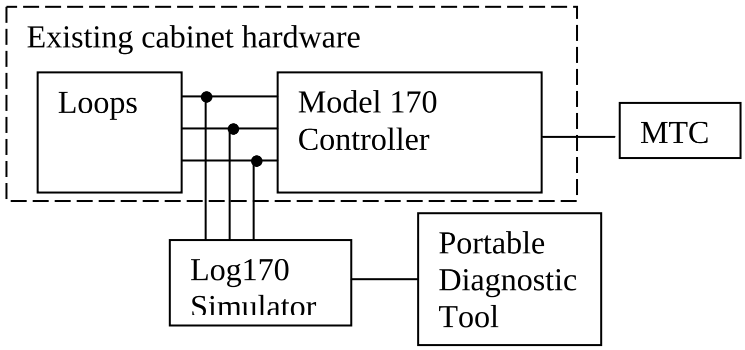

Figure 9.2 – Diagnostic Hardware Configuration

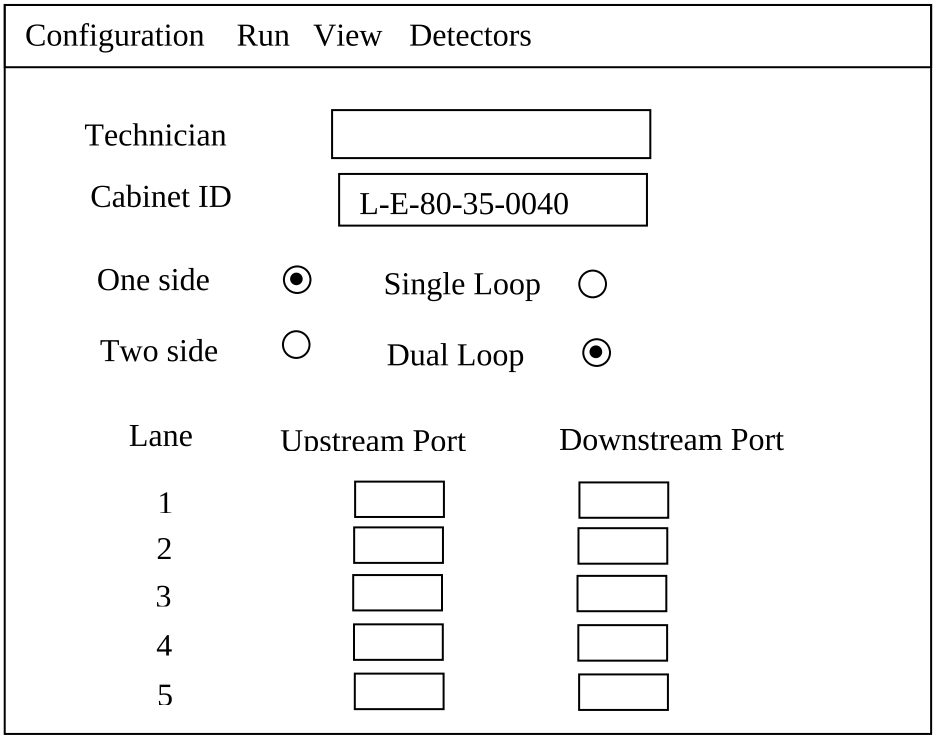

Figure 9.3 – Diagnostic Tool Configuration

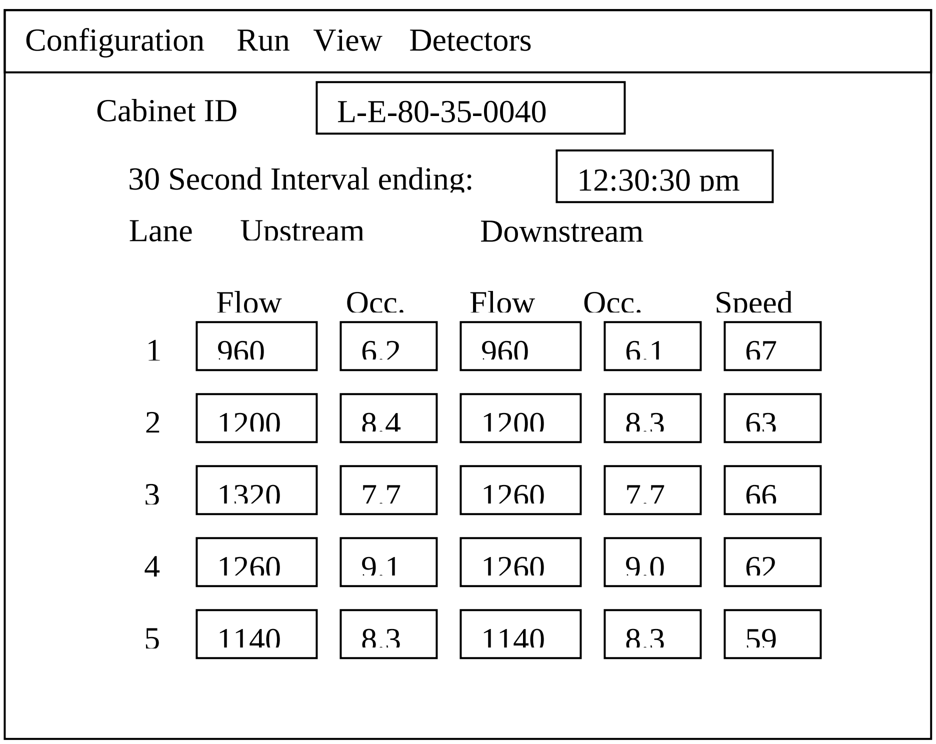

Figure 9.4 – Macroscopic Checks

Configuration Run View Detectors

Detector Summary:

Side 1:

Lane 1 Upstream No Activity

Lane 3 Upstream Low Sensitivity

Side 2:

No Problems Found

Figure 9.5 – Detector Summary View

Configuration   Run   View   Detectors

Detector: Side 1 Lane 1   Upstream

Test	Result	Failure %
Activity	Pass	
Min On Time	Fail	8%
Max On Time	Pass	3%
Mode On Time	Fail	11%
Dynamic Min On Time	Pass	3%
Dynamic Max On Time	Pass	2%
Dynamic Min Off Time	Pass	1%
Max Off Time	Pass	3%
Dual On Time Difference	Fail	8%

Test Results View

Figure 9.6 – Test Results View

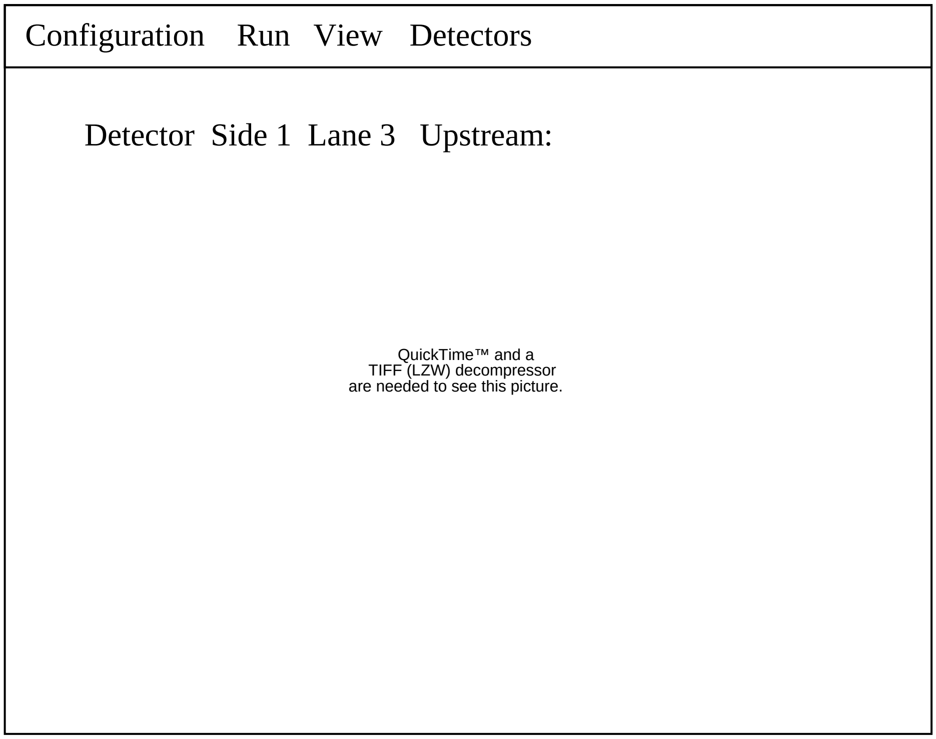

Figure 9.7 – On Time Distribution View - Crosstalk

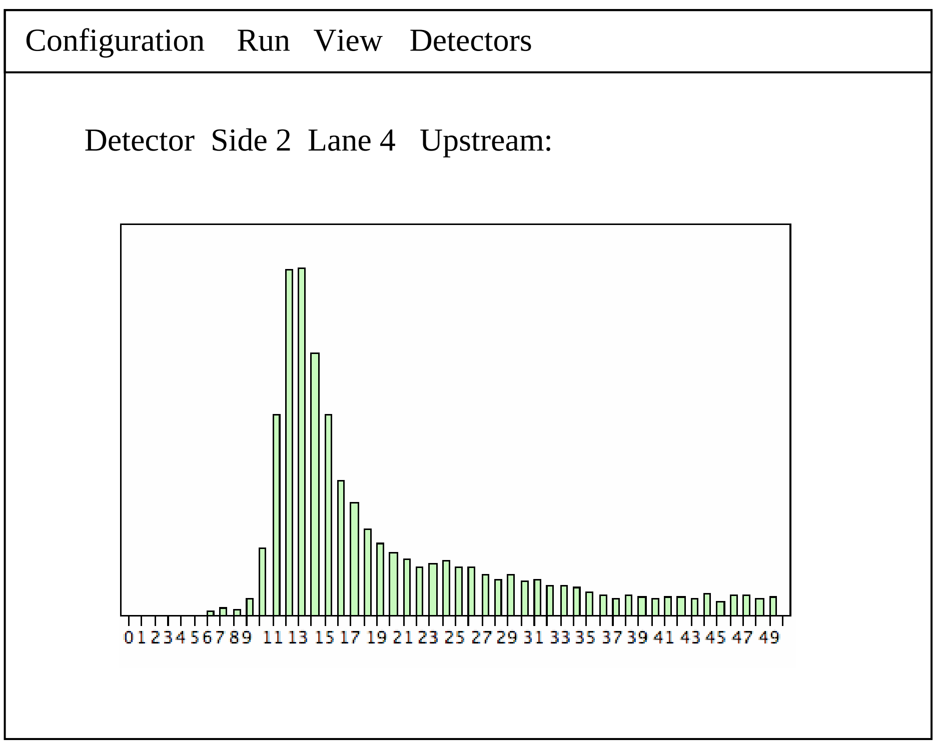

Figure 9.8 – On Time Distribution View – Expected distribution

10. BHL Web Site

The BHL website provides a central point for viewing the operation and output of the BHL system and serves as a information source for other researchers interested in the project. The BHL website is at: http://www.its.berkeley.edu/bhl/.

As part of moving the BHL system to CCIT, the BHL website was revised and updated. The website was installed on a new server and some additional pages for diagnostics were added. The web server is implemented as a mixture of static html pages and dynamic pages written as java server pages (JSP). The web server software was changed to Apache running with Tomcat as the servlet engine. Several changes and enhancements were made to the website including:

- Better network error recovery
- Improvements in the speed of BHL servlets
- Addition of long term diagnostic pages
- Addition of a occupancy-flow graph for displaying historical traffic
- Incorporation of an additional detector station in graphs and table displays

The BHL website serves several different purposes. For project personnel, it provides a simple interface for monitoring the operation of the BHL and for identifying and correcting operational problems. For other researchers and Caltrans personnel, it provides information on the BHL project and on the data being collected and available. For the general public, it provides educational information on traffic in general and on an important freeway corridor.

Figure 10.1 shows the main page for the BHL website. There are two types of pages available on the site, dynamic pages which pull data from the BHL database and display it and static informational pages about the project. There are seven main sections to the BHL website:

- About the BHL
- Current Traffic
- Historical Traffic
- System Diagnostics
- Detector Diagnostics
- Data Sets
- BHL Research

10.1 About the BHL

This section provides basic information about the BHL. This includes some background into the history of the BHL data collection project, the physical facility, and the system architecture. Figure 10.2 shows the about the BHL page. The map on the top of the page is used throughout the BHL website to orient the viewer as to the numbering and placement of detector stations relative to major roadway features. There are 8 pairs of stations spread between Gilman Street on the North and Powell Street on the south. Each pair of stations, one on each side of the freeway, is numbered sequentially 1 to 8, North to South. As can be seen on the map, station 1 is just South of the Gilman Street ramps. Stations 2 and 3 are between the on and off ramps at

University Avenue. Stations 4 and 5 are in the straight line section between University Avenue and Ashby Avenue. Stations 6 and 7 are between the on and off ramps at Ashby Avenue. Station 8 is between the on and off ramps at Powell Street. The BHL has several video surveillance cameras installed on the top of the Emeryville Tower that are used for research in the BHL. The Emeryville Tower is shown on the map along with an rough indication of the area covered by the video camera's field of view. The scale along the bottom of the map shows the distance in feet along the section of I-80 in the BHL area.

10.2 Current Traffic

The website provides current status information on the traffic at each station in the BHL. Two kinds of information are provided, 30 second summary data and travel time data between pairs of stations. Figure 10.3 shows the summary data for one of the BHL stations. For each lane, the flow, in vehicles per hour, the occupancy percentage, and the speed for the last 30 seconds are shown. The flow and occupancy values are the average of the values calculated for the upstream and the downstream loops. The speed is the average of all the vehicles seen in the 30 second interval and is calculated by dividing the time spent traveling between the upstream and downstream loops by the distance (20 feet) between the loops. The current 30 second summary data for an individual station is shown in Figure 10.3. All 8 stations (paired stations for both sides of the road) are accessible from the row of links numbered 1 to 8 above the data table. The data table shows the current data for each lane ordered spatially from the outside lane in the Westbound direction on the far left, labeled W5, to the outside lane in the Eastbound direction on the far right, labeled E5. Below the table, the time and date of the 30 second period show is displayed.

Figure 10.4 shows the travel time display page. For each lane, the median value of the last 3 travel times for vehicles matched between stations is shown. Travel times are measured between pairs of stations so the two stations are shown in the title of the page. Travel times between any other pair of sequential stations can be accessed through the row of links above the data table. Travel times between stations 7 and 8 are not available because station 7 has 5 lanes in each direction and station 8 has 6 lanes in each direction. While some theoretical work has been done to match vehicle streams between stations with unequal numbers of lanes, the necessary algorithms have not yet been incorporated into the BHL travel time processor software. The data table is structured in the same way as the table of data for a single station shown in Figure 10.3 with the outside Westbound lane on the left and the outside Eastbound lane on the right. The second table below the travel time table shows the arrival time at the downstream station of the most recently matched vehicle for each lane.

10.3 Historical Traffic

The BHL database contains 5 minute averages across all lanes at each station collected since May 2000. The averages provide flow, occupancy and speed data for each station. This data is used to provide historical on-demand graphs of station performance. There are 6 graphs which can be produced for an individual station, speed vs time, flow vs time, occupancy vs time, density vs time, flow vs density, and flow vs occupancy. Sample graphs are shown in Figure 10.5. In addition, a density contour chart can be produced showing the density over time for all 8 stations simultaneously.

Figure 10.6 shows the graph selection page that allows specification of the station to be graphed, the type of graph and the date to be graphed. Any date after May 1, 2000 may be entered in the text box and the graph for that day will be produced. There are two special data specifications, “Yesterday” and “Today”. The Today specification will produce a graph of all the data for the current day collected so far with the right of the graph left blank. The graph selection choices are repeated at the bottom of every graph display page as can be seen in Figure 10.7 showing a speed graph for station 1. There are some days for which no data is available in the historical database. This is particularly true for station 8 which did not become operational until several years after the other stations. If no data is available, a graph will still be produced but will show no values.

The contour map shows data for all 8 stations on a single graph (see Figure 10.8). Stations are shown in order by position along the freeway with the upstream station on the left and the downstream station on the right. Selecting the opposite traffic direction will reverse the station order. Position of the bars along the x-axis is proportional to the distance between each station. The small map above the graph is an aid to orienting the viewer as to where each station lies. Time is shown running from the beginning of the day (midnight) at the top of the graph downwards to midnight at the end of the day at the bottom. The graph shows traffic density with three possible colors. Green indicates density less than 40 vehicles per mile, yellow indicates density between 40 and 60 vehicles per mile, and red indicates density greater than 60 vehicles per mile. Areas of white indicate missing data.

10.4 System Diagnostics

The system monitor software component collects information every 2 minutes for all the other system components. It also provides a query interface that the web server uses to provide a system status page. Figure 10.9 shows the overall system status page that is presented. This page summarizes the status of the major system components. The Diagnostic Processor module was developed after the System Monitor page was developed and has not been added to the status page. The remaining components are shown with a simple status message indicating either success or that there is a failure.

A more detailed page is provided via a link at the bottom. This is shown in Figure 10.10. The detailed page provides access to some internal information, such as the times of the last packets received from each cabinet, which can used to troubleshoot system problems. This page is useful for the BHL system administrators to determine where the likely cause of any problem lies. For each of the monitored components information on the times associated with different operation is shown. For the freeway data collector, the timestamp of the last data packet received from each station is shown. This allows the operator to easily identify a problem with a particular station or, if the times are old for all stations, to identify network problems with the data collector. For other modules, such as the travel time calculator and the Caltrans D4 link, the detailed status page shows the last time that data was read from the database and the timestamp on the data record that was read. This shows database access problems and processing problems with a particular module. For the Caltrans D4 link processor, the time of the last request received from the TMC is available which allows BHL personnel to determine when there is a problem with the software running in District 4’s TMC. For the data archiver, the times when various data sets were last written to disk are shown. This helps identify database problems where a problem with a particular data record in one table causes an error in processing the archive set. It also helps monitor the overall health of the database since problems in the database can result in significantly longer running times for various operations.

10.5 Detector Diagnostics

A significant achievement of the BHL project over the last year has been the implementation and refinement of the set of detector diagnostics. The BHL website provides a way to view the results of all the diagnostic tests for every loop detector in the BHL. The detector diagnostics pages provide progressively more detailed views of the operation of the loop detectors for each station. Figure 10.11 shows the top level of the detector diagnostics pages. This page shows a summary of each side of all the stations in the BHL. Detector status is color-coded based on whether any detector failed any tests and, if so, which tests were failed. A red light indicates that at least one detector of the set failed the activity test, the minimum on time test, or the maximum on time test. These tests are unlikely to fail on any loop that is operating correctly so are considered critical tests of detector operation. The yellow light indicates that at least one detector failed one of the other tests. These other tests are more dynamic in nature and false negatives are possible should traffic conditions be particularly unusual. So it is possible to have a correctly operating detector fail some of these tests. A yellow light is a signal that data quality may be questionable. A green light means all detectors for that station passed all tests.

Clicking on either of the two lights for a particular station takes the user to a lane by lane breakdown of diagnostic status of that station (Figure 10.12). This more detailed page uses the same color code as the previous page but for each lane in both directions. From here, the user can look at two more detailed pages, the results of the most recent set of tests for each detector at that station (Figure 10.13), or the results of the same set of diagnostic tests run over a much larger set of vehicles (Figure 10.14). The longer term diagnostics are much less susceptible to momentary variations in the vehicle stream but require almost a full day to run. They are particularly useful for identifying cases where the loop detector sensitivity is set wrong. The same detectors fail the same tests day after day for the long term diagnostics while they may successfully pass some of the short term diagnostic tests.

Figure 10.13 shows the detailed results page for a station. Each test is shown for each detector. A green light indicates the detector passed the test, a red light indicates the detector failed the test, and a black light indicates that that particular test has never completed for that detector. A black light generally indicates a non-functioning detector such as for station 8 lane 6 Westbound. Since no data is produced, a 100 vehicle sample is never seen so the test never completes. The time after the test result shows how long it has been since the test was last completed. This is useful for when a detector fails the activity test. The activity test fails but the previous results of the other tests are still shown. However, the time since the tests were completed grows large. For some tests, the mode on time and dual loop difference tests, which do not run during periods of congestion, the time since the last completed test may be several hours. The long term diagnostic tests page (Figure 10.14) is almost identical though the times since last completed test are very long. There is no long term activity test as the length of inactivity can be seen in the times on the short term diagnostic test page.

10.6 Data Sets

The data produced by the BHL is of interest to many researchers for many purposes. To facilitate use of the data, the BHL website provides some details about the kinds of data produced and archived at the BHL. It also provides documentation of the format of each data set and information about the time periods for which different kinds of data are available. Figure 10.15 shows the data sets page. Most of the web content is in the data reference section. Another project is planning on making some or all datasets available over the web so a placeholder for downloadable data was put on this page.

The data reference manual page is shown in Figure 10.16 This page lists all the available data sets with information on how they are named. Following the links on this page will give greater detail about the format and content of each data set. For each data set, the format of the file, the type of data contained in the data set, and information on how to interpret the data is given.

10.7 BHL Research

The BHL system was developed over many years with different aspects developed under separate projects. The research page (Figure 10.17) tries to collect all the reports generated by the projects in one place. As the data collected is used in other research, the intention is to place links to the reports and papers produced. At the moment, only reports on the research projects responsible for developing the BHL loop detector system are included. However, the data from the BHL has been an important research resource in a number of other projects. As reports from those projects are produced, links to those reports will be added.

Figure 10.1 – BHL Home Page

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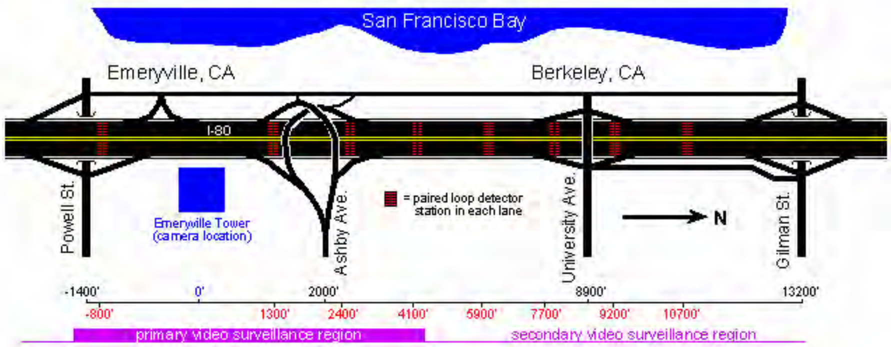
About The Berkeley Highway Laboratory

- BHL Home
- About the BHL
- Current Traffic
- Historical Traffic
- System Diagnostics
- Detector Diagnostics
- Data Sets
- BHL Research
- ITS Home



Facility Description - some details about the BHL site and its infrastructure

History - about the development of the BHL

System Architecture - a description of the major components of the system and what they do

Vehicle Reidentification Algorithm - a key innovation of the BHL was the development of an algorithm to identify vehicles between pairs of loop detector stations.

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Figure 10.2 – About the BHL

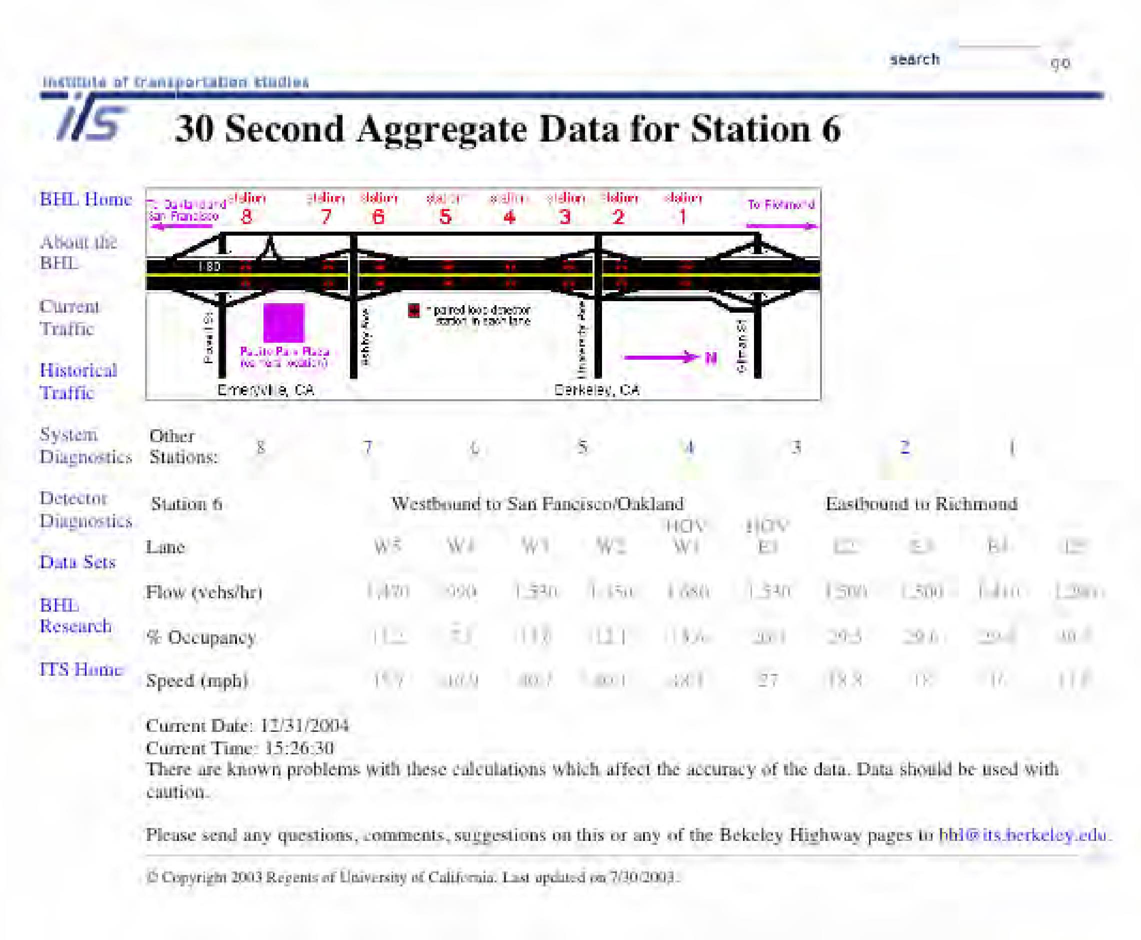

Figure 10.3 – BHL Summary Data for a Single Station

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Travel Times Between Stations 7 And 6

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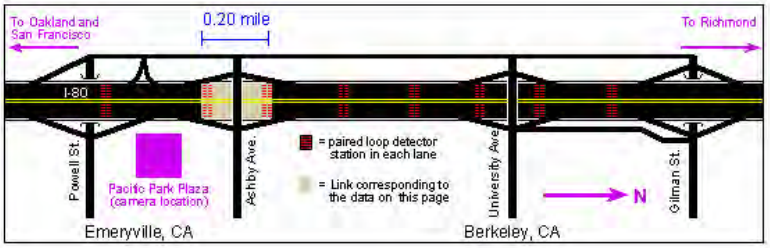


Other Sections: 7 to 6 | 6 to 5 | 5 to 4 | 4 to 3 | 3 to 2 | 2 to 1 | Home

	Westbound to San Francisco/Oakland					Eastbound to Richmond				
Lane	W5	W4	W3	W2	HOV W1	HOV E1	E2	E3	E4	E5
Speed (mph)	62	65	65	70	78	75	68	61	54	59
Travel Time (seconds)	12	12	12	11	10	10	11	12	14	13
Delay ** (seconds)	0	0	0	0	0	0	0	0	0	0
Density *** (vehicles per mile)	10	24	29	29	29	14	14	24	24	43

* NA indicates the detectors are not operational for this lane. OLD indicates the most recent vehicle identification is too old to be accurate.
** delay = travel_time - (travel time at delay_threshold_speed) or 0; where delay_threshold_speed = 55 mph.
*** density = the number of vehicles to pass the upstream detector during the period that a matched vehicle traverses the link divided by the length of the link. .

Lane	Most Recent Measurement	
W5	13:26:39	2/7/2005
W4	13:26:31	2/7/2005
W3	13:26:00	2/7/2005
W2	13:25:36	2/7/2005
W1	13:24:47	2/7/2005
E1	13:22:59	2/7/2005
E2	13:24:18	2/7/2005
E3	13:26:12	2/7/2005
E4	13:26:42	2/7/2005
E5	13:25:20	2/7/2005
Status Time	13:26:48	2/7/2005

Figure 10.4 – Travel Times Between a Pair of Stations

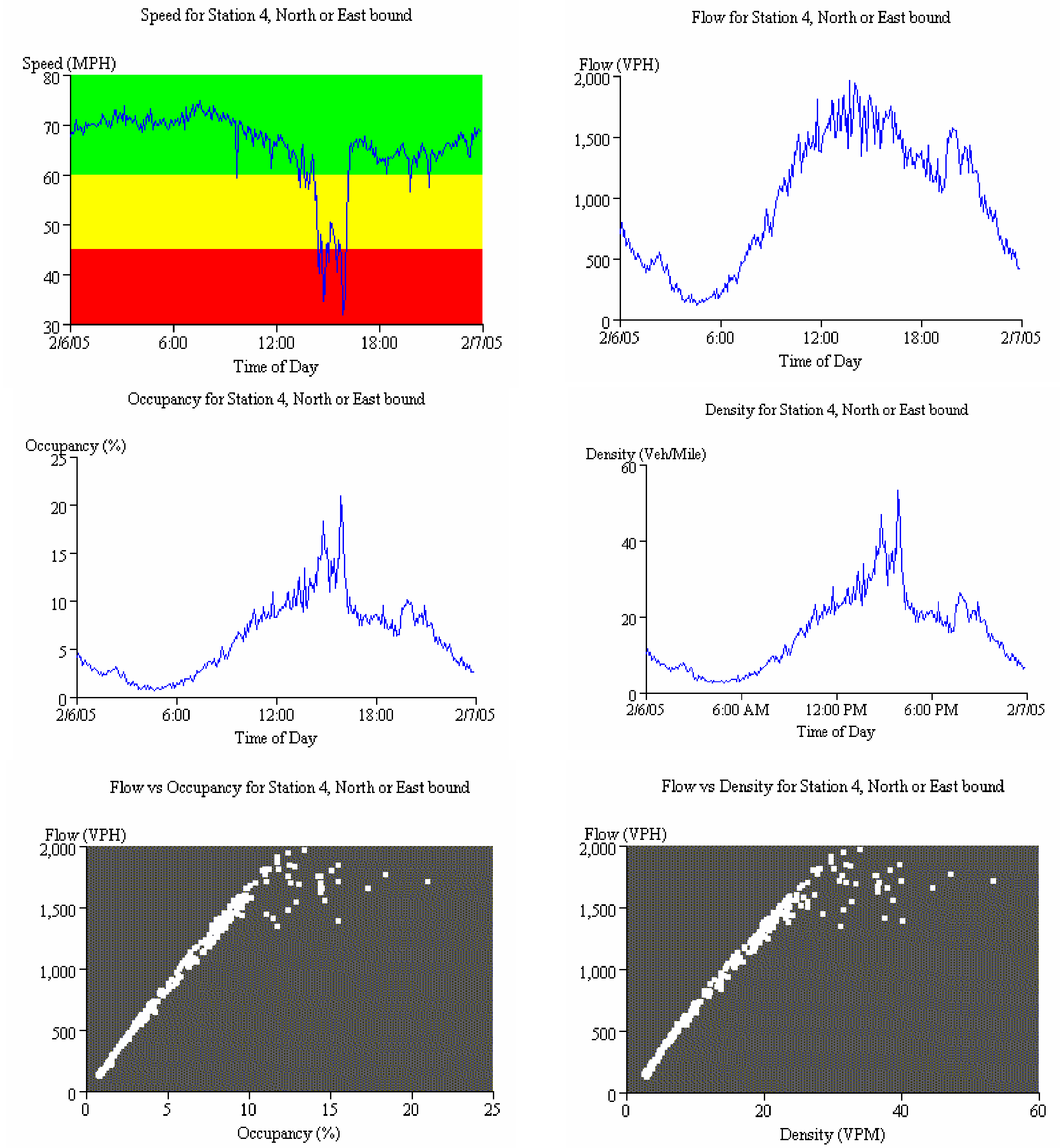


Figure 10.5 – Historical Traffic Graph Types

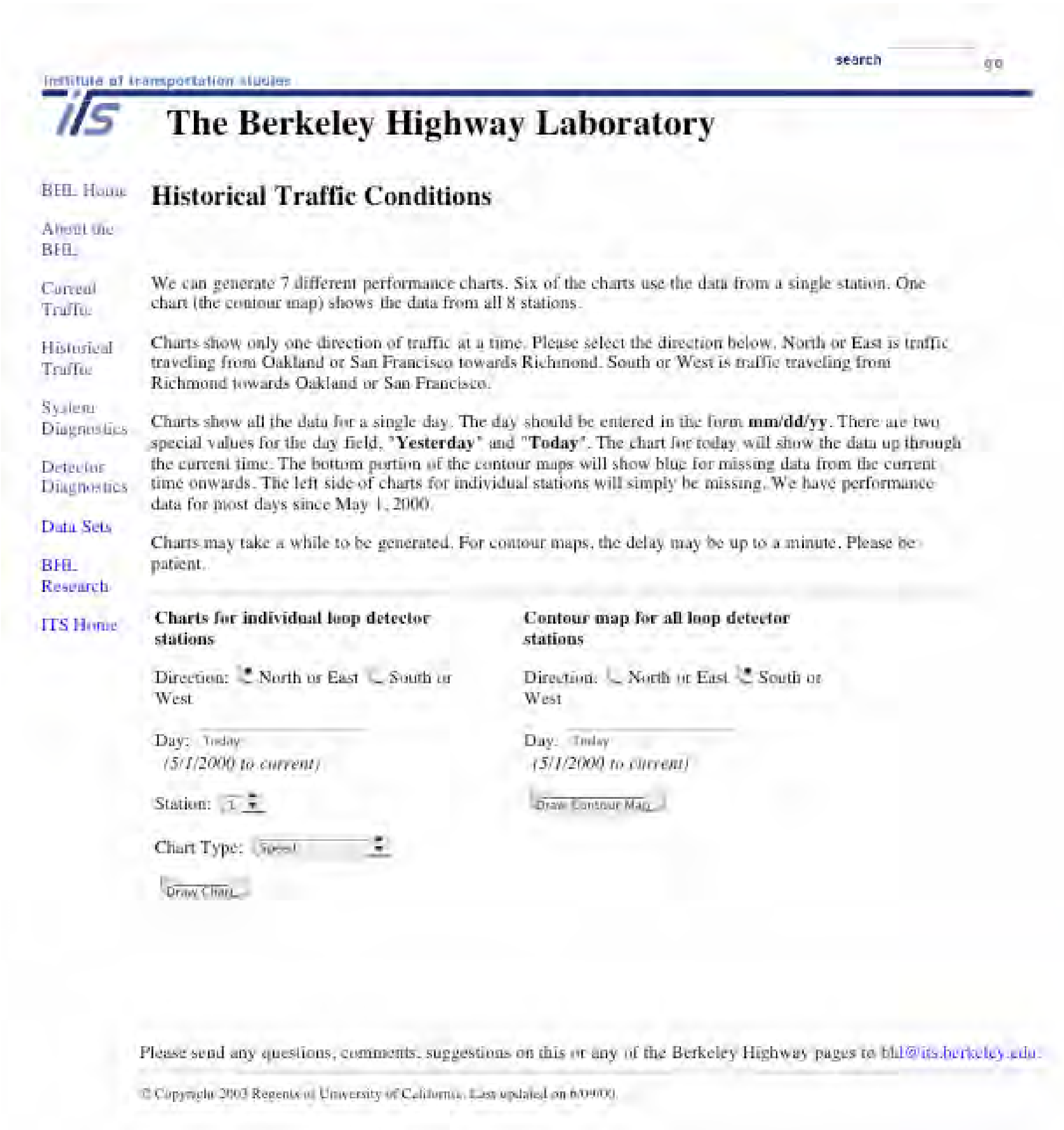


Figure 10.6 – Historical Chart Selection Page

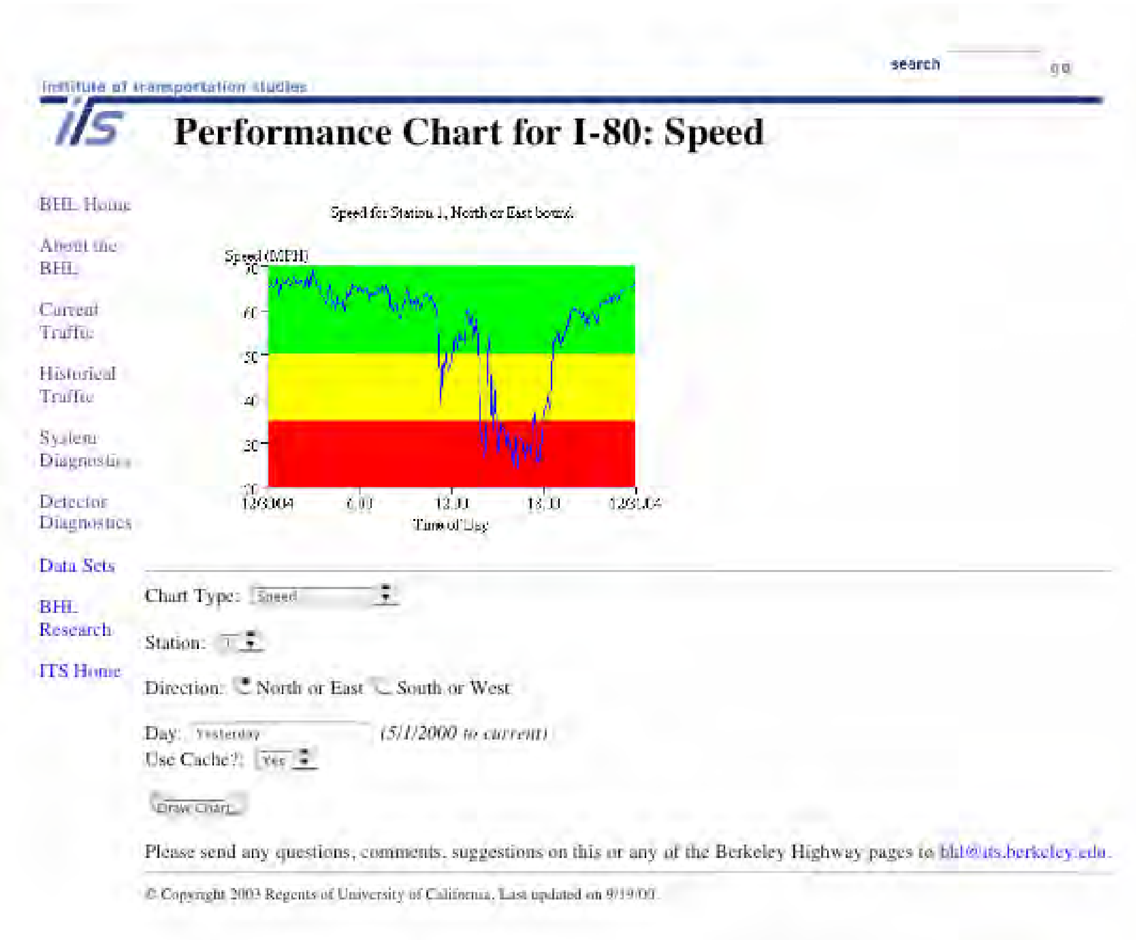


Figure 10.7 – Daily Speed Chart for Station 1

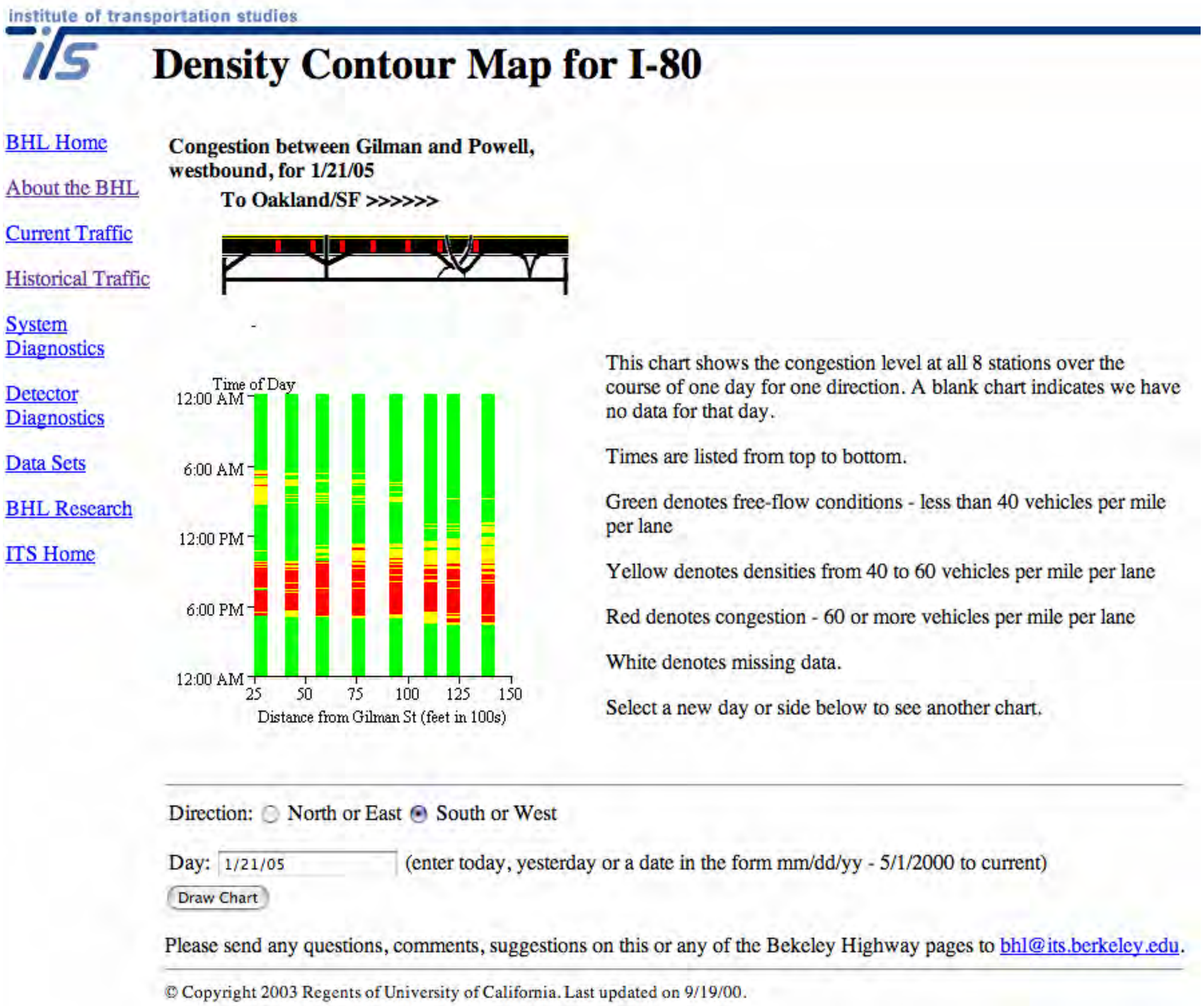
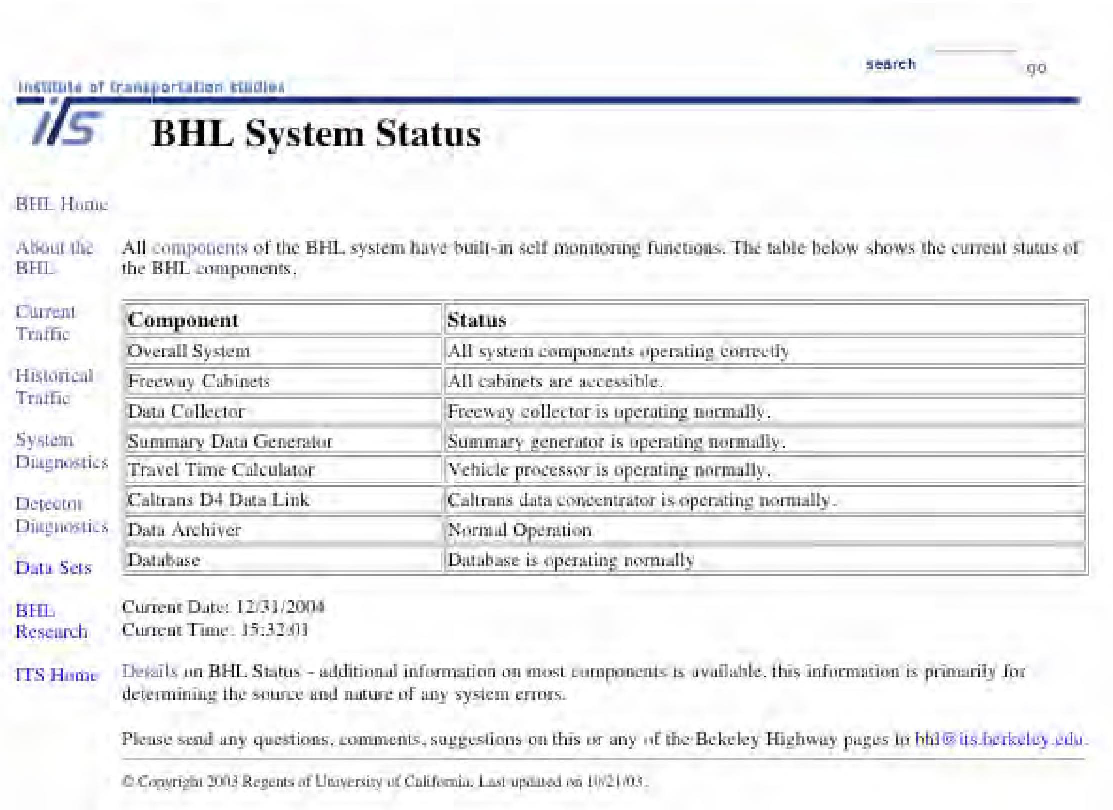


Figure 10.8 – Contour Map



search go

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BHL System Status

BHL Home

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Detector Diagnostics

Data Sets

BHL Research

ITS Home

All components of the BHL system have built-in self monitoring functions. The table below shows the current status of the BHL components.

Component	Status
Overall System	All system components operating correctly
Freeway Cabinets	All cabinets are accessible.
Data Collector	Freeway collector is operating normally.
Summary Data Generator	Summary generator is operating normally.
Travel Time Calculator	Vehicle processor is operating normally.
Caltrans D4 Data Link	Caltrans data concentrator is operating normally.
Data Archiver	Normal Operation
Database	Database is operating normally

Current Date: 12/31/2004
Current Time: 15:32:01

Details on BHL Status - additional information on most components is available. this information is primarily for determining the source and nature of any system errors.

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Figure 10.9 – System Diagnostics Page

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Detailed BHL System Status

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Component	Status
Overall System	All system components operating correctly
Freeway Cabinets	All cabinets are accessible.
Data Collector	Cabinet 9 side 2 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 8 side 1 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 7 side 1 receiving data. Last = Feb 7, 2005 11:19:38 AM Cabinet 7 side 2 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 6 side 1 receiving data. Last = Feb 7, 2005 11:19:40 AM Cabinet 6 side 2 receiving data. Last = Feb 7, 2005 11:19:40 AM Cabinet 5 side 1 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 5 side 2 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 4 side 1 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 4 side 2 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 3 side 1 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 3 side 2 receiving data. Last = Feb 7, 2005 11:19:39 AM Cabinet 2 side 1 receiving data. Last = Feb 7, 2005 11:19:40 AM Cabinet 2 side 2 receiving data. Last = Feb 7, 2005 11:19:40 AM Cabinet 1 side 1 receiving data. Last = Feb 7, 2005 11:19:27 AM Cabinet 1 side 2 receiving data. Last = Feb 7, 2005 11:19:27 AM
Summary Data Generator	Summary generator is operating normally.
Travel Time Calculator	Last data timestamp = Feb 7, 2005 11:18:59 AM Last database read = Feb 7, 2005 11:19:30 AM
Caltrans D4 Data Link	Last data timestamp = Feb 7, 2005 11:18:00 AM Last database read = Feb 7, 2005 11:19:34 AM
Data Archiver	Starting database cleanup Feb 7, 2005 3:58:20 AM Archiving raw cabinet data Feb 7, 2005 3:58:20 AM Archiving raw station data Feb 7, 2005 4:00:50 AM Archiving vehicle traveltime data by cabinet Feb 7, 2005 4:05:03 AM Archiving vehicle traveltime data by side Feb 7, 2005 4:06:17 AM Archiving summary data by cabinet Feb 7, 2005 4:07:05 AM Archiving summary data by side Feb 7, 2005 4:07:21 AM Finished all archiving Feb 7, 2005 4:07:58 AM Ending database cleanup Feb 7, 2005 4:07:58 AM
Database	Database is operating normally

Current Date: 2/7/2005
Current Time: 11:21:40

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Figure 10.10 – Detailed System Diagnostics Page

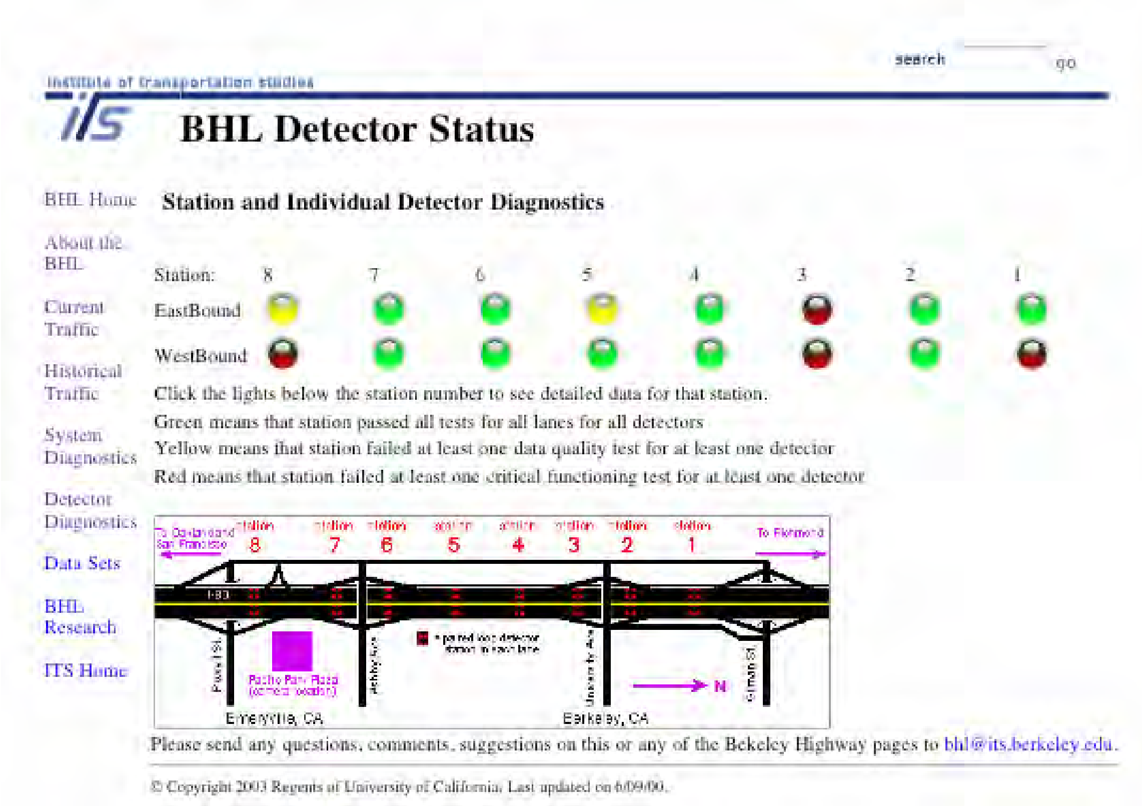

Figure 10.11 – Detector Status for all Stations

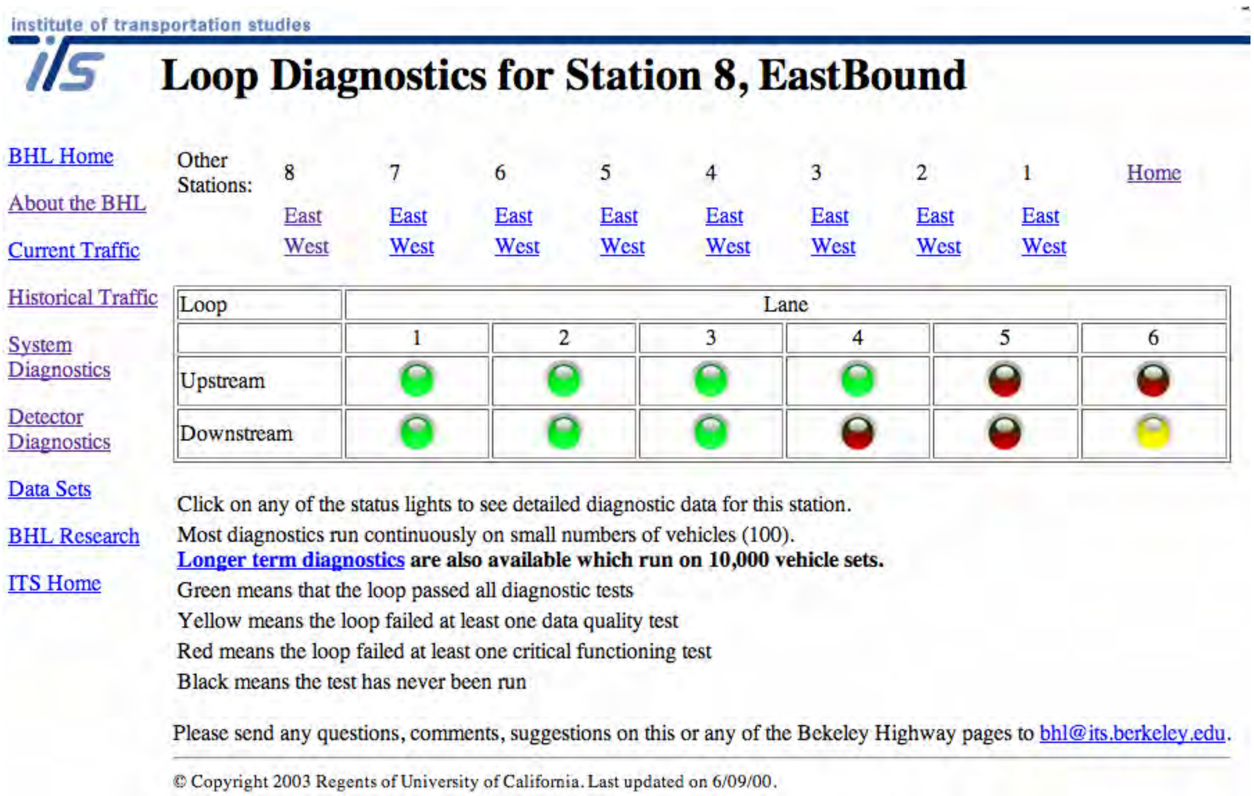

Figure 10.12 – Detector Status by Lane for a Single Station

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ITS

Detector Diagnostics for Station 8, EastBound

BHL Home

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Other Stations:	8	7	6	5	4	3	2	1	Home
	East West	East West	East West	East West	East West	East West	East West	East West	

		Lane											
Detector	Test	1		2		3		4		5		6	
		Status	Last Run	Status	Last Run	Status	Last Run	Status	Last Run	Status	Last Run	Status	Last Run
Upstream	Activity	🟢	14 min	🟢	14 min	🟢	14 min	🟢	14 min	🟢	14 min	🟢	14 min
Upstream	Min On Time	🟢	4 min	🟢	1 min	🟢	1 min	🔴	2 min	🔴	5 min	🔴	1 min
Upstream	Max On Time	🟢	4 min	🟢	1 min	🟢	1 min	🟢	2 min	🟢	5 min	🟢	1 min
Upstream	Mode On Time	🟢	4 min	🟢	2 min	🟢	1 min	🟢	4 min	🟢	1 min	🟢	1 min
Upstream	Dynamic Min On Time	🟢	1 min	🟢	1 min	🟢	1 min	🟢	5 min	🟢	3 min	🟢	2 min
Upstream	Dynamic Max On Time	🟢	1 min	🟢	1 min	🟢	1 min	🟢	5 min	🟢	3 min	🟢	2 min
Upstream	Min Off Time	🟢	1 min	🟢	1 min	🟢	5 min	🟢	4 min	🟢	1 min	🟢	1 min
Upstream	Dynamic Max Off Time	🟢	3 min	🟢	1 min	🟢	6 min	🟢	2 min	🟢	1 min	🟢	5 min
Downstream	Activity	🟢	14 min	🟢	14 min	🟢	14 min	🟢	14 min	🟢	14 min	🟢	14 min
Downstream	Min On Time	🟢	4 min	🟢	4 min	🟢	1 min	🟢	2 min	🟢	4 min	🔴	3 min
Downstream	Max On Time	🟢	4 min	🟢	4 min	🟢	1 min	🟢	2 min	🟢	4 min	🟢	3 min
Downstream	Mode On Time	🟢	3 min	🟢	1 min	🟢	4 min	🟢	1 min	🟢	4 min	🟢	4 min
Downstream	Dynamic Min On Time	🟢	3 min	🟢	3 min	🟢	4 min	🟢	4 min	🟢	3 min	🟢	4 min
Downstream	Dynamic Max On Time	🟢	3 min	🟢	3 min	🟢	4 min	🟢	4 min	🟢	3 min	🟢	4 min
Downstream	Min Off Time	🟢	1 min	🟢	3 min	🟢	5 min	🟢	4 min	🟢	1 min	🟢	1 min
Downstream	Dynamic Max Off Time	🟢	1 min	🟢	3 min	🟢	3 min	🟢	1 min	🟢	3 min	🟢	3 min
Dual	On Time Differential	🟢	4 min	🟢	1 min	🟢	3 min	🟢	3 min	🟢	3 min	🟢	1 min

Figure 10.13 – Detailed Detector Diagnostics Page

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its

Daily Detector Diagnostics for Station 8, EastBound

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System Diagnostics
Detector Diagnostics
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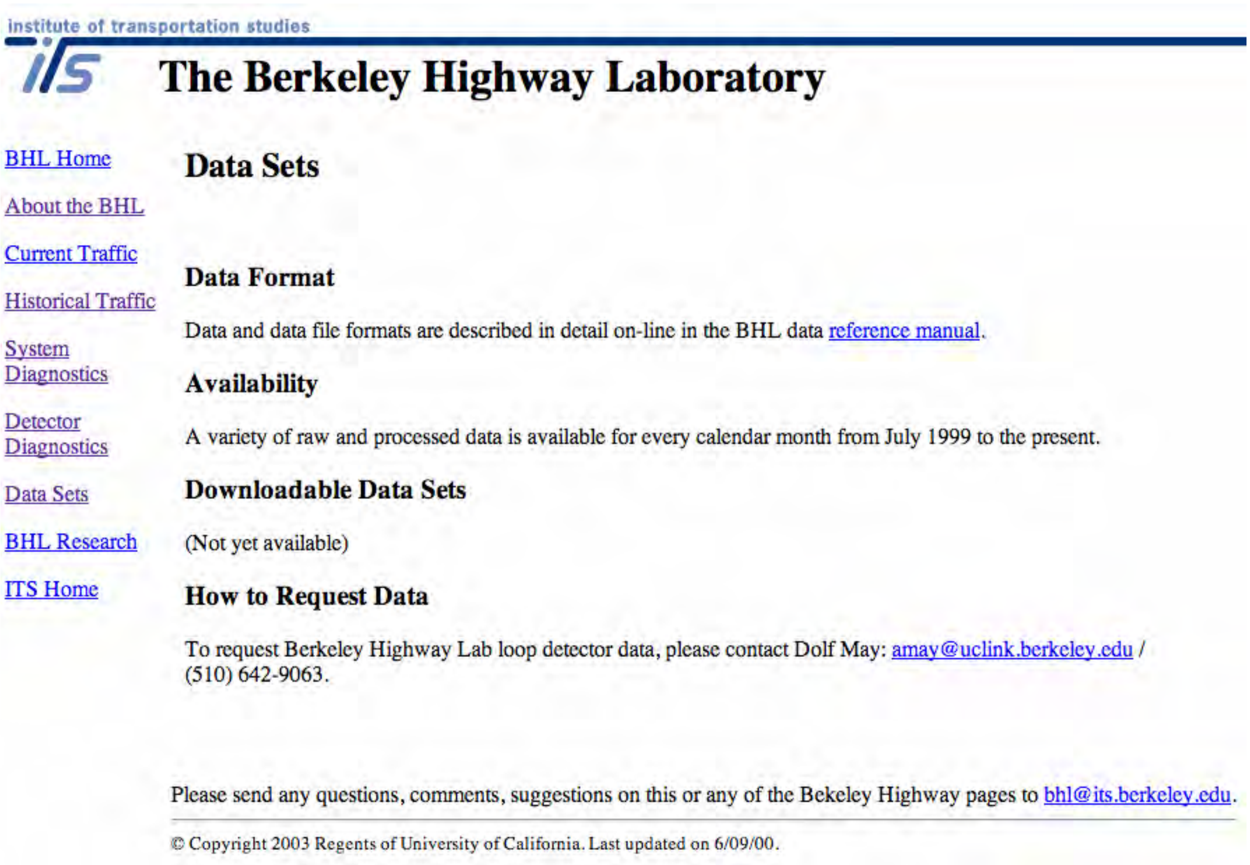
Other Stations:	8	7	6	5	4	3	2	1	Home
	East	East	East	East	East	East	East	East	
	West	West	West	West	West	West	West	West	

These are the standard diagnostic tests run over large 10,000 vehicle data sets. Tests run approximately once a day.

		Lane											
Detector	Test	1		2		3		4		5		6	
		Status	Last Run	Status	Last Run	Status	Last Run	Status	Last Run	Status	Last Run	Status	Last Run
Upstream	Activity		2 min		2 min		2 min		2 min		2 min		2 min
Upstream	Min On Time		1066 min		143 min		291 min		383 min		33 min		79 min
Upstream	Max On Time		1066 min		143 min		291 min		383 min		33 min		79 min
Upstream	Mode On Time		215 min		95 min		79 min		155 min		2 min		294 min
Upstream	Dynamic Min On Time		1055 min		128 min		280 min		371 min		19 min		67 min
Upstream	Dynamic Max On Time		1055 min		128 min		280 min		371 min		19 min		67 min
Upstream	Min Off Time		1065 min		141 min		290 min		381 min		32 min		77 min
Upstream	Dynamic Max Off Time		1054 min		127 min		279 min		369 min		18 min		66 min
Downstream	Activity		2 min		2 min		2 min		2 min		2 min		2 min
Downstream	Min On Time		1036 min		195 min		319 min		451 min		369 min		324 min
Downstream	Max On Time		1036 min		195 min		319 min		451 min		369 min		324 min
Downstream	Mode On Time		180 min		129 min		136 min		175 min		452 min		227 min
Downstream	Dynamic Min On Time		1027 min		182 min		308 min		427 min		355 min		313 min
Downstream	Dynamic Max On Time		1027 min		182 min		308 min		427 min		355 min		313 min
Downstream	Min Off Time		1035 min		193 min		318 min		449 min		367 min		323 min
Downstream	Dynamic Max Off Time		1025 min		180 min		307 min		425 min		354 min		312 min
Dual	On Time Differential		1 min		4 min		5 min		5 min		1 min		3 min

Figure 10.14 – Long Term Diagnostic Tests Page



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Data Sets

Data Format

Data and data file formats are described in detail on-line in the BHL data reference manual.

Availability

A variety of raw and processed data is available for every calendar month from July 1999 to the present.

Downloadable Data Sets

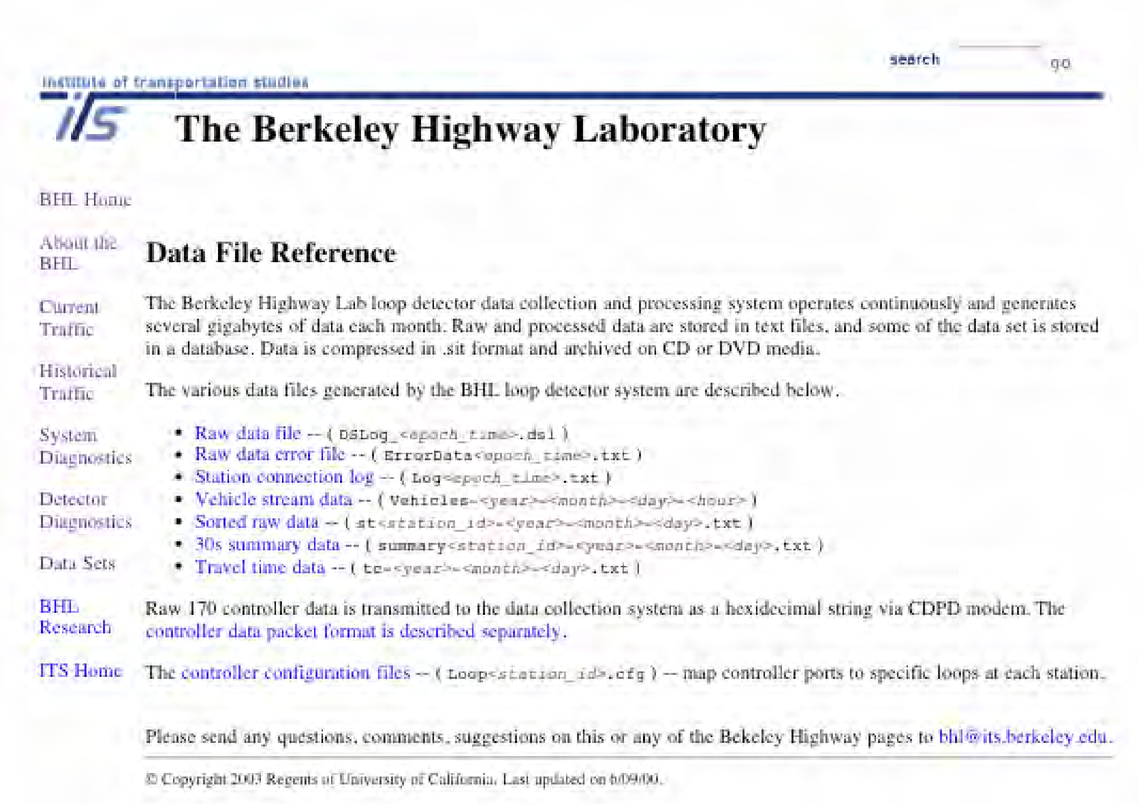
(Not yet available)

How to Request Data

To request Berkeley Highway Lab loop detector data, please contact Dolf May: amay@uclink.berkeley.edu / (510) 642-9063.

Please send any questions, comments, suggestions on this or any of the Bekeley Highway pages to bhl@its.berkeley.edu.

Figure 10.15 – Data Sets Page



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Data File Reference

The Berkeley Highway Lab loop detector data collection and processing system operates continuously and generates several gigabytes of data each month. Raw and processed data are stored in text files, and some of the data set is stored in a database. Data is compressed in .sit format and archived on CD or DVD media.

The various data files generated by the BHL loop detector system are described below.

- Raw data file -- (DSLog_<epoch_time>.dsl)
- Raw data error file -- (ErrorData<epoch_time>.txt)
- Station connection log -- (Log<epoch_time>.txt)
- Vehicle stream data -- (Vehicles-<year>-<month>-<day>-<hour>)
- Sorted raw data -- (st<station_id>-<year>-<month>-<day>.txt)
- 30s summary data -- (summary<station_id>-<year>-<month>-<day>.txt)
- Travel time data -- (tt-<year>-<month>-<day>.txt)

Raw 170 controller data is transmitted to the data collection system as a hexidecimal string via CDPD modem. The controller data packet format is described separately.

The controller configuration files -- (Loop<station_id>.cfg) -- map controller ports to specific loops at each station.

Please send any questions, comments, suggestions on this or any of the Bekeley Highway pages to bhl@its.berkeley.edu.

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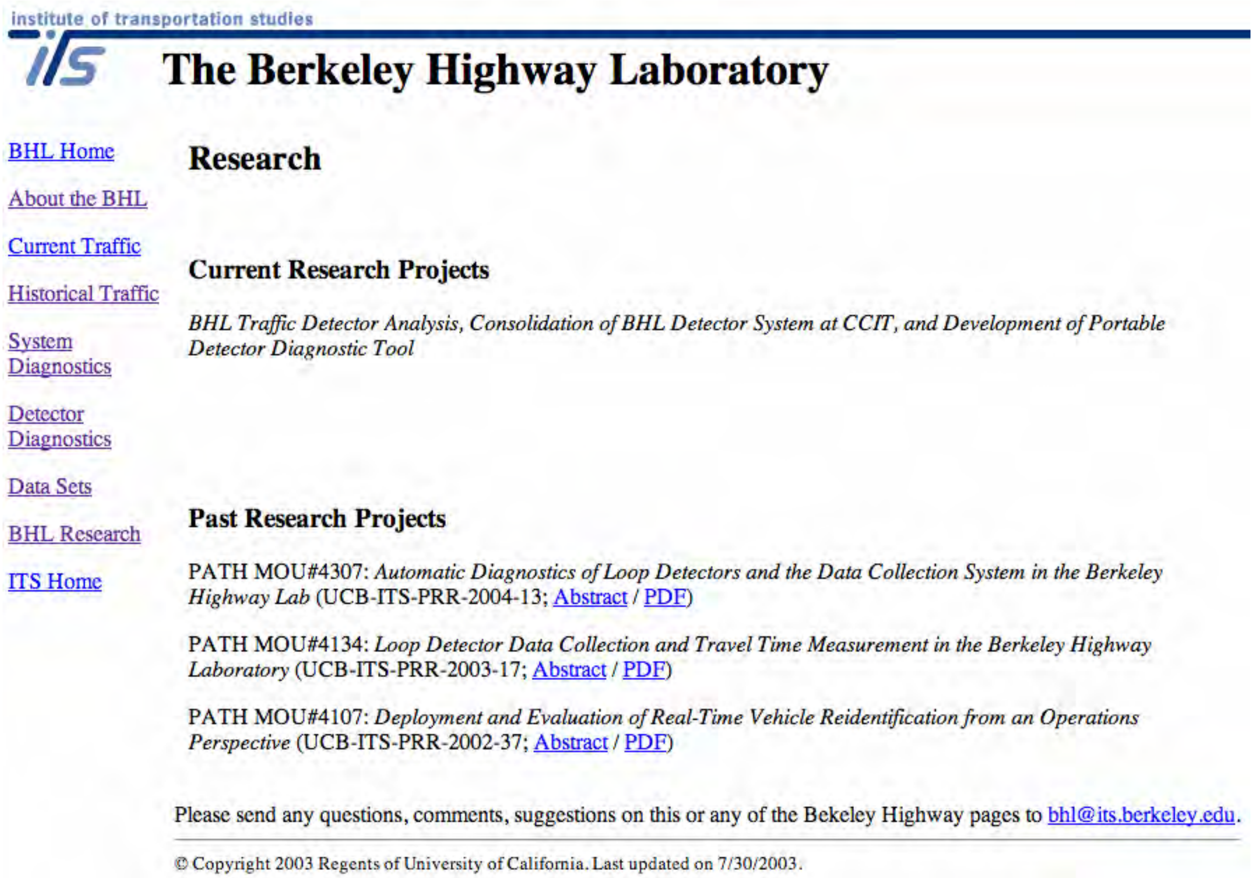
Figure 10.16 – Data Reference Page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Research

Current Research Projects

BHL Traffic Detector Analysis, Consolidation of BHL Detector System at CCIT, and Development of Portable Detector Diagnostic Tool

Past Research Projects

PATH MOU#4307: *Automatic Diagnostics of Loop Detectors and the Data Collection System in the Berkeley Highway Lab* (UCB-ITS-PRR-2004-13; Abstract / PDF)

PATH MOU#4134: *Loop Detector Data Collection and Travel Time Measurement in the Berkeley Highway Laboratory* (UCB-ITS-PRR-2003-17; Abstract / PDF)

PATH MOU#4107: *Deployment and Evaluation of Real-Time Vehicle Reidentification from an Operations Perspective* (UCB-ITS-PRR-2002-37; Abstract / PDF)

Please send any questions, comments, suggestions on this or any of the Bekeley Highway pages to bhl@its.berkeley.edu.

Figure 10.17 – BHL Research Page

11. Progress Reports, Advisory Meetings, Final Report (Task 7)

This Berkeley Highway Laboratory project began on February 1, 2004 and ended on February 28, 2005. The four Caltrans staff members who served as principal monitors on the project were Alan Chow and Charles Price of District 04, and Joe Palen and Martha Styer of Headquarters.

Progress reports were submitted to Caltrans through the PATH program at the end of March 2004, June 2004, September 2004, and December 2004.

Half-day advisory meetings were held in the Caltrans District 04 Office Building in May 2004, August 2004, and February 2005. The objectives of these advisory meetings were to present the results of completed research, to identify plans for continued research, and to obtain feedback and guidance from Caltrans staff members. These meetings were generally attended by about 10 to 15 persons.

This final report is divided into two major parts. The first part is the progress report presented and distributed at the August 2004 advisory meeting dealing exclusively with early research on project tasks 1 and 2. The second part of this final report contains the results of further research undertaken since September 2004 on tasks 1 and 2 as well as all research undertaken on tasks 3, 4, 5, 6, and 7.

A draft copy of the final report was distributed in mid-December 2004 to about 15 Caltrans staff members for their review and comment. Highlights of the final report were presented at the mid-February 2005 advisory meeting. Based on review comments submitted by Caltrans staff members and comments offered at the February 2005 advisory meeting, a final version of the project’s final report was prepared and submitted to PATH for distribution to Caltrans.

Conclusion

This one year research project extended from February 2004 through February 2005 and included seven major tasks. The highlights of each of the tasks are contained in the following paragraphs followed by specific accomplishments.

Task 1, Macroscopic Freeway Traffic Performance Measures, included the assessment of individual lane and directional roadway performance, the evaluation of HOV lane performance, a comparison of single-detector and dual-detector speed estimates, a methodology for substituting for missing data, and the development of macroscopic detector diagnostics. Specific accomplishments included:

- Individual lane flow-occupancy-speed relationships have been defined,
- Flow-occupancy-speed relationships between lanes have been identified,
- Estimation procedures for HOV lane speeds with and without congestion in the adjacent mixed-flow lanes have been developed,
- Estimating lane speeds from single detectors have been found to be not significantly different from estimating lane speeds from dual detectors,
- Algorithms have been formulated for estimating missing detector data from data obtained from other freeway lanes, and
- Procedures for detector diagnostics based on macroscopic flow relationships have been developed.

Task 2, Assessment and Improvements of Detector Diagnostics, included the testing and refinement of nine detector diagnostic tests. Specific accomplishments included:

- Improved parameter settings for detector diagnostic tests
- Continuous on-line implementation of the refined nine detector diagnostic tests.
- Immediately available test results for monitoring detector performance,
- Permanent record of previous detector diagnostic test results,
- Graphically presentations of 24-hour summaries of test results, and
- Identification of detectors providing acceptable data and those providing unacceptable data

Task 3, Installation and Testing of New BHL System at CCIT, was part of a long term goal to consolidate the ITS testbeds and data collection efforts in a single location. Some of the code in the software modules was cleaned up, the backend database was changed, and the software functions were consolidated onto fewer, higher powered computers.

Task 4, Maintaining and Operating BHL Detector System, included the day-to-day operation of data collection and processing. Several modes of failure were encountered during the course of the project, and each problem was addressed. Archived all standard raw, processed, and diagnostic data sets off-site.

Task 5, Preliminary Design of Portable Detector Diagnostic Tool included an examination of how the BHL diagnostic suite could be applied in the field by installation and maintenance technicians to evaluate and trouble shoot loop detector installations. The functionality of the proposed tool is described in this report.

Task 6, Progress Reports and Advisory Meetings, included the submission of PATH progress reports each quarter and sponsoring three advisory meetings with Caltrans staff during the life of the project. This provided for a close working relationship between the project team and the Caltrans sponsors.

Task 7, Preparation and Submission of Final Project Report, resulted in the preparation and distribution of a draft final report, soliciting and obtaining review comments from Caltrans staff, and incorporated suggestions and distributing this final report. This resulted in a comprehensive final report that was responsive to the comments by Caltrans sponsors.

BHL data was distributed to other researchers doing independent work in traffic studies or data analysis. In each case, data was shared with the approval of Caltrans.

While not a specific project Task, the BHL Web site was revised and updated during the course of this project. These changes, including the display of additional diagnostics, are described in Chapter 10.

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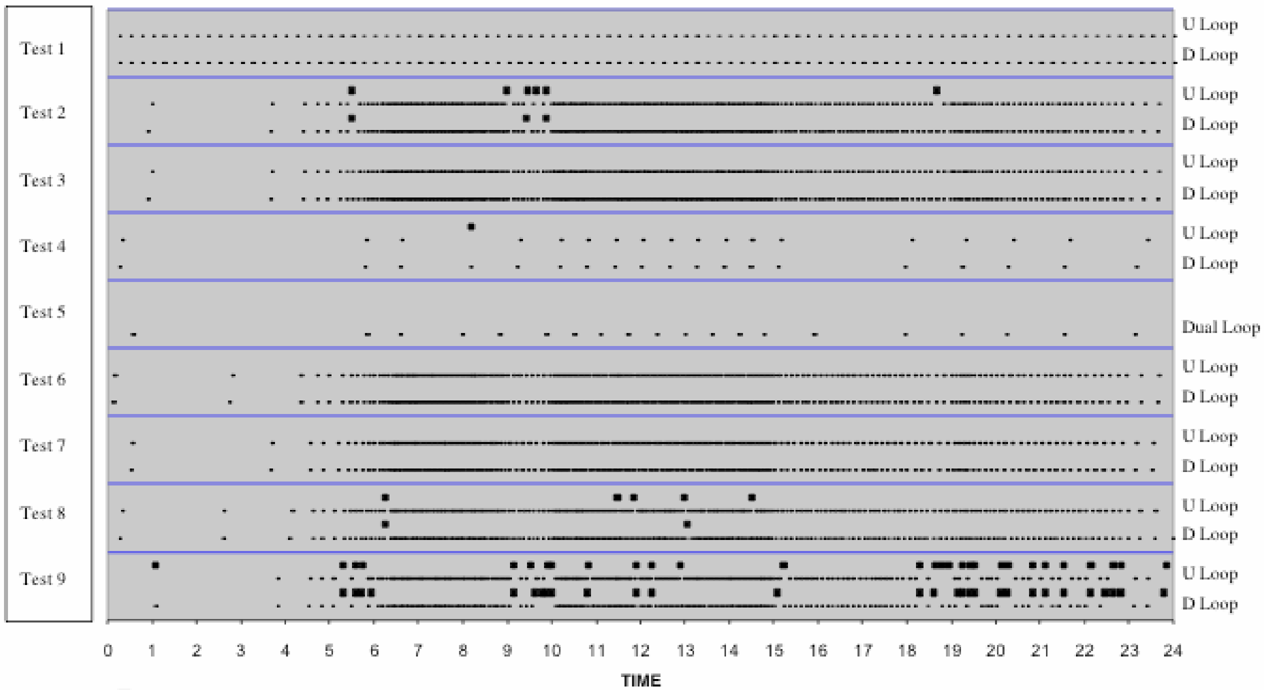
.

APPENDIX A - Illustrations for Chapter 2

Illustration 2.1 Summary of Detector Diagnostic Results – Lane 1 at Station 5W (Tuesday 3/2/04)

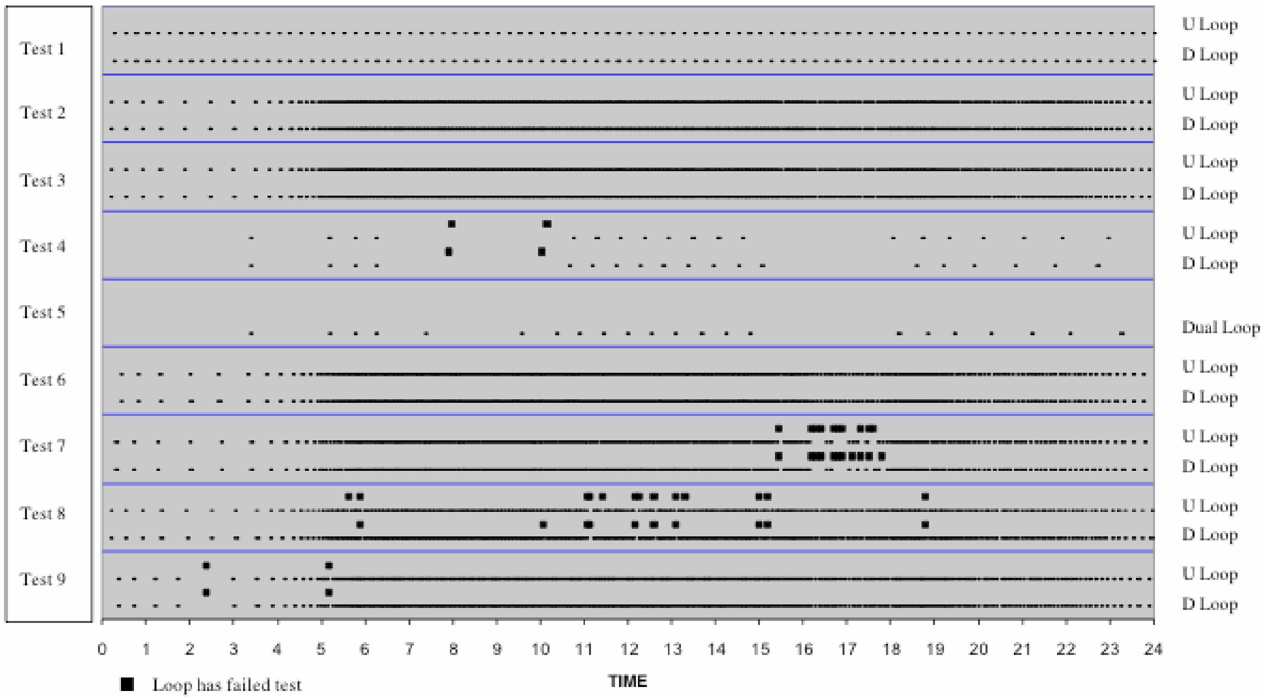


■ Loop has failed test

Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.2 Summary of Detector Diagnostic Results – Lane 2 at Station 5W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.3 Summary of Detector Diagnostic Results – Lane 3 at Station 5W (Tuesday 3/2/04)

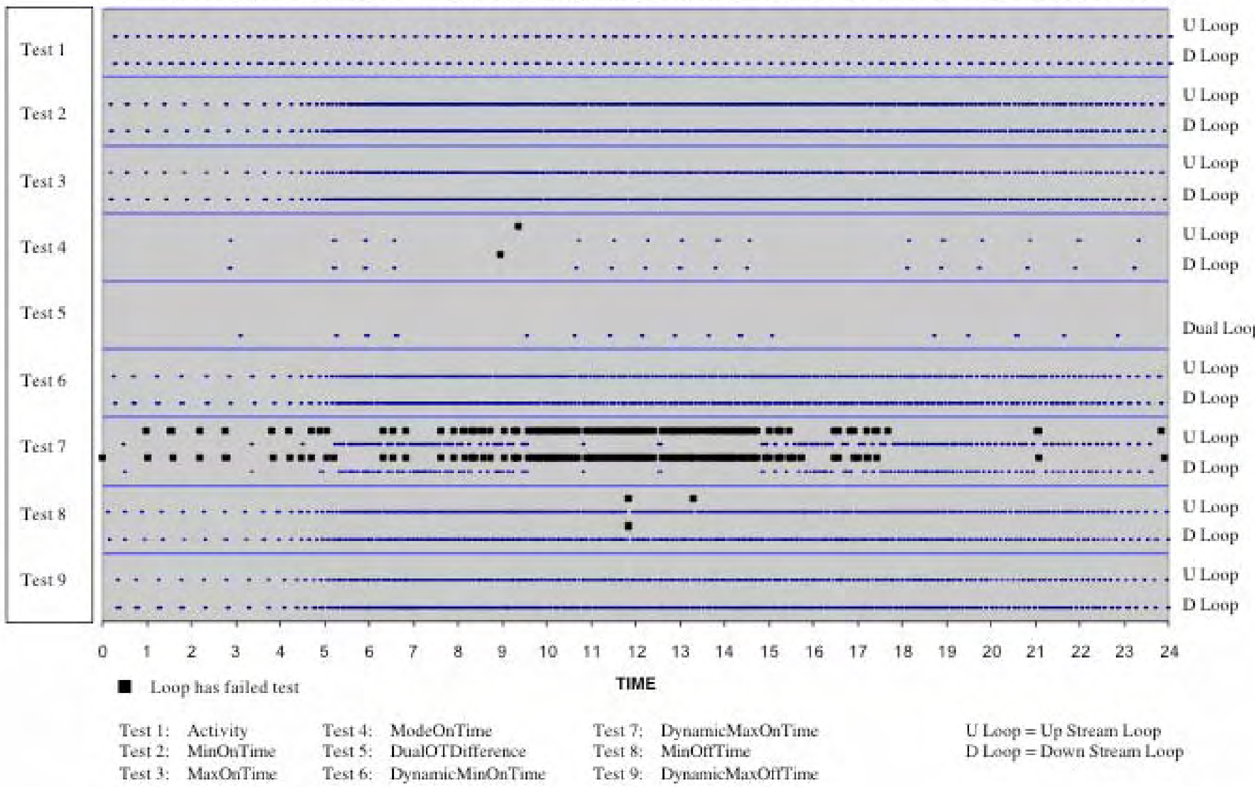
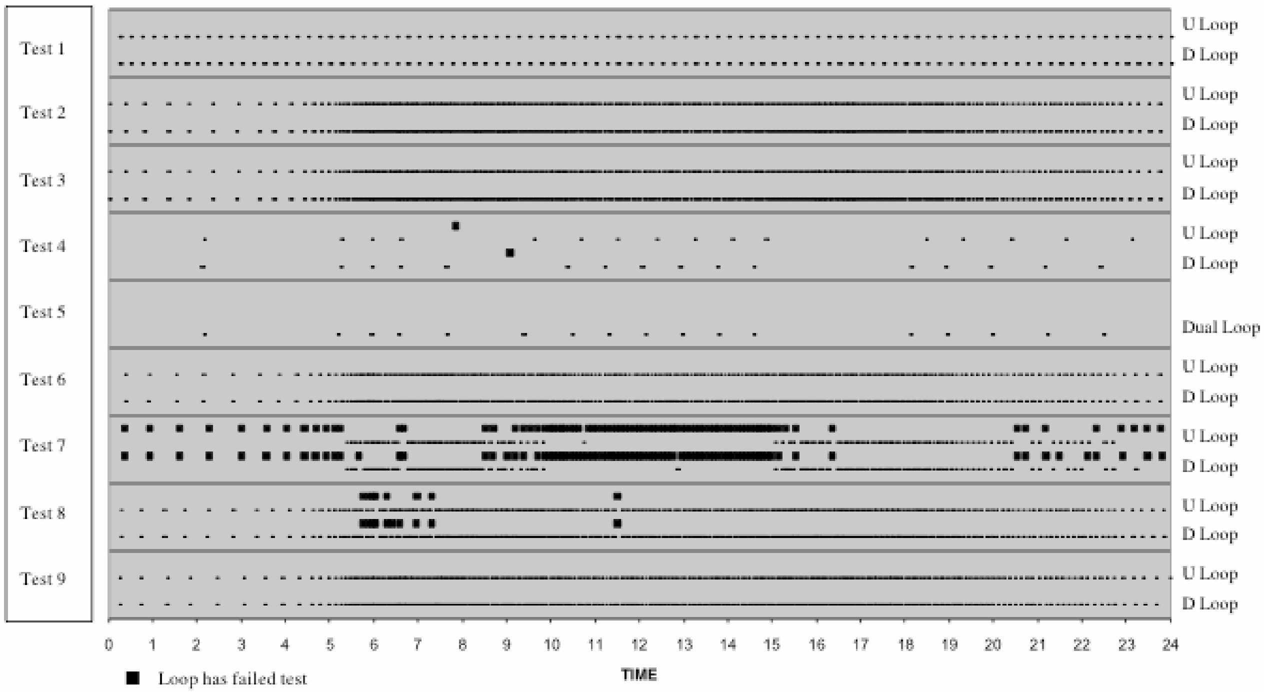


Illustration 2.4 Summary of Detector Diagnostic Results – Lane 4 at Station 5W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.5 Summary of Detector Diagnostic Results – Lane 5 at Station 5W (Tuesday 3/2/04)

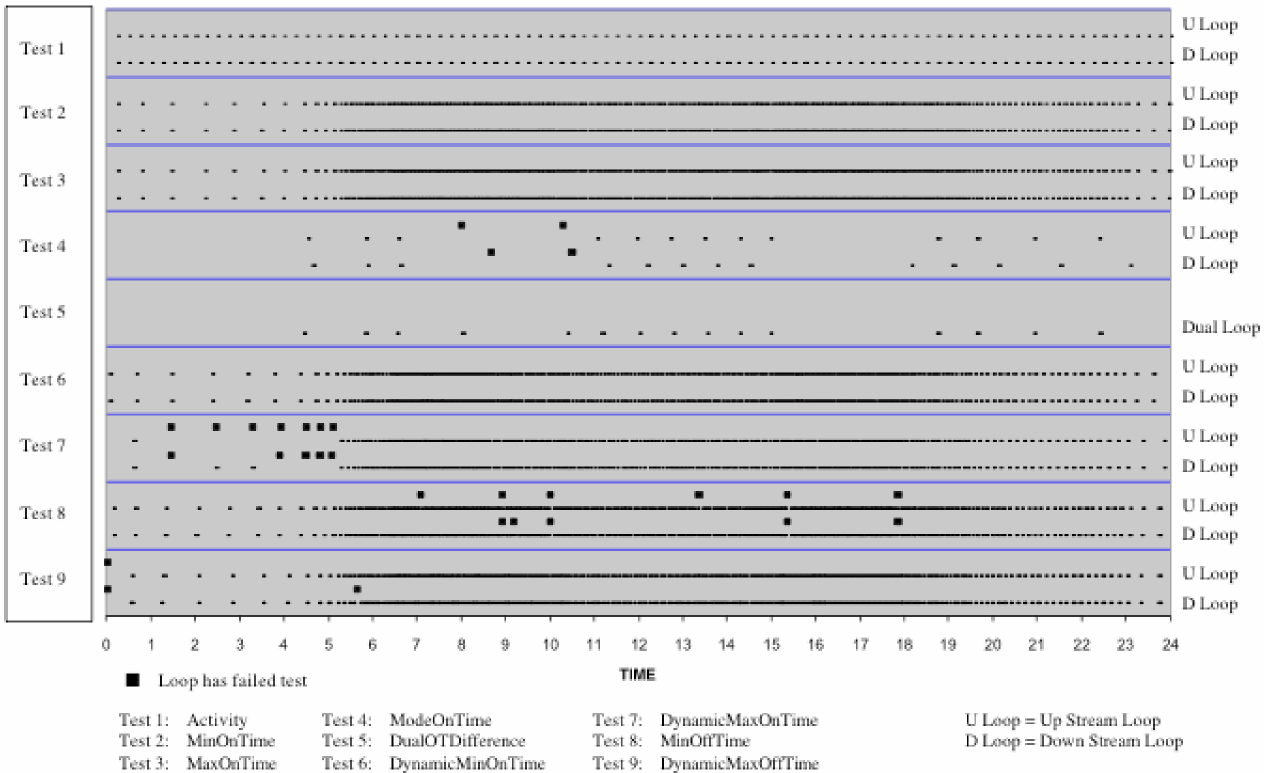
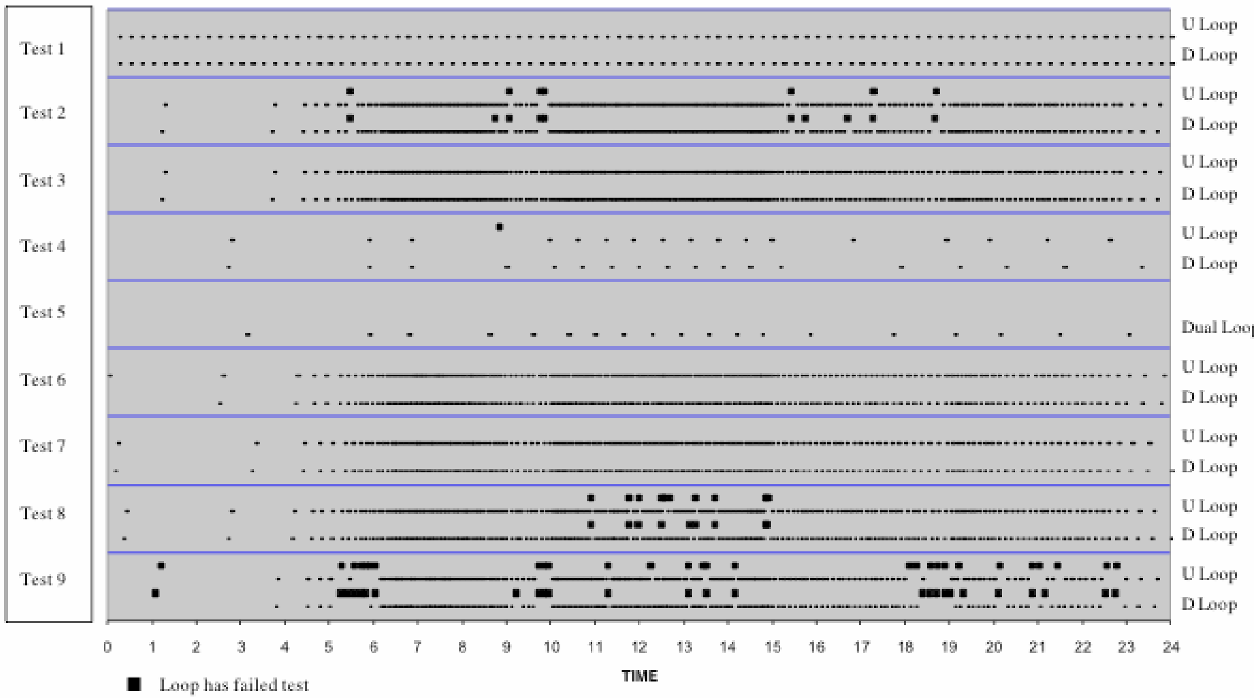


Illustration 2.6 Grand Summary of Detector Diagnostic Results – Station 5W (Tuesday 3/2/04)

DIAGNOSTIC TEST	DETECTOR LOCATION	0000-0400 LOW	0400-0700 MODERATE	0700-1000 HEAVY	1000-1500 MEDIUM	1500-1800 CONGESTED	1800-2400 MODERATE	0000-2400 TOTAL
1. ACTIVITY	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
2. MIN ON-TIME	UPSTREAM	0-0-0-0-0	**1-0-0-0-0**	**2-0-0-0-0**	**2-0-0-0-0**	0-0-0-0-0	**1-0-0-0-0**	**6-0-0-0-0**
	DOWNSTREAM	0-0-0-0-0	**1-0-0-0-0**	**1-0-0-0-0**	**1-0-0-0-0**	0-0-0-0-0	0-0-0-0-0	**3-0-0-0-0**
3. MAX ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
4. MODE ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	**1-1-1-1-1**	**0-1-0-0-1**	NO TESTS	0-0-0-0-0	**1-2-1-1-2**
		0-0-0-0-0	0-0-0-0-0	**0-1-1-1-1**	**0-1-0-0-1**	NO TESTS	0-0-0-0-0	**0-2-1-1-2**
5. DUAL DIFF	UP AND DOWN	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	NO TESTS	0-0-0-0-0	0-0-0-0-0
6. DYN MIN ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
7. DYN MAX ON-TIME	UPSTREAM	**0-0-5-6-4**	**0-0-5-6-4**	**0-0-8-5-0**	**0-0-12-12-0**	**0-5-5-3-0**	**0-0-2-6-0**	**0-5-37-38-8**
	DOWNSTREAM	**0-0-6-6-2**	**0-0-6-6-2**	**0-0-8-6-0**	**0-0-12-12-0**	**0-7-5-3-0**	**0-0-2-6-0**	**0-7-39-39-4**
8. MIN OFF-TIME	UPSTREAM	0-0-0-0-0	**1-2-0-0-0**	**0-0-0-2-2**	**4-6-2-1-2**	**0-1-0-0-2**	**0-1-0-0-0**	**5-10-2-3-6**
	DOWNSTREAM	0-0-0-0-0	**1-1-0-0-0**	**0-0-0-2-2**	**1-5-1-1-1**	**0-1-0-0-2**	**0-1-0-0-0**	**2-8-1-3-5**
9. DYN MAX OFF-TIME	UPSTREAM	**1-1-0-0-1**	**3-1-0-0-1**	**3-0-0-0-0**	**5-0-0-0-0**	**1-0-0-0-0**	**12-0-0-0-0**	**25-2-0-0-2**
	DOWNSTREAM	**0-1-0-0-1**	**4-1-0-0-1**	**3-0-0-0-0**	**4-0-0-0-0**	**1-0-0-0-0**	**12-0-0-0-0**	**24-2-0-0-2**

1-1-0-0-1 NUMBER OF TEST FAILURES IN SELECTED TIME PERIOD IN LANES 1, 2, 3, 4, AND 5 RESPECTIVELY

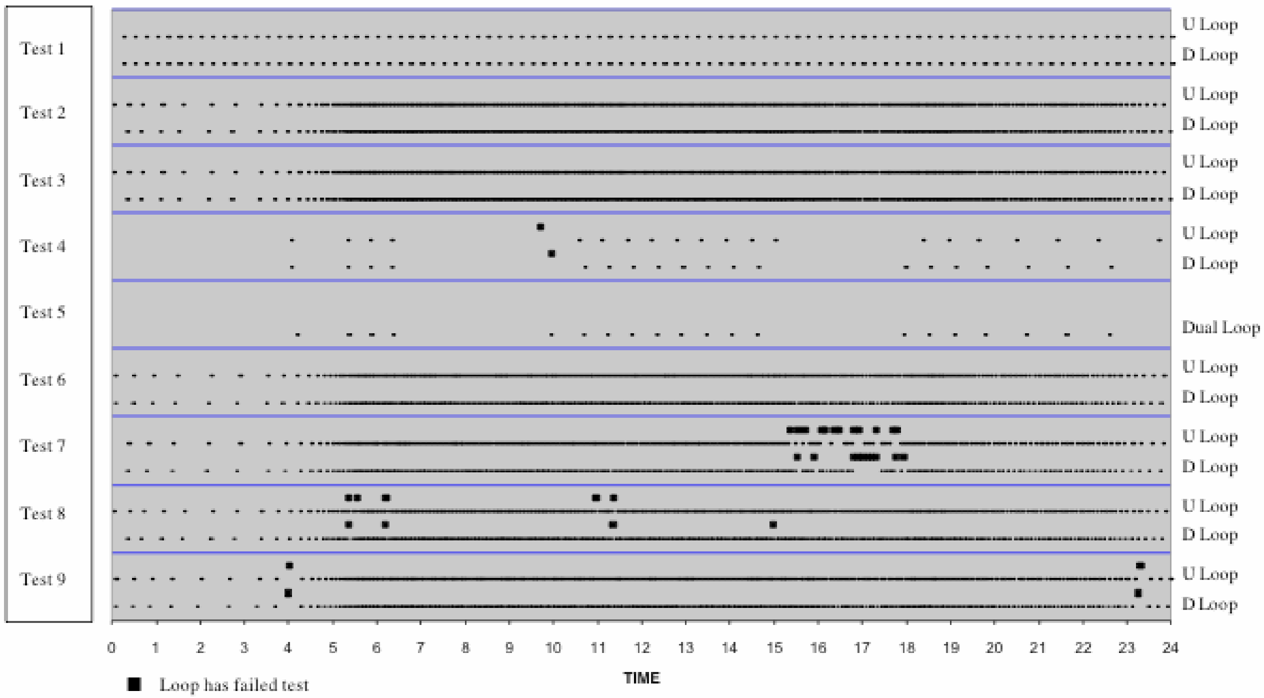
Illustration 2.7 Summary of Detector Diagnostic Results – Lane 1 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.8 Summary of Detector Diagnostic Results – Lane 2 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.9 Summary of Detector Diagnostic Results – Lane 3 at Station 4W (Tuesday 3/2/04)

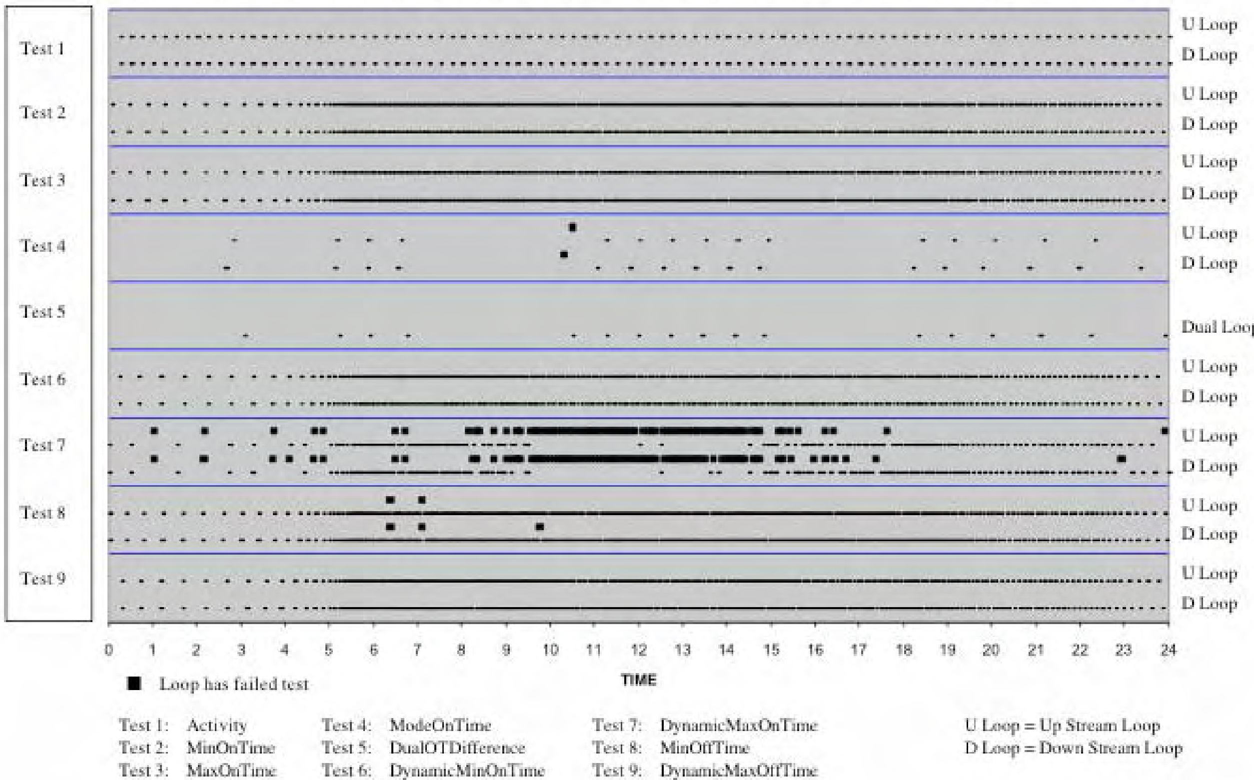
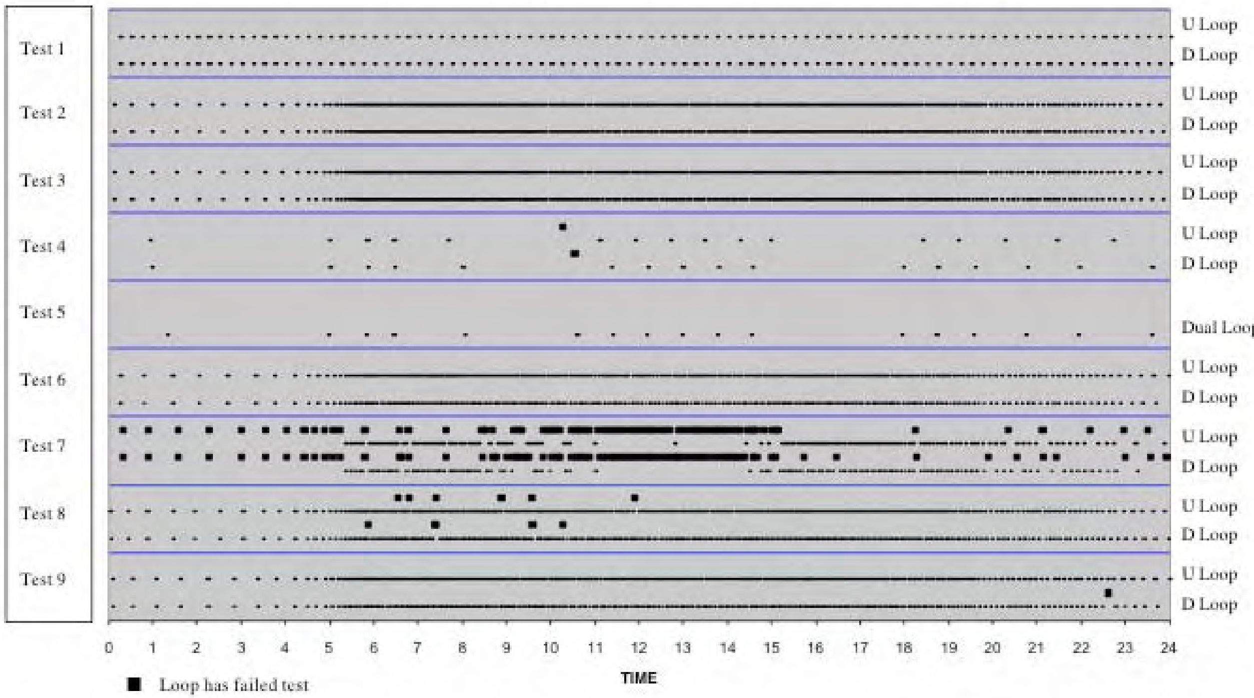


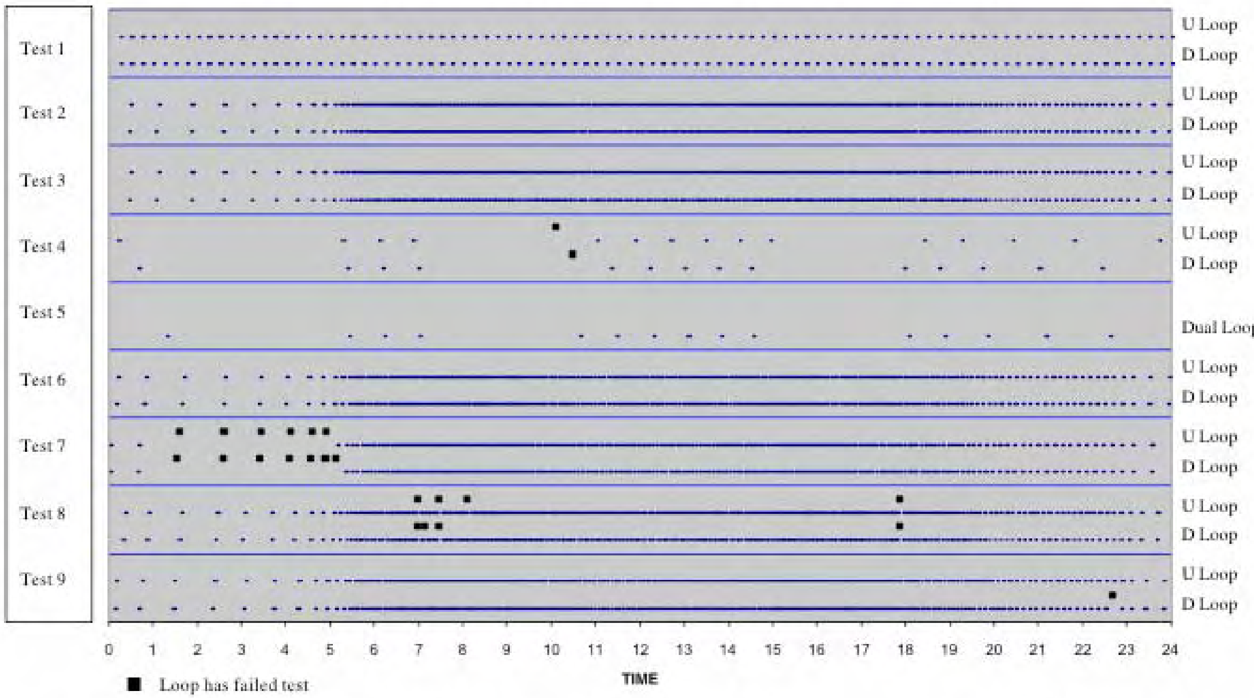
Illustration 2.10 Summary of Detector Diagnostic Results – Lane 4 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.11 Summary of Detector Diagnostic Results – Lane 5 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.12 Grand Summary of Detector Diagnostic Results – Station 4W (Tuesday 3/2/04)

DIAGNOSTIC TEST	DETECTOR LOCATION	0000-0400 LOW	0400-0700 MODERATE	0700-1000 HEAVY	1000-1500 MEDIUM	1500-1800 CONGESTED	1800-2400 MODERATE	0000-2400 TOTAL
1. ACTIVITY	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
2. MIN ON-TIME	UPSTREAM	0-0-0-0-0	1-0-0-0-0	3-0-0-0-0	0-0-0-0-0	2-0-0-0-0	1-0-0-0-0	7-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	1-0-0-0-0	4-0-0-0-0	0-0-0-0-0	4-0-0-0-0	1-0-0-0-0	10-0-0-0-0
3. MAX ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
4. MODE ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	1-1-0-0-0	0-0-1-1-1	NO TESTS	0-0-0-0-0	1-1-1-1-1
		0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-1-1-1-1	NO TESTS	0-0-0-0-0	0-1-1-1-1
5. DUAL DIFF	UP AND DOWN	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	NO TESTS	0-0-0-0-0	0-0-0-0-0
6. DYN MIN ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
7. DYN MAX ON-TIME	UPSTREAM	0-0-3-6-3	0-0-4-9-3	0-0-9-9-0	0-0-19-19-0	0-8-6-2-0	0-0-0-6-0	0-8-41-51-6
	DOWNSTREAM	0-0-3-6-3	0-0-5-9-4	0-0-9-9-0	0-0-19-19-0	0-7-7-3-0	0-0-0-8-0	0-7-43-54-7
8. MIN OFF-TIME	UPSTREAM	0-0-0-0-0	0-3-1-2-1	0-0-1-3-2	8-2-0-1-0	0-0-0-0-1	0-0-0-0-0	8-5-2-6-4
	DOWNSTREAM	0-0-0-0-0	0-2-1-1-1	0-0-2-2-2	8-2-0-1-0	0-0-0-0-1	0-0-0-0-0	8-4-3-4-4
9. DYN MAX OFF-TIME	UPSTREAM	1-0-0-0-0	5-1-0-0-0	2-0-0-0-0	6-0-0-0-0	0-0-0-0-0	12-1-0-0-0	26-2-0-0-0
	DOWNSTREAM	1-0-0-0-0	5-1-0-0-0	3-0-0-0-0	4-0-0-0-0	0-0-0-0-0	11-1-0-1-1	24-2-0-1-1

1-1-0-0-1 NUMBER OF TEST FAILURES IN SELECTED TIME PERIOD IN LANES 1, 2, 3, 4, AND 5 RESPECTIVELY

Illustration 2.13 Summary of Detector Diagnostic Results – Lane 1 at Station 8W (Tuesday 3/2/04)

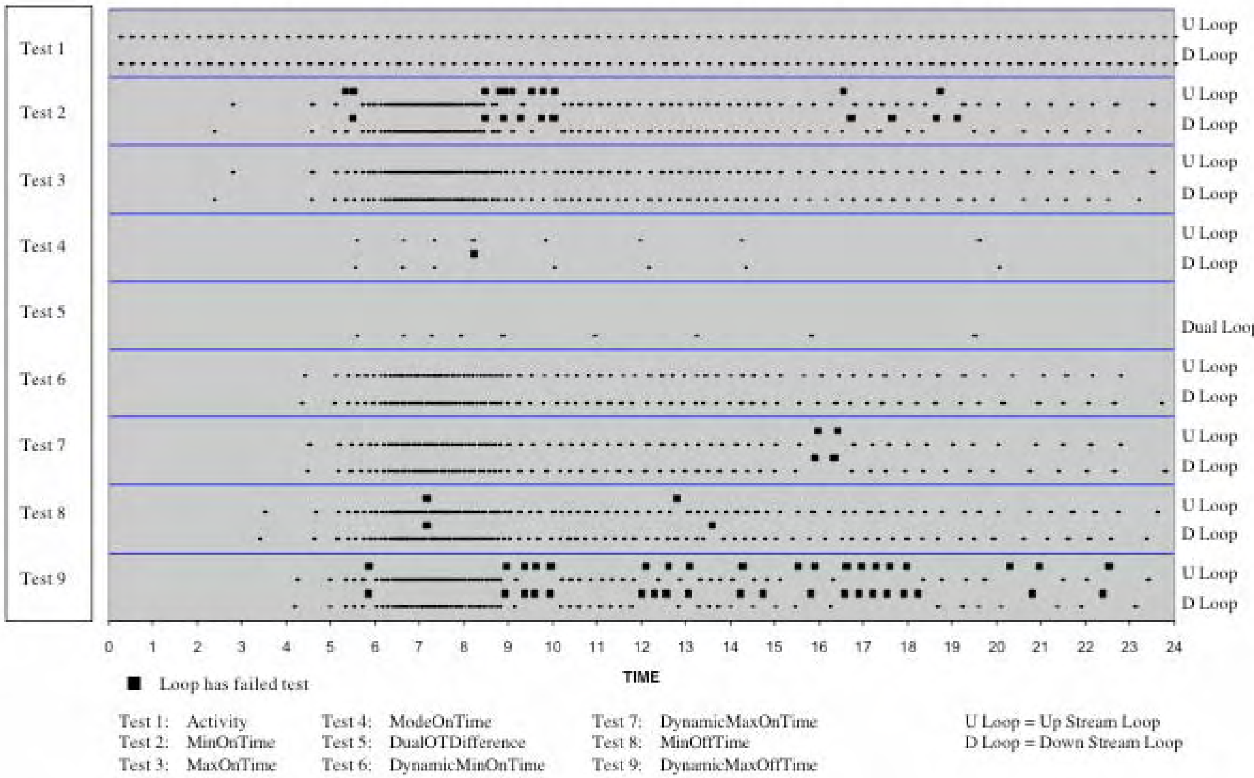
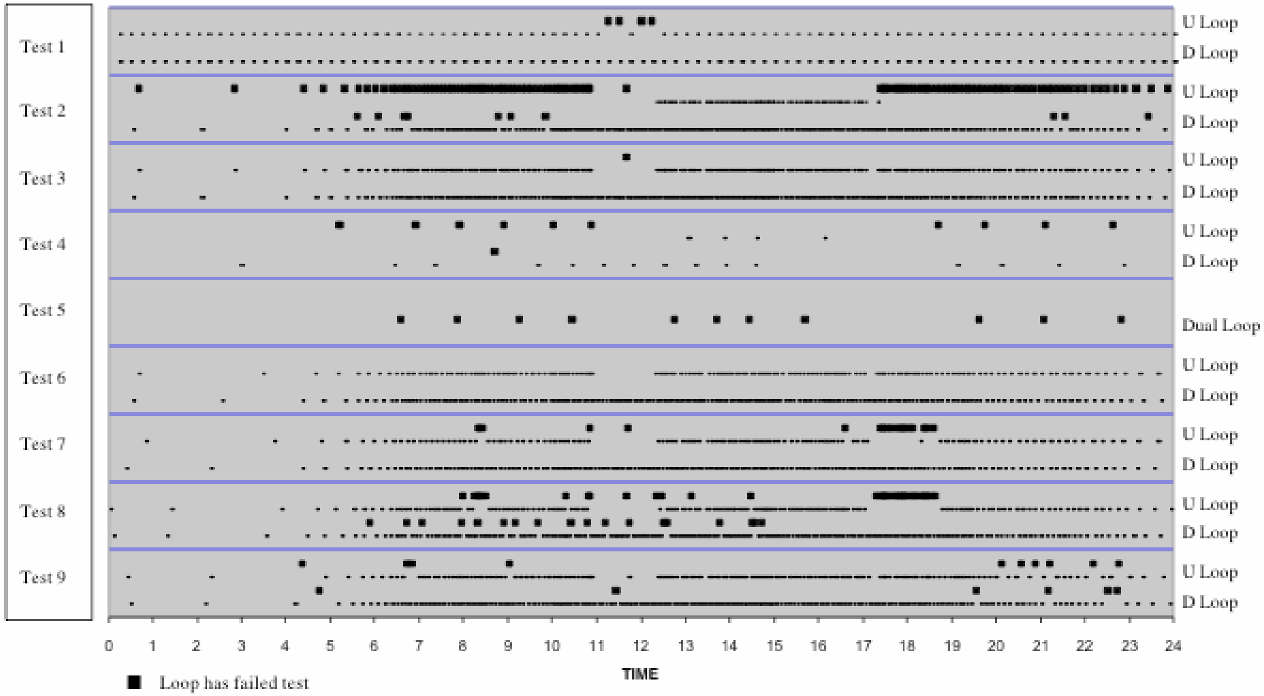


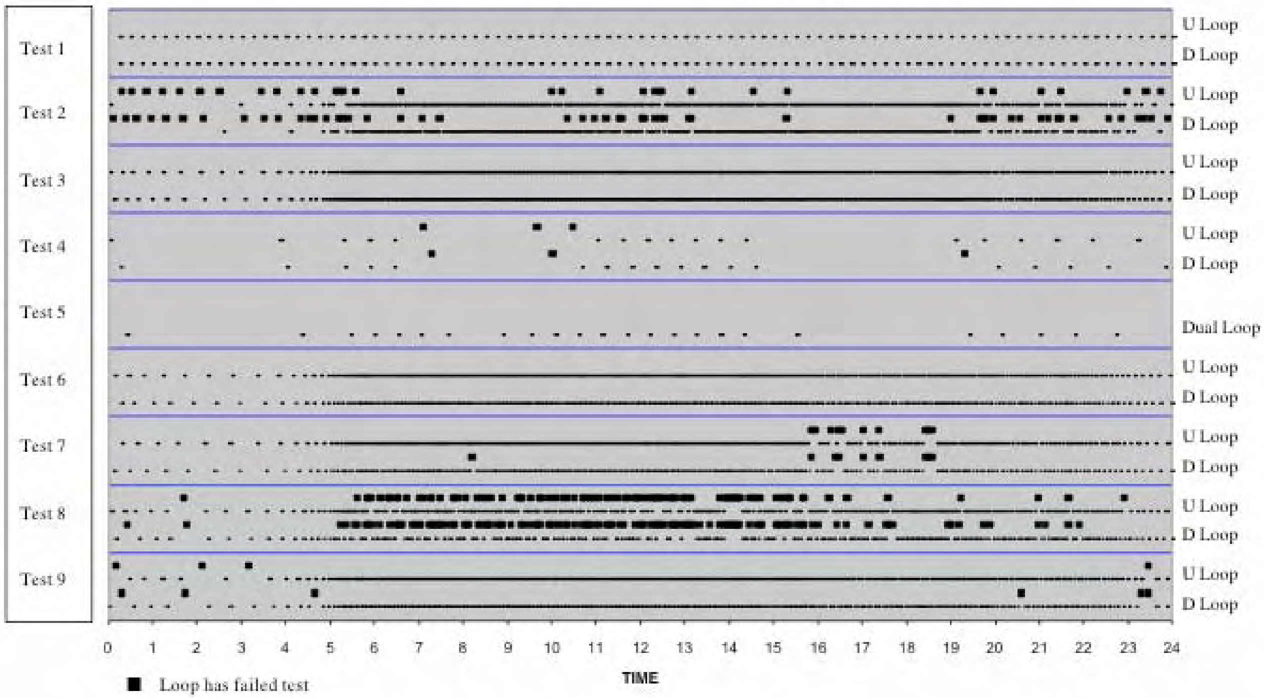
Illustration 2.14 Summary of Detector Diagnostic Results – Lane 2 at Station 8W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

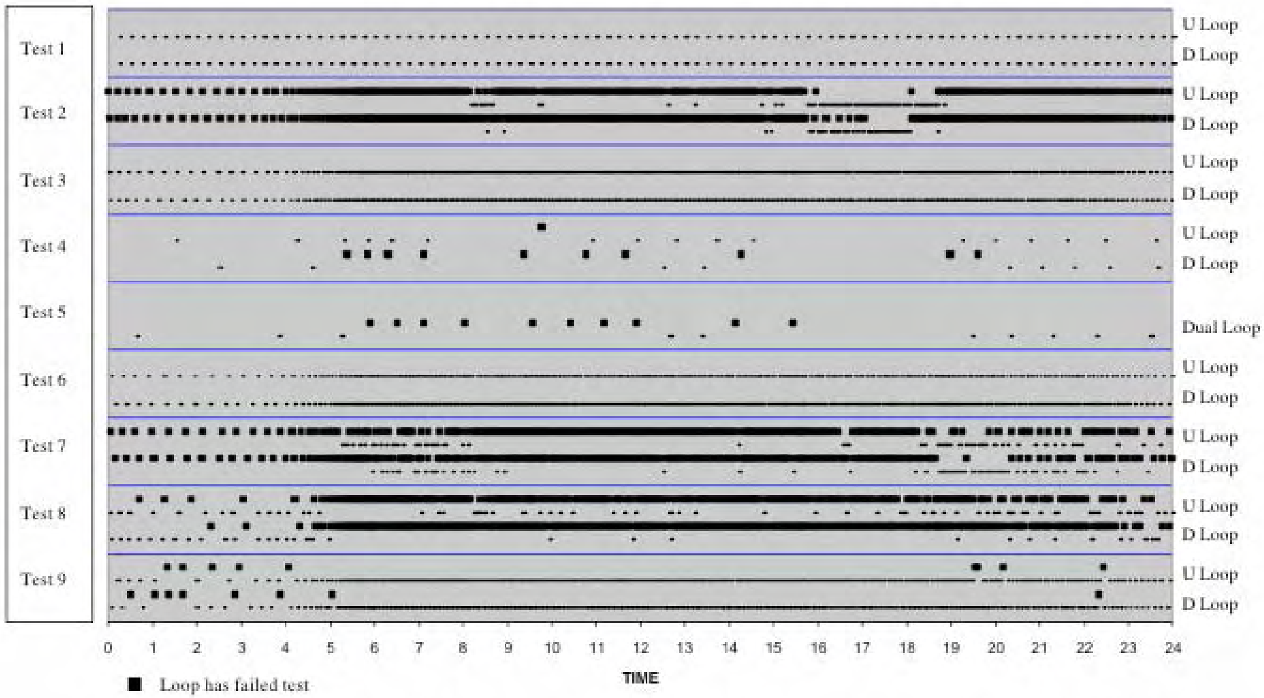
Illustration 2.15 Summary of Detector Diagnostic Results – Lane 3 at Station 8W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.16 Summary of Detector Diagnostic Results – Lane 4 at Station 8W (Tuesday 3/2/04)

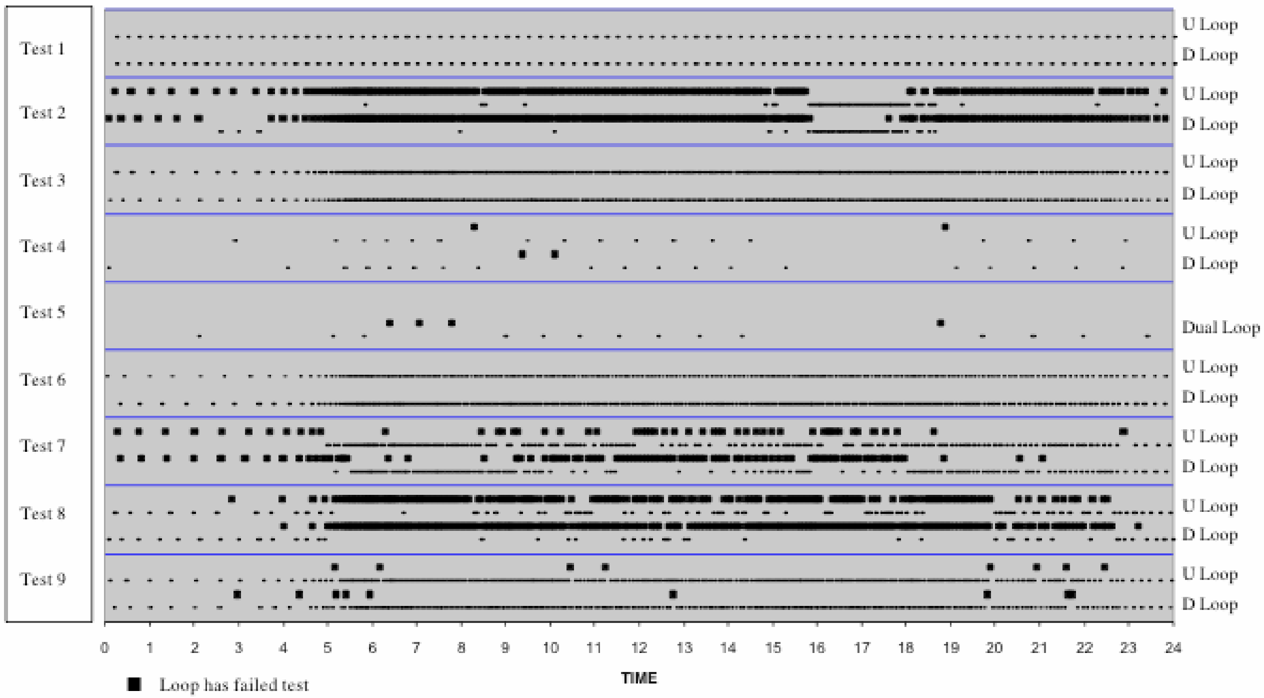


■ Loop has failed test

Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.17 Summary of Detector Diagnostic Results – Lane 5 at Station 8W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 2.18 Grand Summary of Detector Diagnostic Results – Station 8W (Tuesday 3/2/04)

DIAGNOSTIC TEST	DETECTOR LOCATION	0000-0400 LOW	0400-0700 MODERATE	0700-1000 HEAVY	1000-1500 MEDIUM	1500-1800 CONGESTED	1800-2400 MODERATE	0000-2400 TOTAL
1. ACTIVITY	UPSTREAM	0-0-0-0-0-X	0-0-0-0-0-X	0-0-0-0-0-X	0-**4**-0-0-0-X	0-0-0-0-0-X	0-0-0-0-0-X	0-**4**-0-0-0-X
	DOWNSTREAM	0-0-0-0-0-X	0-0-0-0-0-X	0-0-0-0-0-X	0-0-0-0-0-X	0-0-0-0-0-X	0-0-0-0-0-X	0-0-0-0-0-X
2. MIN ON-TIME	UPSTREAM	0-**2-9-15-9**	**2-11-6-20-18**	**6-20-1-19-19**	**1-6-7-30-30**	**1-5-1-6-5**	**1-30-7-28-27**	**11-74-31-108-108**
	DOWNSTREAM	0-0-**10-16-7**	**1-4-9-20-18**	**4-3-1-20-20**	**1**-0-**9-30-30**	**2**-0-**1-9-7**	**2-3-14-30-29**	**10-10-44-125-111**
3. MAX ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-**1**-0-0-0	0-0-0-0-0	0-0-0-0-0	0-**1**-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
4. MODE ON-TIME	UPSTREAM	0-0-0-0-0	0-**2**-0-0-0	0-**3-2-1-1**	0-**1-1**-0-0	NO TESTS	0-**4**-0-0-**1**	0-**10-3-1-2**
		0-0-0-0-0	0-0-0-**3**-0	**1-1-1-2-1**	0-0-**1-3-1**	NO TESTS	0-0-**1-2**-0	**1-1-3-10-2**
5. DUAL DIFF	UP AND DOWN	0-0-0-0-0	0-**1**-0-**2-2**	0-**2**-0-**3-1**	0-**4**-0-**4**-0	NO TESTS	0-**3**-0-0-**1**	0-**10**-0-**9-4**
6. DYN MIN ON-TIME	UPSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
	DOWNSTREAM	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0	0-0-0-0-0
7. DYN MAX ON-TIME	UPSTREAM	0-0-0-**12-7**	0-0-0-**18-5**	0-**1**-0-**19-6**	0-**2**-0-**30-25**	**2-5-5-19-11**	0-**3-2-20-2**	**2-11-7-118-56**
	DOWNSTREAM	0-0-0-**12-7**	0-0-0-**19-10**	0-0-**1-19-5**	0-0-0-**30-29**	**2**-0-**4-20-18**	0-0-**2-18-3**	**2**-0-**7-118-72**
8. MIN OFF-TIME	UPSTREAM	0-0-**1-4-1**	0-0-**8-18-15**	**1-3-18-19-19**	**1-6-25-30-27**	0-**5-7-19-18**	0-**5-4-25-15**	**2-19-63-115-95**
	DOWNSTREAM	0-0-**2-2**-0	0-**2-10-18-15**	**1-6-18-20-20**	**1-8-28-30-28**	0-0-**12-20-20**	0-0-**8-28-20**	**2-16-78-118-103**
9. DYN MAX OFF-TIME	UPSTREAM	0-0-**3-4**-0	**1-3**-0-**1-2**	**4-1**-0-0-0	**4**-0-0-0-**2**	**7**-0-0-0-0	**3-6-1-3-4**	**19-10-4-8-8**
	DOWNSTREAM	0-0-**2-6-1**	**1-1-1-1-4**	**4**-0-0-0-0	**6-1**-0-0-**1**	**6**-0-0-0-0	**3-4-3-1-3**	**20-6-6-8-9**

1-1-0-0-1 NUMBER OF TEST FAILURES IN SELECTED TIME PERIOD IN LANES 1, 2, 3, 4, AND 5 RESPECTIVELY

APPENDIX B - Illustrations for Chapter 3

Illustration 3.1 Location Map of the I-80 BHL Detector System

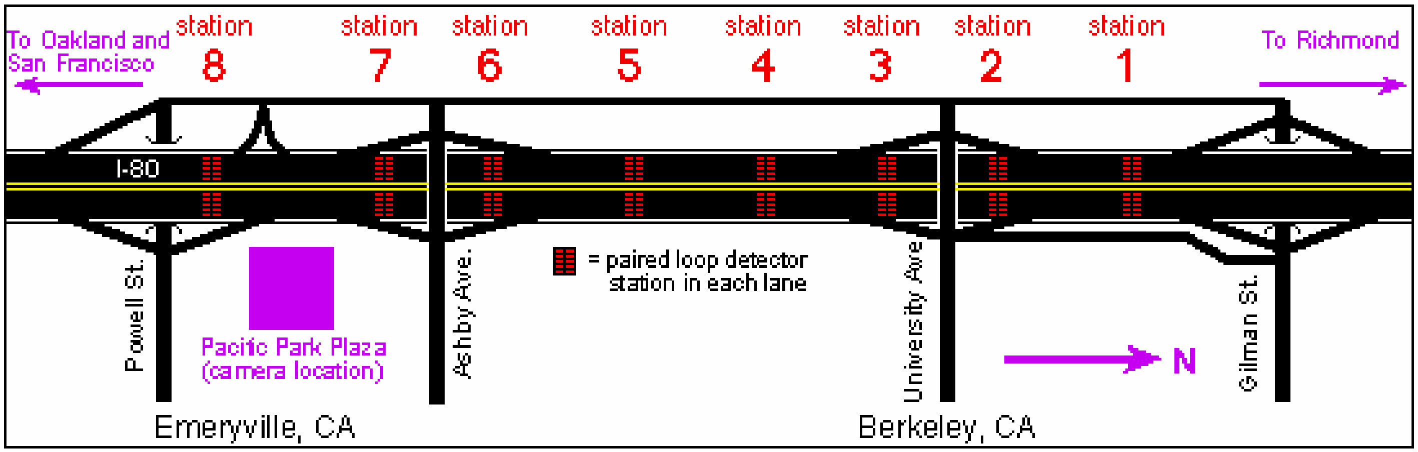


Illustration 3.2 Lane 1 Flow Rate Versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

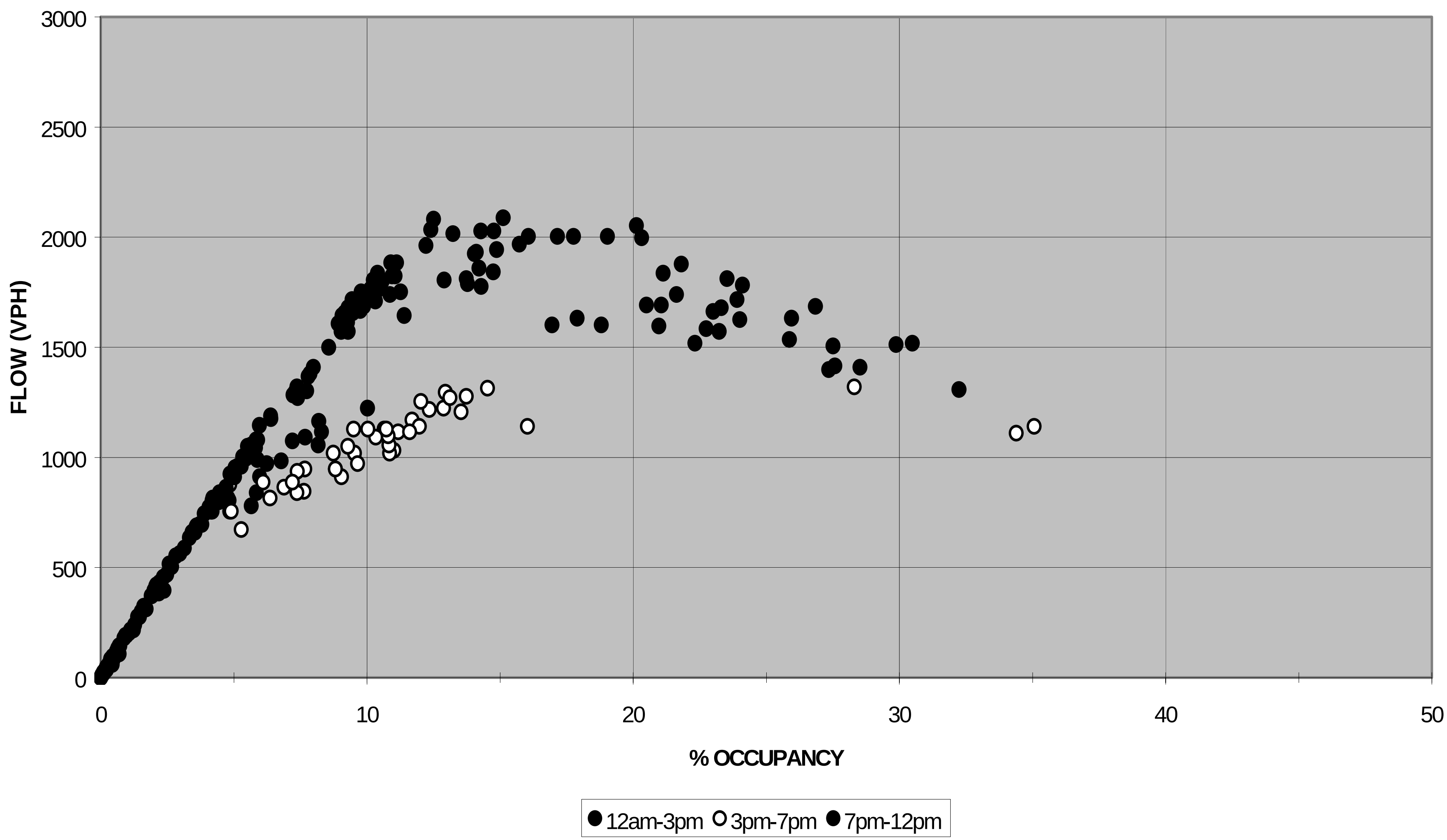


Illustration 3.3 Lane 1 Average Speed versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

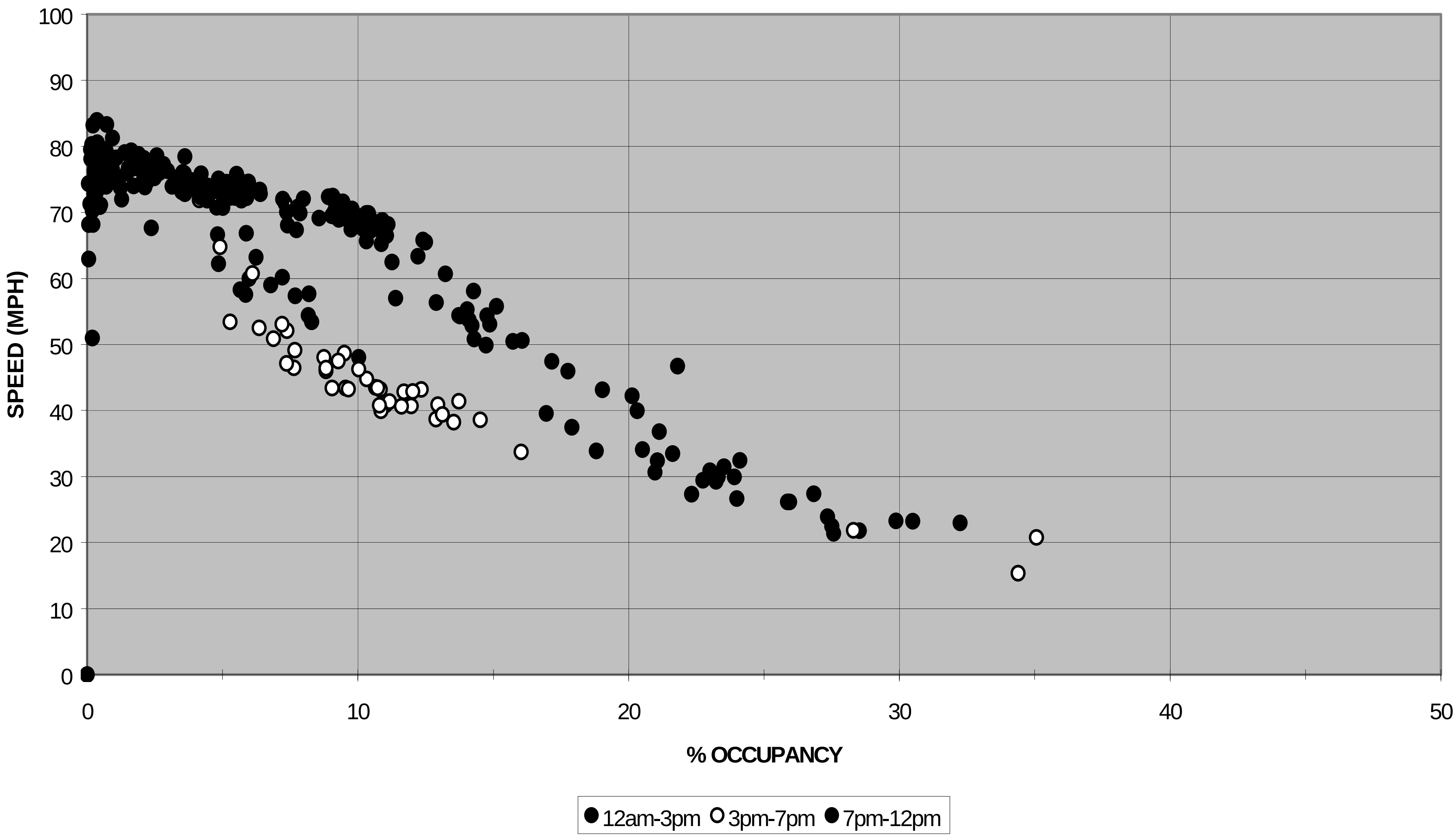


Illustration 3.4 Lane 1 Average Speed Versus Flow Rate Relationship at Station 5W (Thurs 3/4/04)

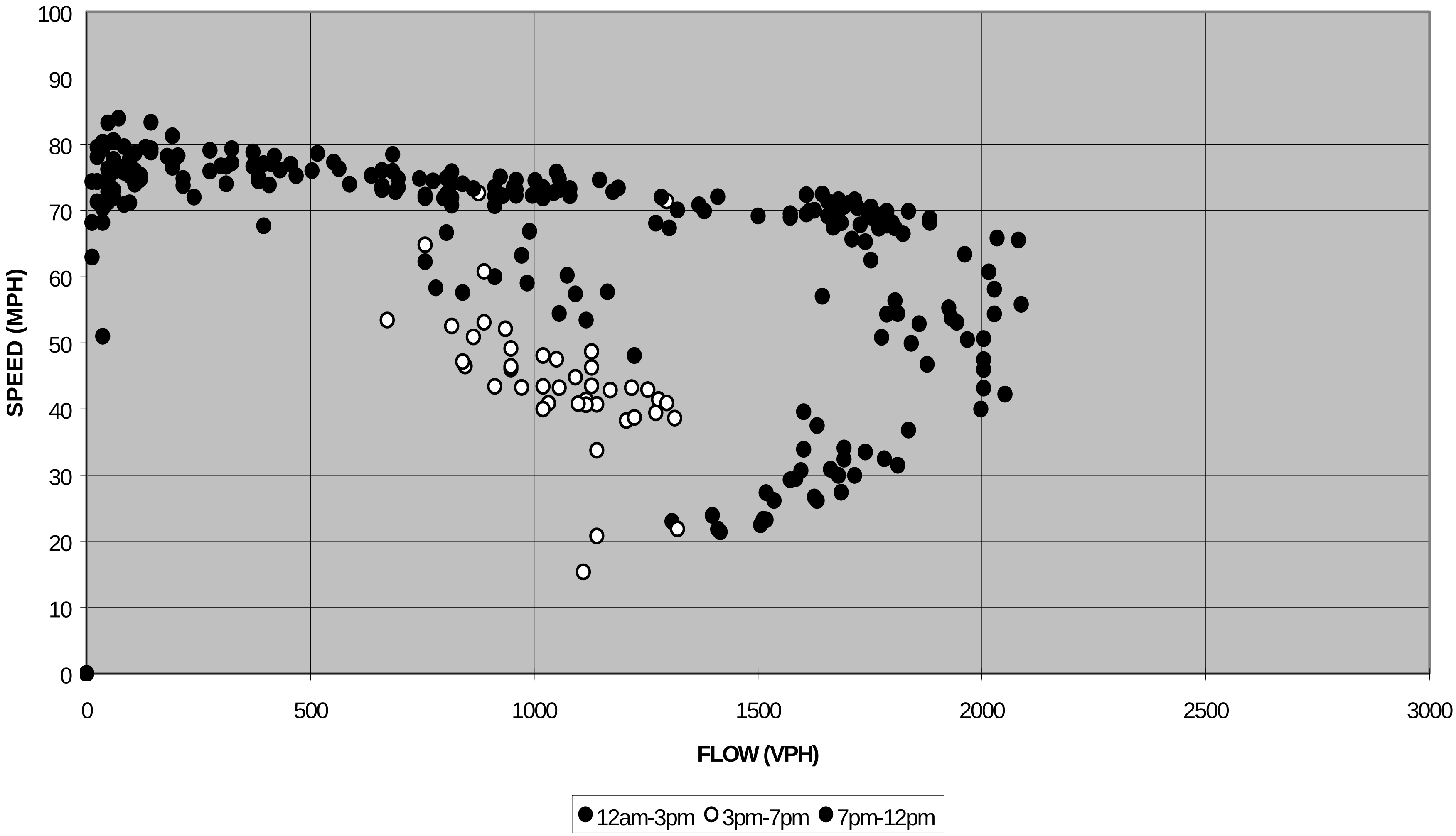


Illustration 3.5 Lane 2 Flow Rate versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

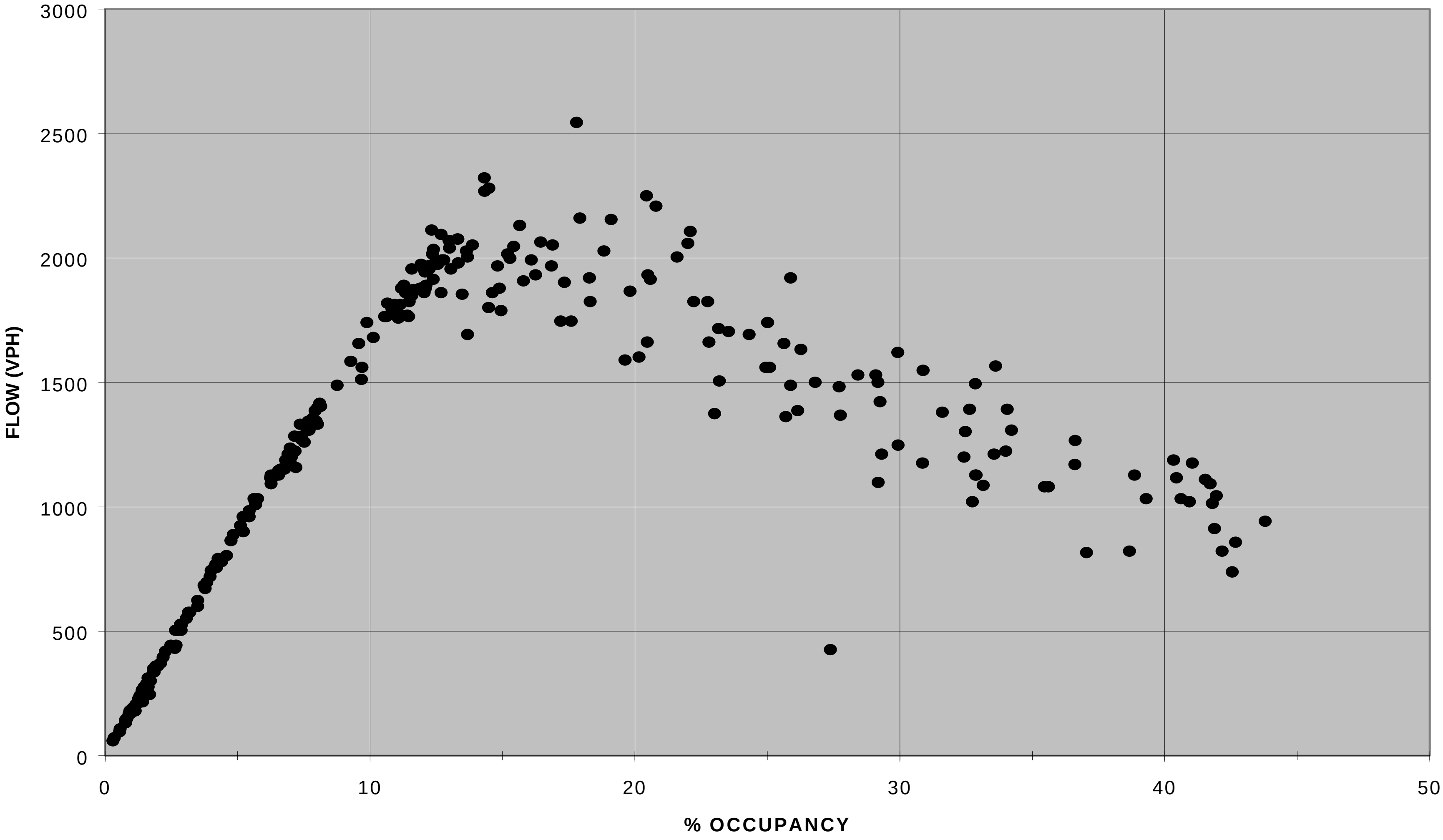


Illustration 3.6 Lane 2 Average Speed versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

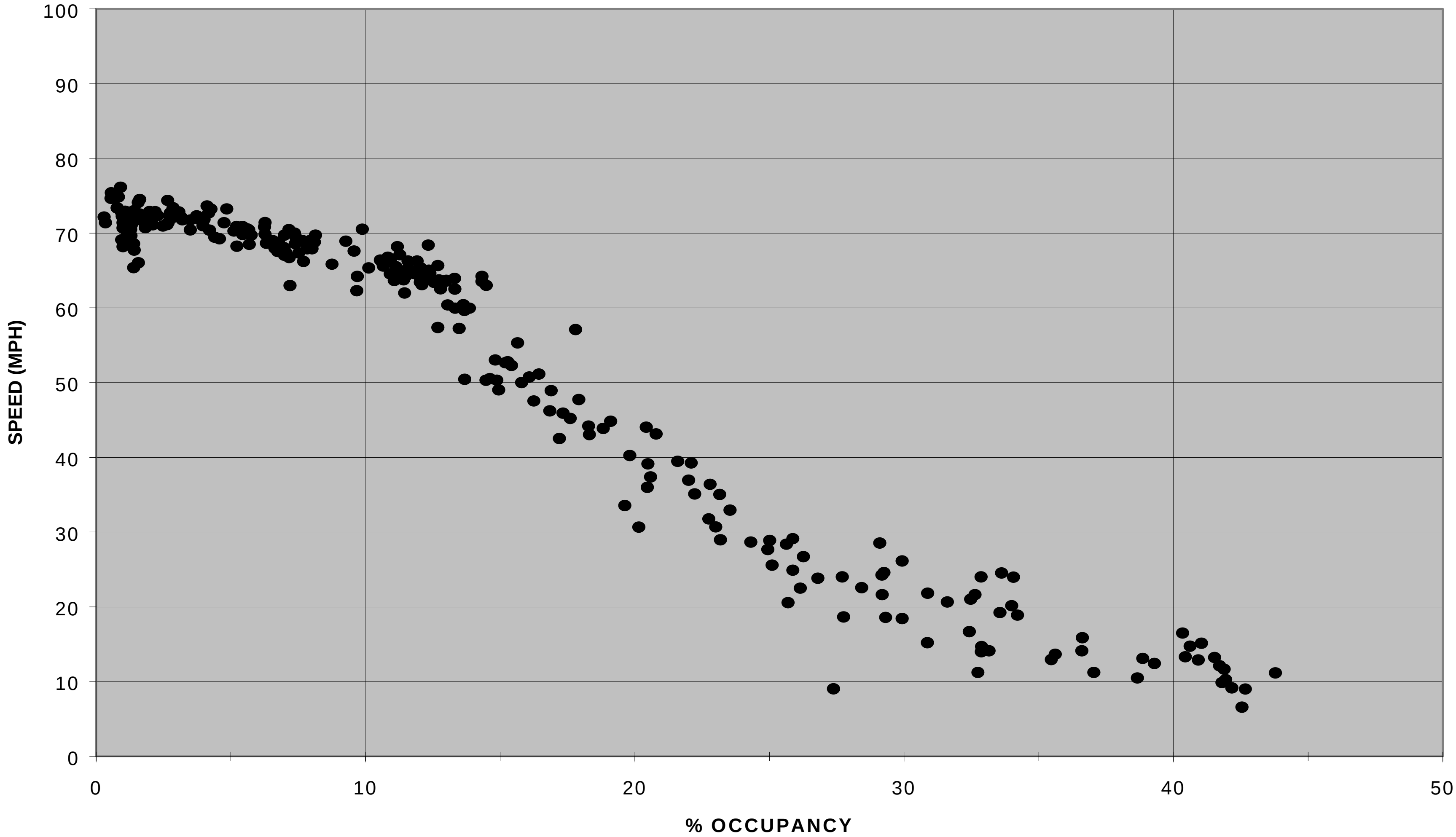


Illustration 3.7 Lane 2 Average Speed Versus Flow Rate Relationship at Station 5W (Thurs 3/4/04)

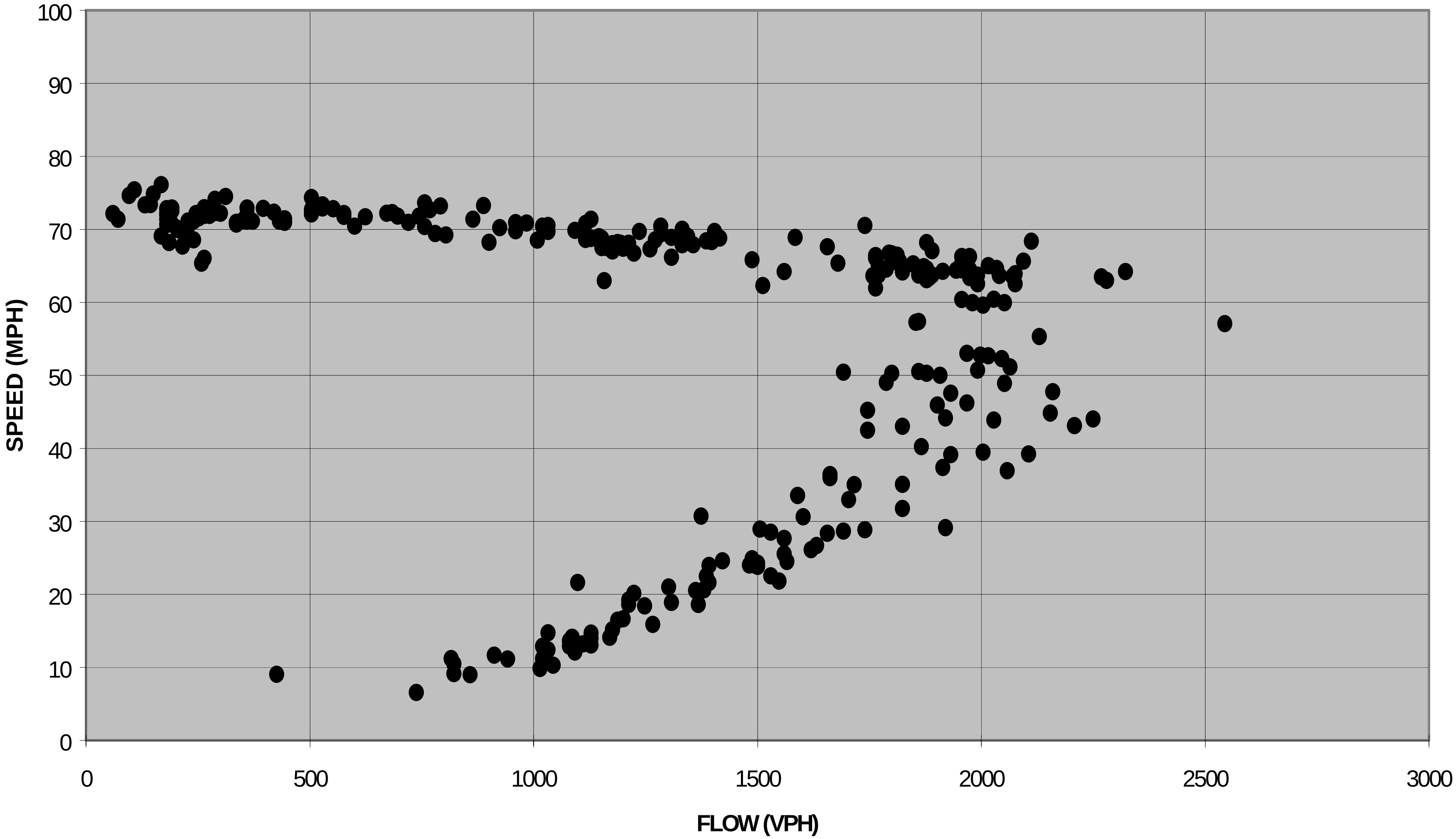


Illustration 3.8 Lane 3 Flow Rate versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

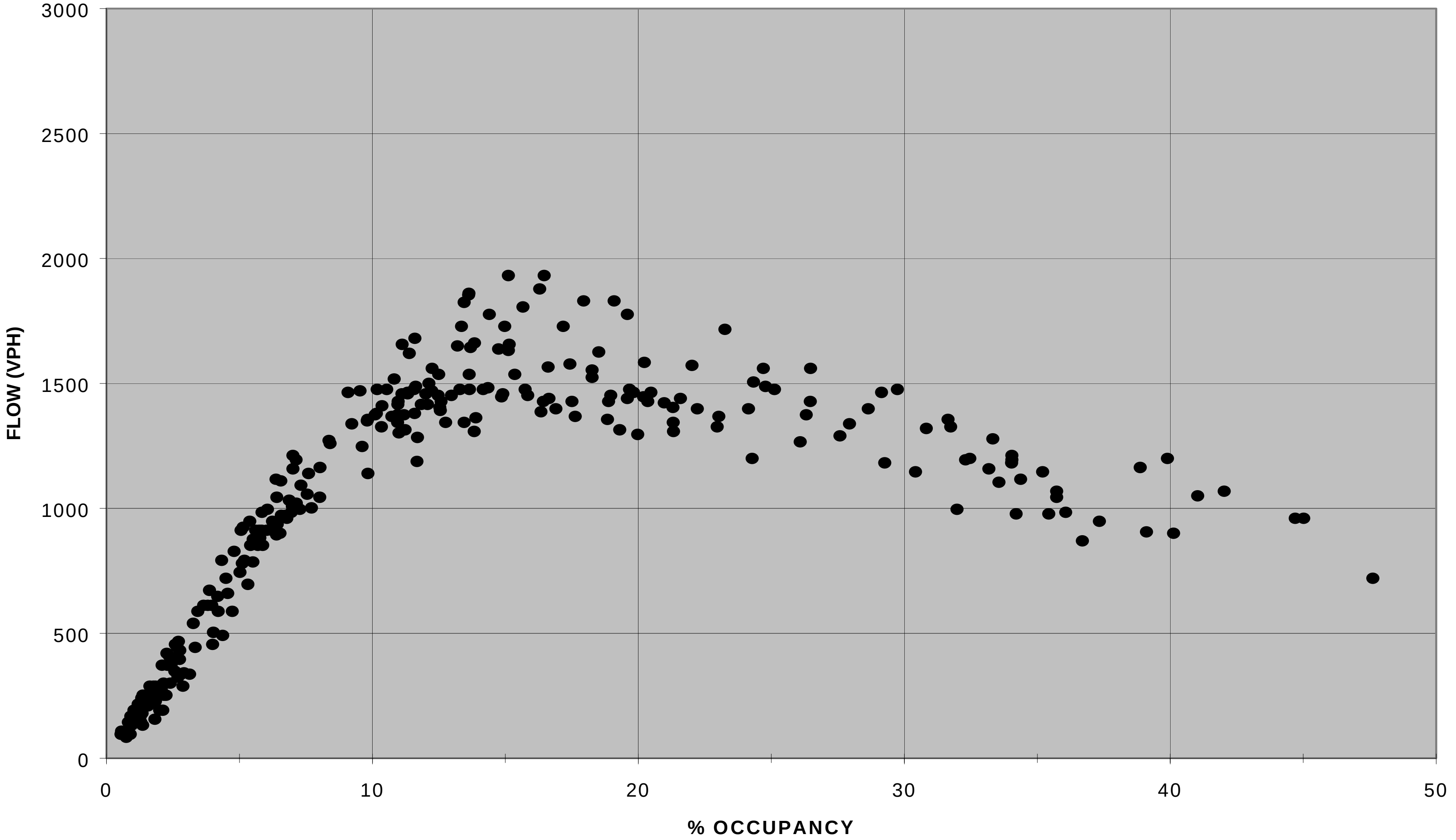


Illustration 3.9 Lane 3 Average Speed versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

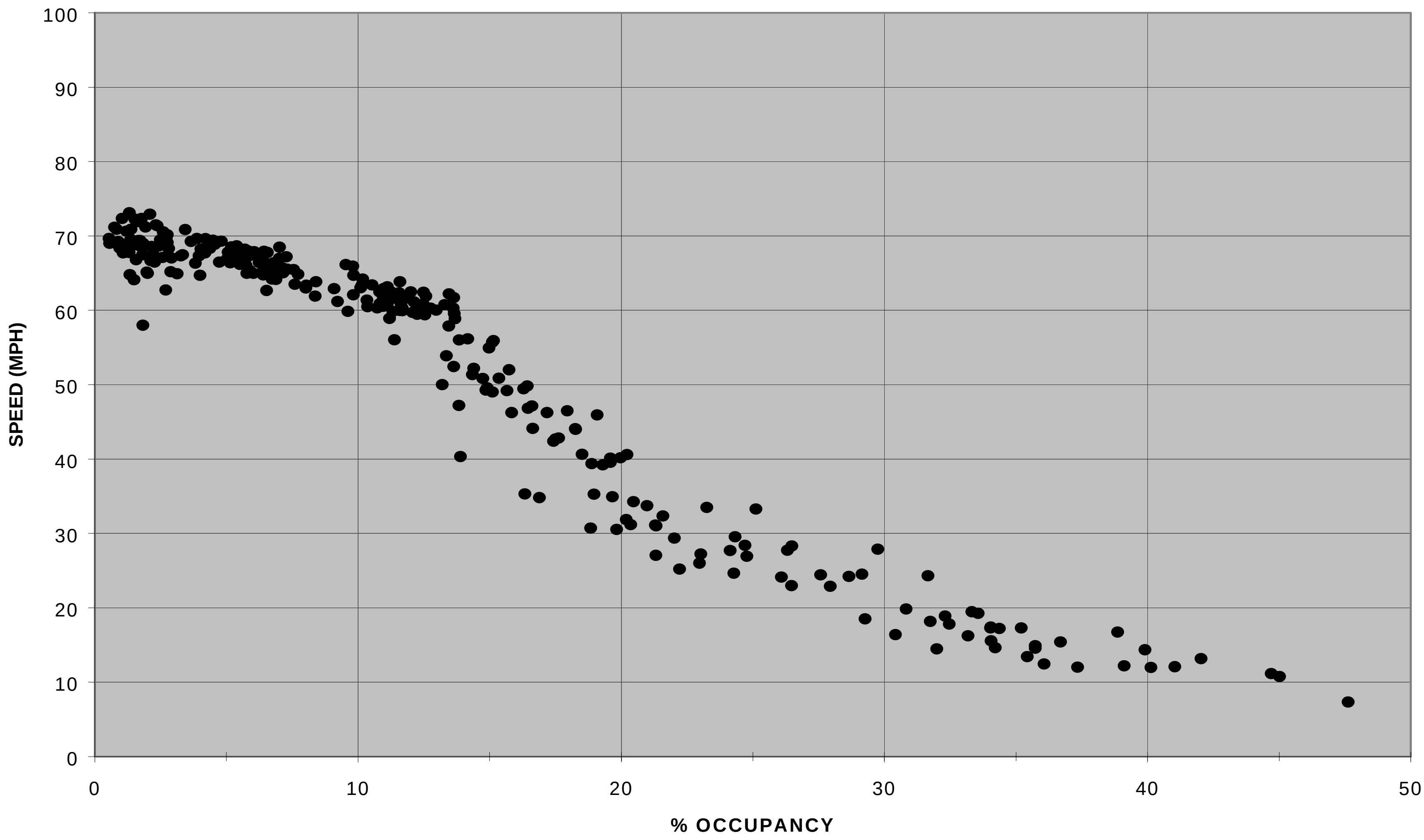


Illustration 3.10 Lane 3 Average Speed versus Flow Rate Relationship at Station 5W (Thurs 3/4/04)

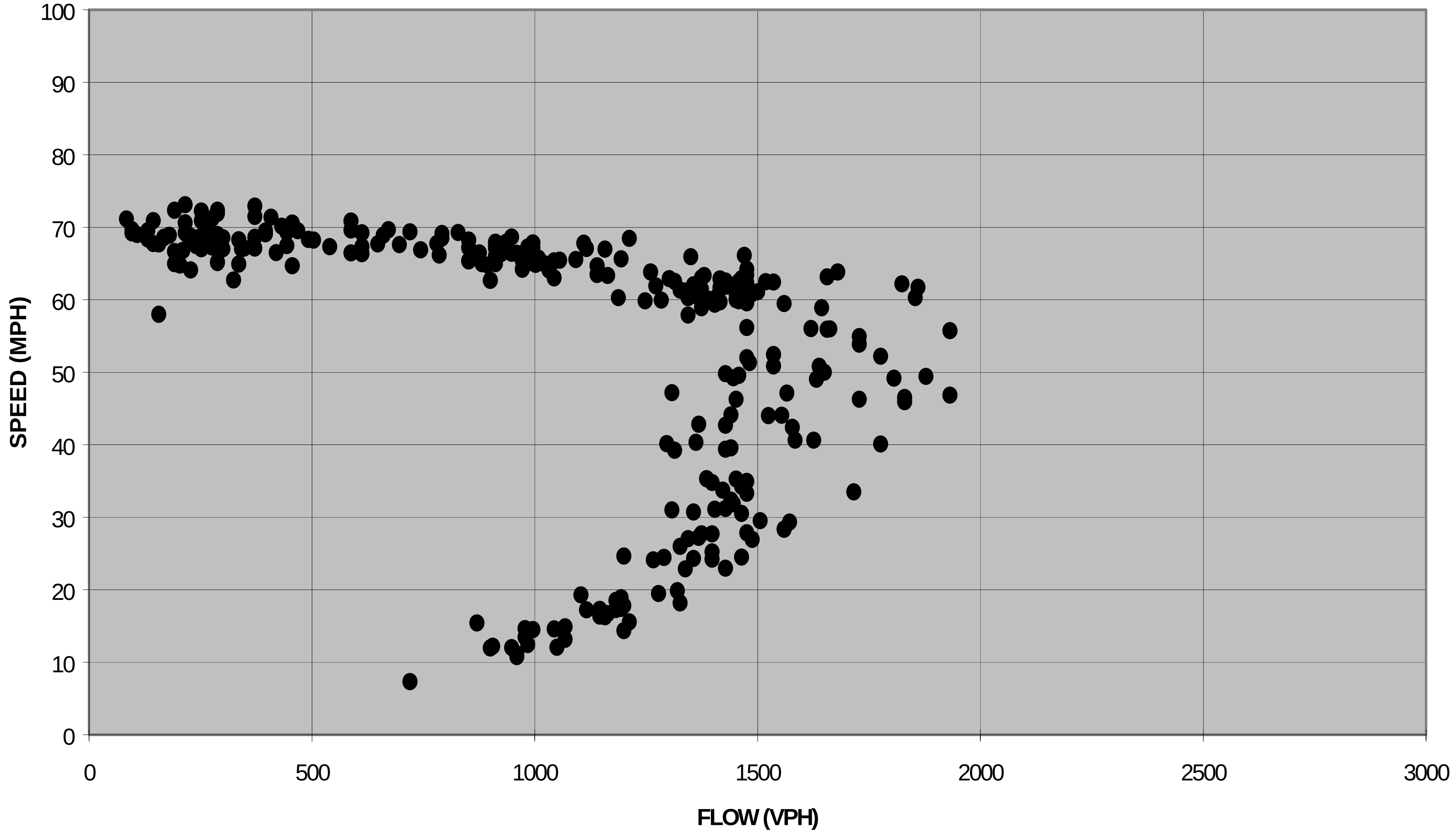


Illustration 3.11 Lane 4 Flow Rate versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

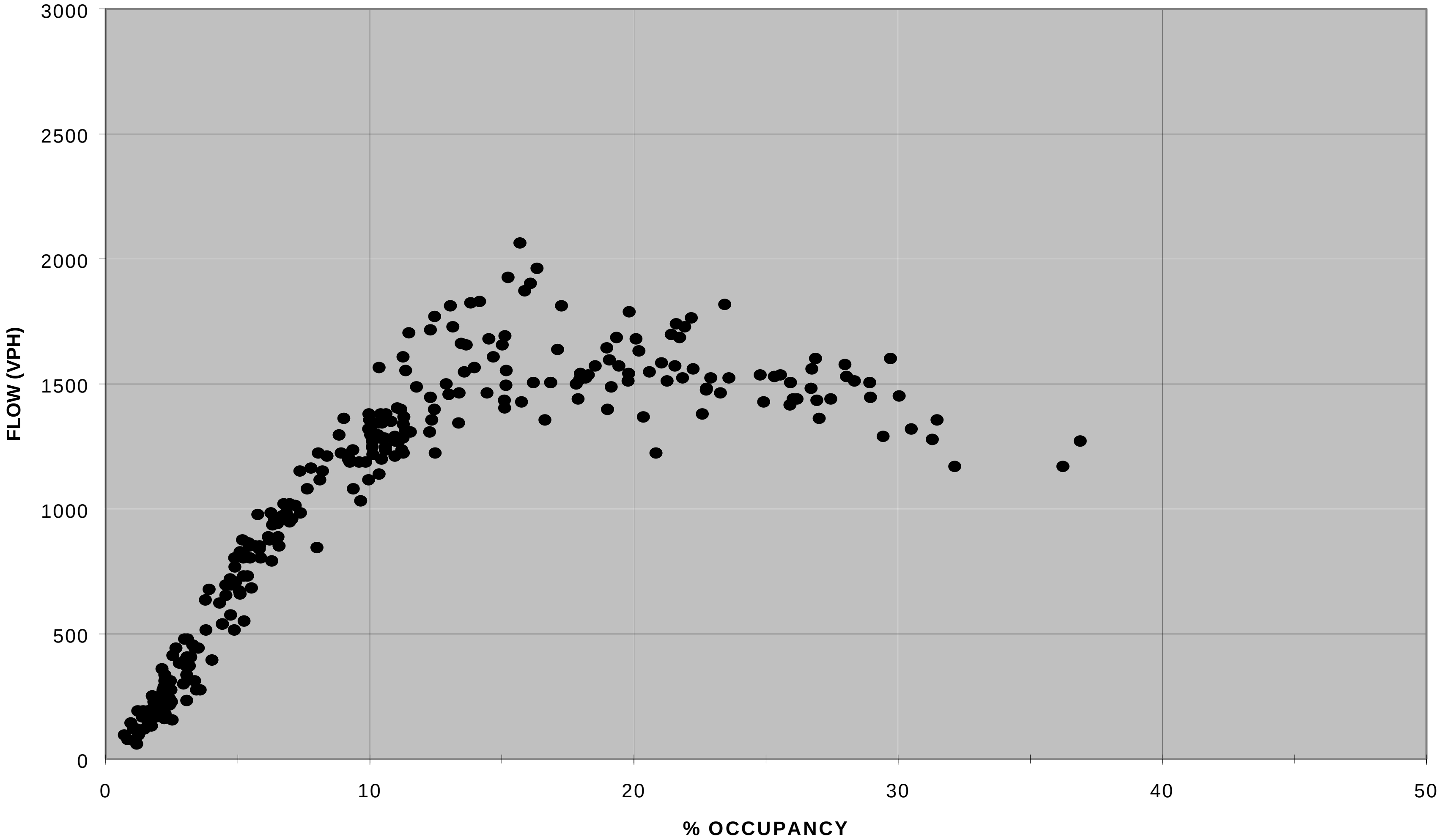


Illustration 3.12 Lane 4 Average Speed versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

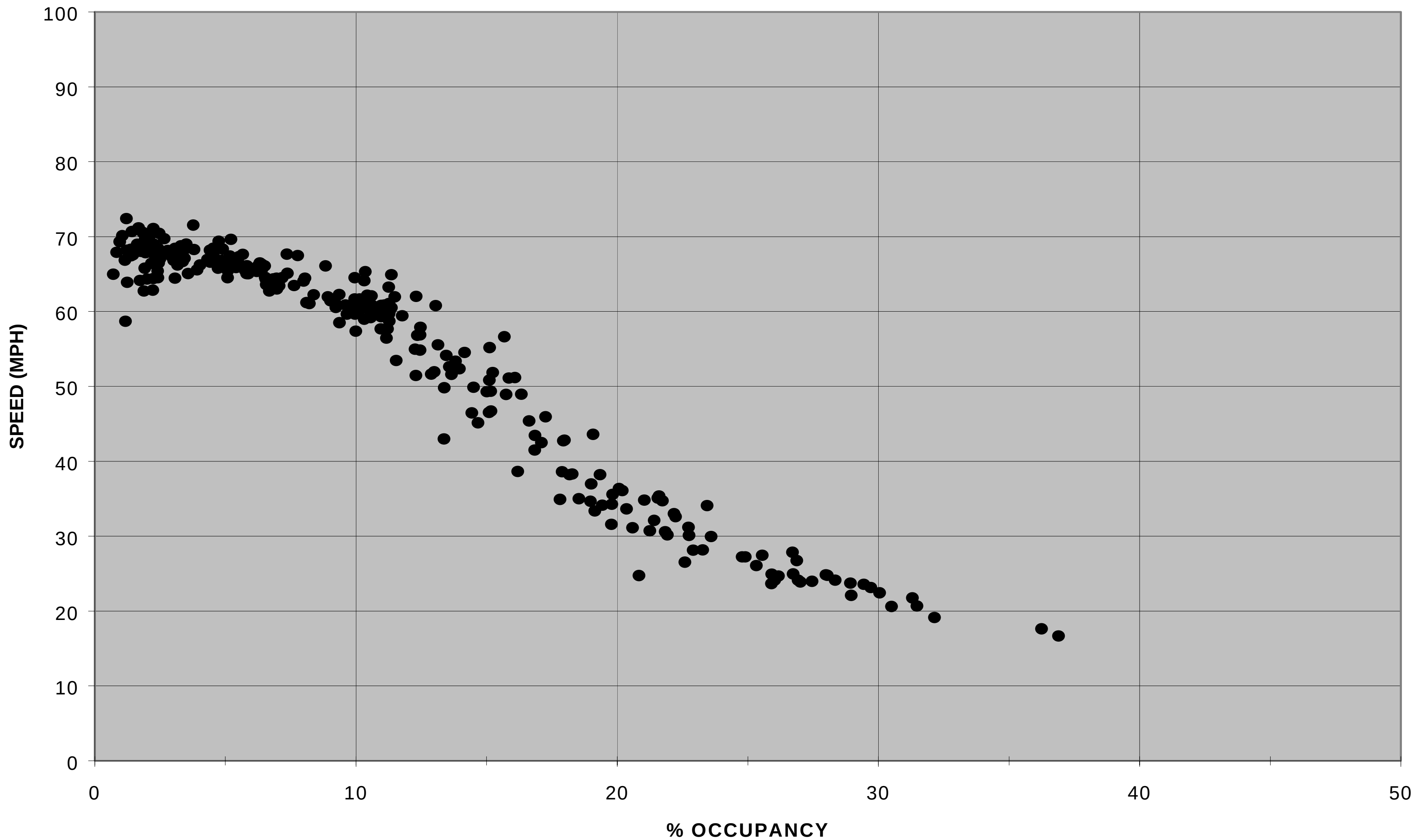


Illustration 3.13 Lane 4 Average Speed versus Flow Rate Relationship at Station 5W (Thurs 3/4/04)

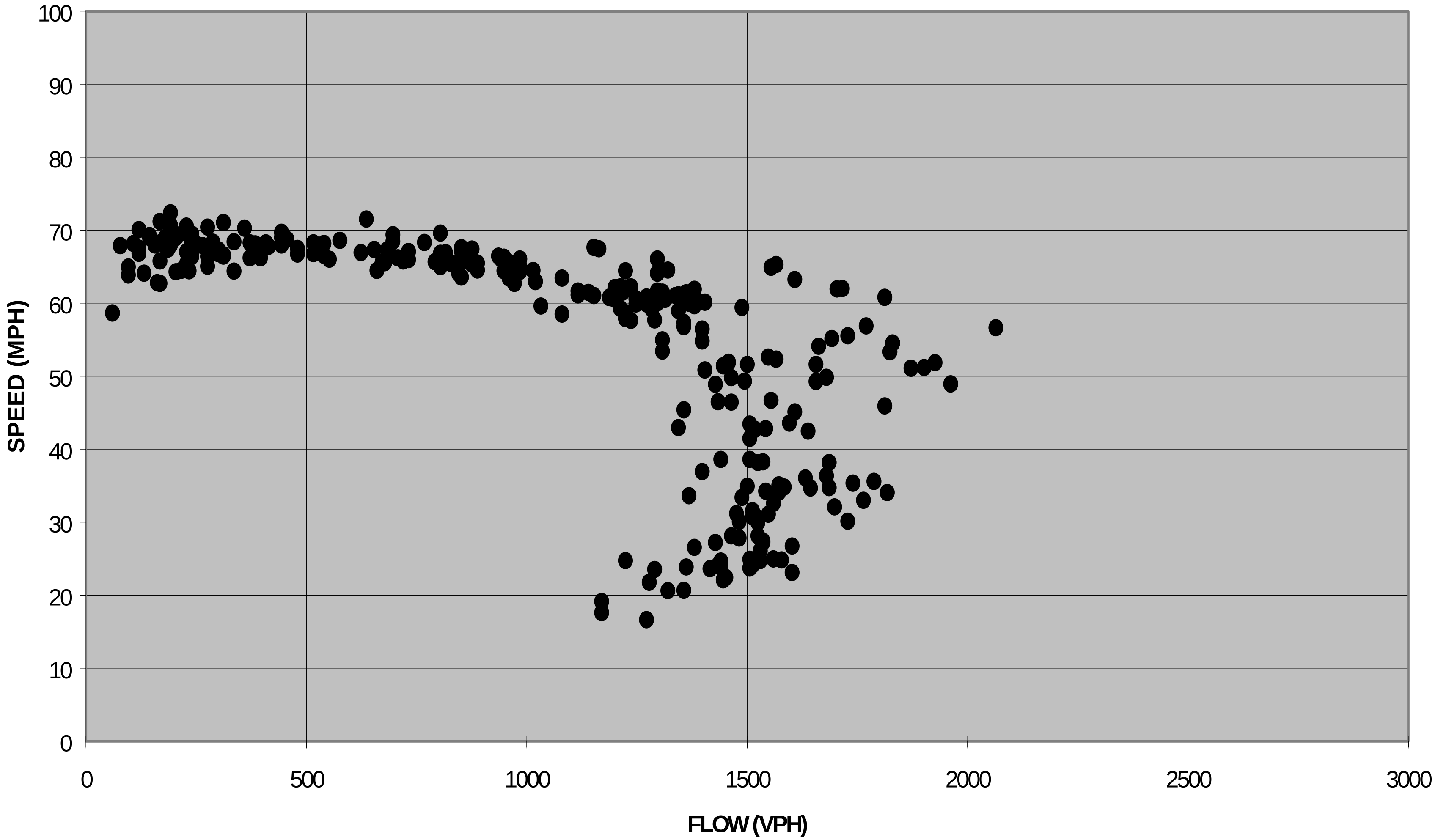


Illustration 3.14 Lane 5 Flow Rate versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

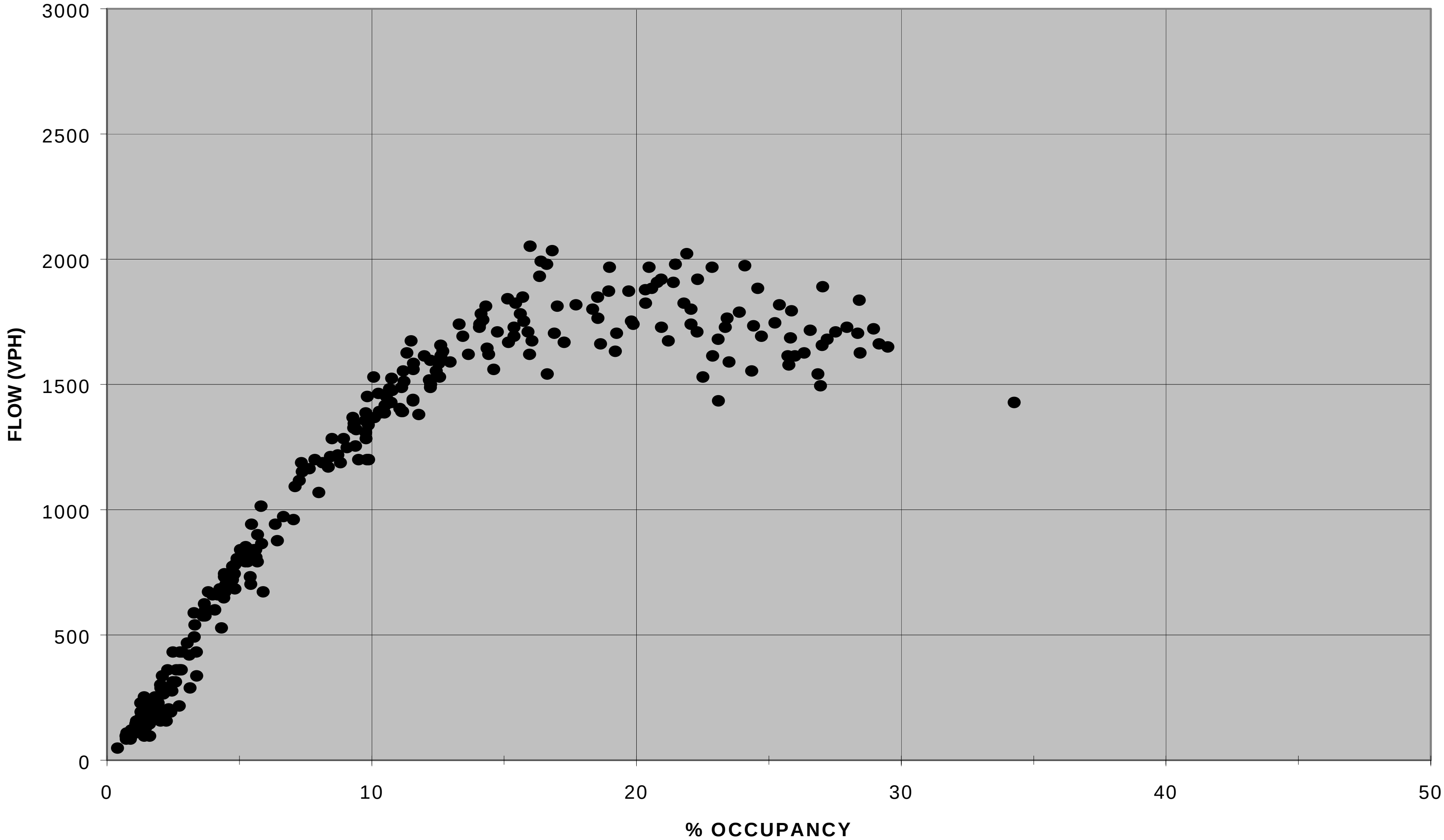


Illustration 3.15 Lane 5 Average Speed versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

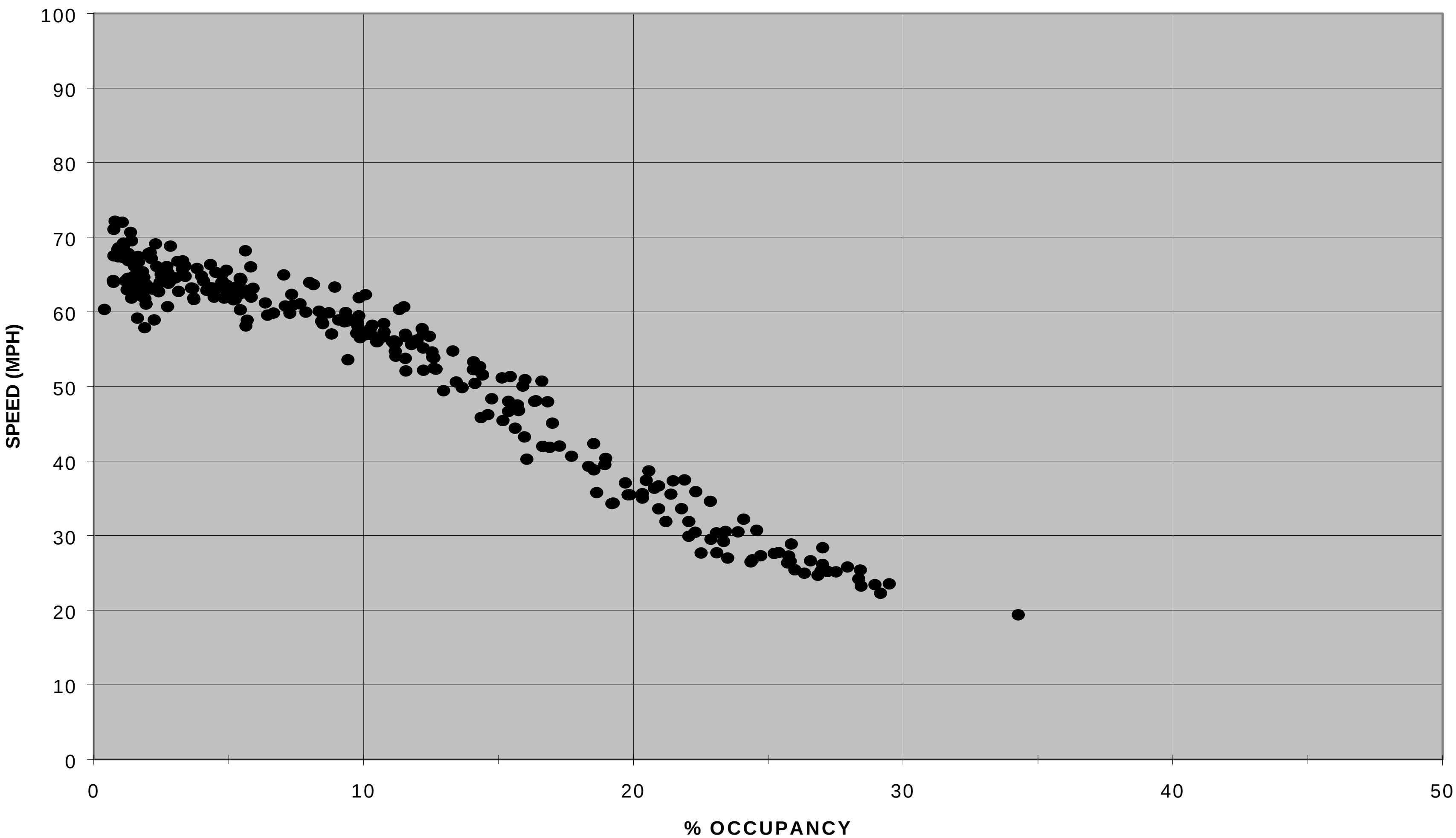


Illustration 3.16 Lane 5 Average Speed versus Flow Rate Relationship at Station 5W (Thurs 3/4/04)

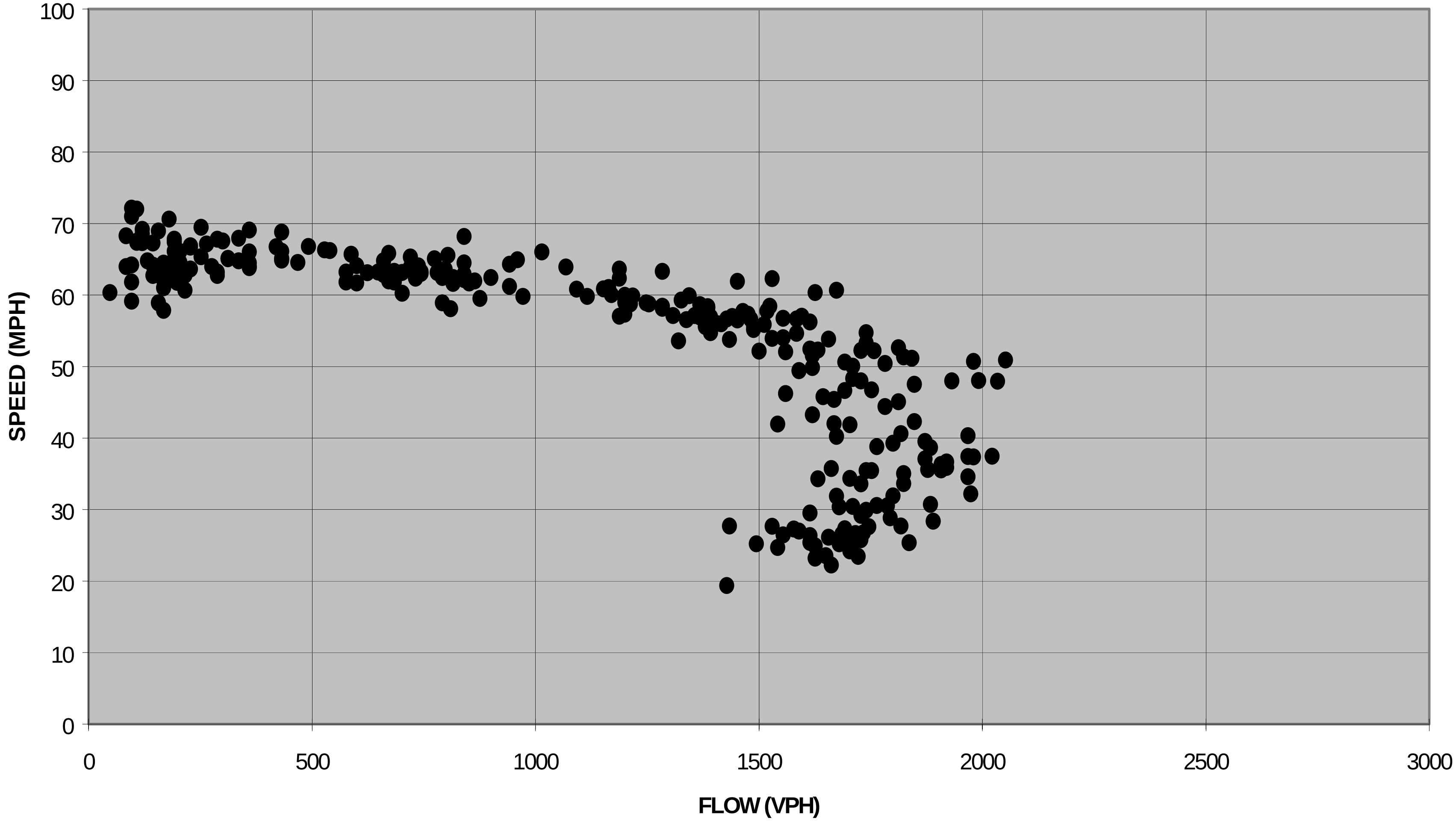


Illustration 3.17 Summary of Individual Lane Traffic Performance Measures for 5W (Thurs 3/4/04)

FLOW CONDITIONS	PERFORMANCE MEASURE RANGE	LANE 1	LANE 2	LANE 3	LANE 4	LANE 5
FREE-FLOW CONDITIONS	FLOW RATE	0 TO 2000	0 TO 2100	0 TO 1800	0 TO 1800	0 TO 1900
	PERCENT OCCUPANCY	0 TO 12	0 TO 12	0 TO 14	0 TO 13	0 TO 16
	AVERAGE SPEED	83 TO 65	75 TO 65	73 TO 60	71 TO 60	71 TO 50
NEAR-CAPACITY CONDITIONS	FLOW RATE	2000 TO 2100	2100 TO 2600	1800 TO 1900	1800 TO 2100	1900 TO 2100
	PERCENT OCCUPANCY	12 TO 20	12 TO 22	14 TO 20	13 TO 20	16 TO 25
	AVERAGE SPEED	65 TO 35	65 TO 45	60 TO 40	60 TO 35	50 TO 35
CONGESTED-FLOW CONDITIONS	FLOW RATE	2000 TO 1100	2100 TO 700	1800 TO 700	1800 TO 1200	1900 TO 1700
	PERCENT OCCUPANCY	20 TO 35	22 TO 44	20 TO 47	20 TO 37	25 TO 34
	AVERAGE SPEED	35 TO 15	45 TO 8	40 TO 9	35 TO 18	35 TO 20

Illustration 3.18 Total Flow over all Lanes (vph) at Station 5W (Thurs 3/4/04)

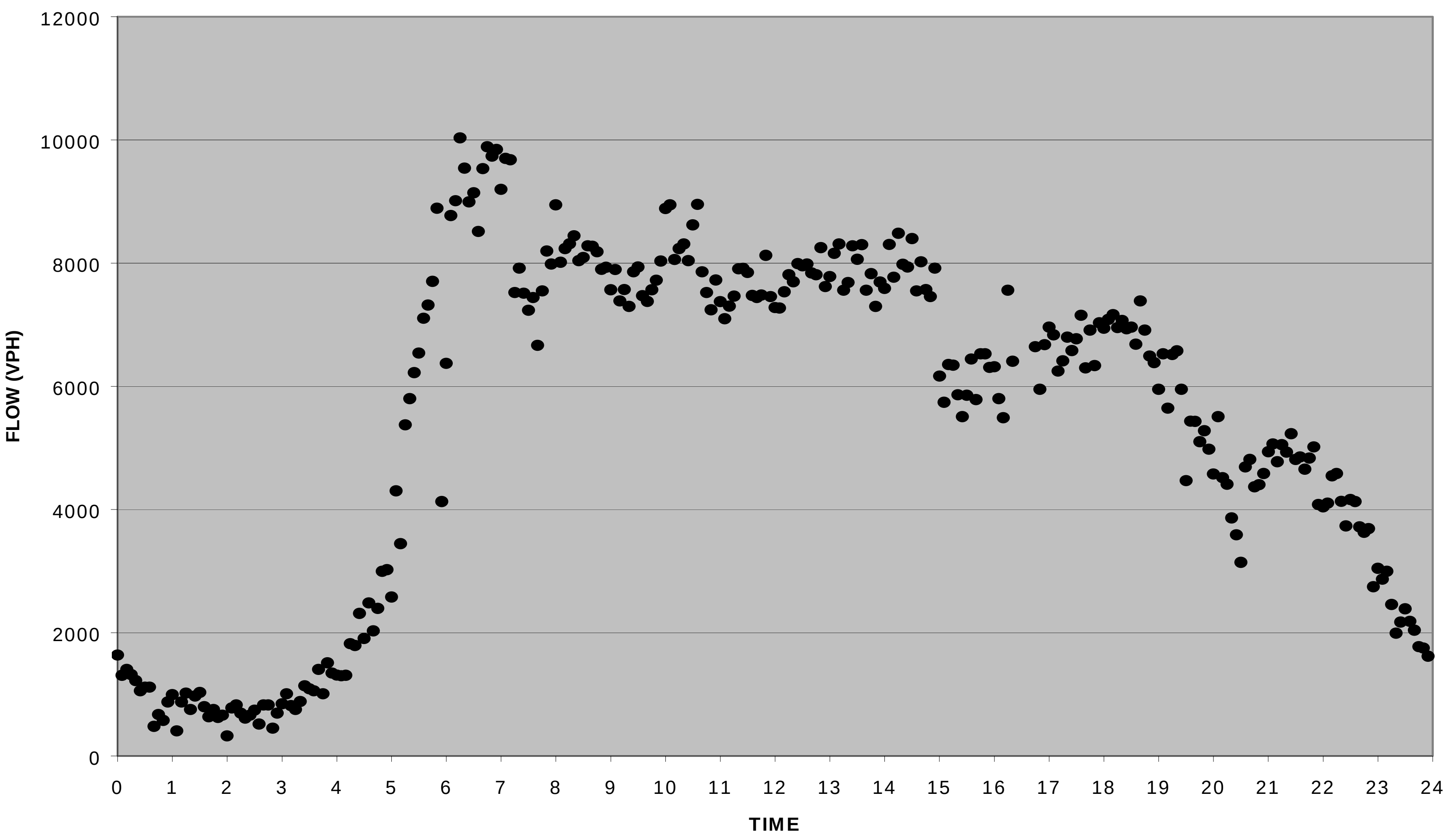


Illustration 3.19 Average Percent Occupancy and Average Speed at Station 5W (Thurs 3/4/04)

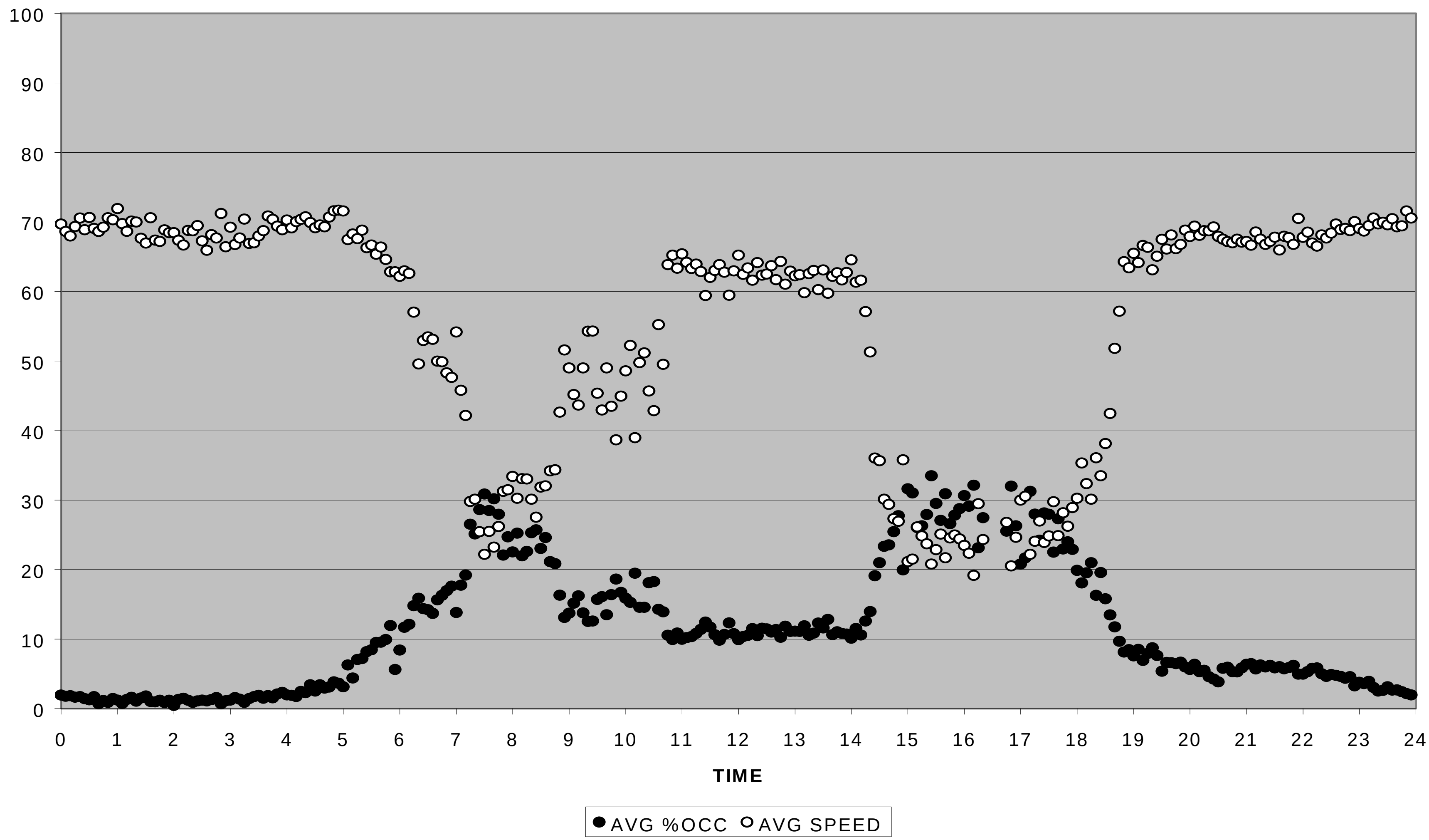


Illustration 3.20 Lane 1 Flow Rate versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

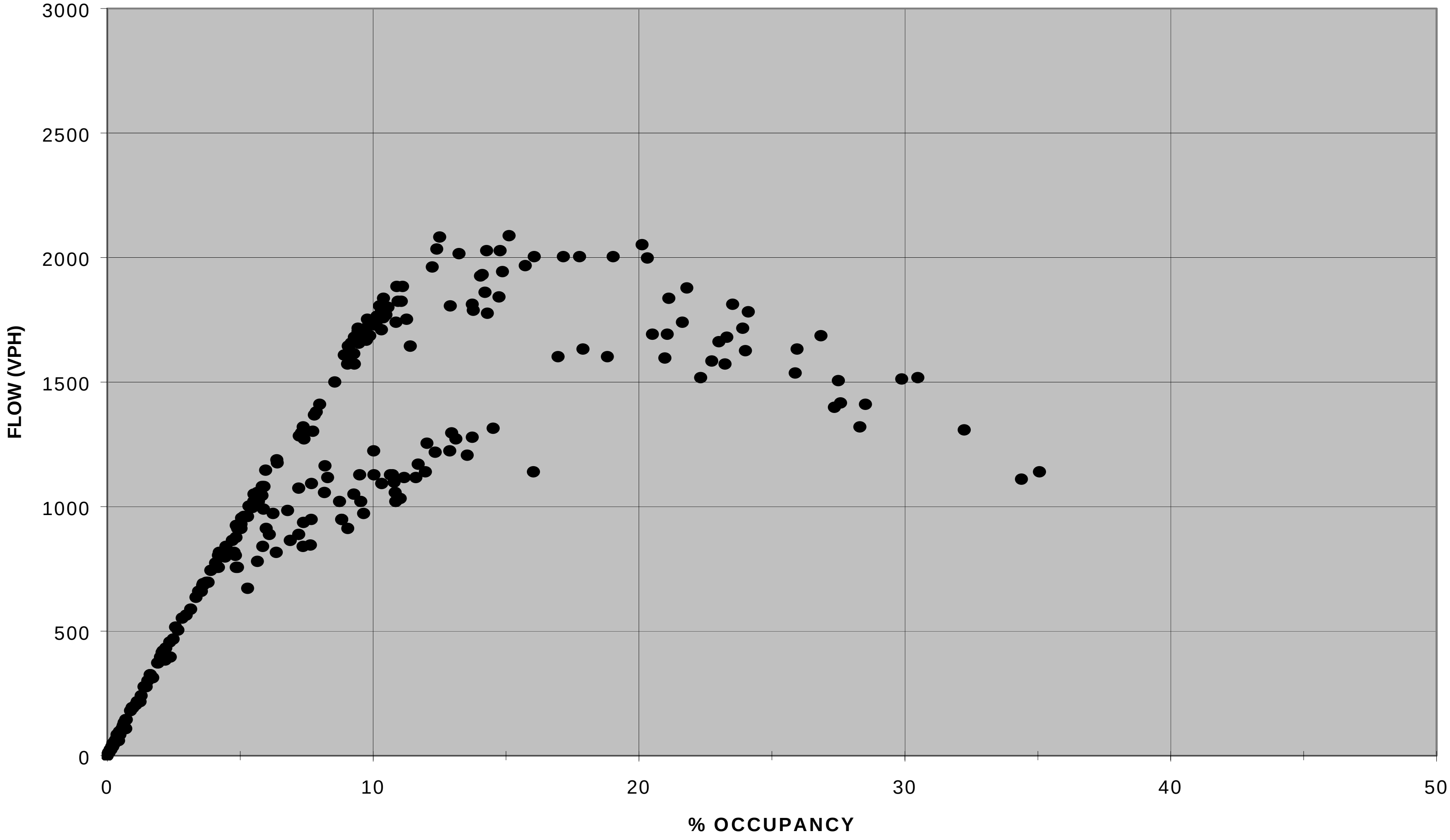


Illustration 3.21 Lane 1 Flow Rate versus Percent Occupancy Relationship (Non-HOV Hours) at Station 5W (Thurs 3/4/04)

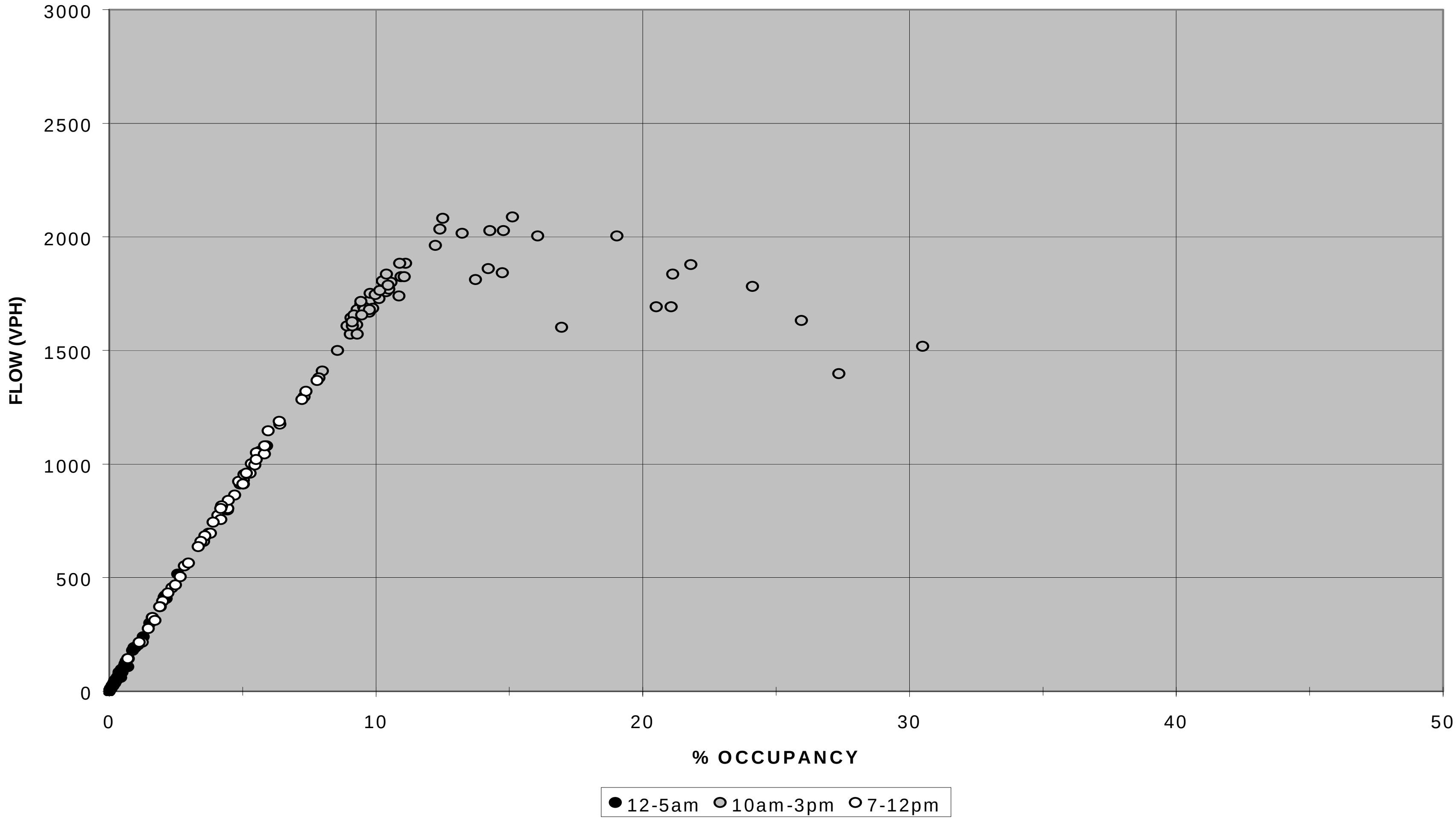


Illustration 3.22 Lane 1 Flow Rate versus Percent Occupancy Relationship (HOV Hours) at Station 5W (Thurs 3/4/04)

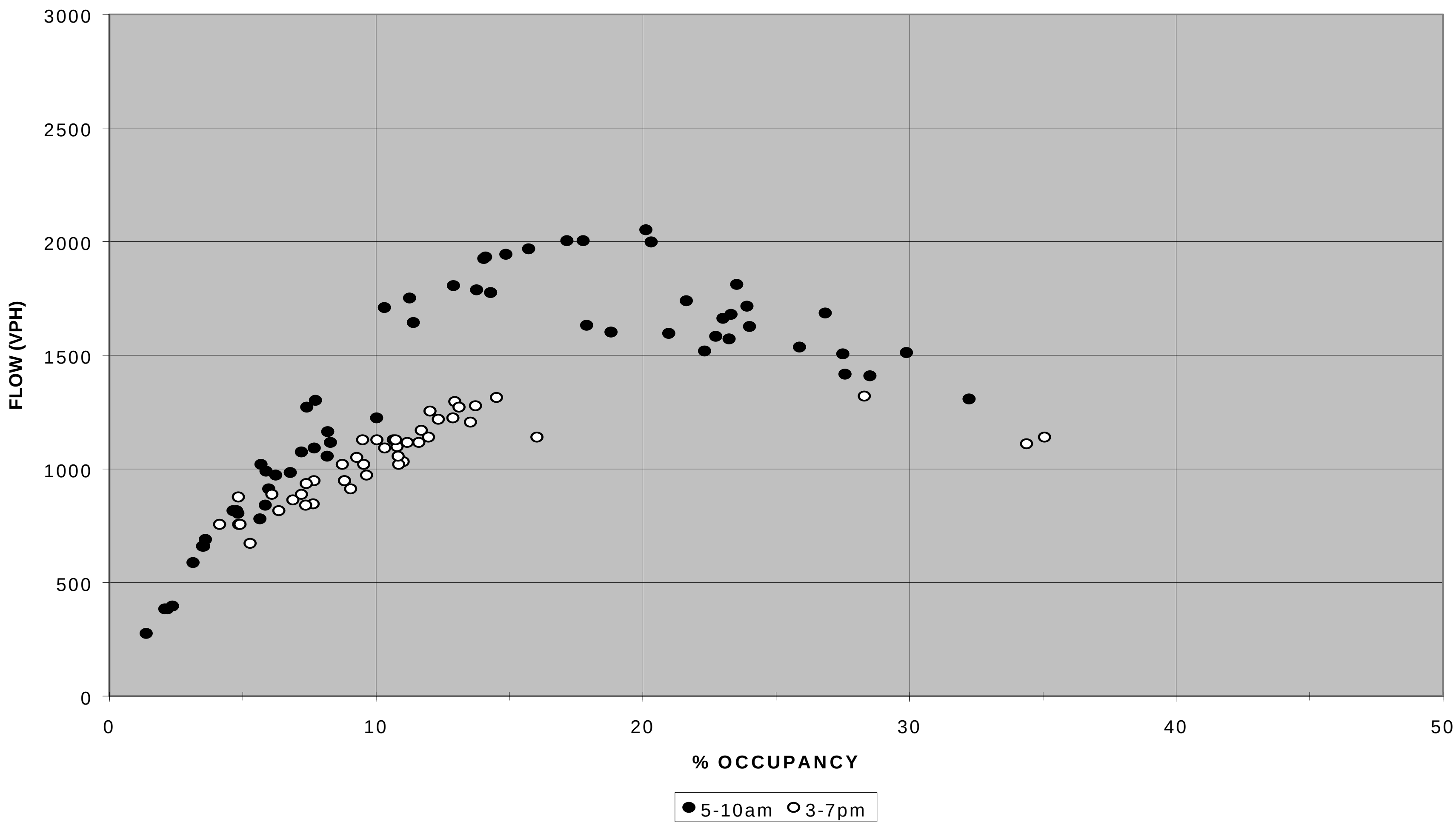


Illustration 3.23 Lane 1 Average Speed versus Percent Occupancy Relationship at Station 5W (Thurs 3/4/04)

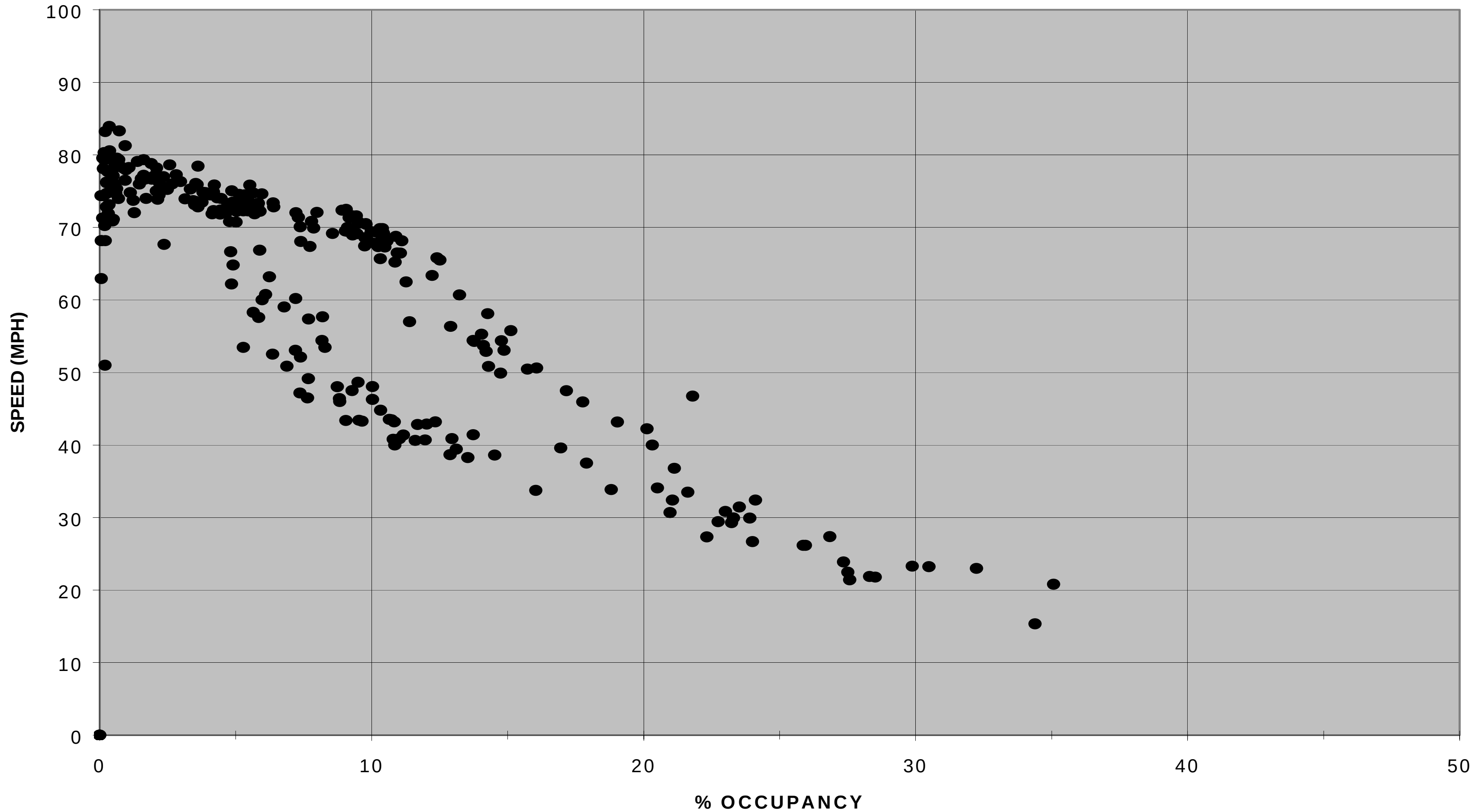


Illustration 3.24 Lane 1 Average Speed versus Percent Occupancy Relationship (Non-HOV Hours) at Station 5W (Thurs 3/4/04)

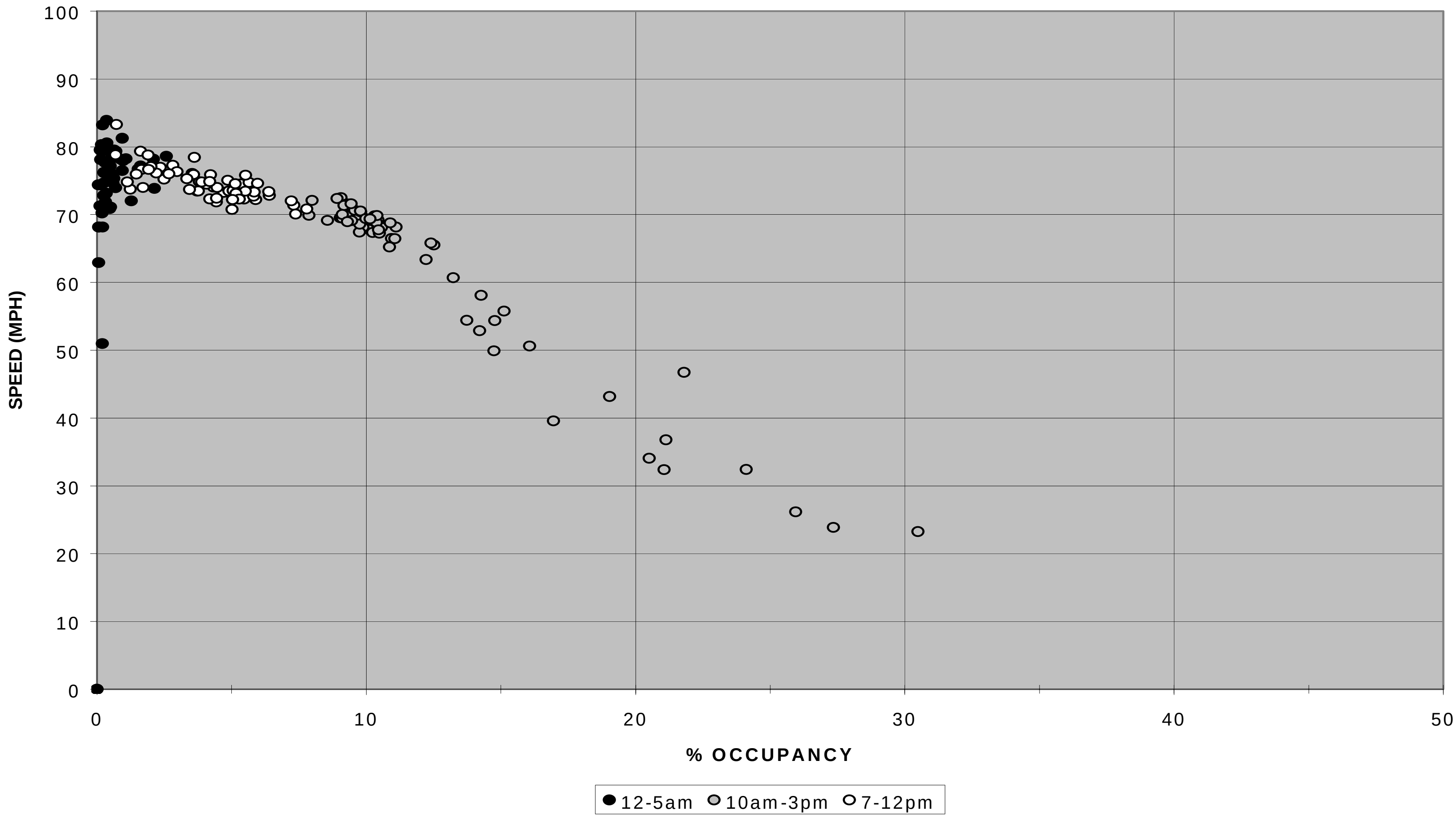


Illustration 3.25 Lane 1 Average Speed versus Percent Occupancy Relationship (HOV Hours) at Station 5W (Thurs 3/4/04)

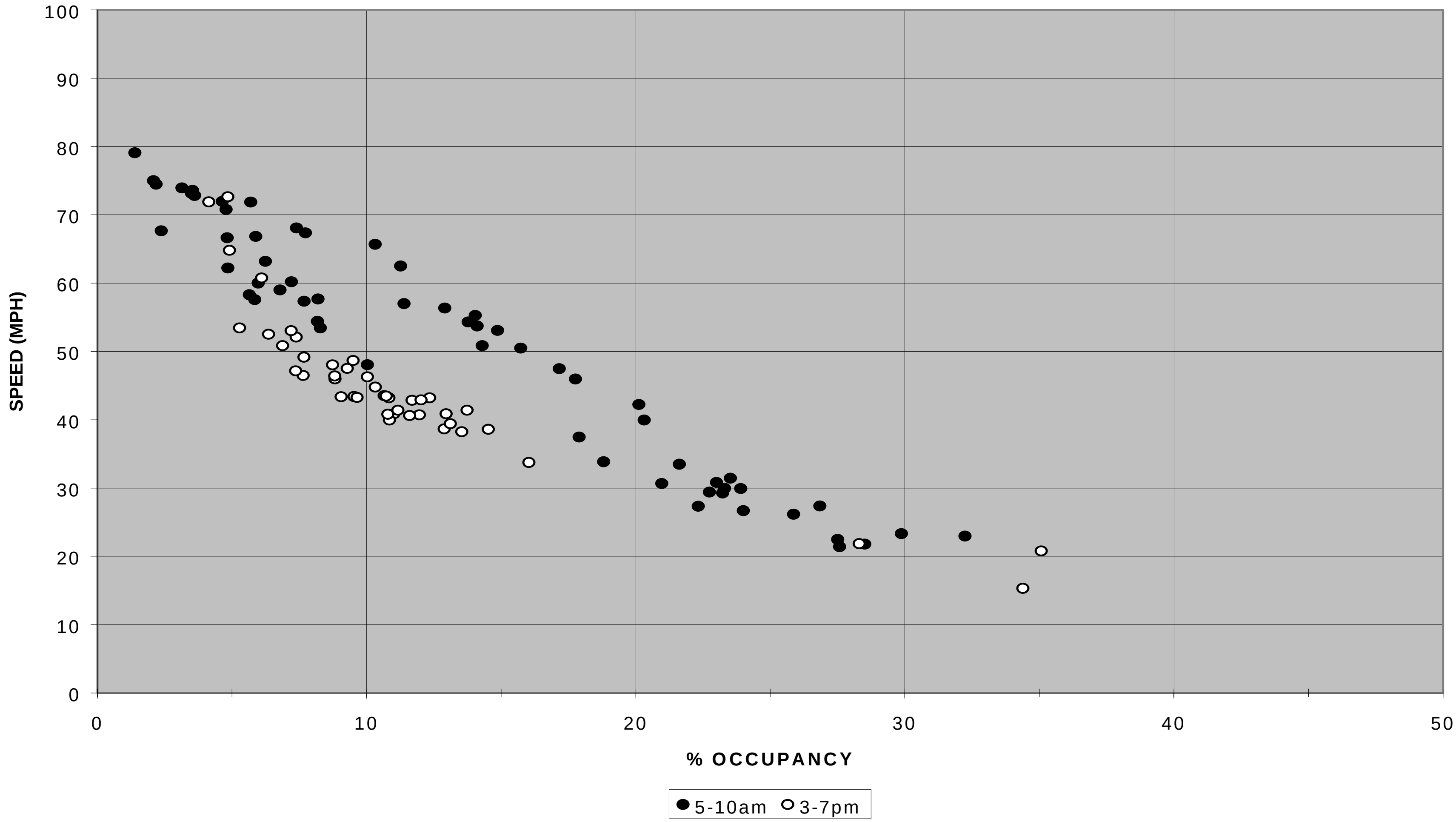


Illustration 3.26 Lane 1 Average Speed versus Lane 2 Average Speed (3-7 pm) at Station 5W (Thurs 3/4/04)

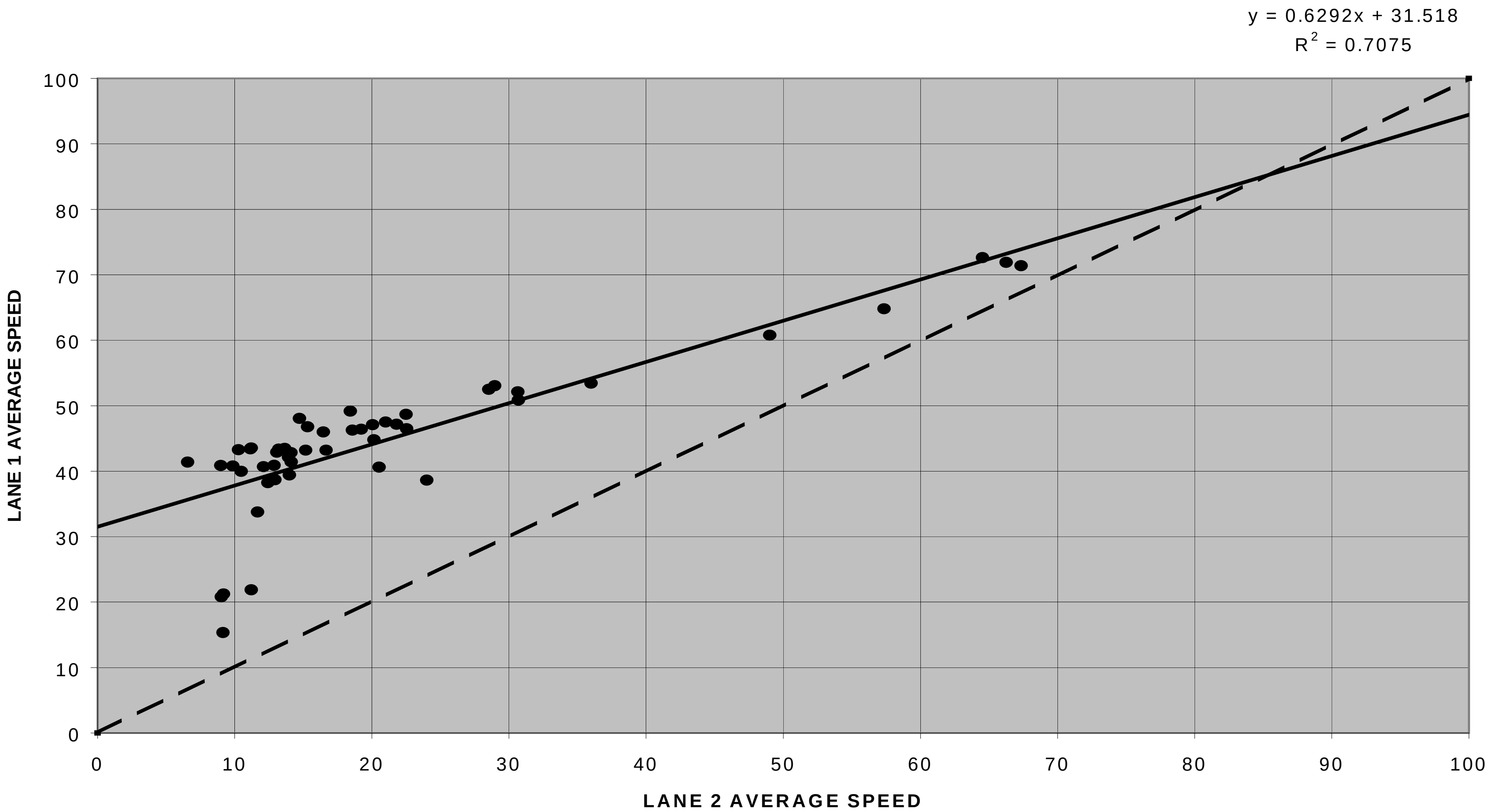


Illustration 3.27 Lane 1 Average Speed versus Percent Occupancy with Trend Line at Station 5W (Thurs 3/4/04)

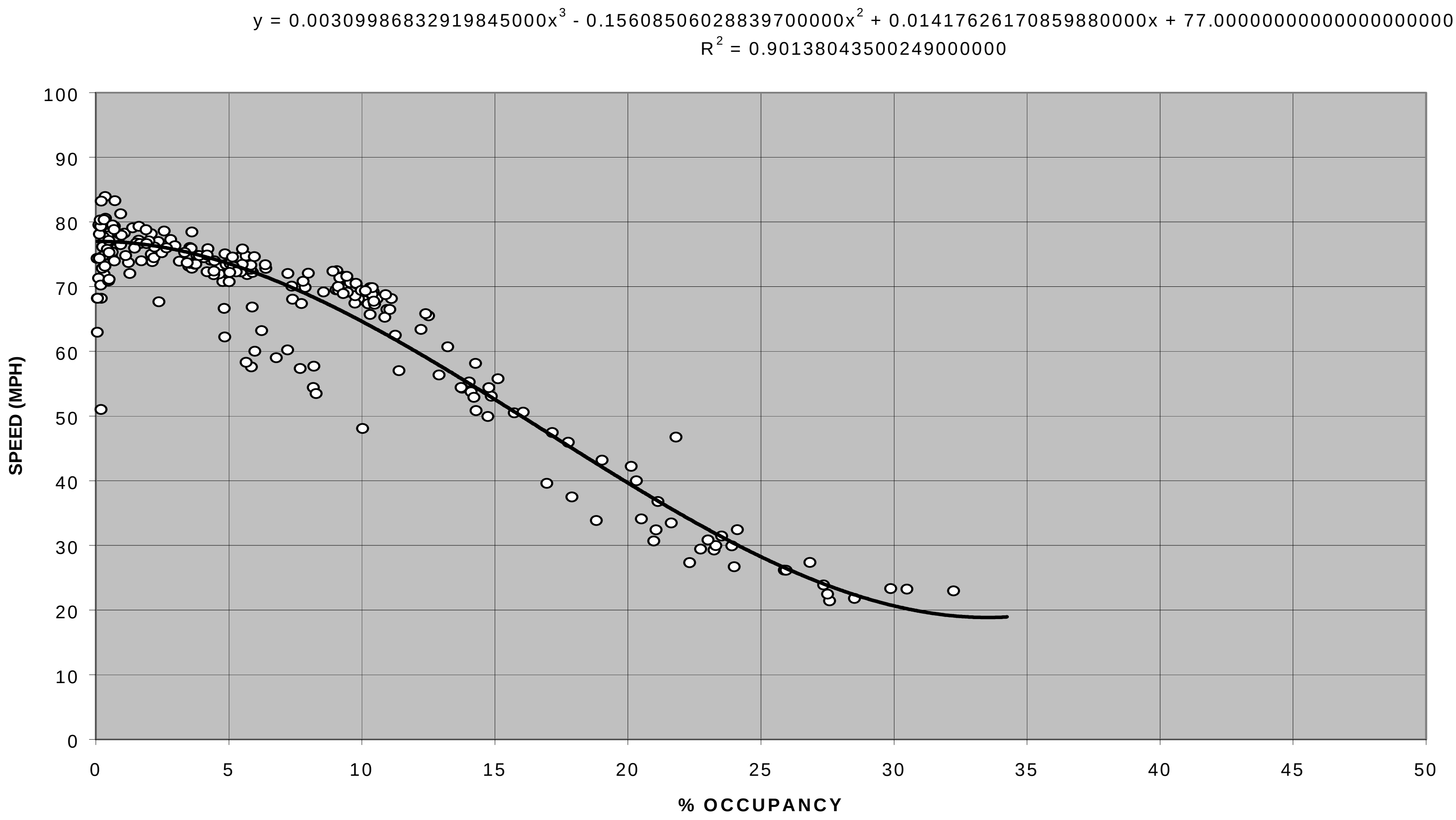


Illustration 3.28 Lane 1 Single-Detector Speed versus Dual Detector Speed at Station 5W (Thurs 3/4/04)

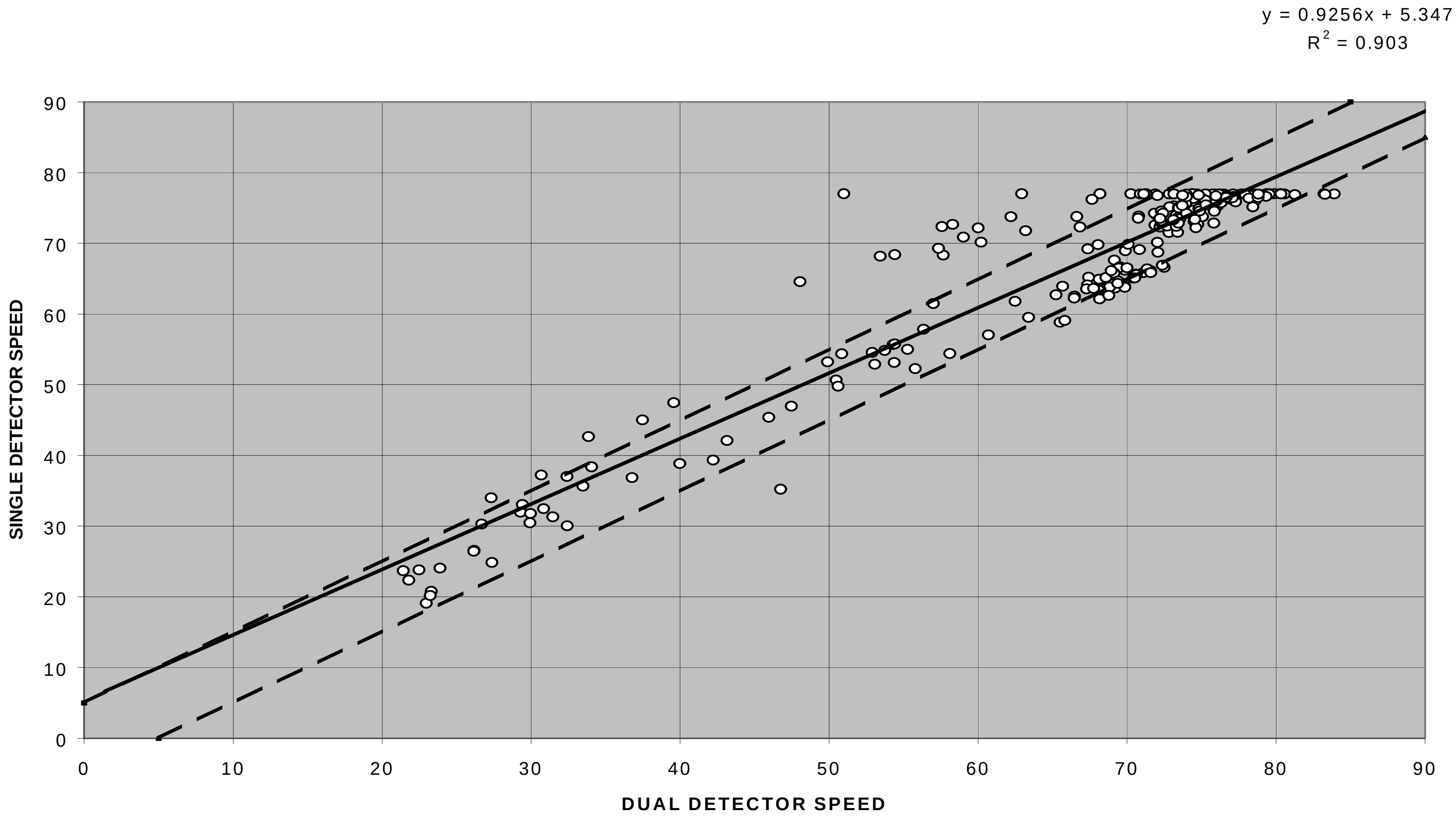


Illustration 3.29 Lane 2 Average Speed versus Percent Occupancy with Trend Line at Station 5W (Thurs 3/4/04)

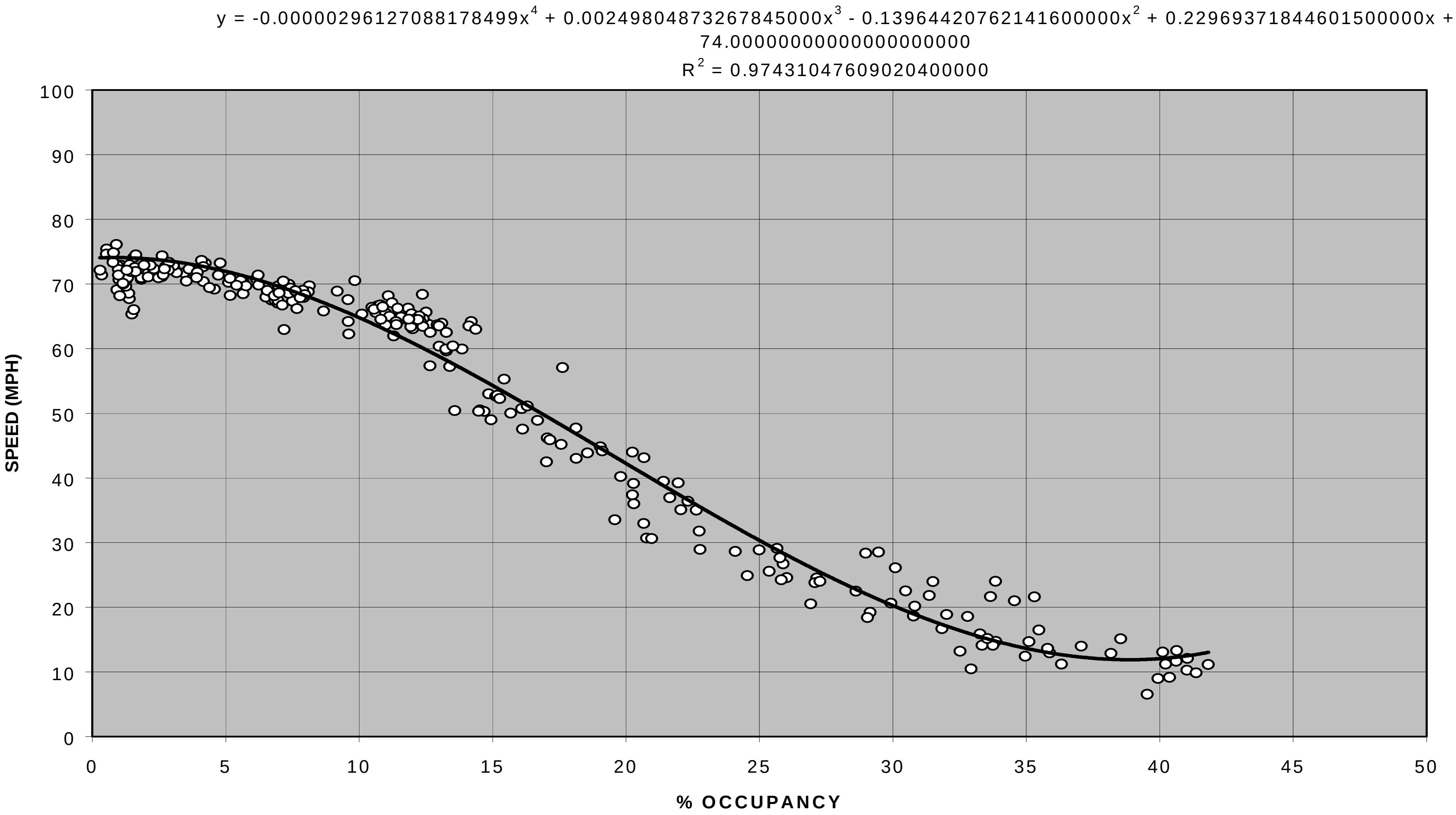


Illustration 3.30 Lane 2 Single-Detector Speed versus Dual Detector Speed at Station 5W (Thurs 3/4/04)

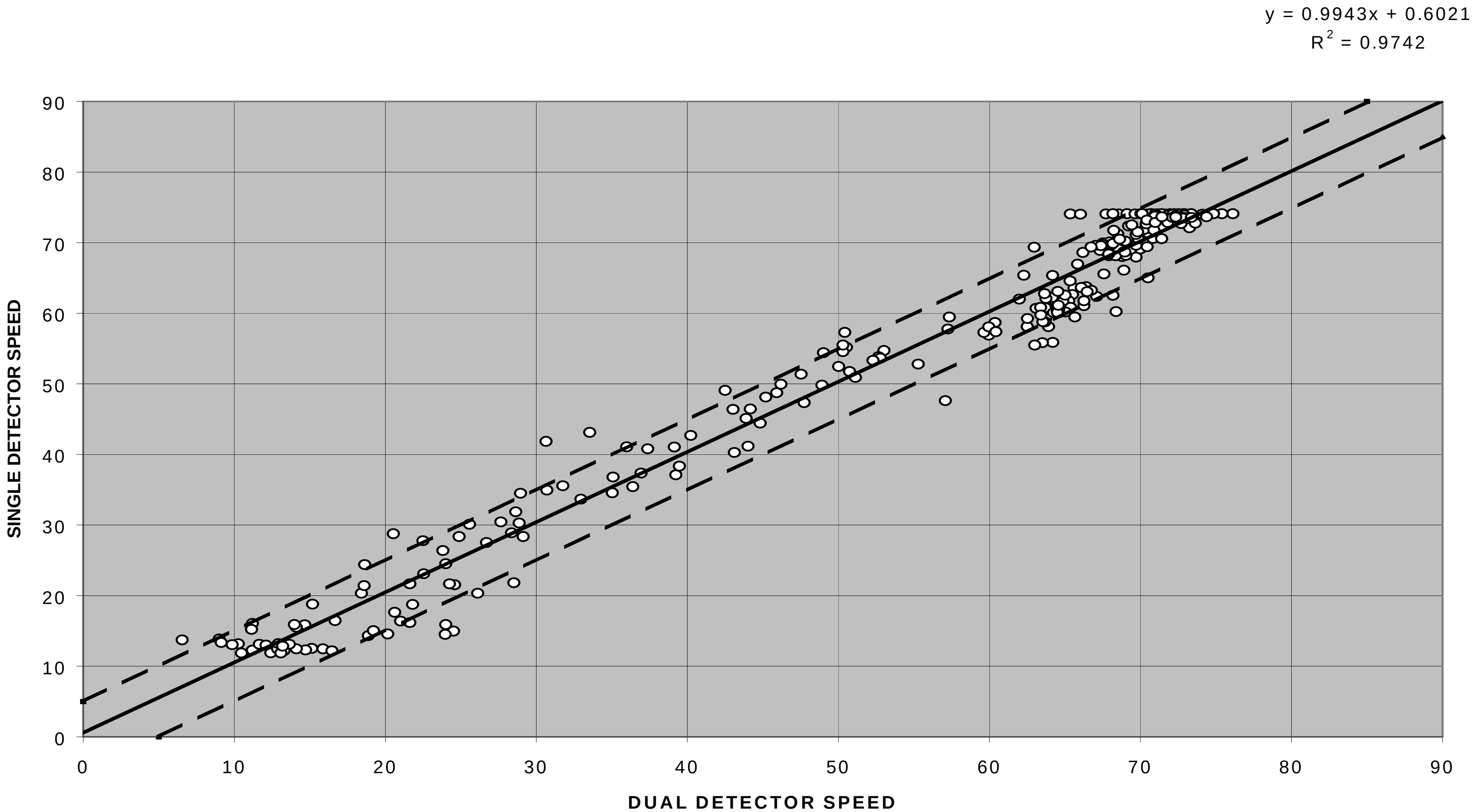


Illustration 3.31 Lane 3 Average Speed versus Percent Occupancy with Trend Line at Station 5W (Thurs 3/4/04)

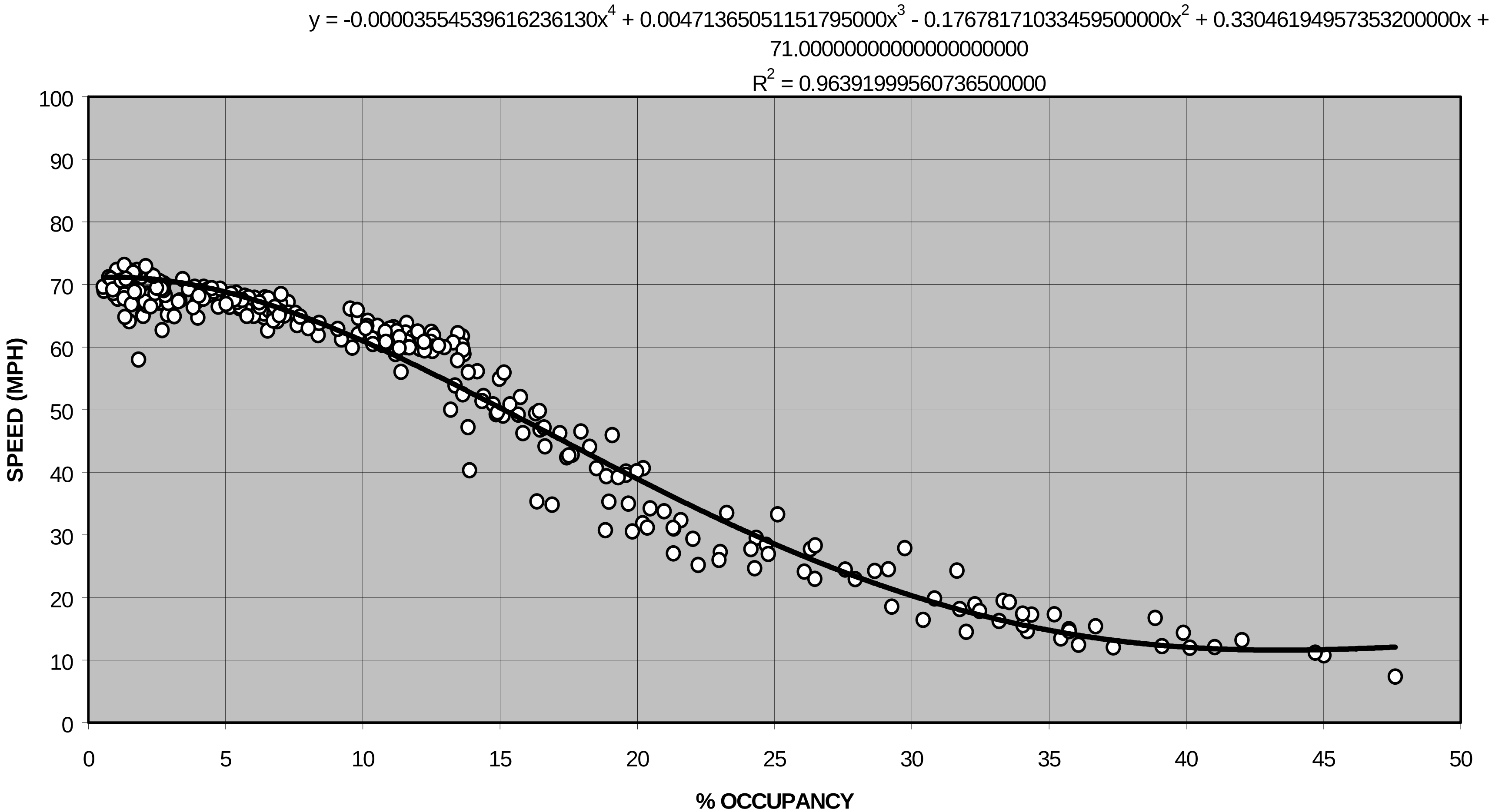


Illustration 3.32 Lane 3 Single-Detector Speed versus Dual Detector Speed at Station 5W (Thurs 3/4/04)

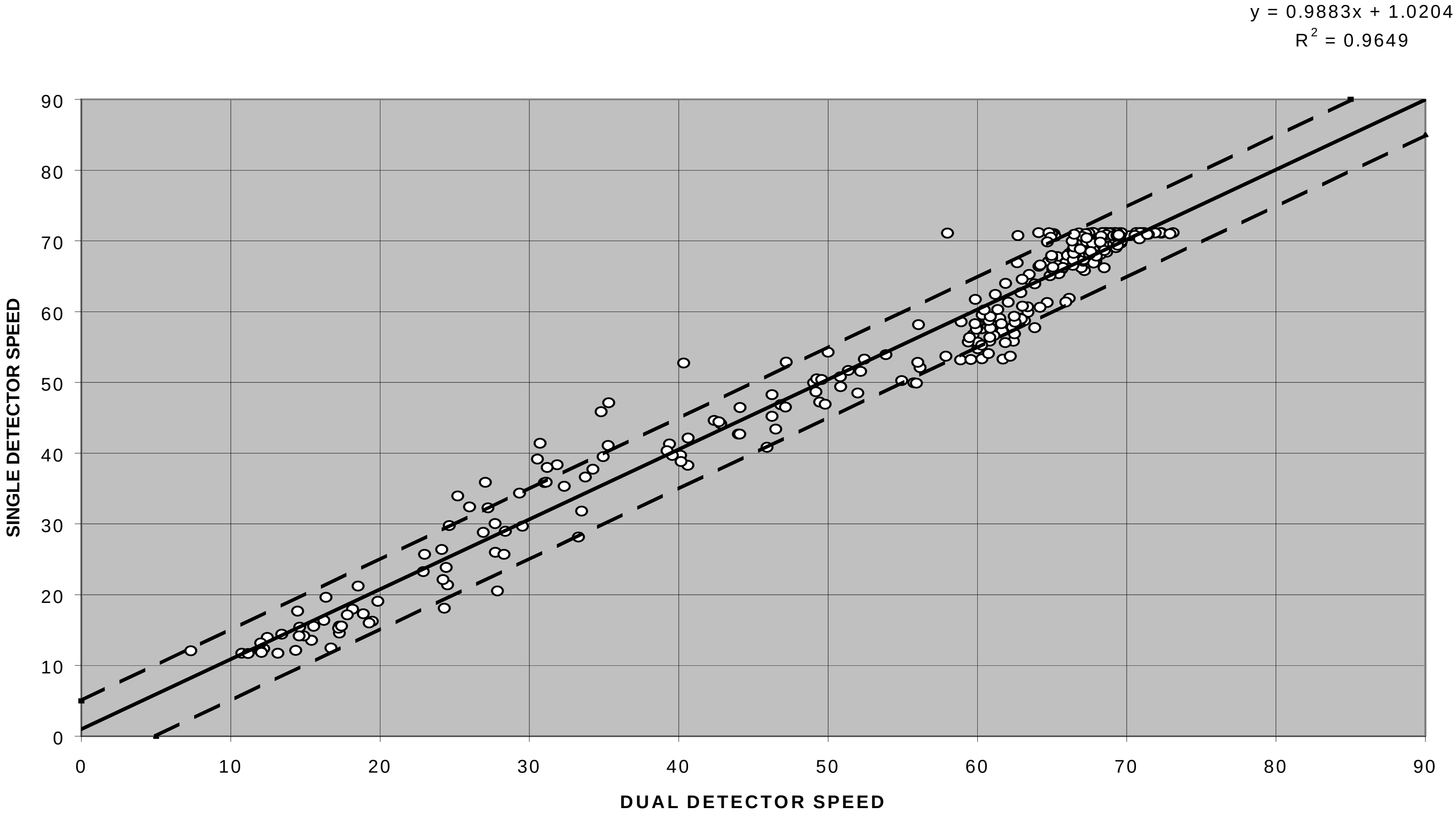


Illustration 3.33 Lane 4 Average Speed versus Percent Occupancy with Trend Line at Station 5W (Thurs 3/4/04)

$y = 0.00284666886375734000x^3 - 0.14525813814615900000x^2 + 0.13340109439019400000x + 70.00000000000000000000$

$R^2 = 0.96403243283768700000$

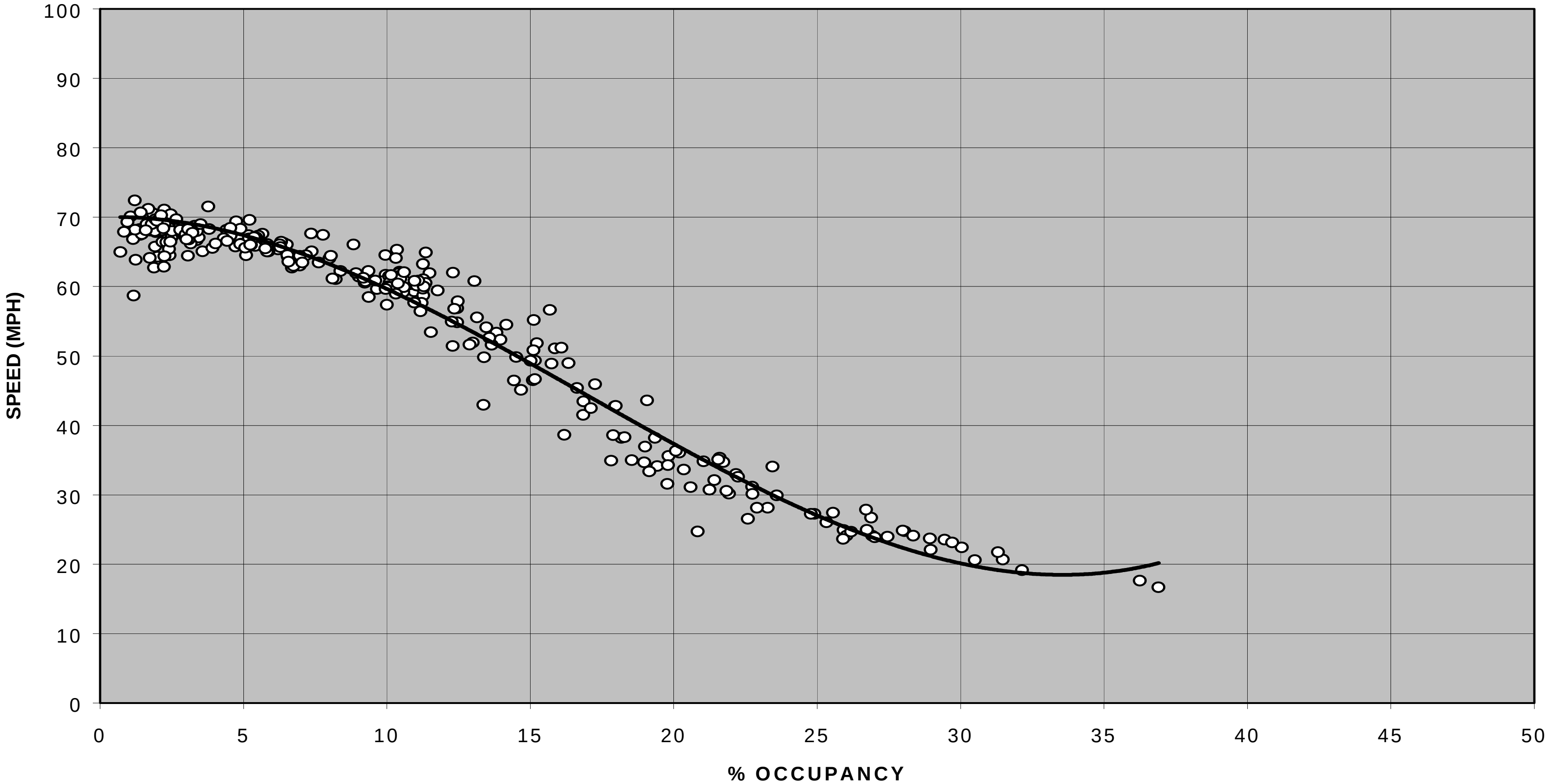


Illustration 3.34 Lane 4 Single-Detector Speed versus Dual Detector Speed at Station 5W (Thurs 3/4/04)

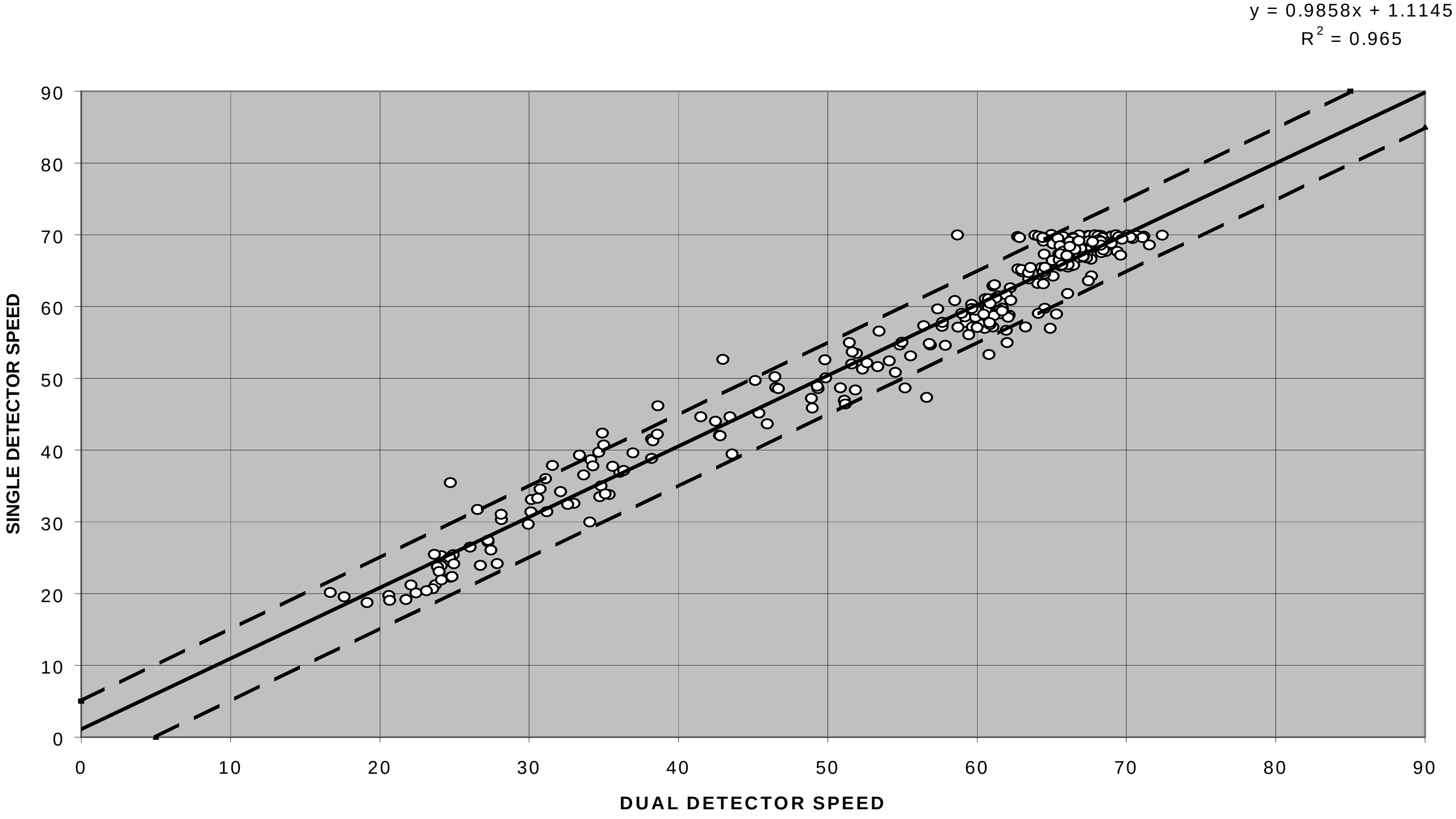


Illustration 3.35 Lane 5 Average Speed versus Percent Occupancy with Trend Line at Station 5W (Thurs 3/4/04)

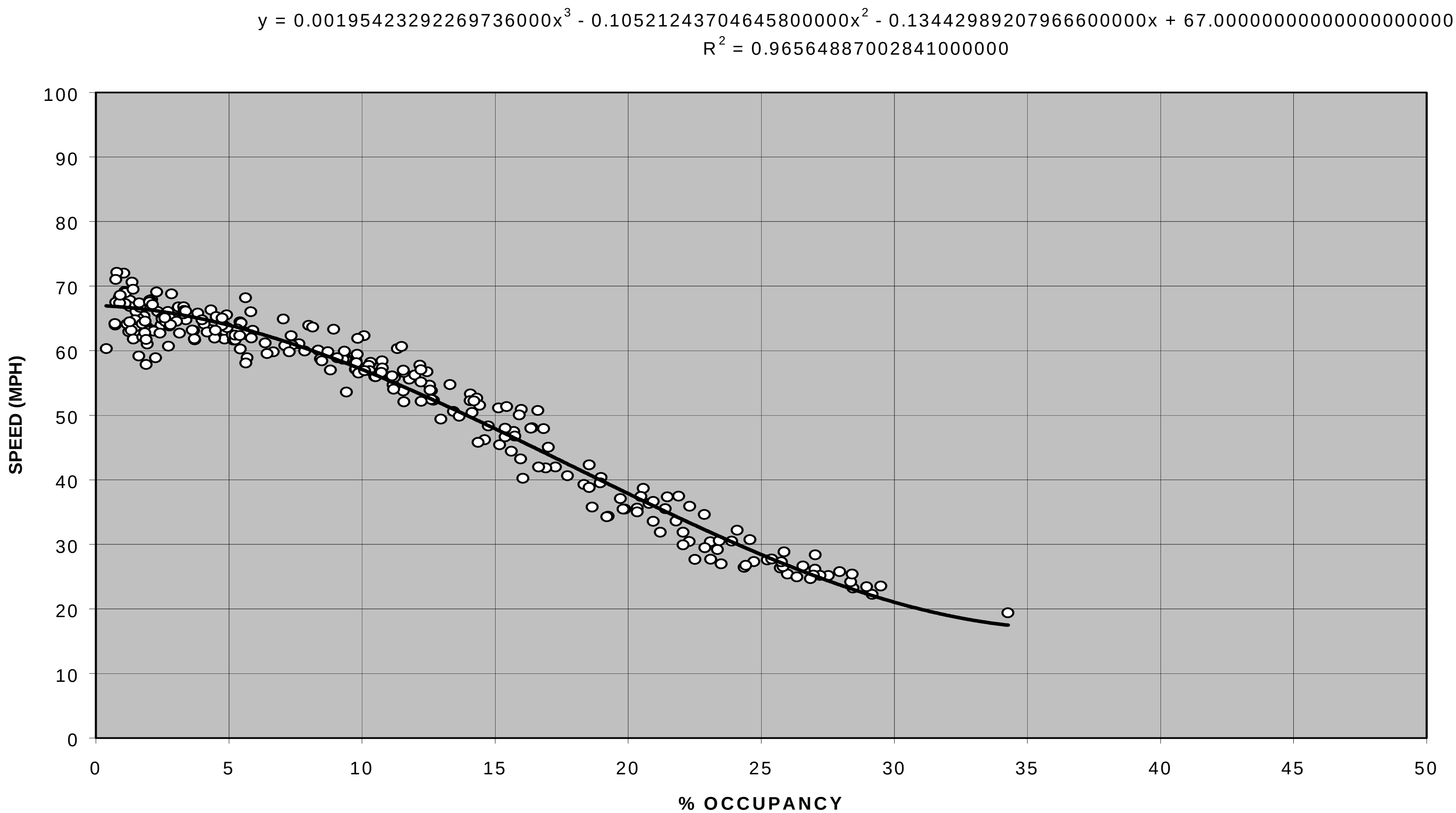


Illustration 3.36 Lane 5 Single-Detector Speed versus Dual Detector Speed at Station 5W (Thurs 3/4/04)

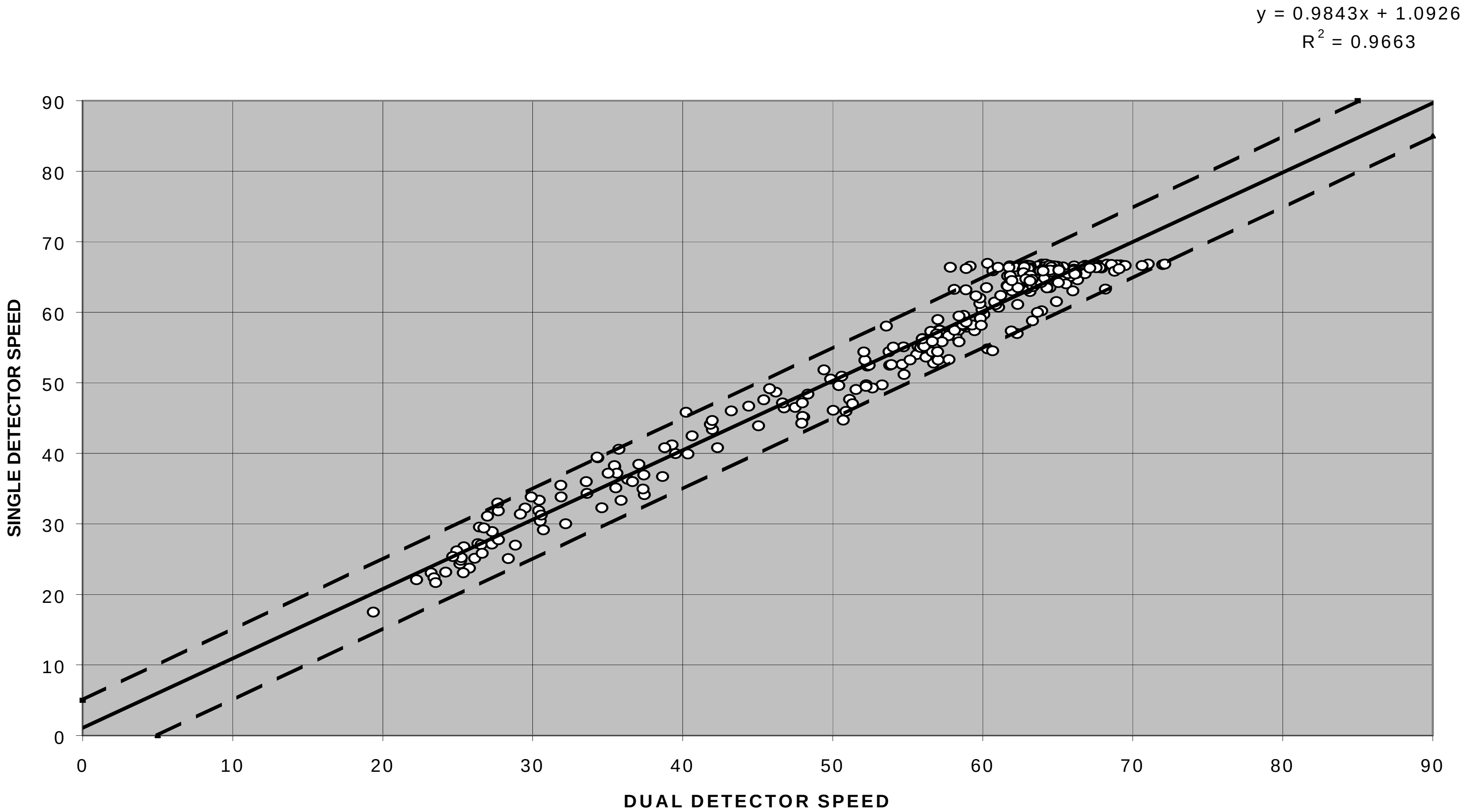


Illustration 3.37 Single Detector Speed Estimation Error at Station W5 (Thurs 3/4/04)

MINIMUM ERROR

		0_5	5_10	10_15	15_20	20_25	25_30	30_35	35_40	40_45	ROAD
L1	MIN	-6.92	-5.88	-6.72	-3.52	-11.50	-2.53	-3.88	NO DATA	NO DATA	-11.50
	AVG	1.17	0.48	-1.95	2.00	1.20	0.00	-3.46			0.49
	MAX	26.02	14.78	16.52	8.81	6.70	2.29	-3.04			26.02
L2	MIN	-2.02	-5.49	-8.35	-9.46	-2.84	-6.69	-9.53	-3.40	-4.30	-9.53
	AVG	1.99	0.85	-2.70	1.58	1.88	1.03	-2.80	-0.57	1.26	0.29
	MAX	8.69	6.38	6.86	9.59	11.21	8.22	4.84	1.41	7.18	11.21
L3	MIN	-1.95	-4.57	-8.52	-6.06	-2.34	-7.34	-6.24	-4.26	-1.44	-8.52
	AVG	2.26	0.60	-2.73	0.97	3.80	-1.33	-0.95	-0.84	-0.27	0.40
	MAX	13.09	4.23	12.39	11.79	8.82	2.73	3.23	1.49	0.52	13.09
L4	MIN	-2.94	-4.77	-7.95	-9.28	-4.08	-3.68	-2.60	1.93	NO DATA	-9.28
	AVG	1.74	0.14	-1.58	0.79	1.46	-1.16	-1.57	2.71		0.34
	MAX	11.28	2.79	9.66	7.55	10.74	1.81	-0.40	3.49		11.28
L5	MIN	-5.31	-4.91	-6.13	-6.01	-3.33	-3.29	-1.89	NO DATA	NO DATA	-6.13
	AVG	1.06	0.04	-1.23	0.33	0.97	-0.55	-1.89			0.26
	MAX	8.54	5.16	3.36	5.59	5.29	1.33	-1.89			8.54

ABSOLUTE MINIMUM ERROR

		0_5	5_10	10_15	15_20	20_25	25_30	30_35	35_40	40_45	ROAD
L1	MIN	0.01	0.06	0.17	0.20	0.08	0.17	3.04	NO DATA	NO DATA	0.01
	AVG	2.82	4.26	3.95	3.43	3.32	1.26	3.46			3.36
	MAX	26.02	14.78	16.52	8.81	11.50	2.53	3.88			26.02
L2	MIN	0.02	0.07	0.04	0.24	0.41	0.03	0.21	0.29	0.36	0.02
	AVG	2.21	1.57	3.71	2.82	3.03	3.02	4.42	1.26	2.86	2.70
	MAX	8.69	6.38	8.35	9.59	11.21	8.22	9.53	3.40	7.18	11.21
L3	MIN	0.02	0.02	0.04	0.01	0.13	0.35	0.01	0.16	0.08	0.01
	AVG	2.53	1.36	3.66	3.27	4.22	2.79	1.93	1.60	0.56	2.66
	MAX	13.09	4.57	12.39	11.79	8.82	7.34	6.24	4.26	1.44	13.09
L4	MIN	0.01	0.01	0.07	0.24	0.05	0.15	0.40	1.93	NO DATA	0.01
	AVG	2.14	1.16	2.71	3.40	2.20	1.60	1.57	2.71		2.16
	MAX	11.28	4.77	9.66	9.28	10.74	3.68	2.60	3.49		11.28
L5	MIN	0.07	0.04	0.01	0.33	0.04	0.01	1.89	NO DATA	NO DATA	0.01
	AVG	2.20	1.67	1.86	2.65	2.17	1.01	1.89			2.00
	MAX	8.54	5.16	6.13	6.01	5.29	3.29	1.89			8.54

Illustration 3.38 Some Initial Thoughts On Replacing Missing Detector Data

STEP ONE

- Determine if any detector has been diagnosed as having failed.
- If none have been diagnosed as having failed, go to next time check period and repeat step one.
- If only one detector in a particular lane has failed, go to step two.
- If both detectors in one particular lane have failed, go to step three.
- If both detectors in more than one particular lane have failed, go to step four.

STEP TWO (If only one detector in a particular lane has failed)

- For flow, extract data from lane detector that did not fail.
- For percent occupancy, extract data from lane detector that did not fail.
- For speed estimate, calculate speed from speed-occupancy graph for the lane in question.

STEP THREE (If both detectors in one particular lane have failed)

- For percent occupancy estimate, calculate percent occupancy from that lane's percent occupancy relationship to the average occupancy of the other four lanes graph.
- For speed estimate, calculate speed from speed-occupancy graph for lane in question.
- For flow estimate, calculate flow from flow-percent occupancy graph for lane in question.

STEP FOUR (If both detectors in more than one lane fail, currently we have no solution except to immediately report the problem to maintenance.)

Illustration 3.39 Lane 1 Percent Occupancy versus Average Percent Occupancy of Other Lanes at Station 5W (Thurs 3/4/04)

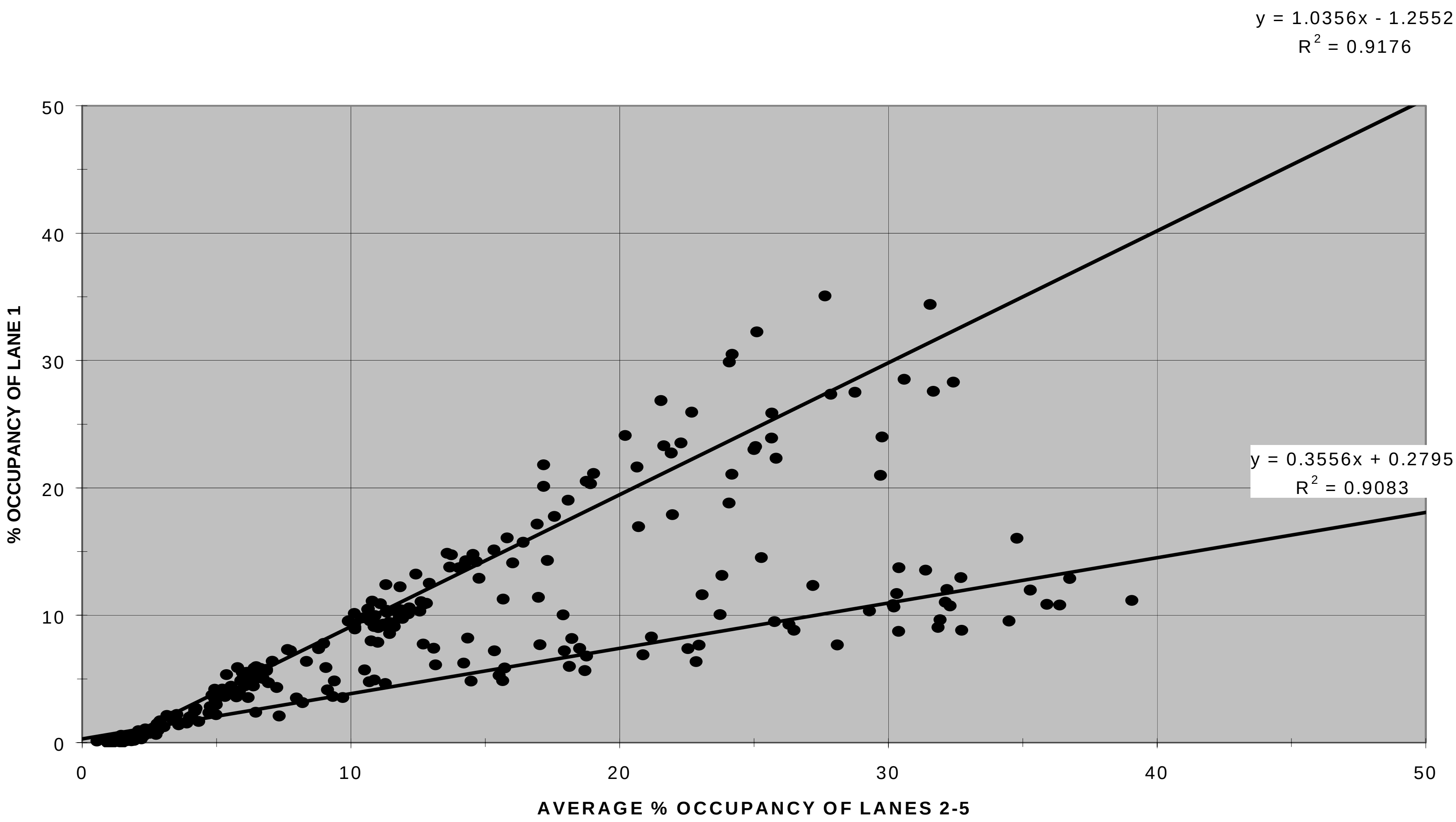


Illustration 3.40 Lane 2 Percent Occupancy versus Average Percent Occupancy of Other Lanes at Station 5W (Thurs 3/4/04)

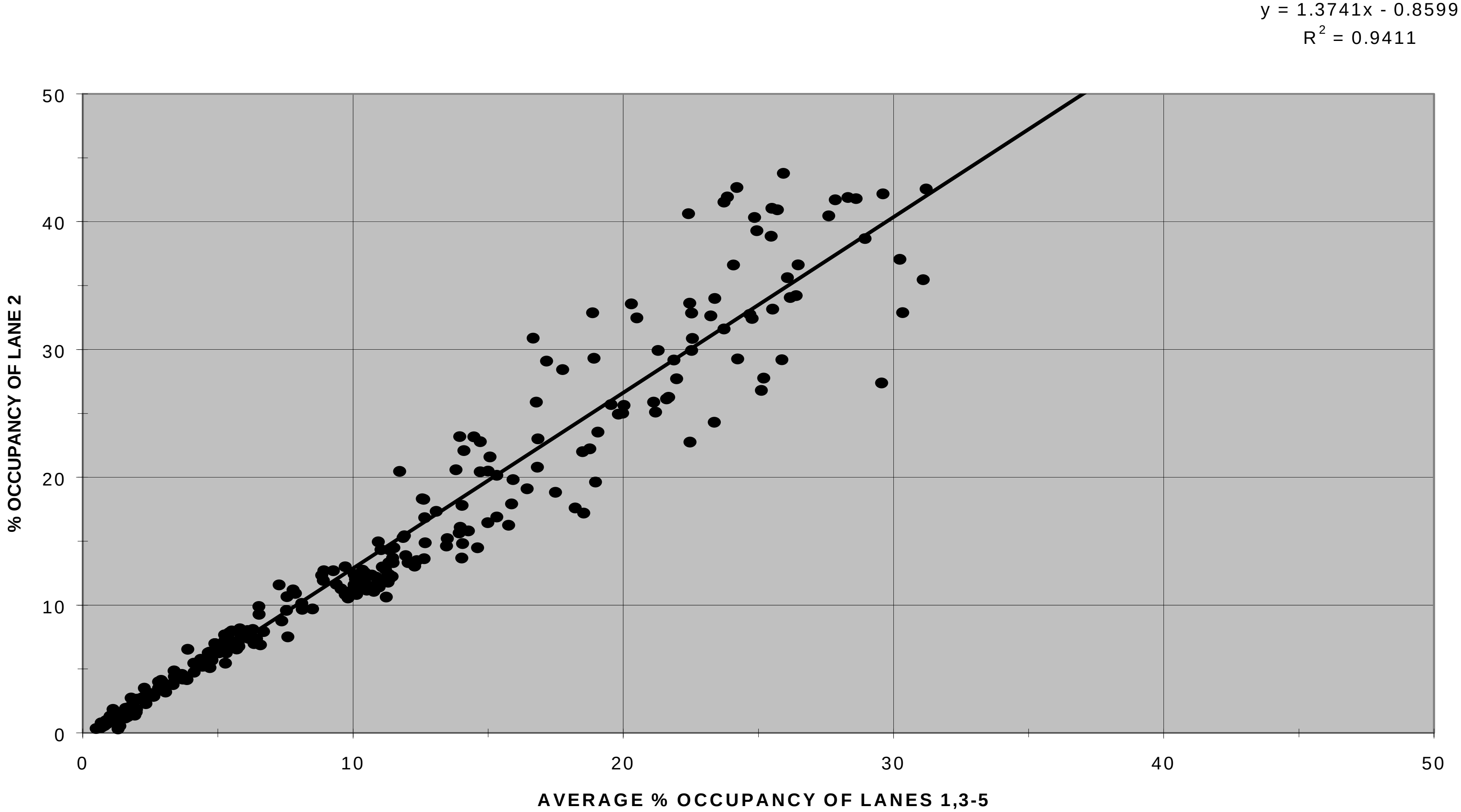


Illustration 3.41 Lane 3 Percent Occupancy versus Average Percent Occupancy of Other Lanes at Station 5W (Thurs 3/4/04)

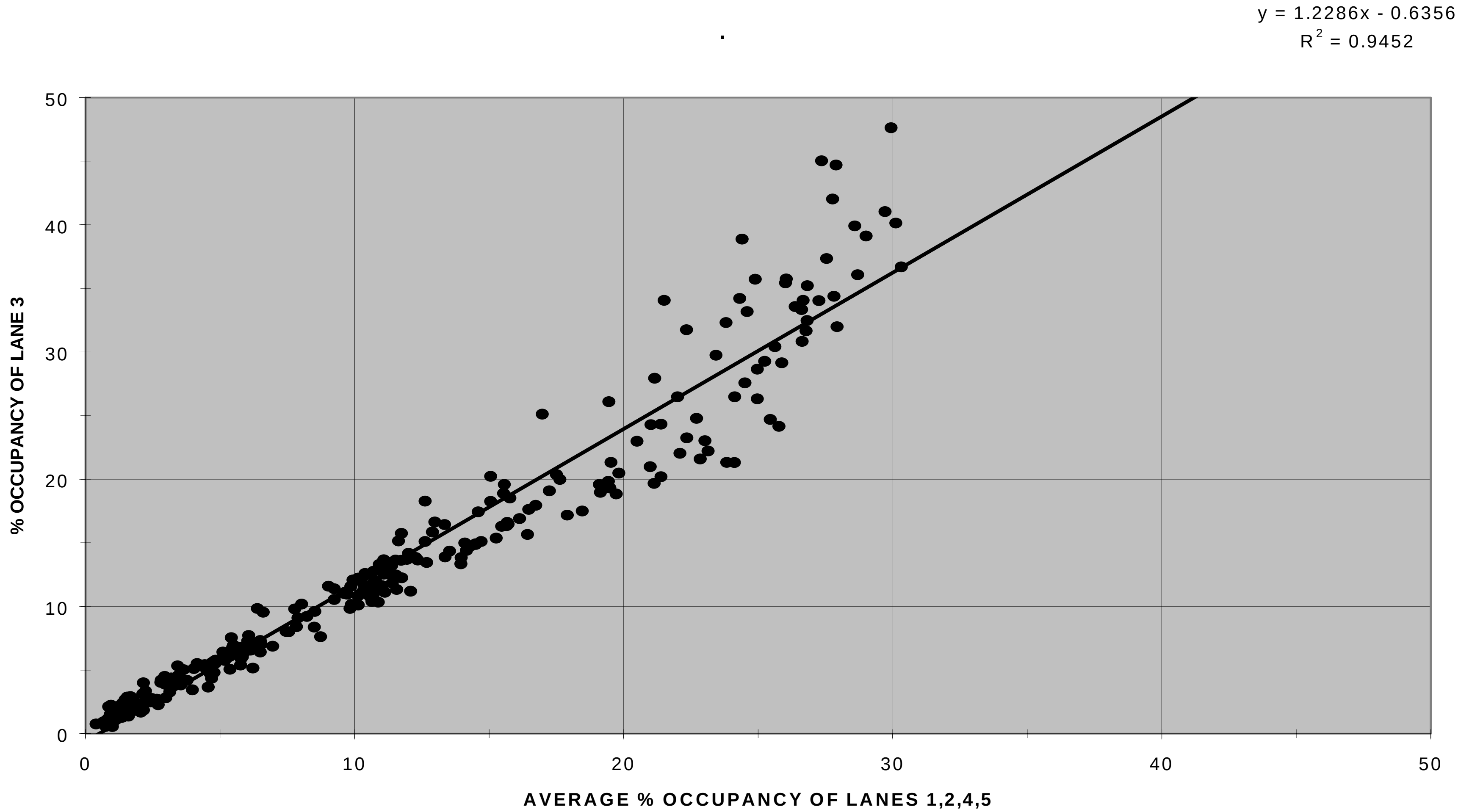


Illustration 3.42 Lane 4 Percent Occupancy versus Average Percent Occupancy of Other Lanes at Station 5W (Thurs 3/4/04)

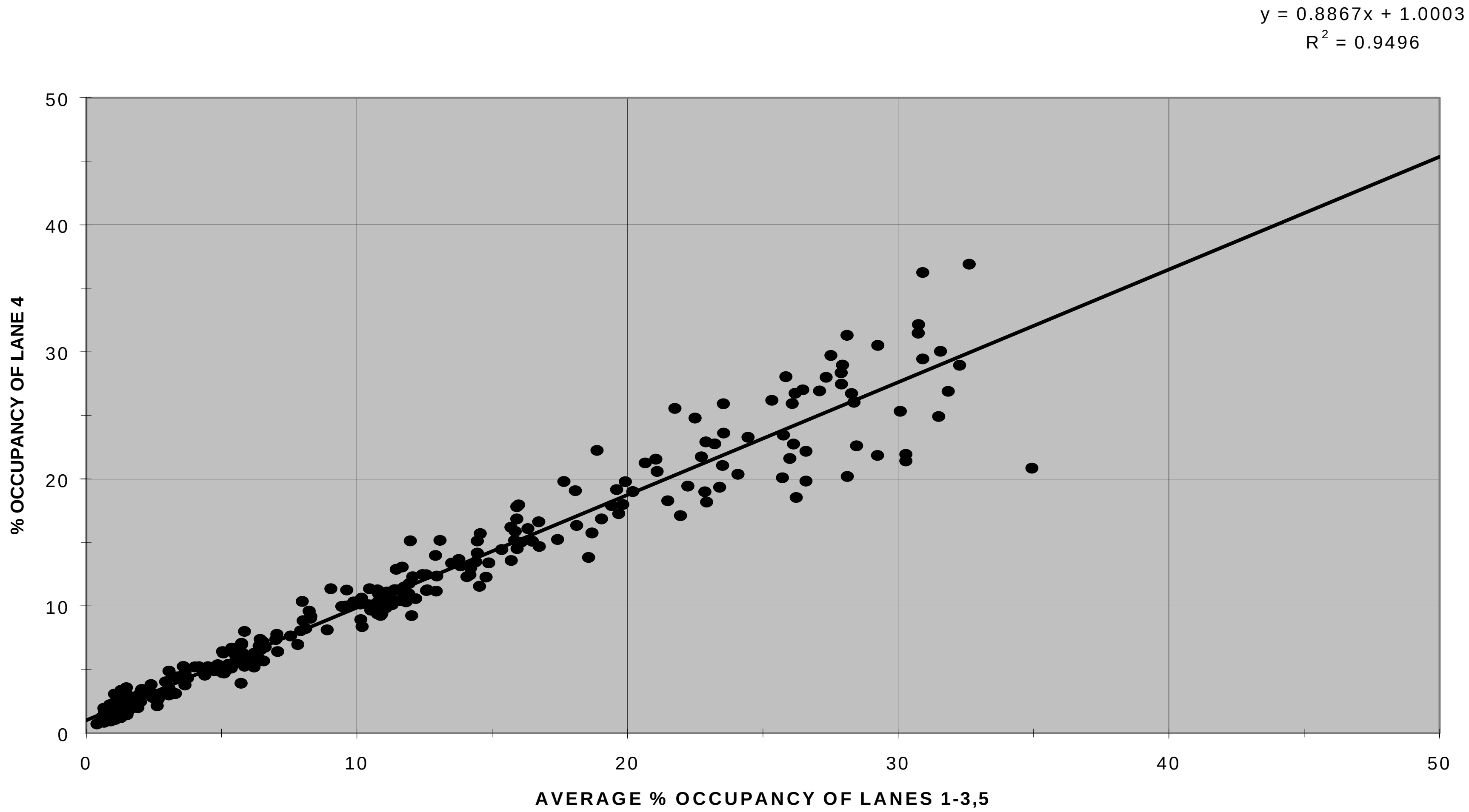
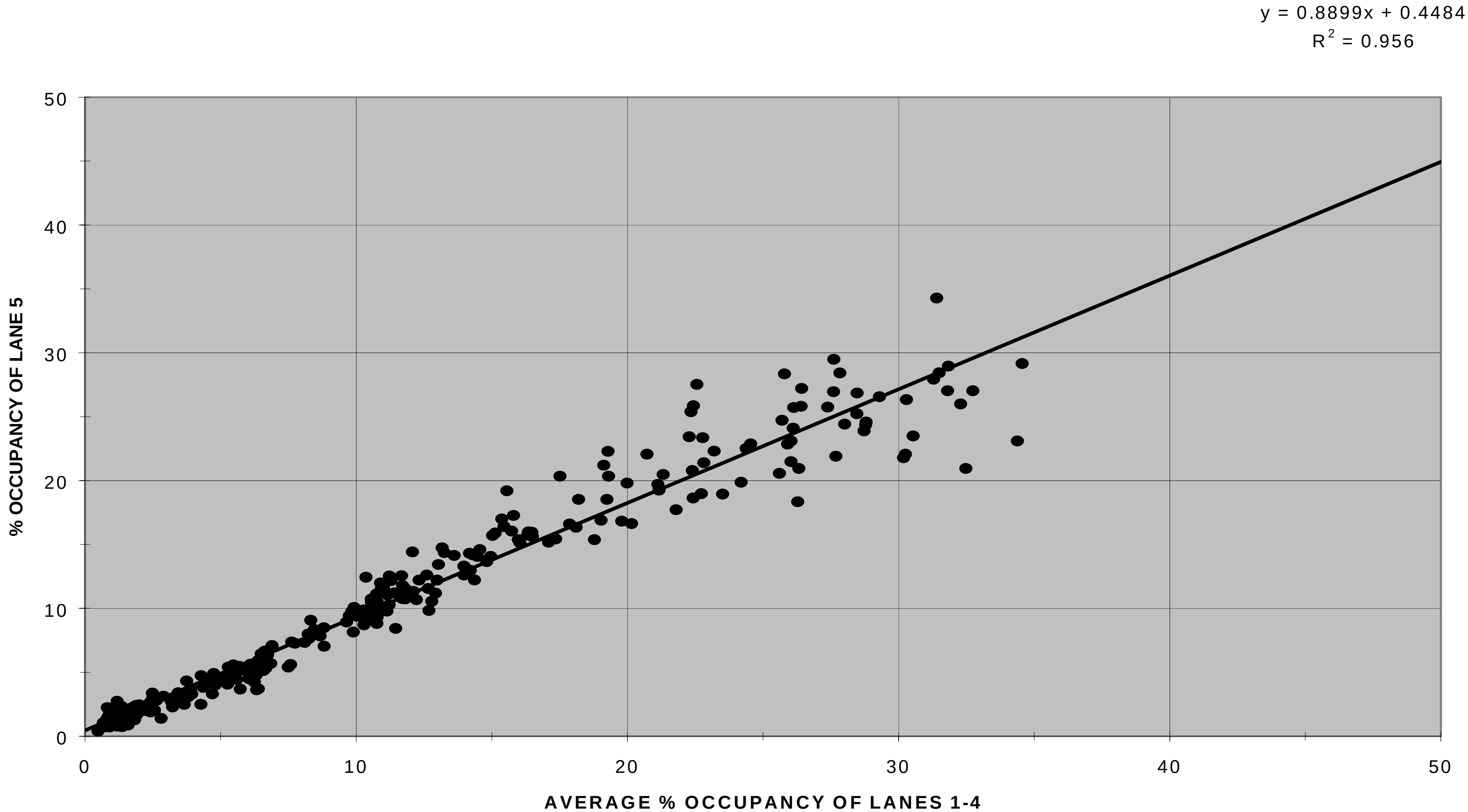


Illustration 3.43 Lane 5 Percent Occupancy versus Average Percent Occupancy of Other Lanes at Station 5W (Thurs 3/4/04)



APPENDIX C - Illustrations for Chapter 4

Illustration 4.1 Freeway Lane Configuration in the Vicinity of Station 8W

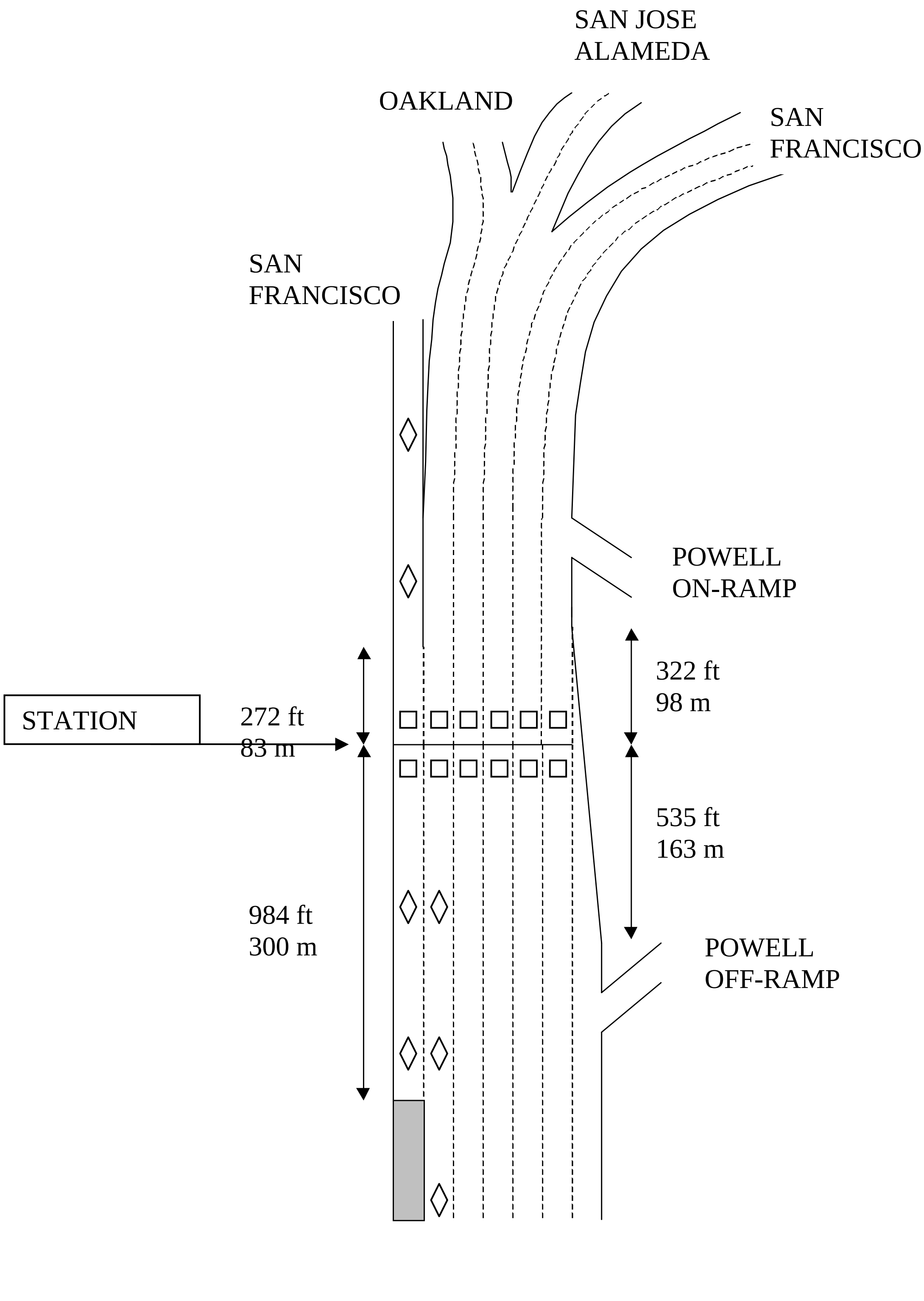


Illustration 4.2 Summary of Detector Diagnostic Results – Lane 1 at Station 8W (Tuesday 3/2/04)

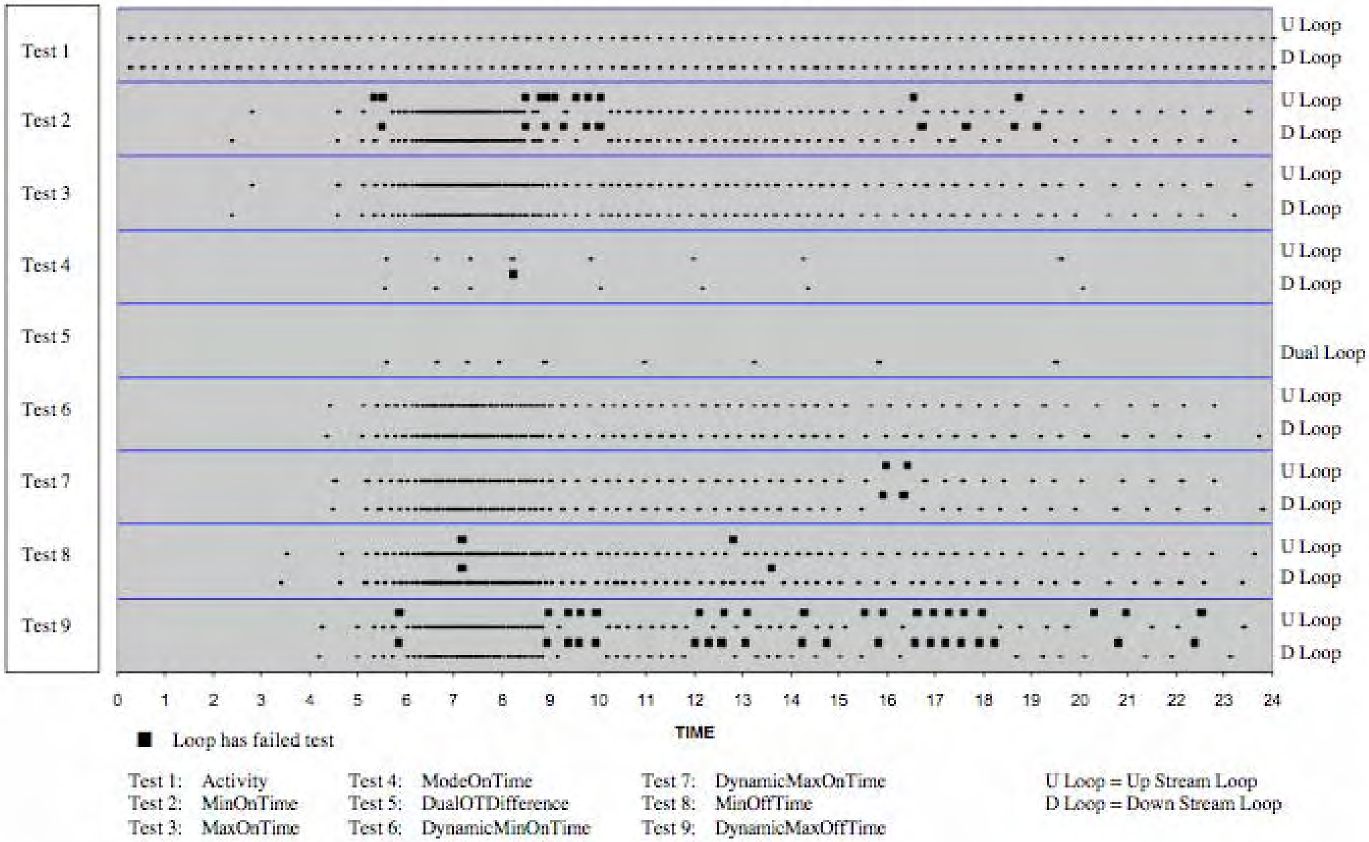
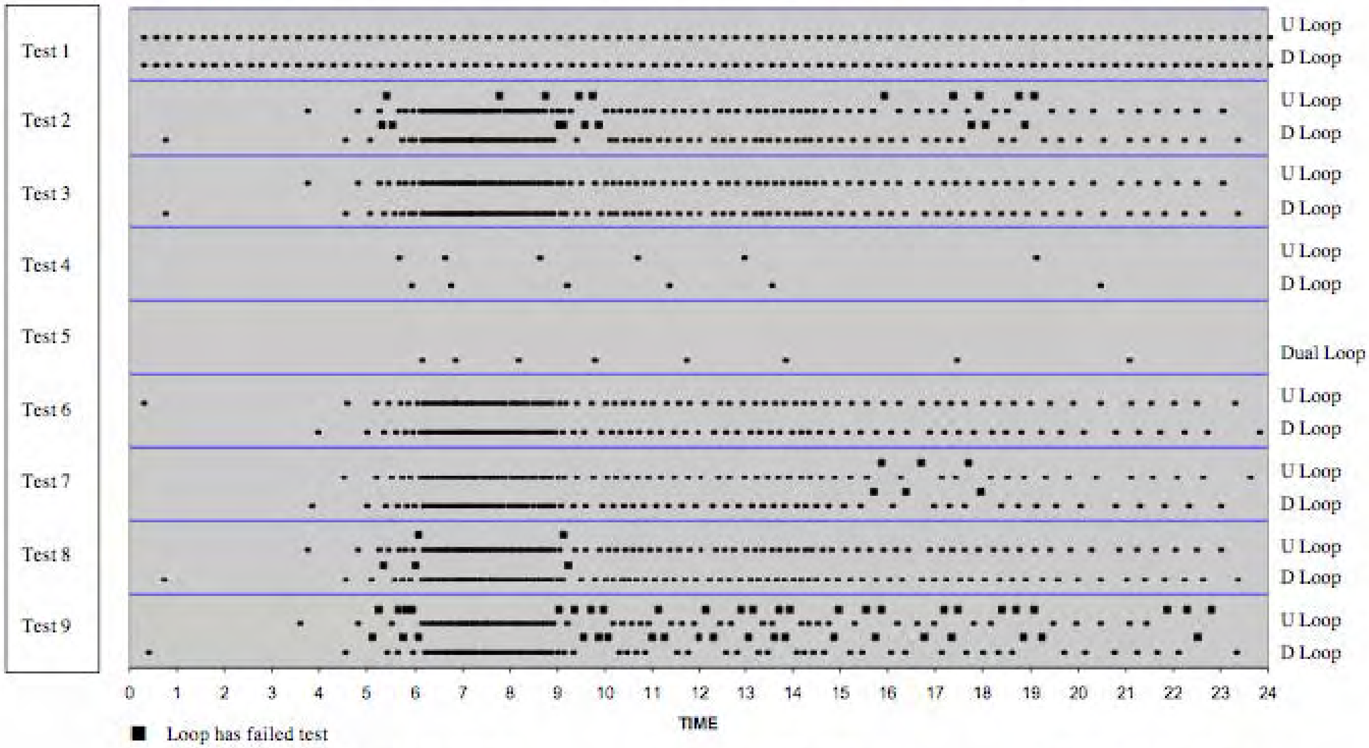


Illustration 4.3 Summary of Detector Diagnostic Results – Lane 1 at Station 8W (Thurs 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 4.4 Lane 1 Upstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

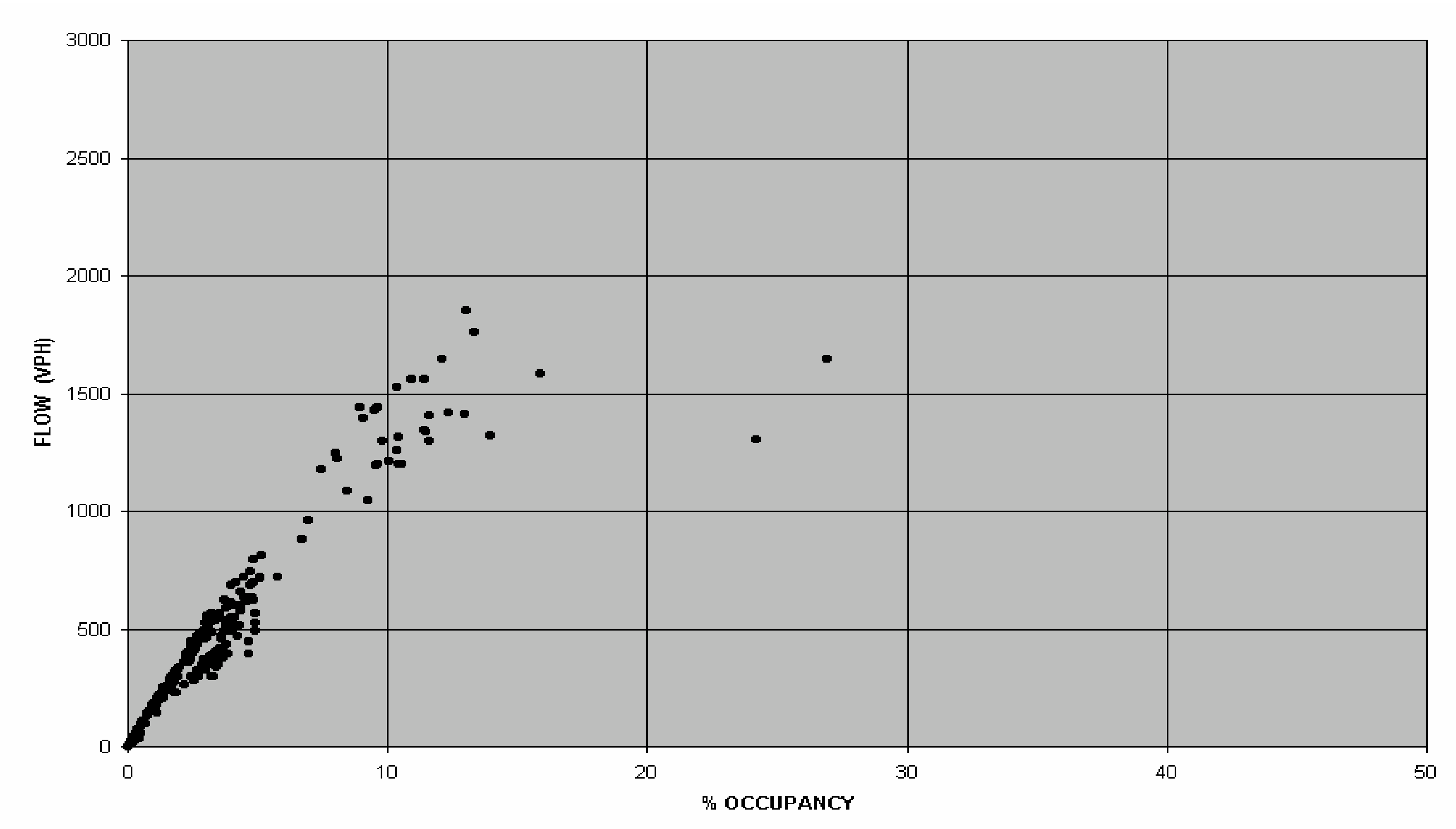


Illustration 4.5 Lane 1 Downstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

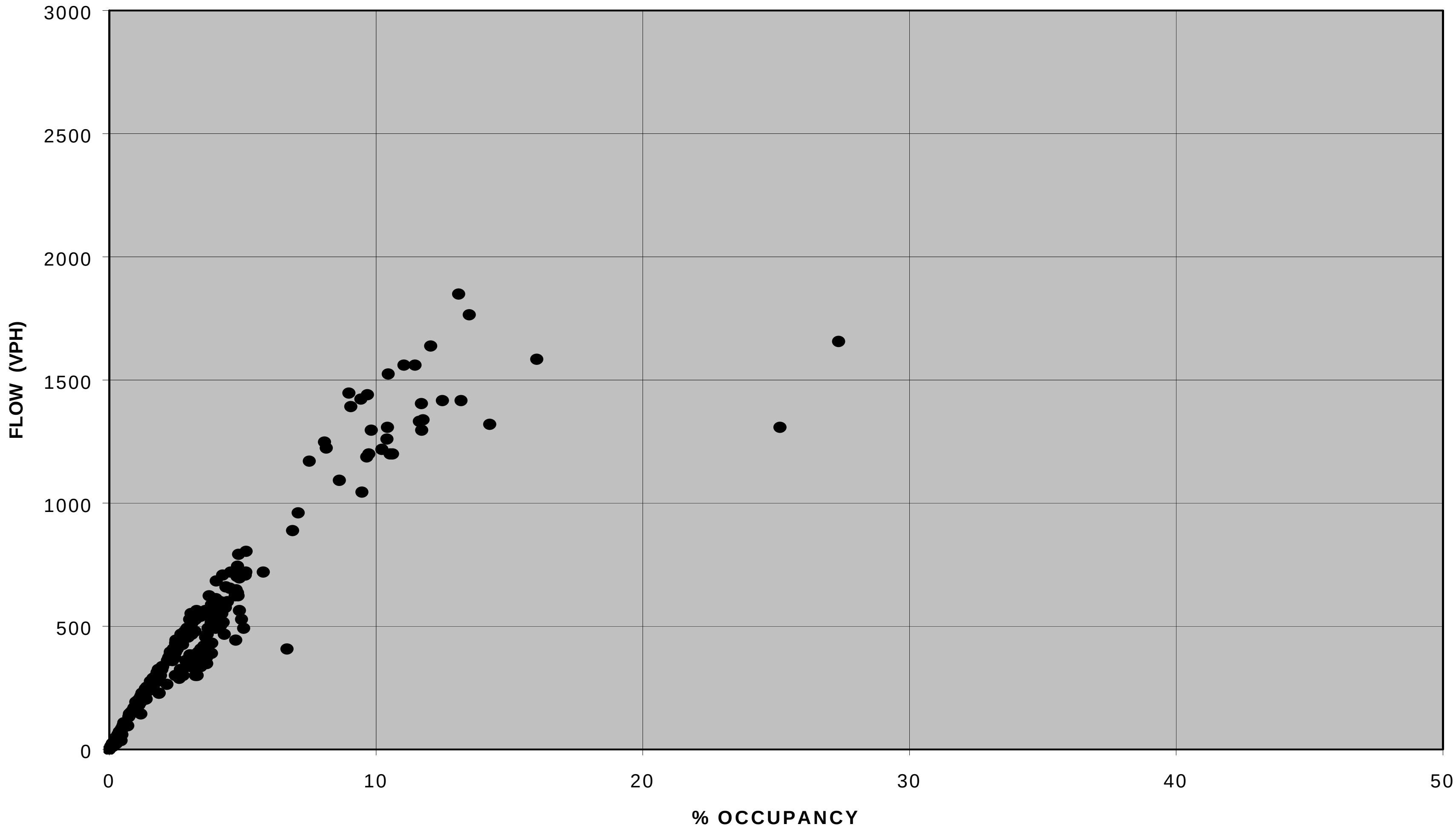


Illustration 4.6 Lane 1 Upstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

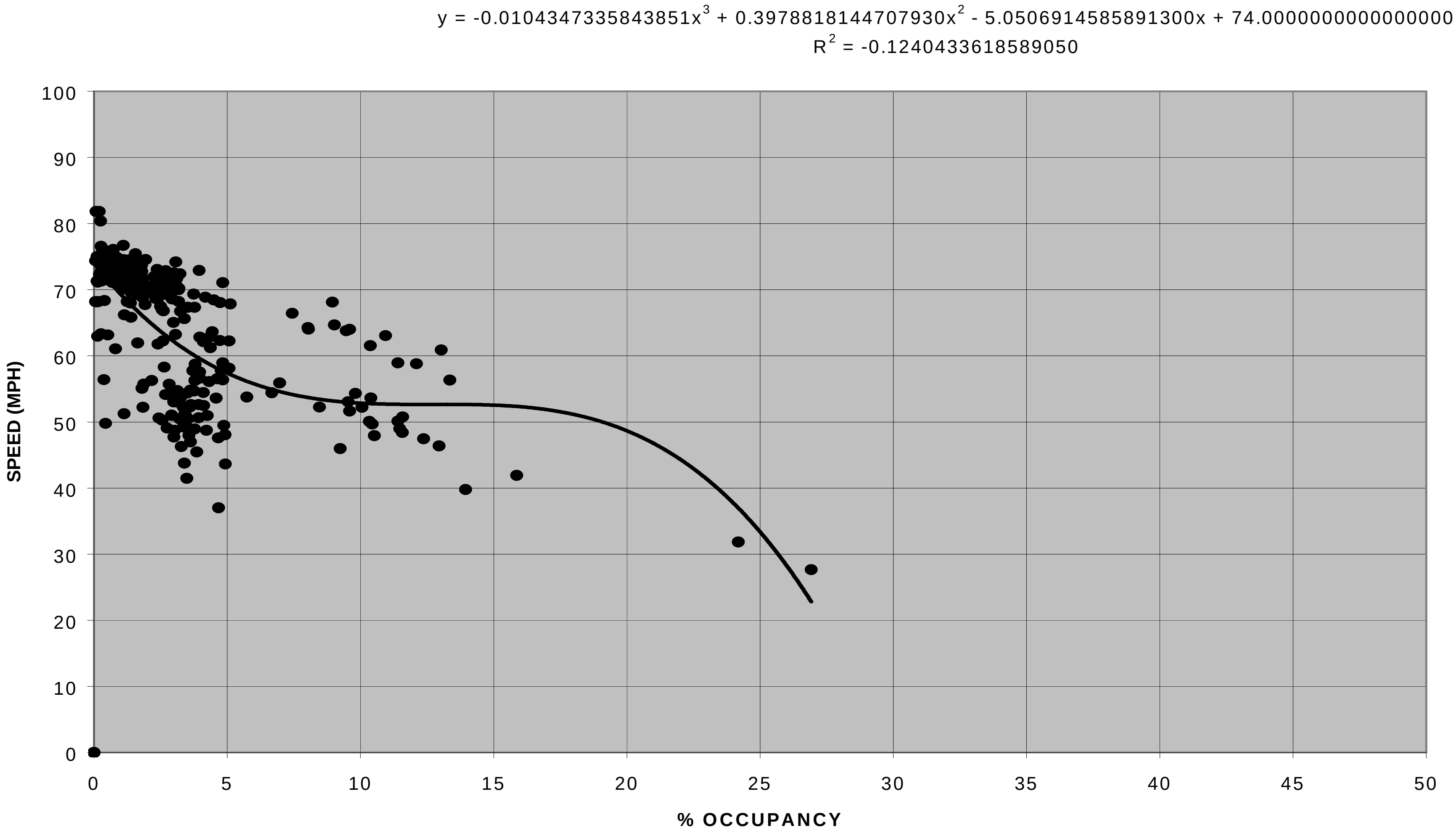


Illustration 4.7 Lane 1 Downstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

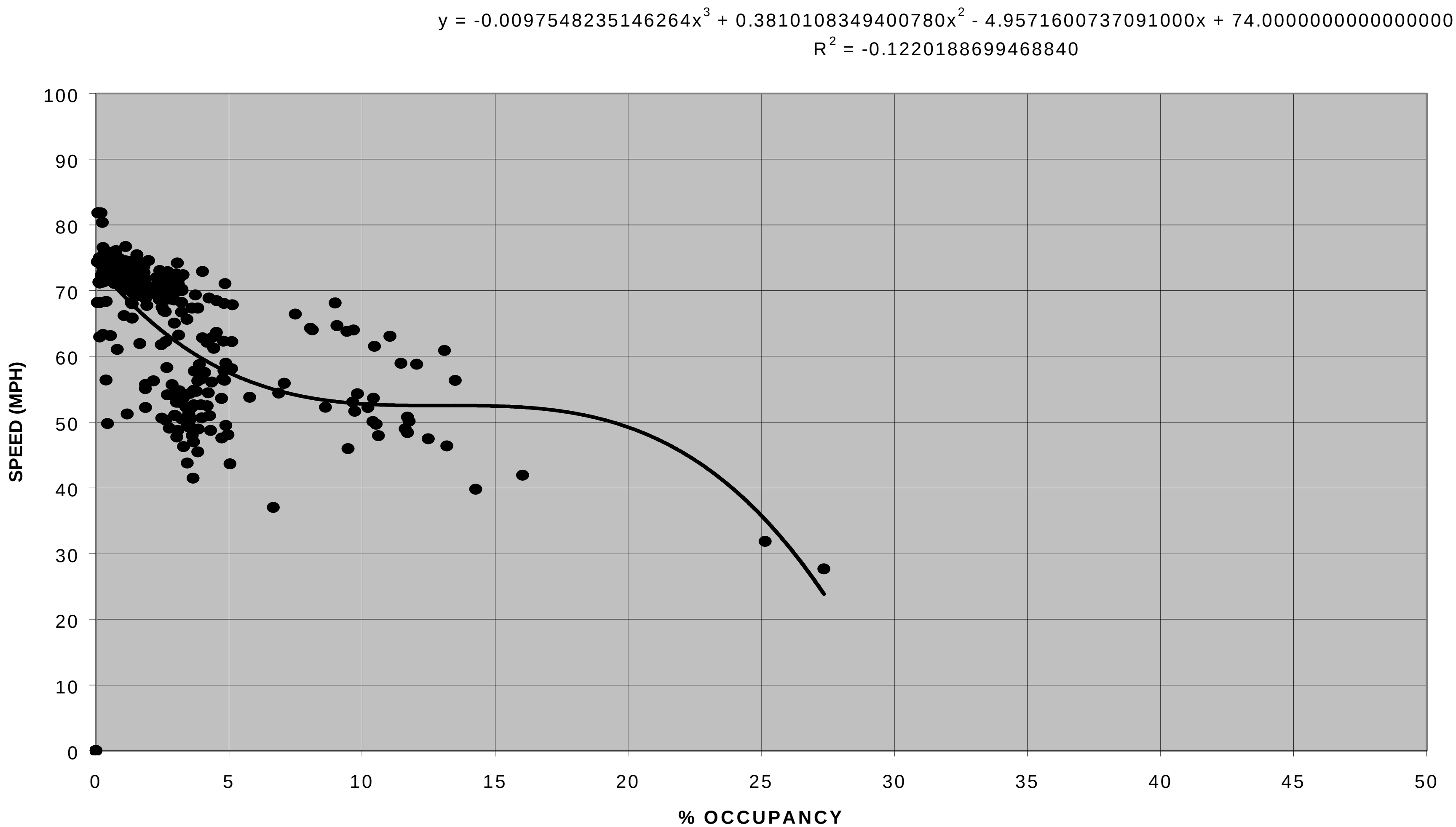


Illustration 4.8 Lane 1 Upstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

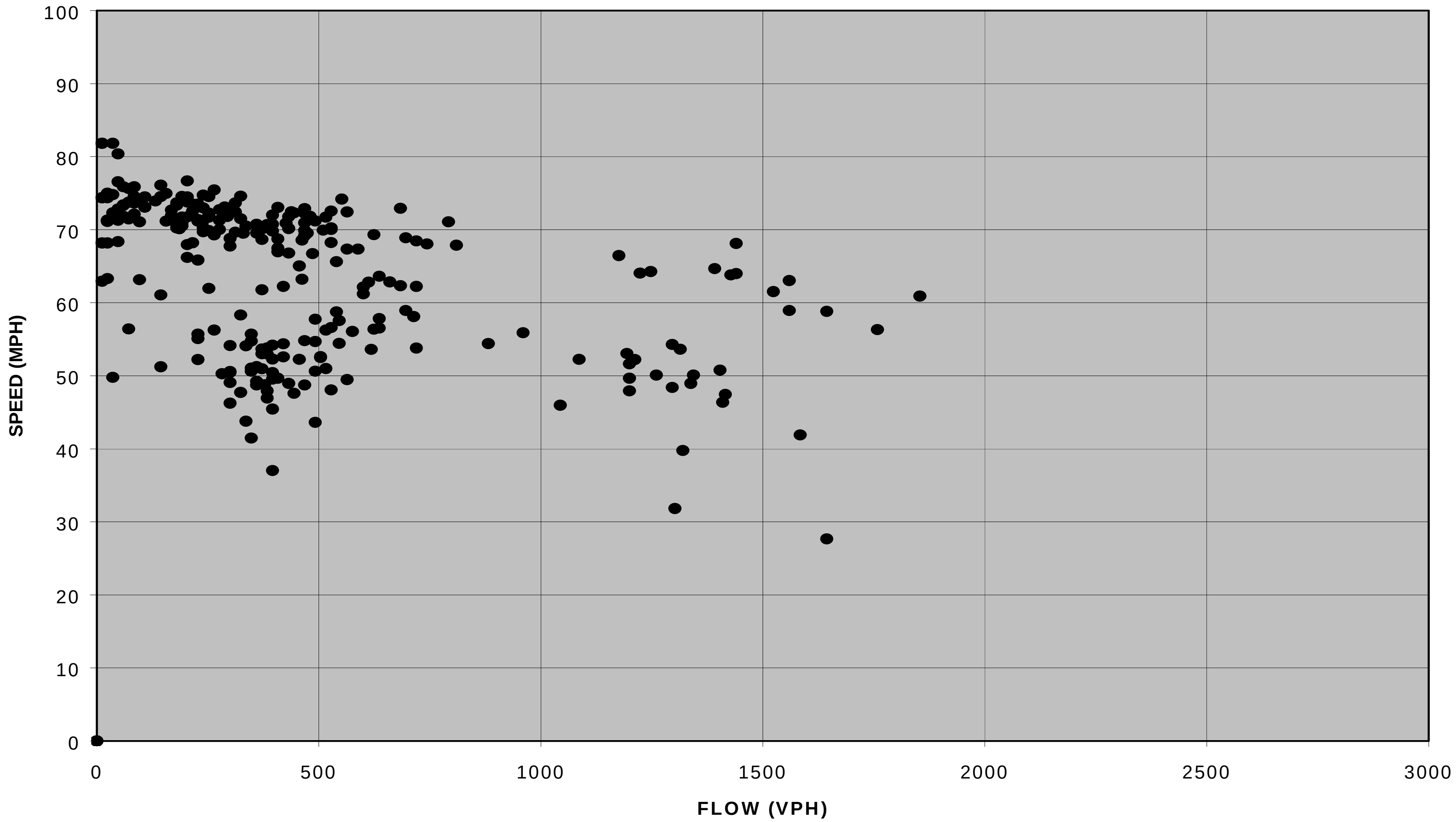


Illustration 4.9 Lane 1 Downstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

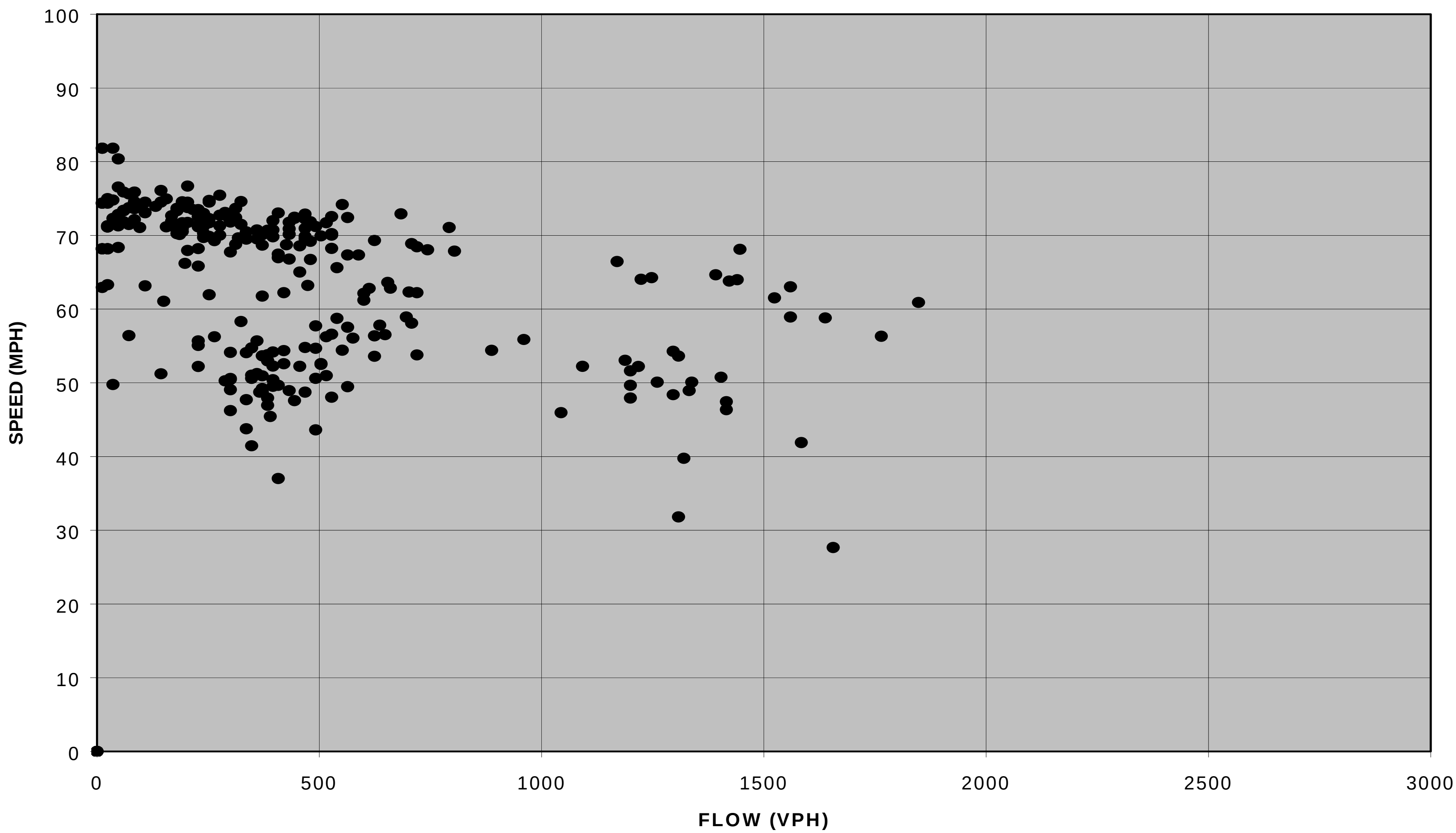


Illustration 4.10 Lane 1 Upstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

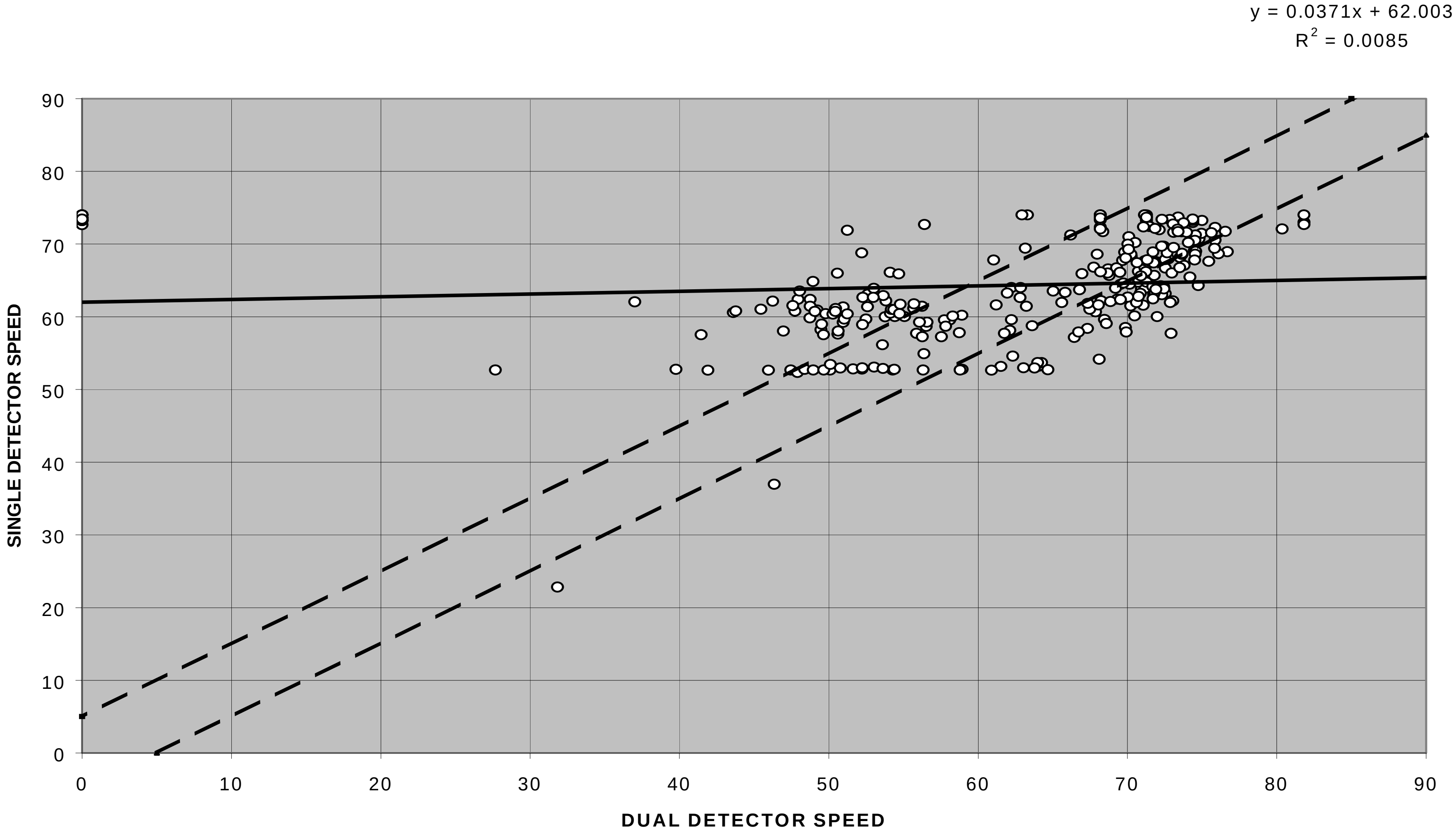


Illustration 4.11 Lane 1 Downstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

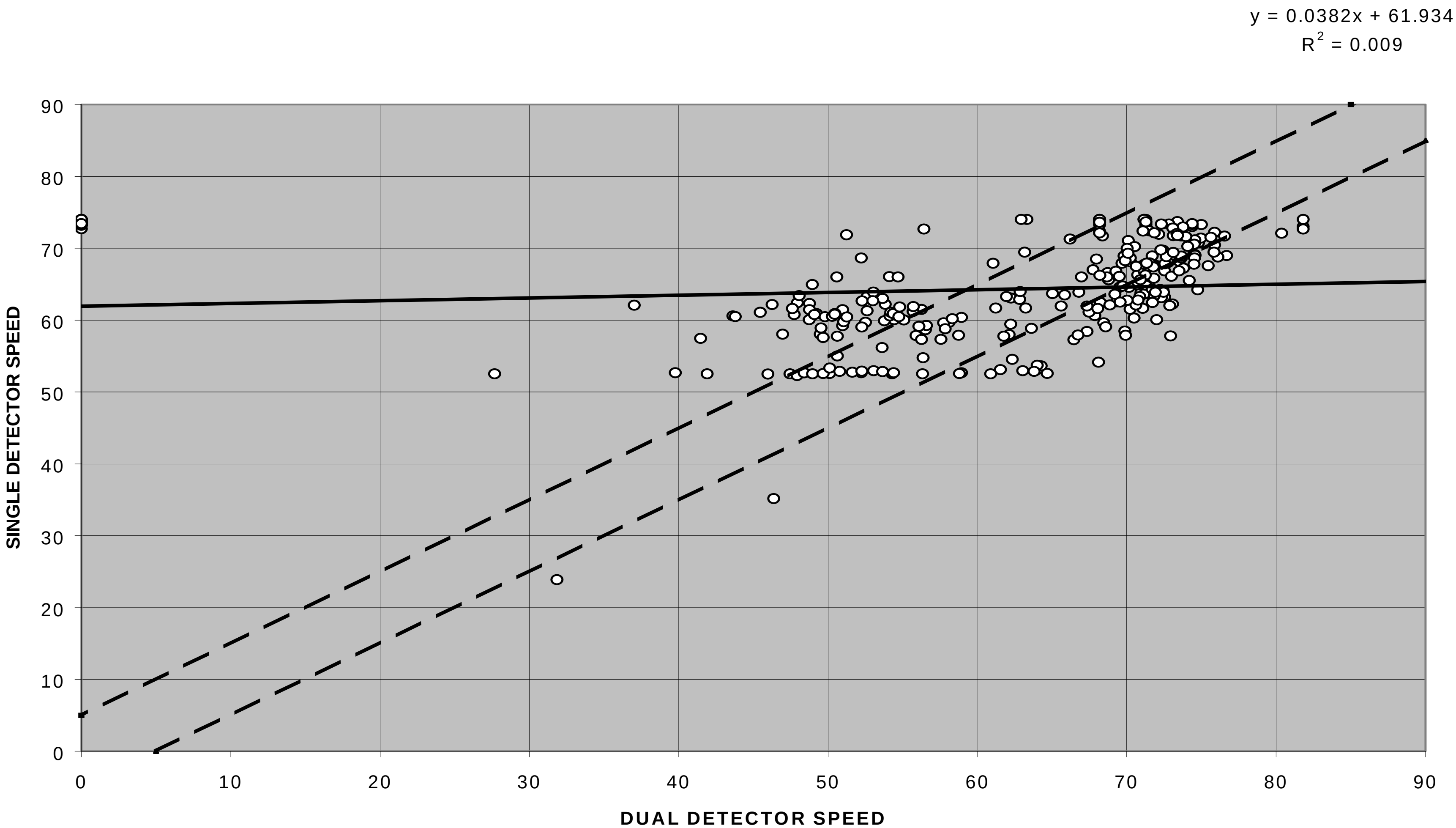
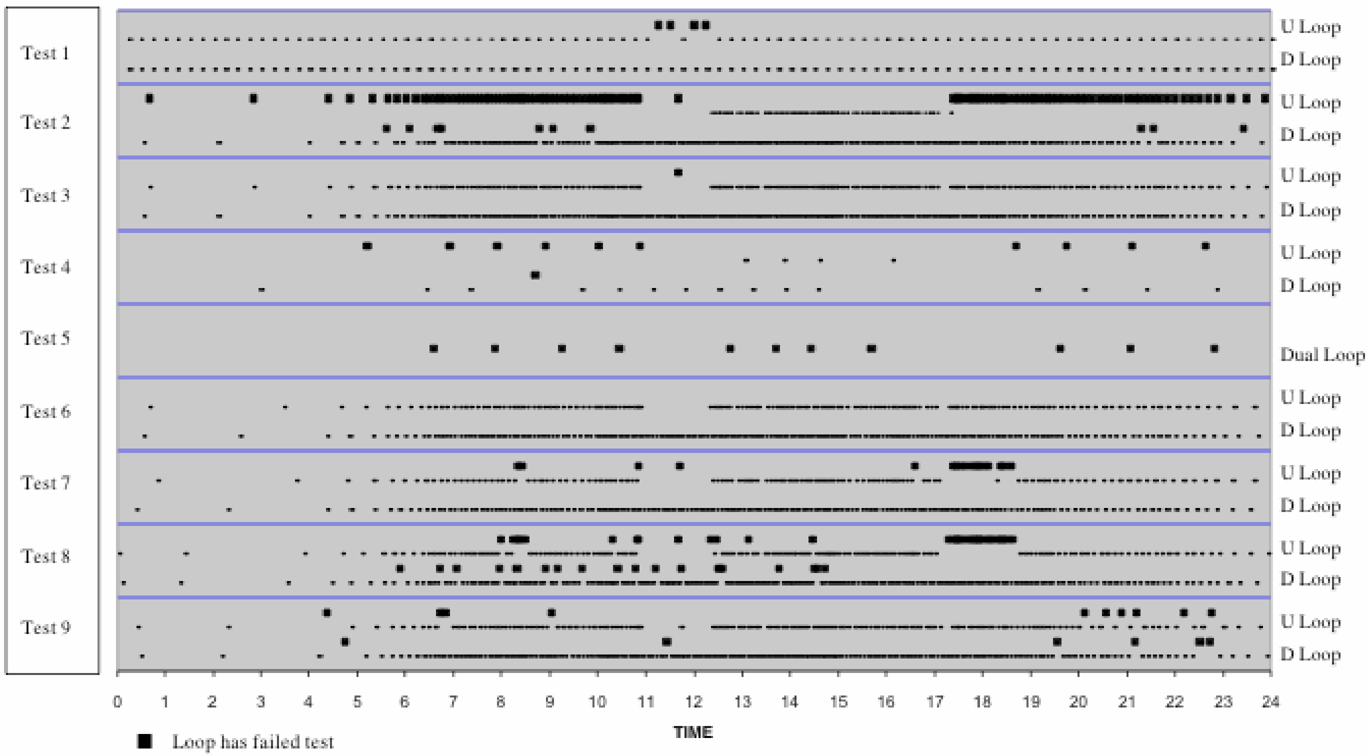


Illustration 4.12 Summary of Detector Diagnostic Results – Lane 2 at Station 8W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 4.13 Summary of Detector Diagnostic Results – Lane 2 at Station 8W (Thurs 3/4/04)

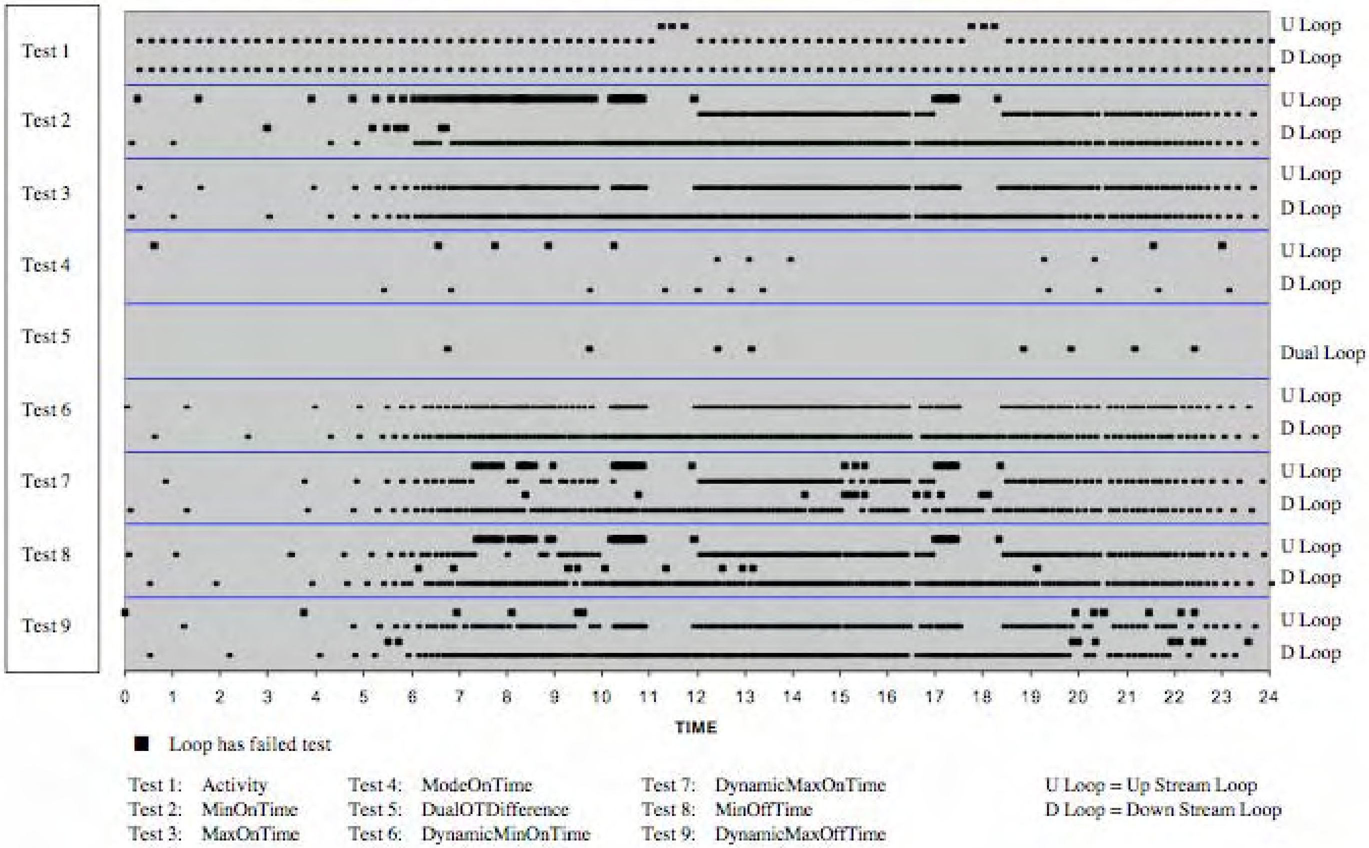


Illustration 4.14 Lane 2 Upstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

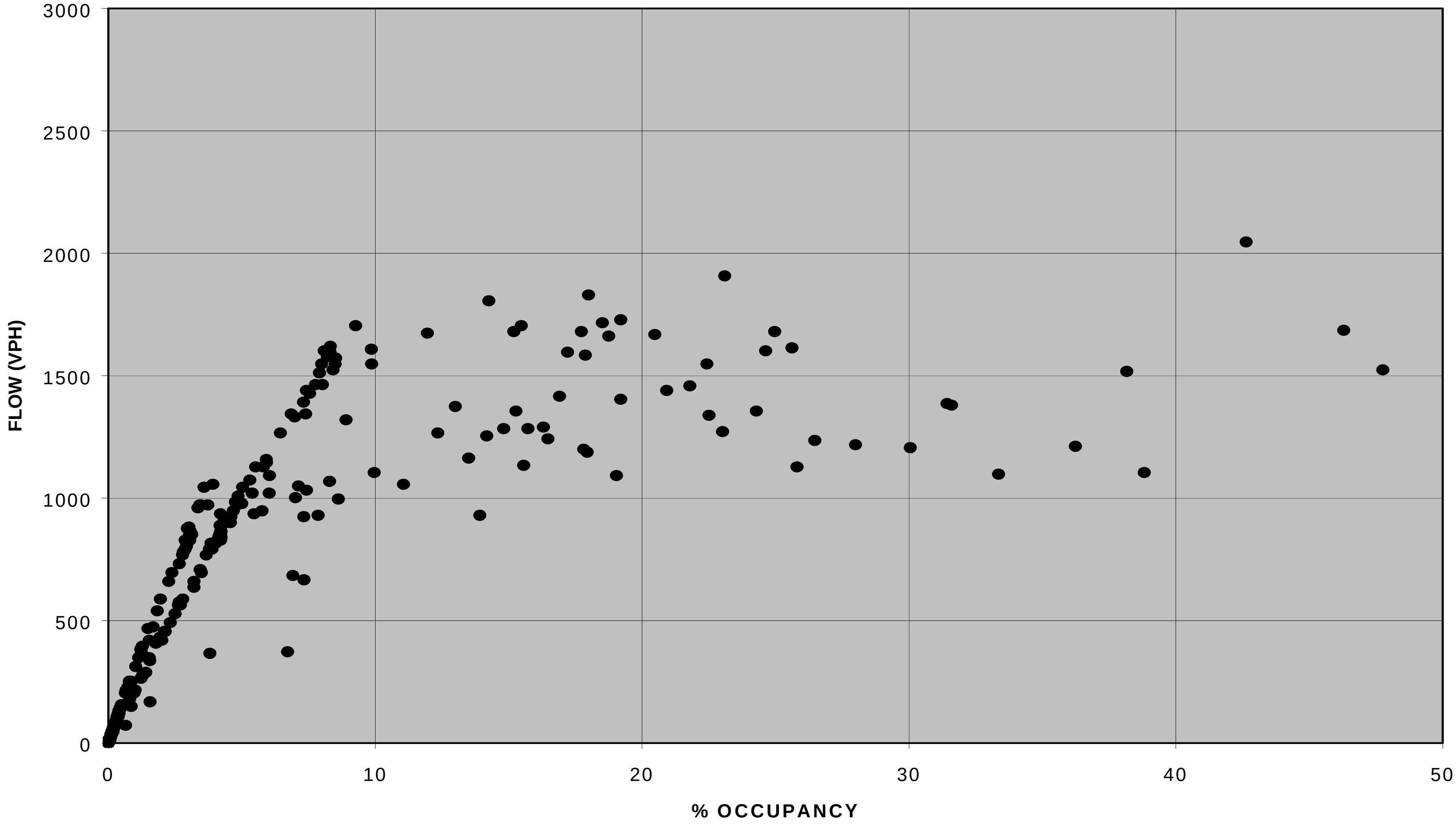


Illustration 4.15 Lane 2 Downstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

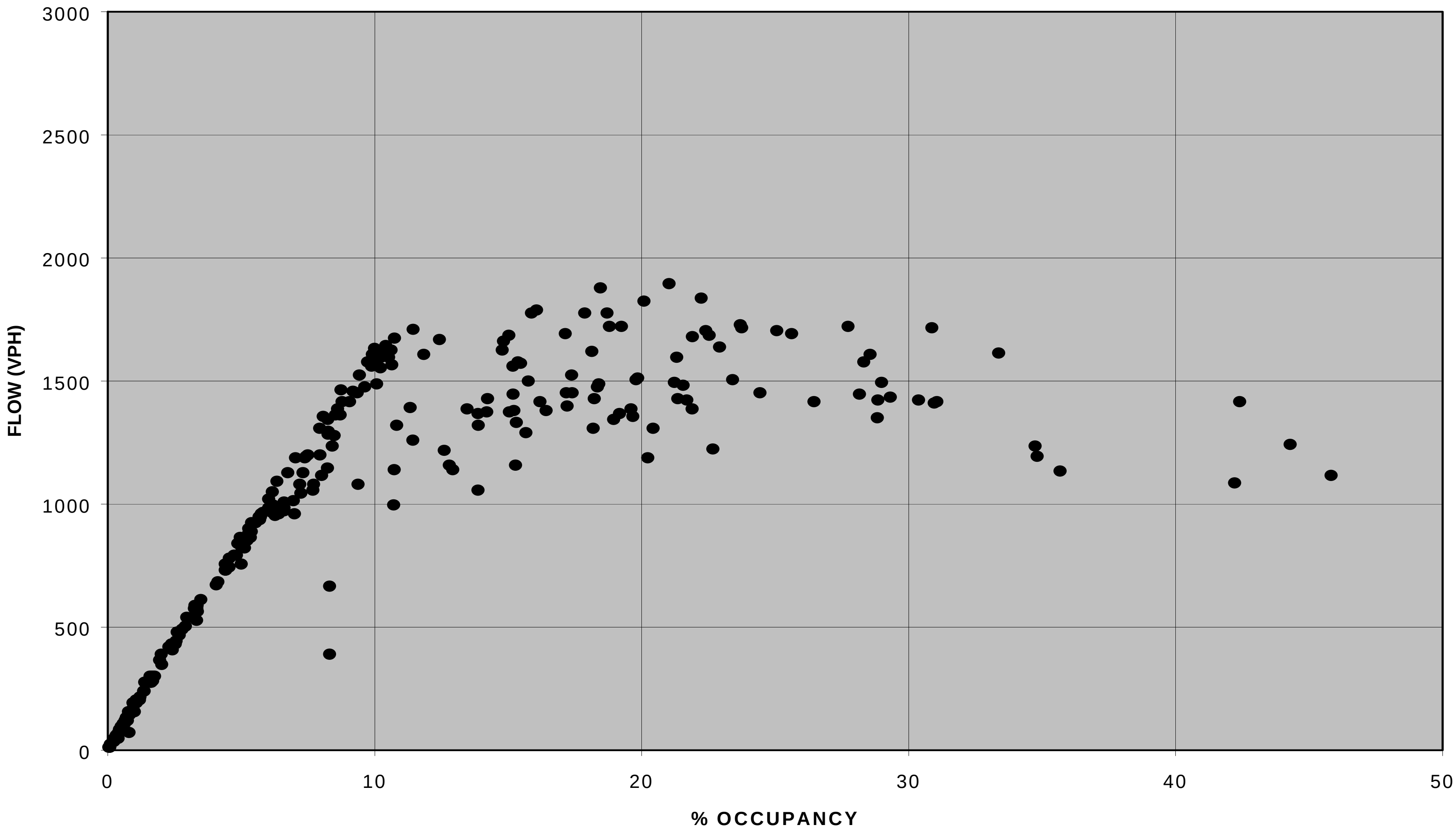


Illustration 4.16 Lane 2 Upstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

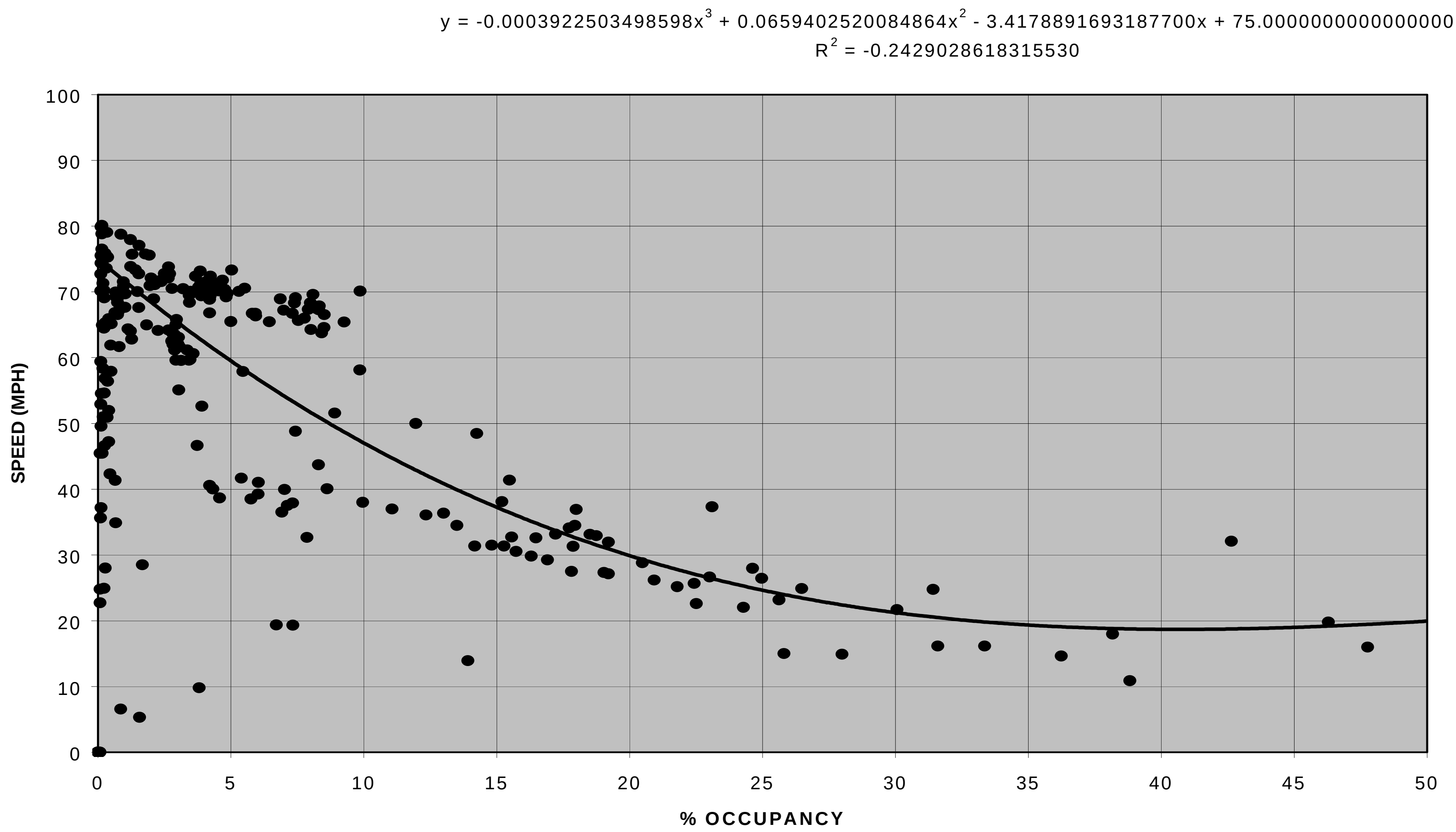


Illustration 4.17 Lane 2 Downstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

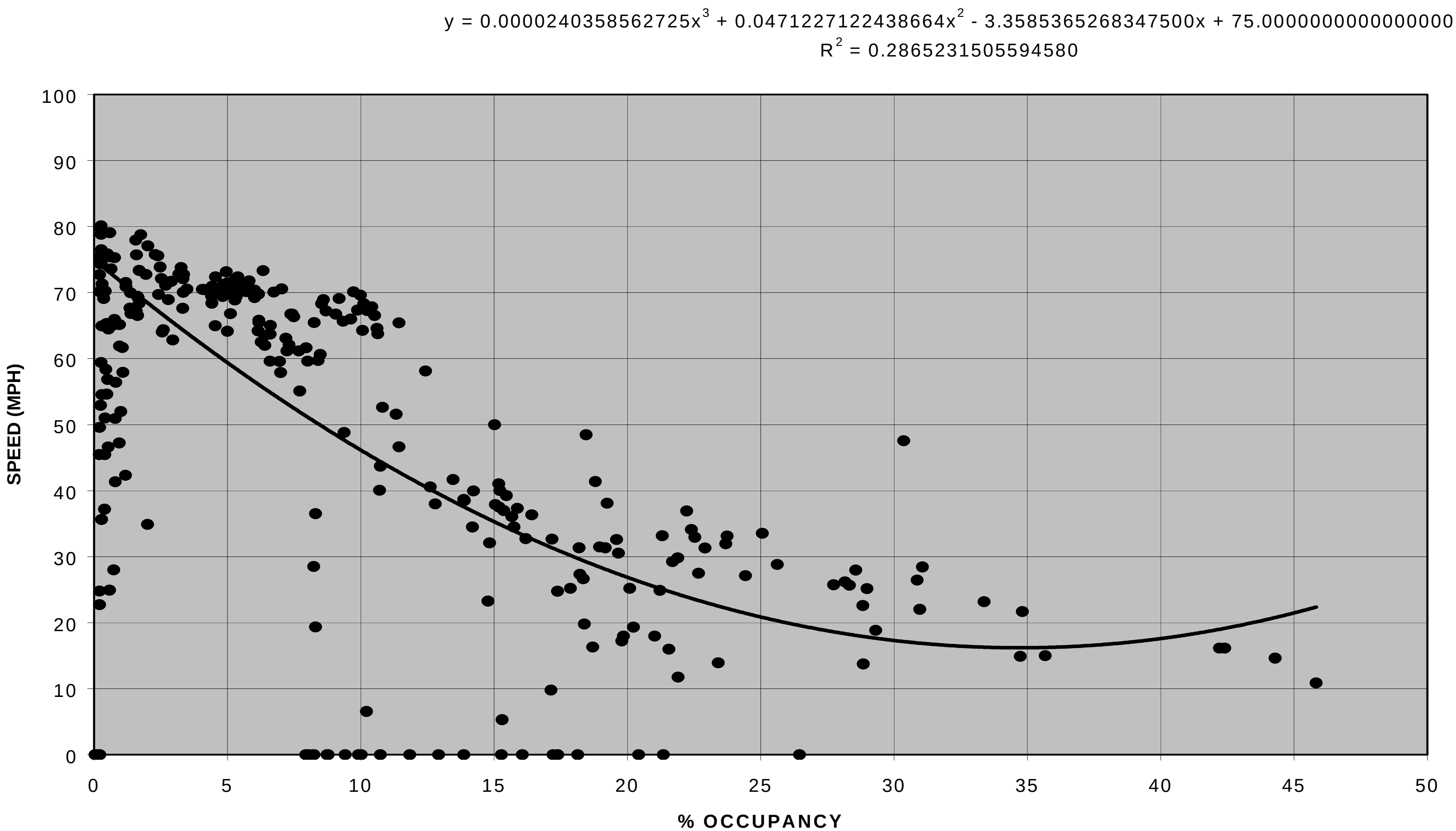


Illustration 4.18 Lane 2 Upstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

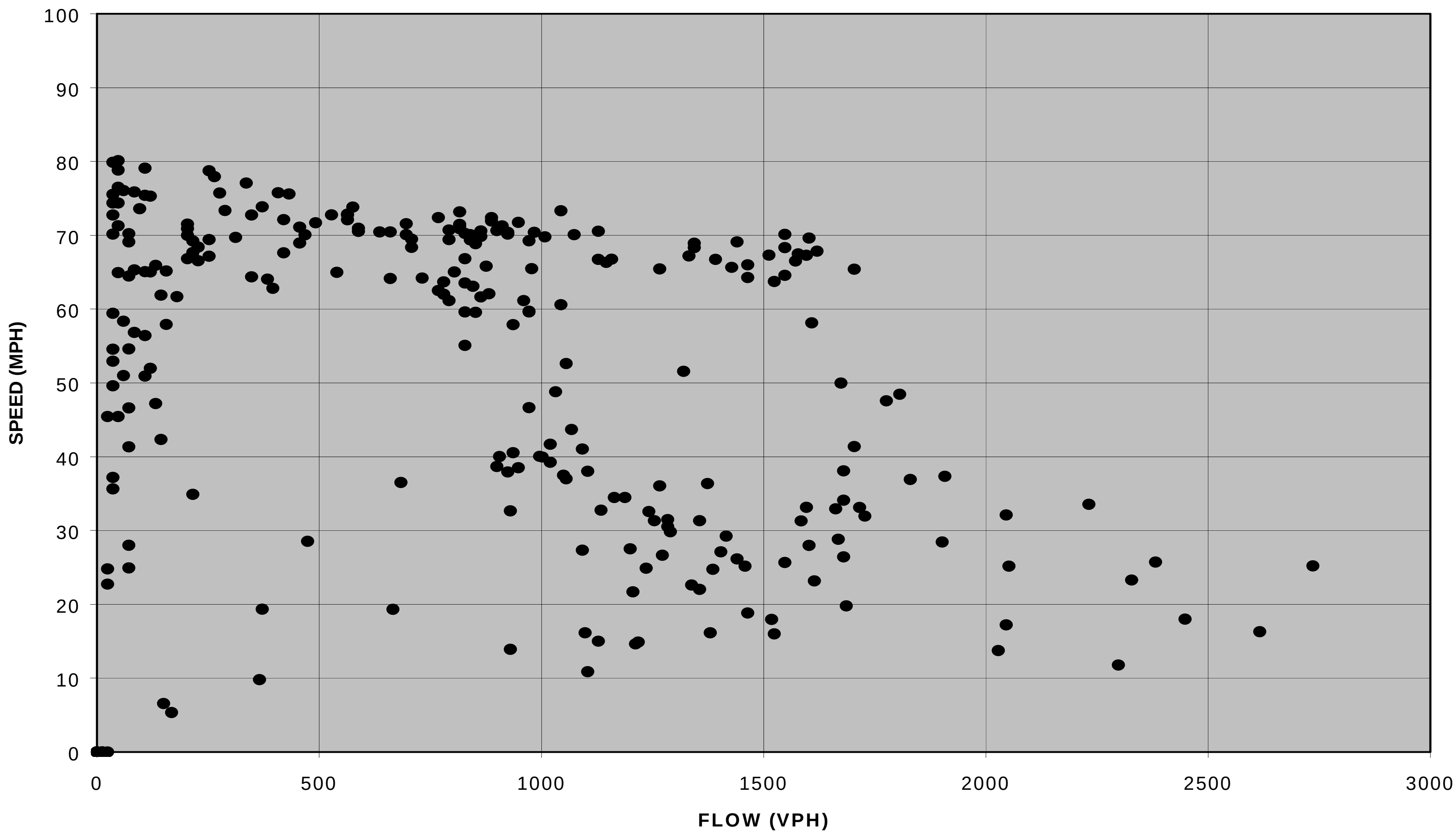


Illustration 4.19 Lane 2 Downstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

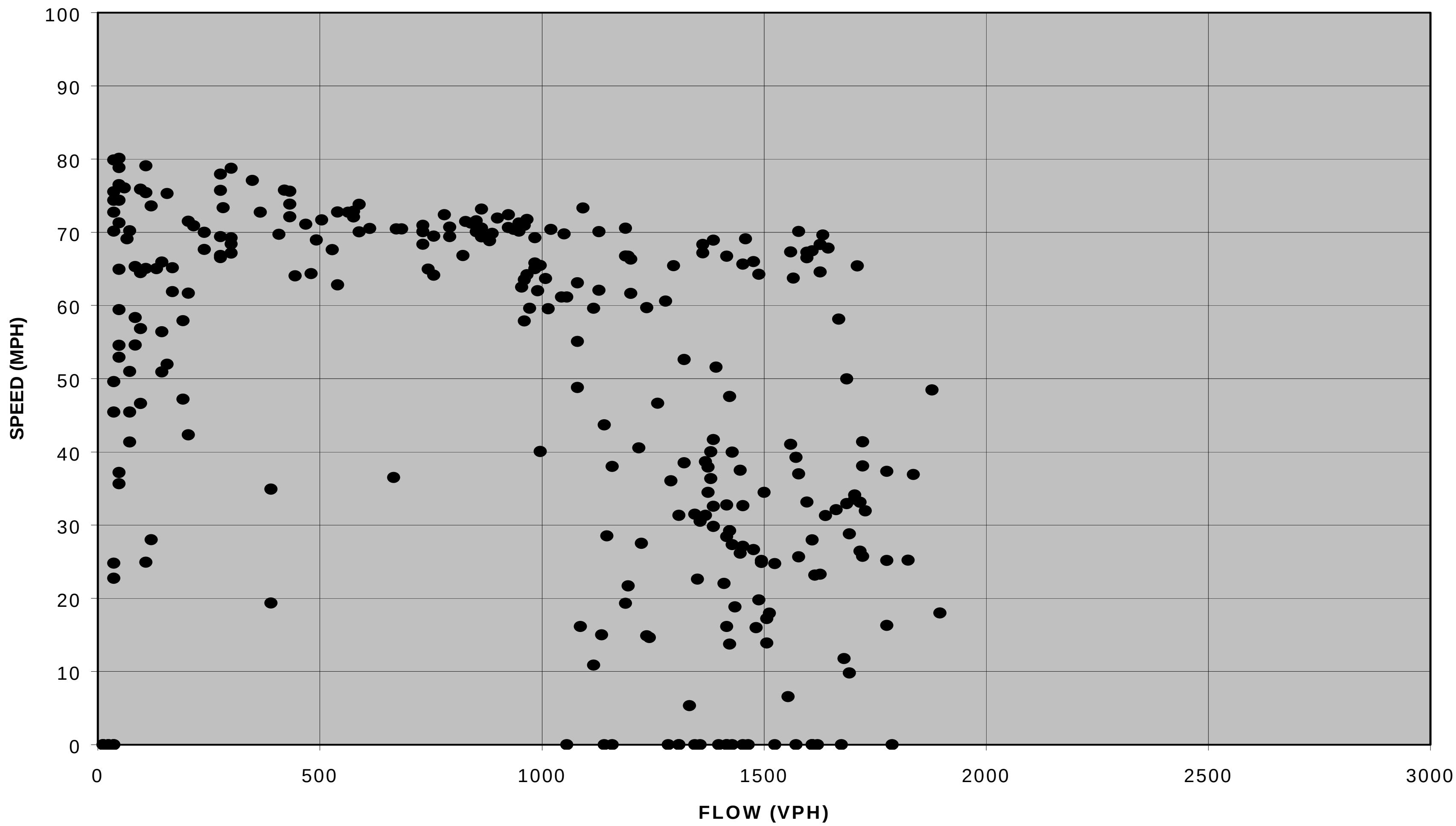


Illustration 4.20 Lane 2 Upstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

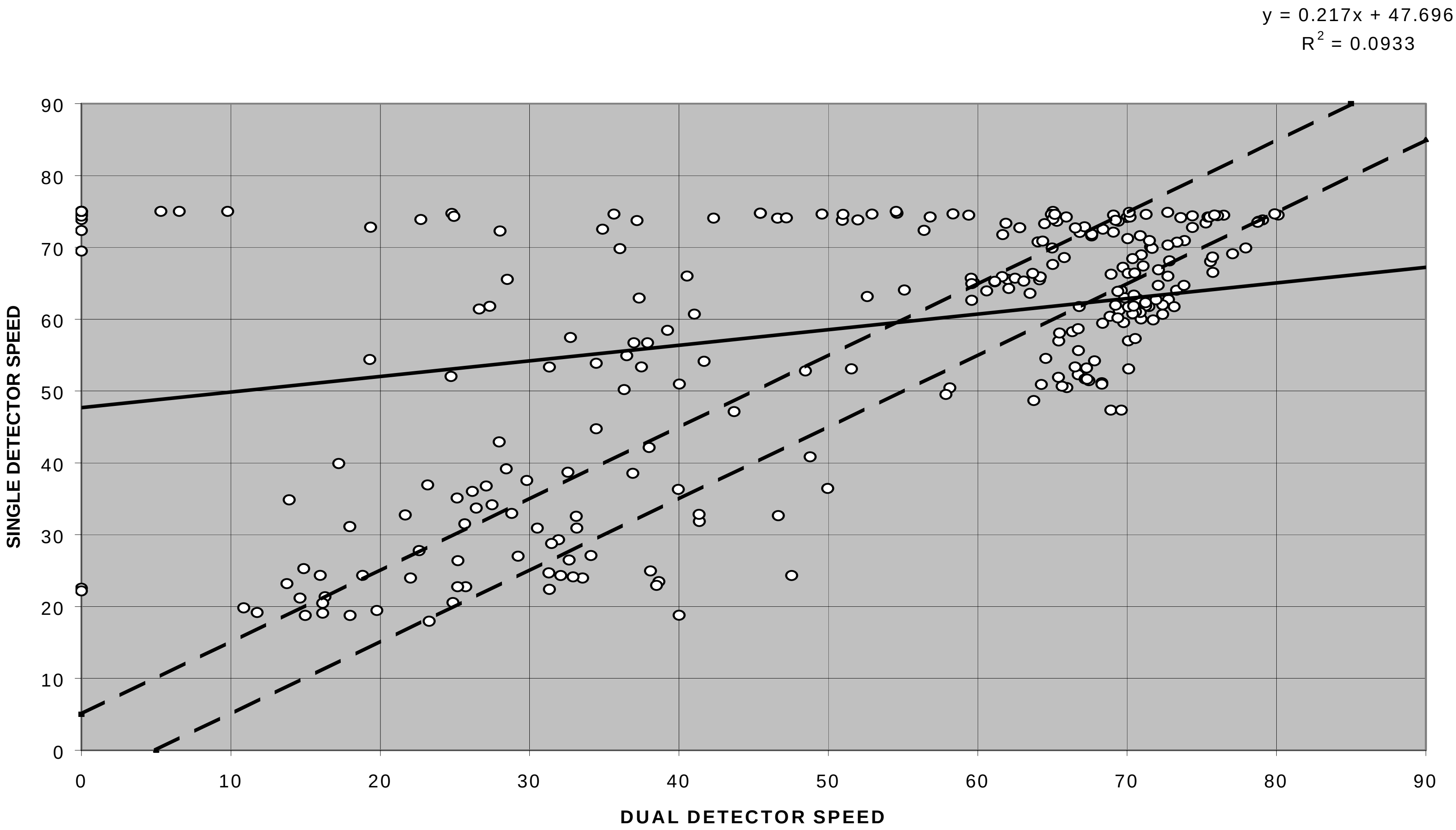


Illustration 4.21 Lane 2 Downstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

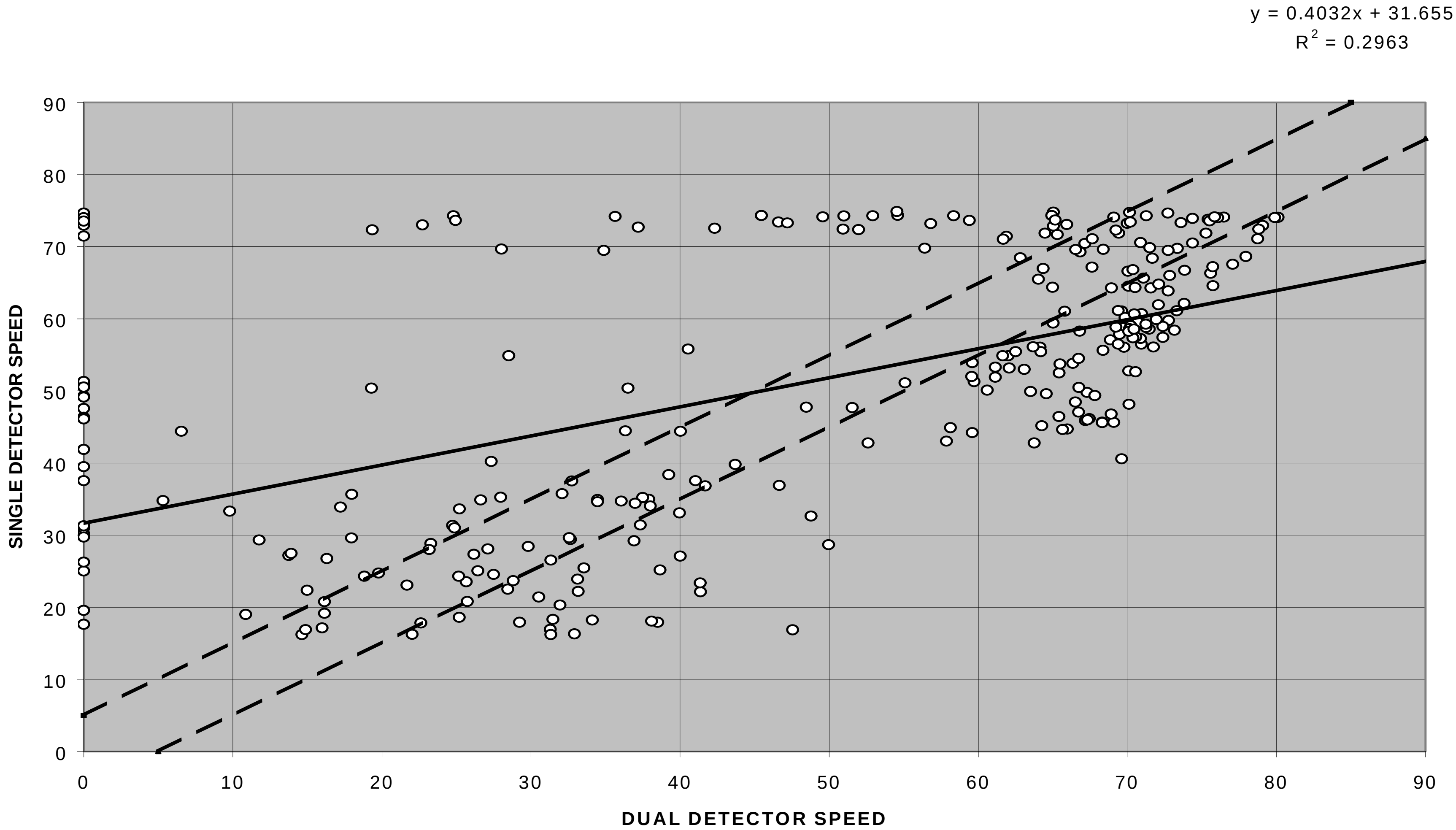


Illustration 4.22 Summary of Detector Diagnostic Results – Lane 3 at Station 8W (Tuesday 3/2/04)

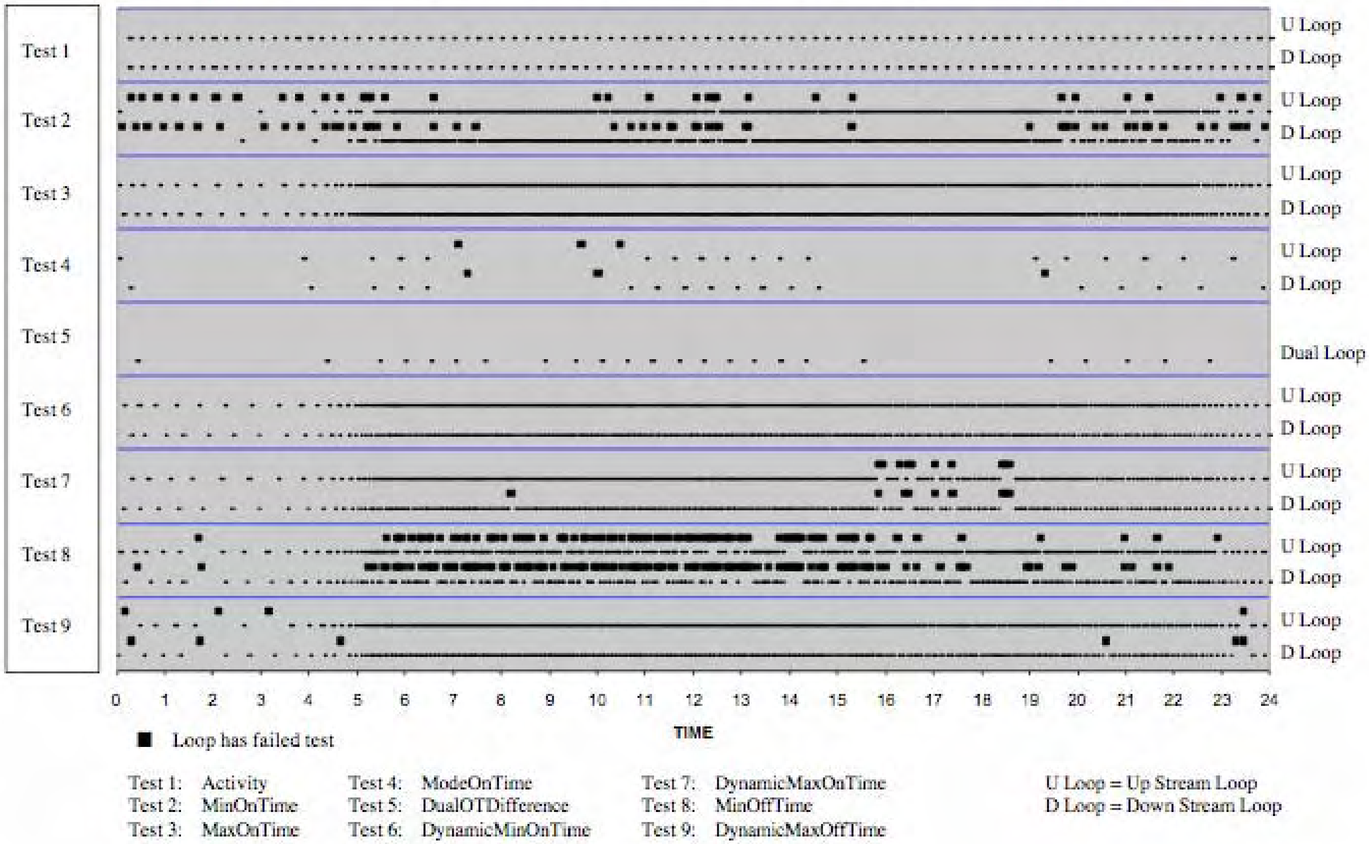
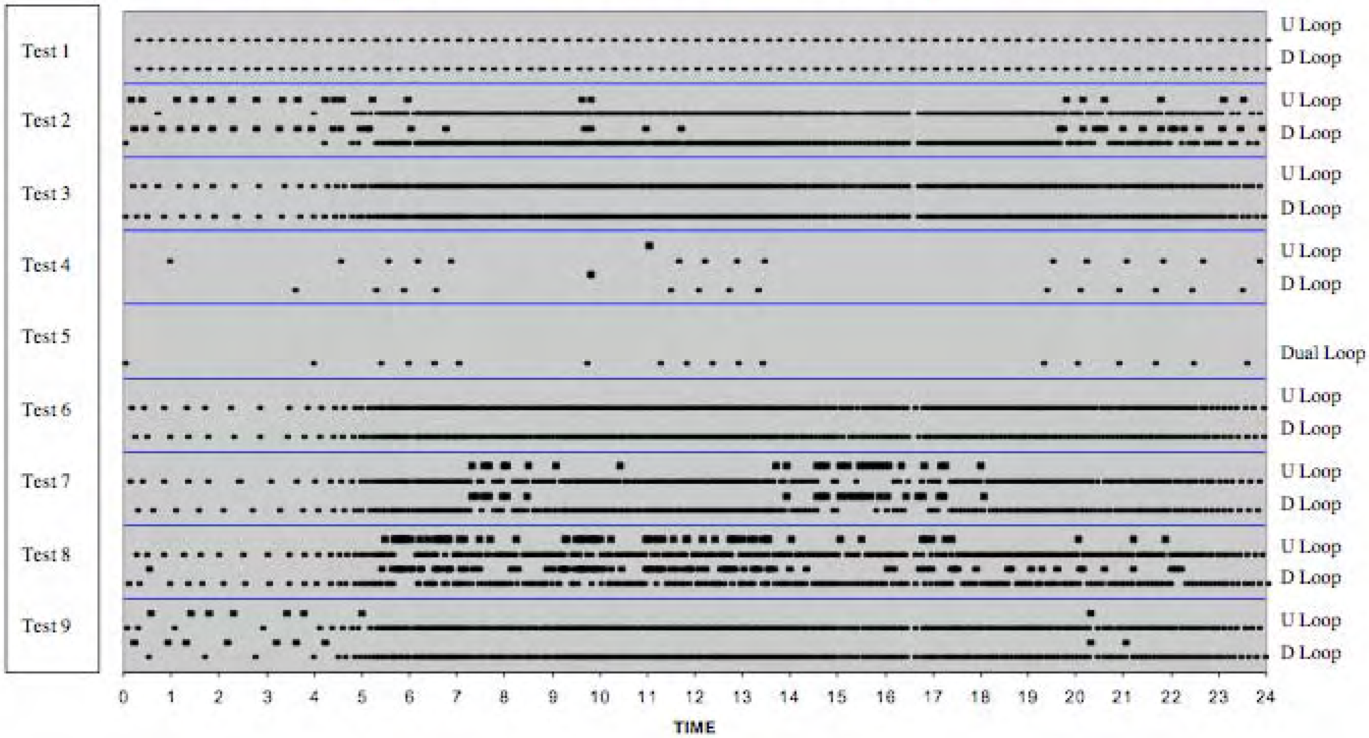


Illustration 4.23 Summary of Detector Diagnostic Results – Lane 3 at Station 8W (Thurs 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

■ Loop has failed test

Illustration 4.24 Lane 3 Upstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

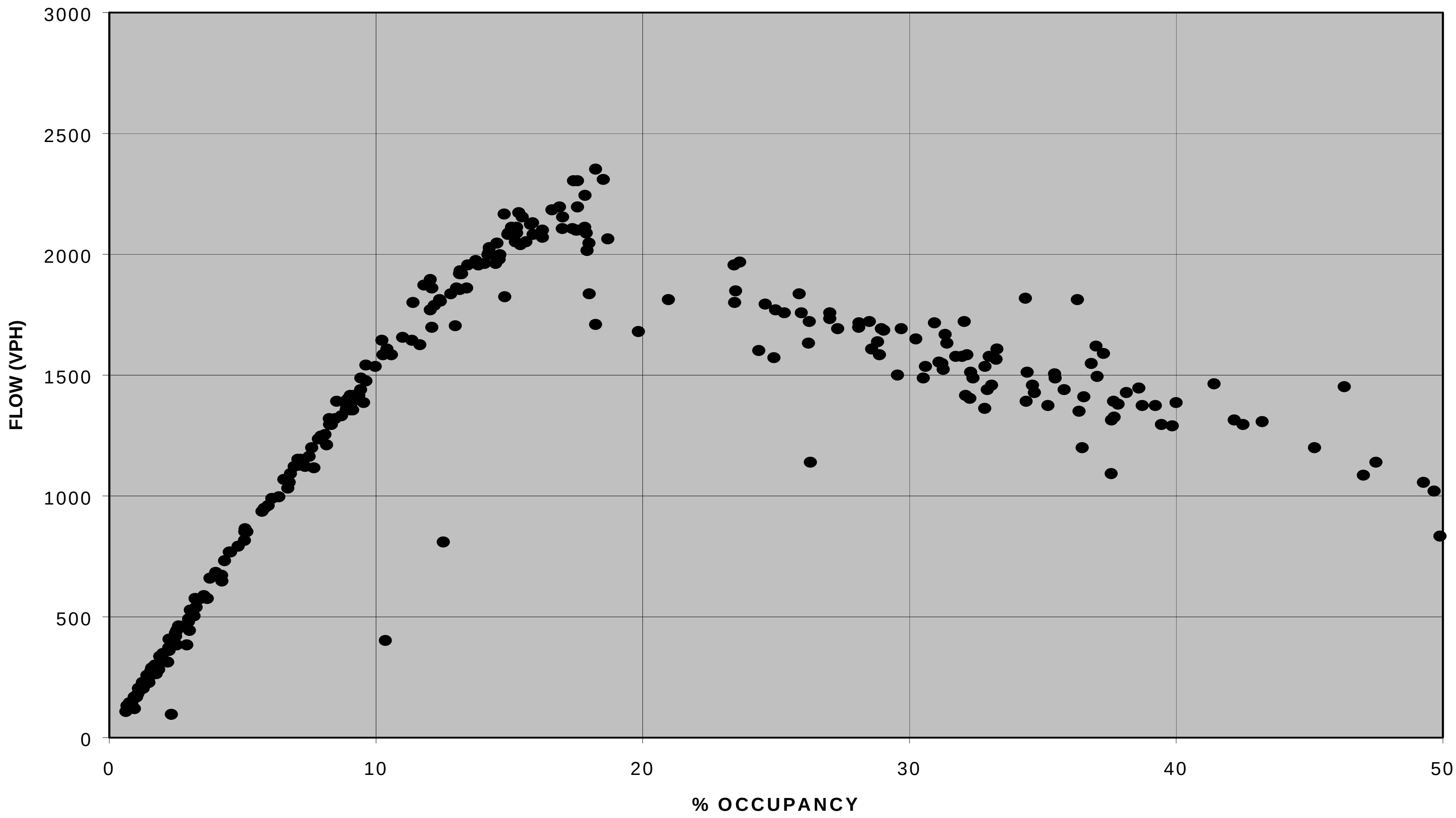


Illustration 4.25 Lane 3 Downstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

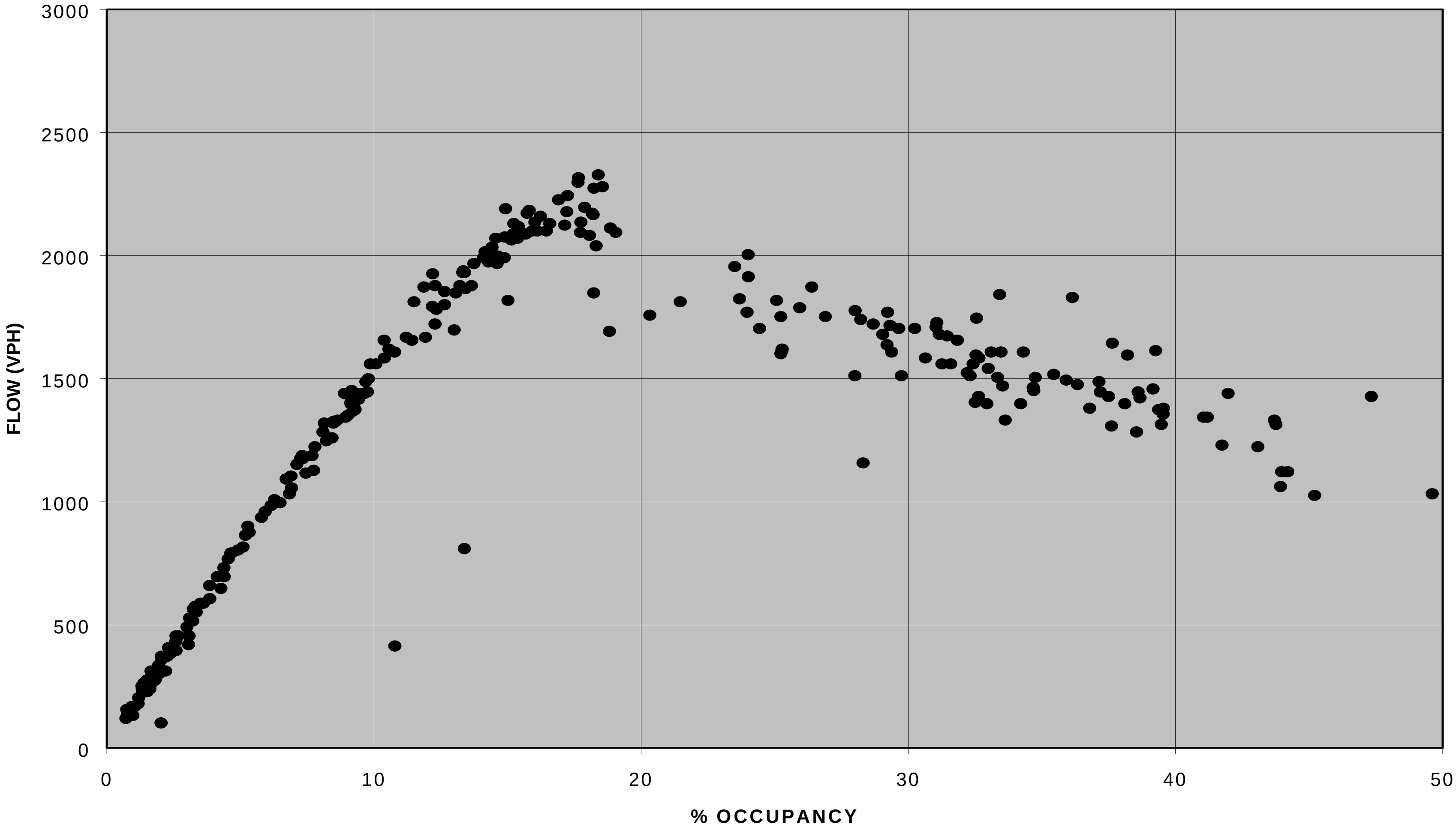


Illustration 4.26 Lane 3 Upstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

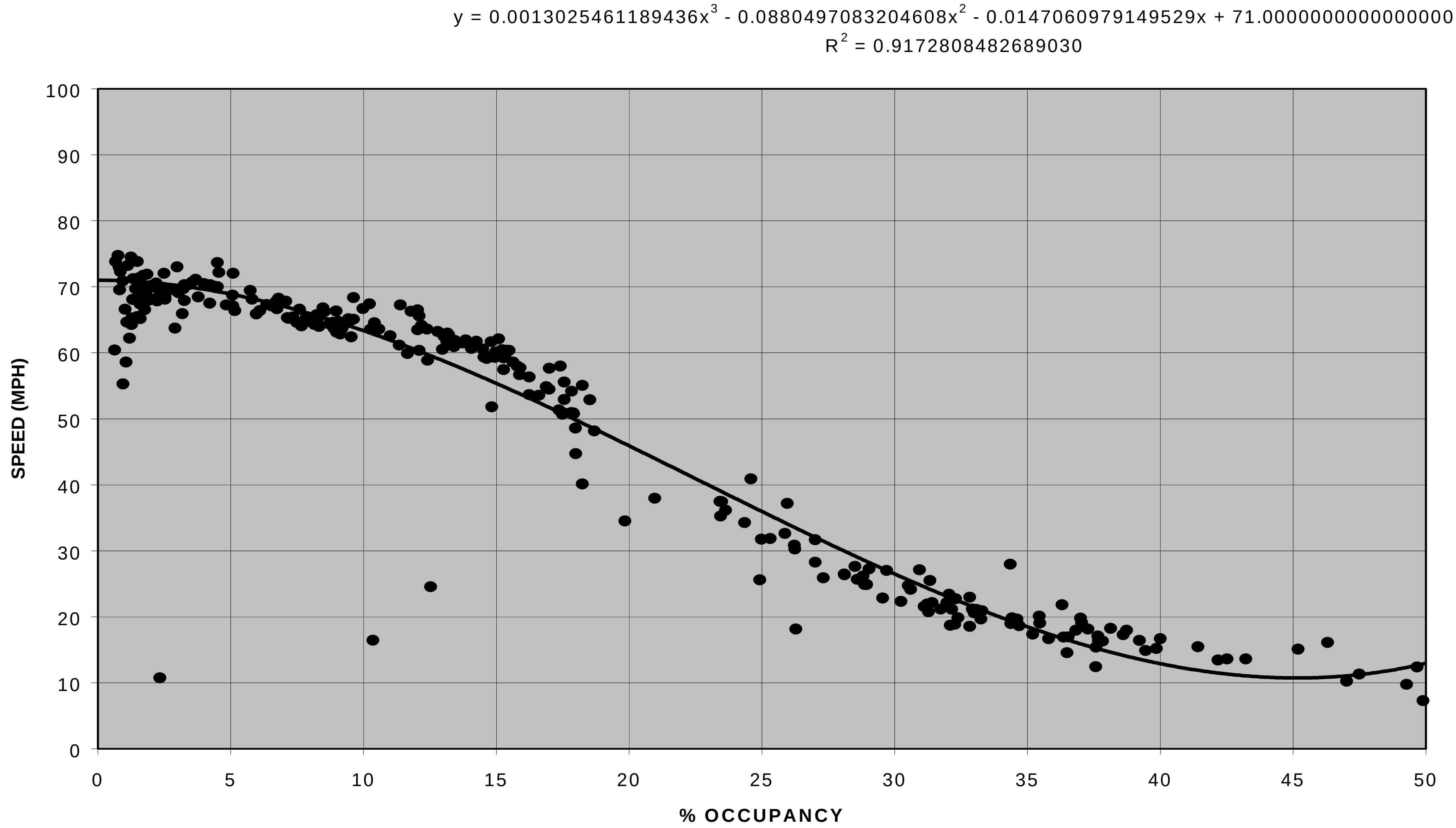


Illustration 4.27 Lane 3 Downstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

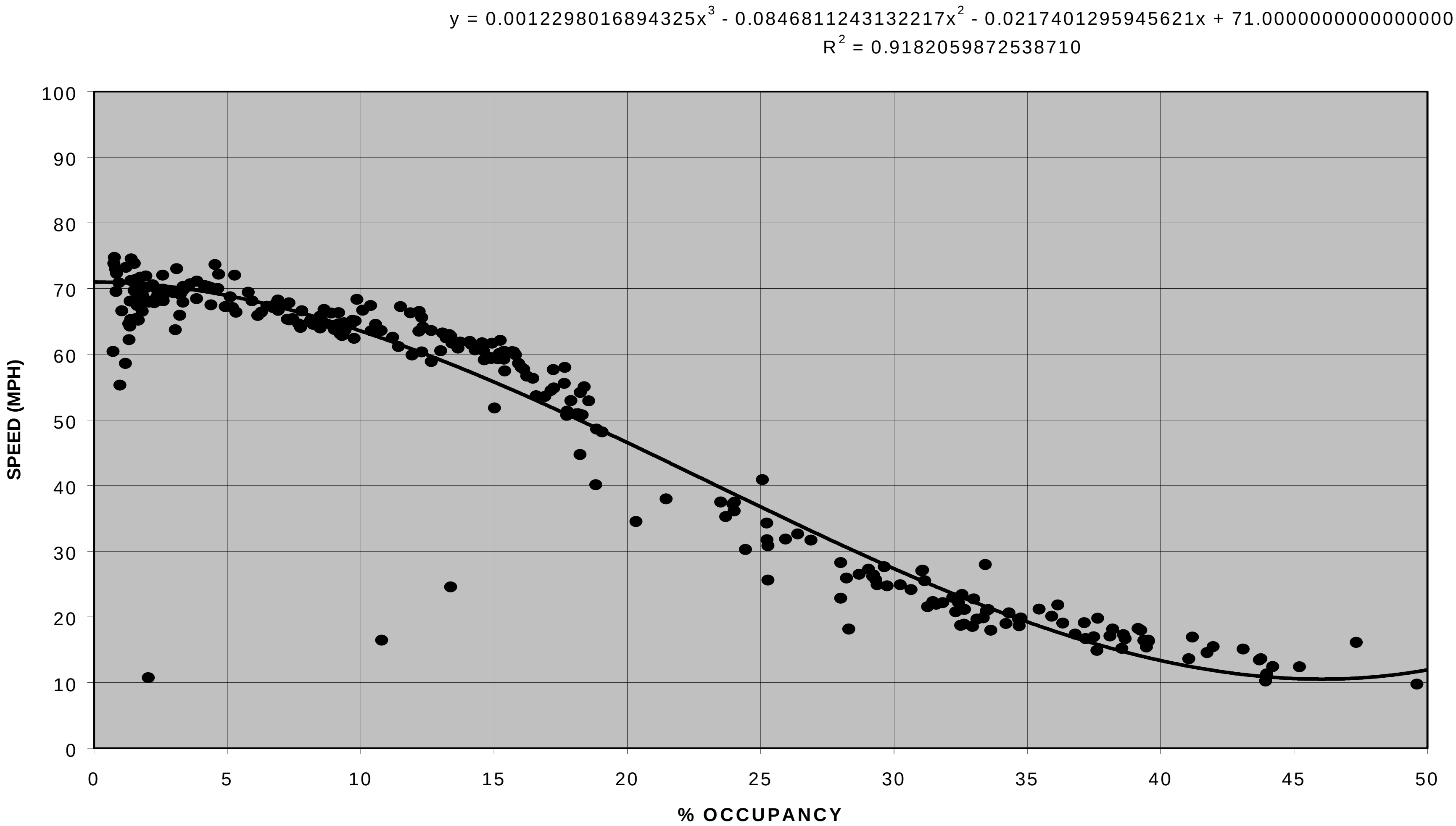


Illustration 4.28 Lane 3 Upstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

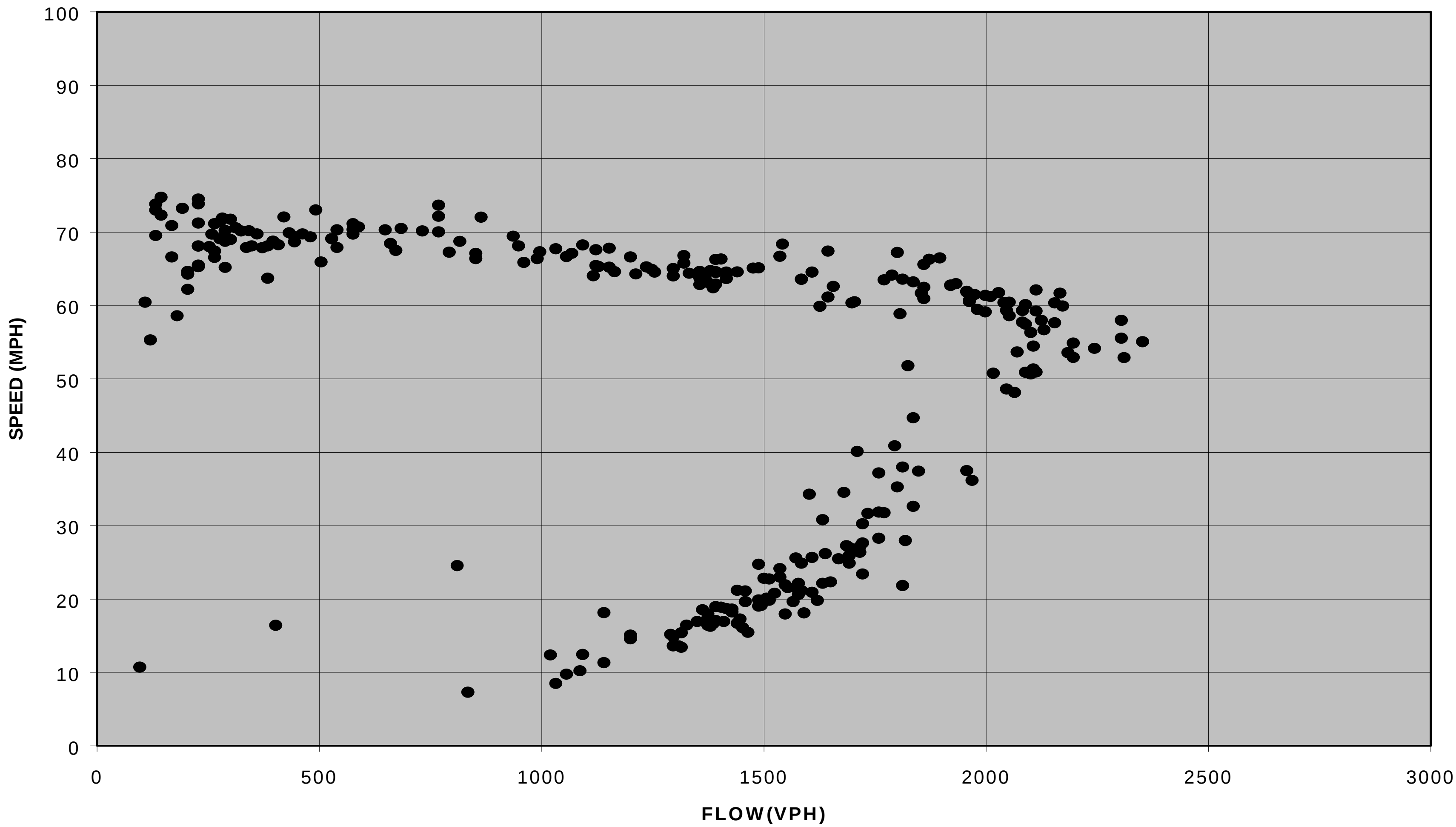


Illustration 4.29 Lane 3 Downstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

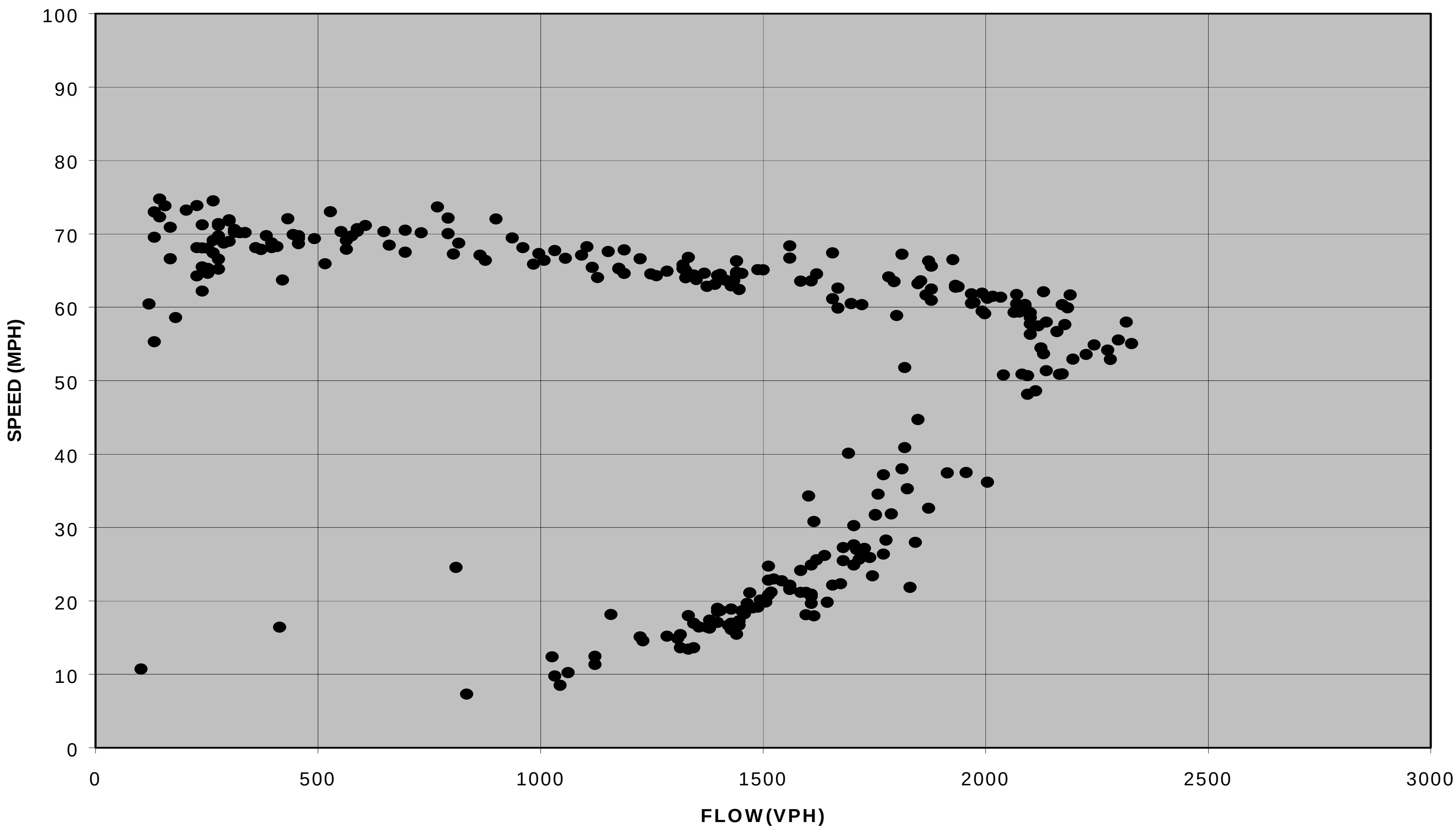


Illustration 4.30 Lane 3 Upstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

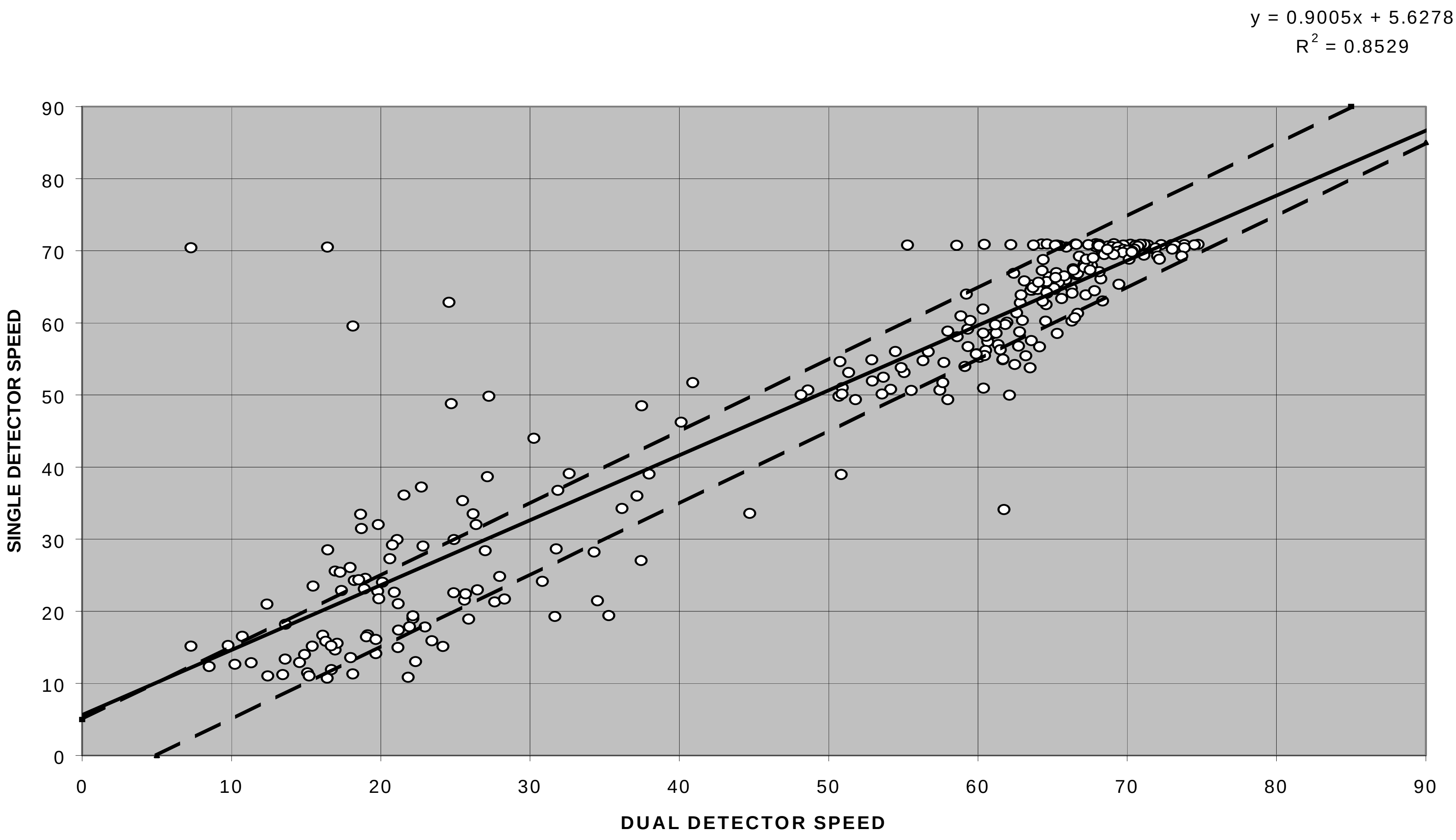


Illustration 4.31 Lane 3 Downstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

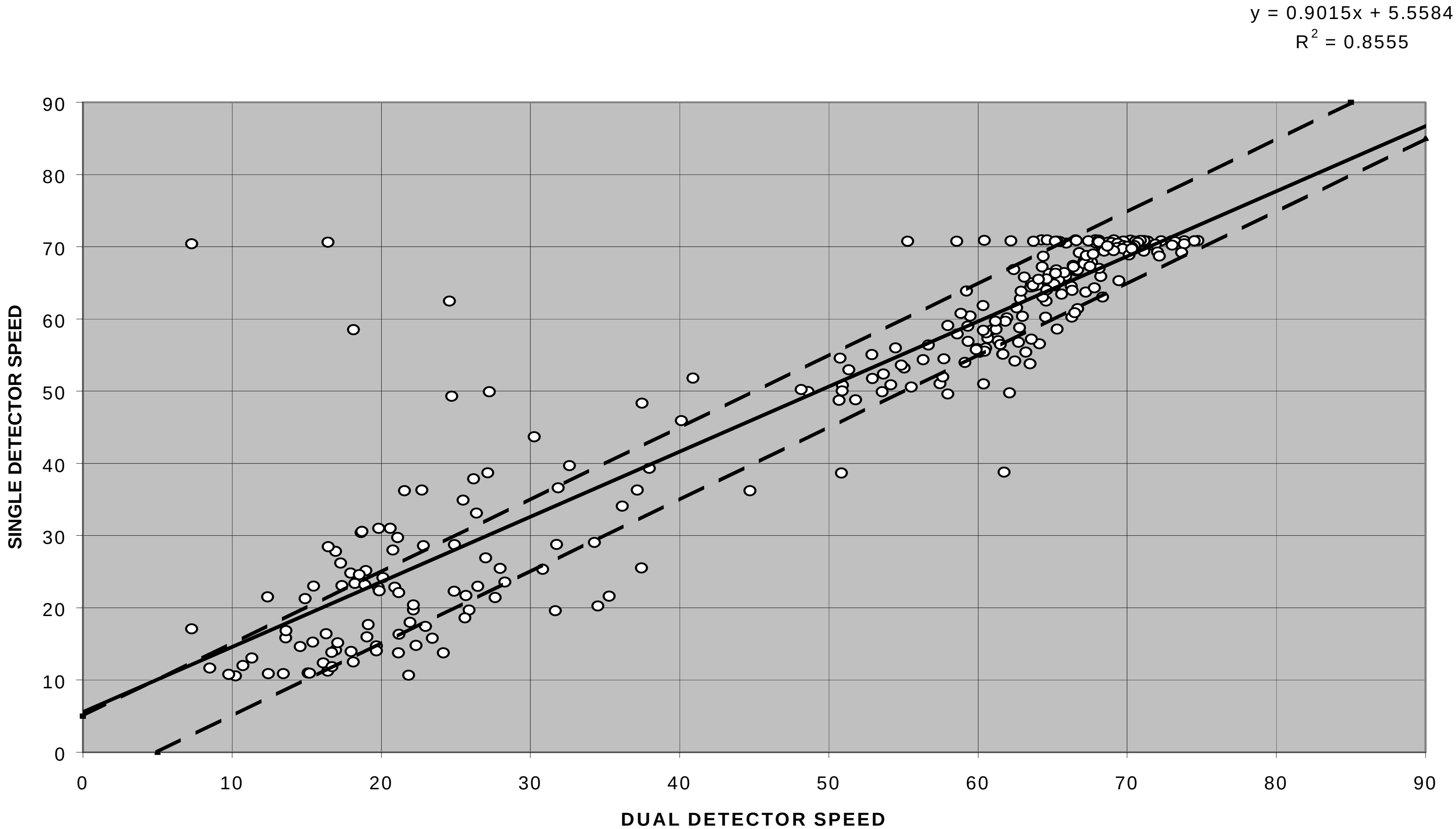
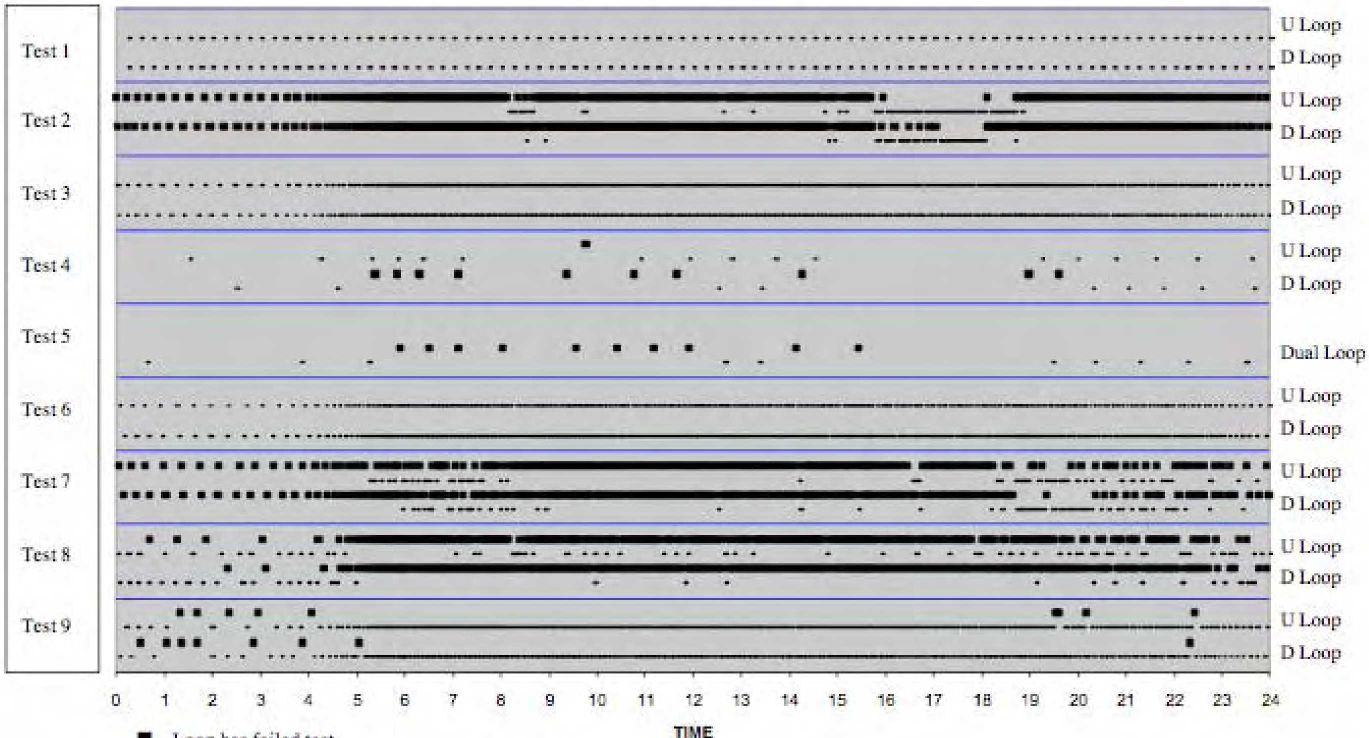


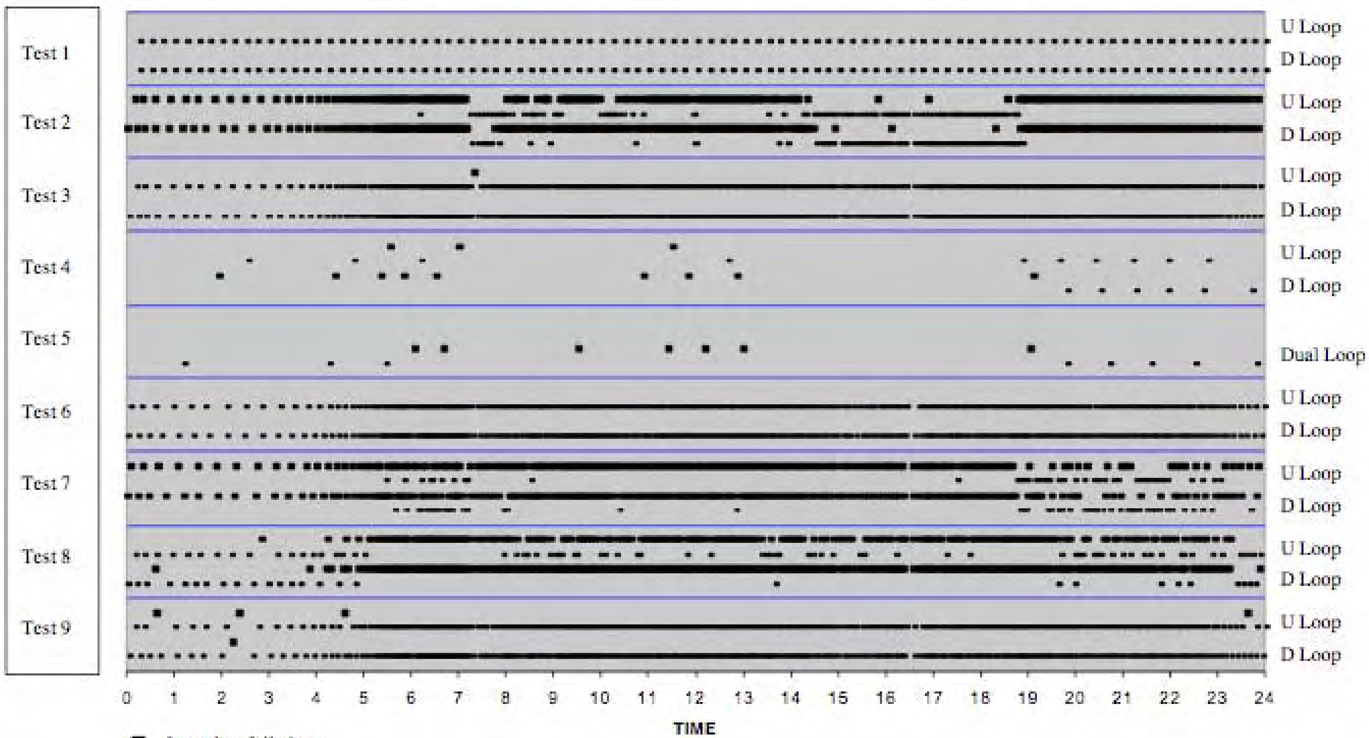
Illustration 4.32 Summary of Detector Diagnostic Results – Lane 4 at Station 8W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 4.33 Summary of Detector Diagnostic Results – Lane 4 at Station 8W (Thurs 3/4/04)



■ Loop has failed test

Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 4.34 Lane 4 Upstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

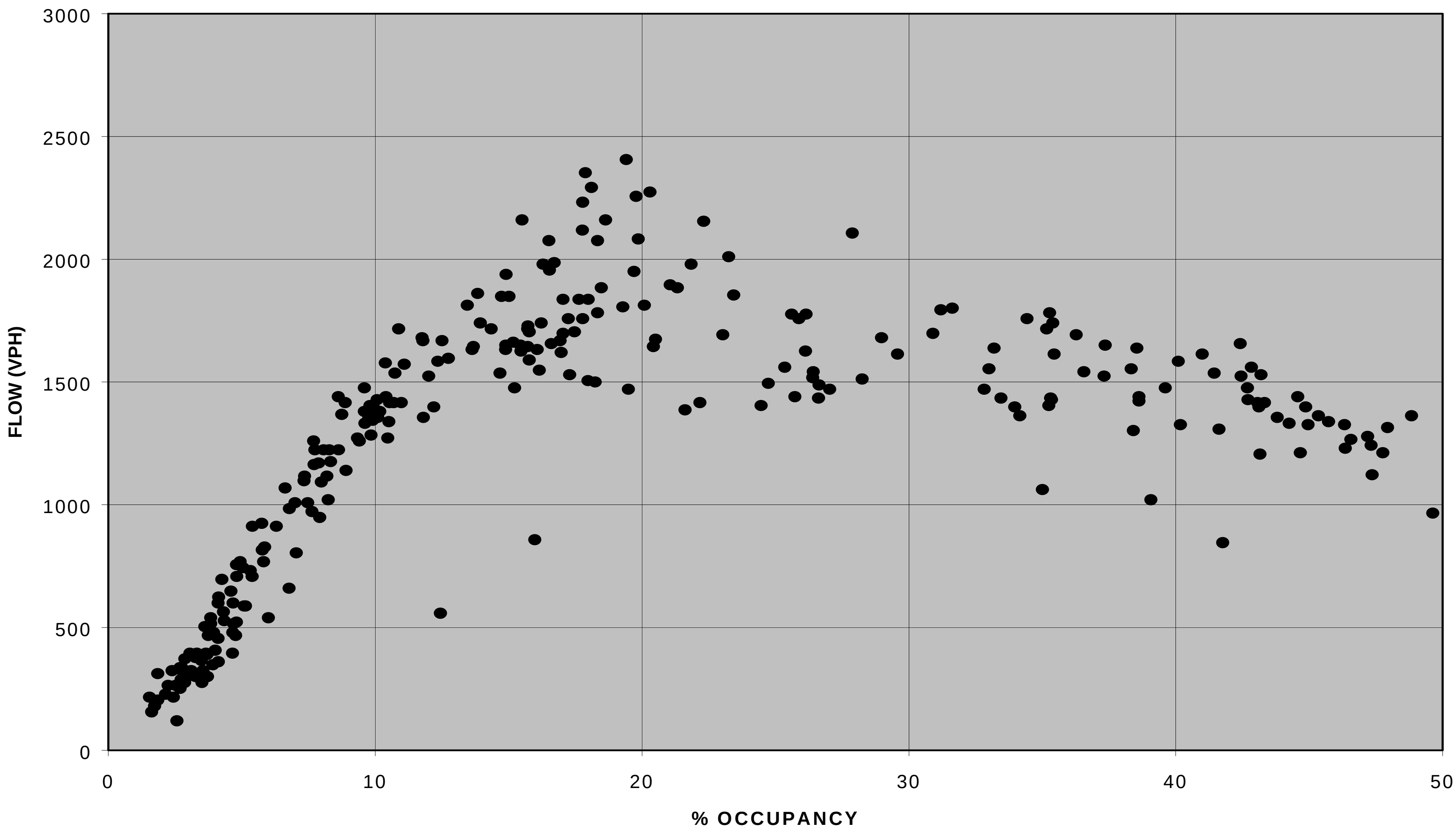


Illustration 4.35 Lane 4 Downstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

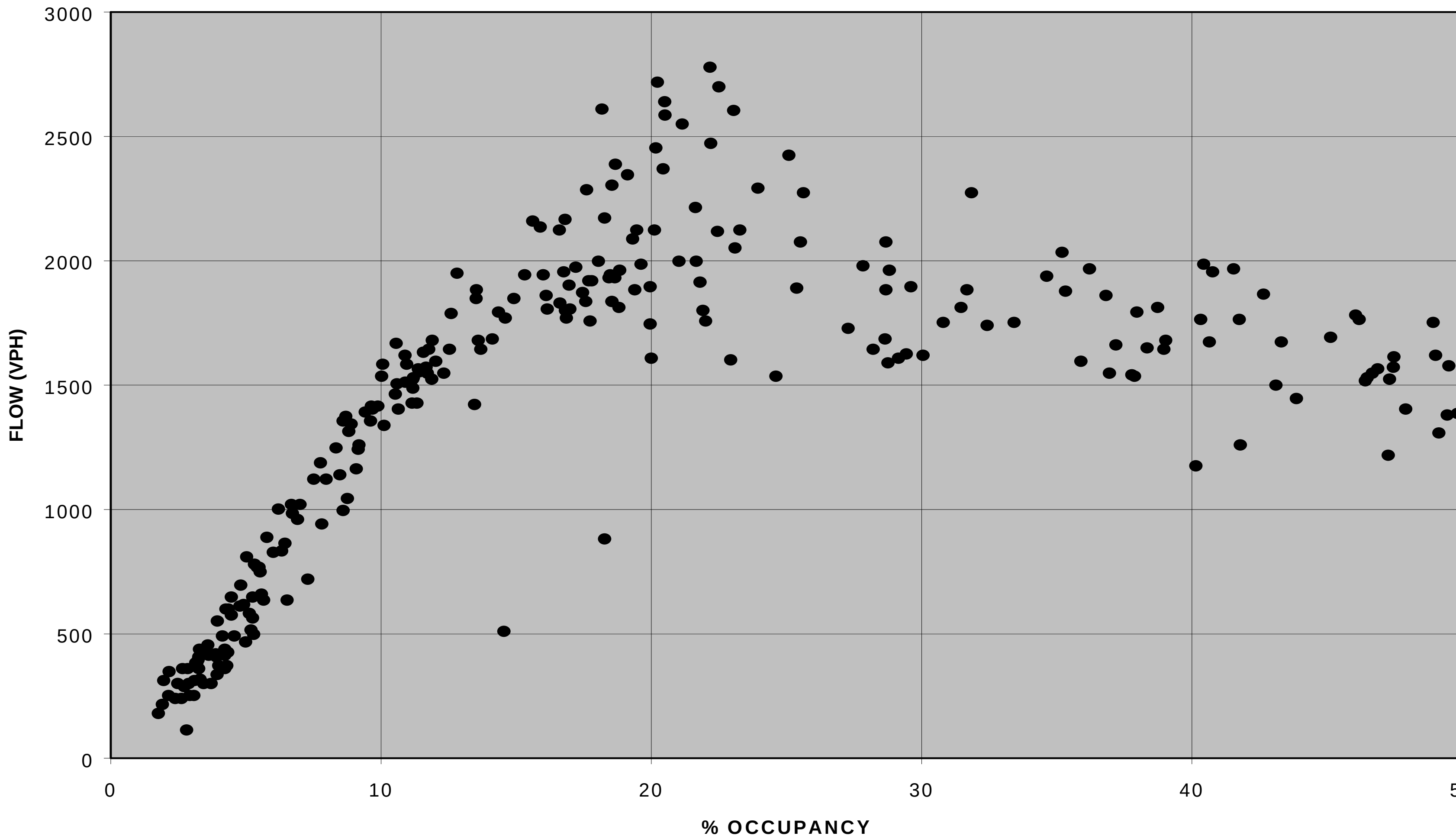


Illustration 4.36 Lane 4 Upstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

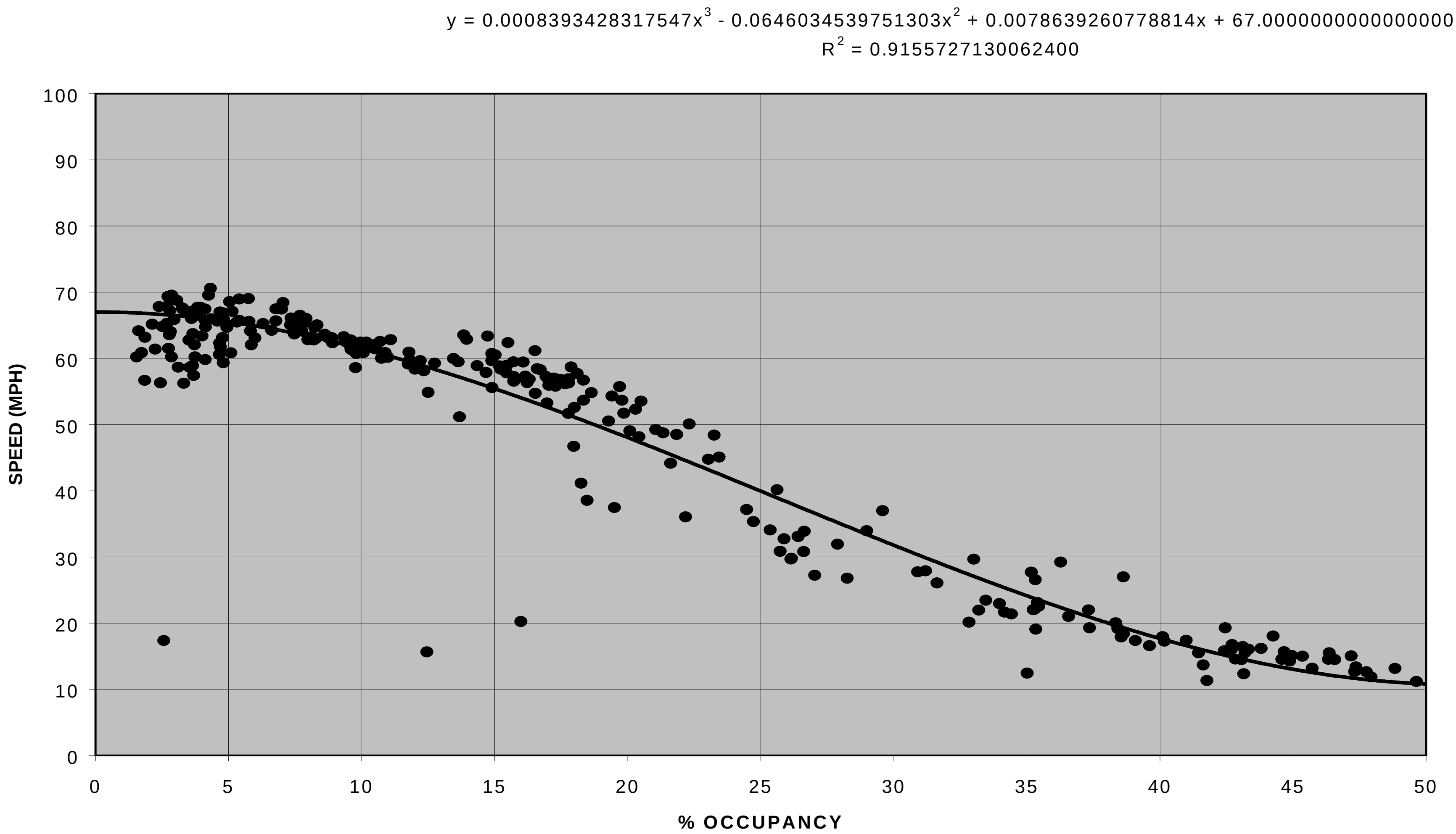


Illustration 4.37 Lane 4 Downstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

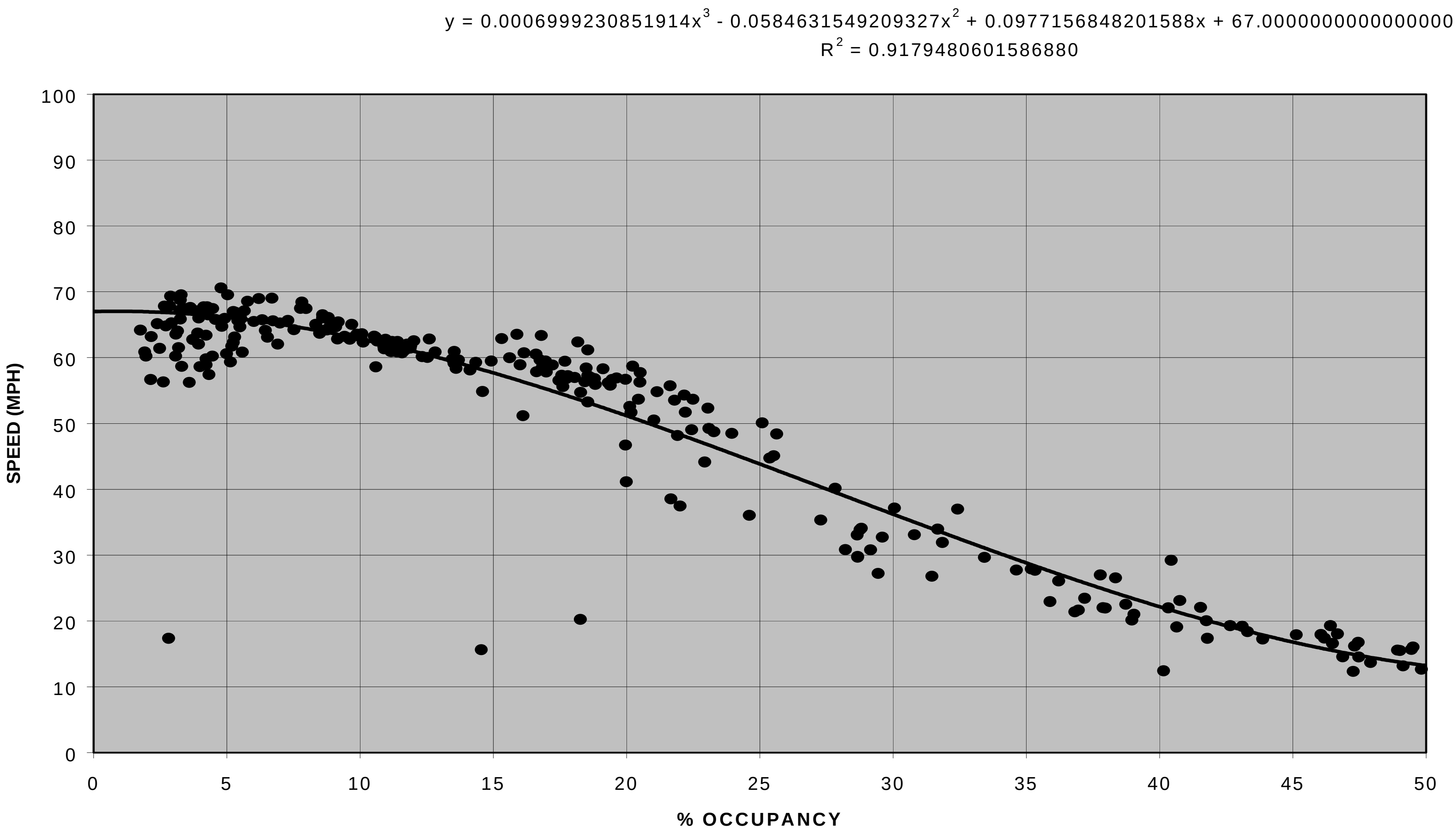


Illustration 4.38 Lane 4 Upstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

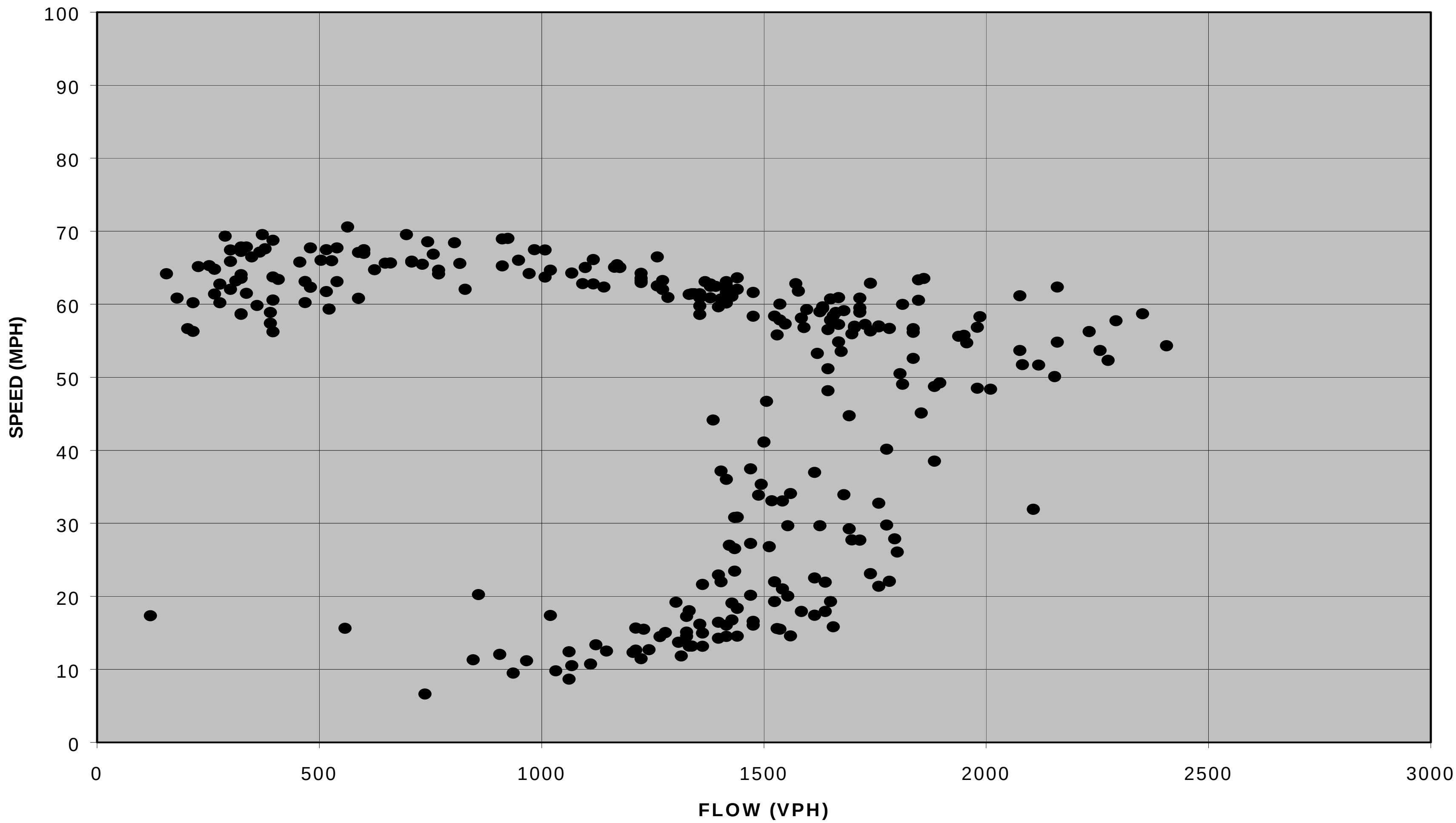


Illustration 4.39 Lane 4 Downstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

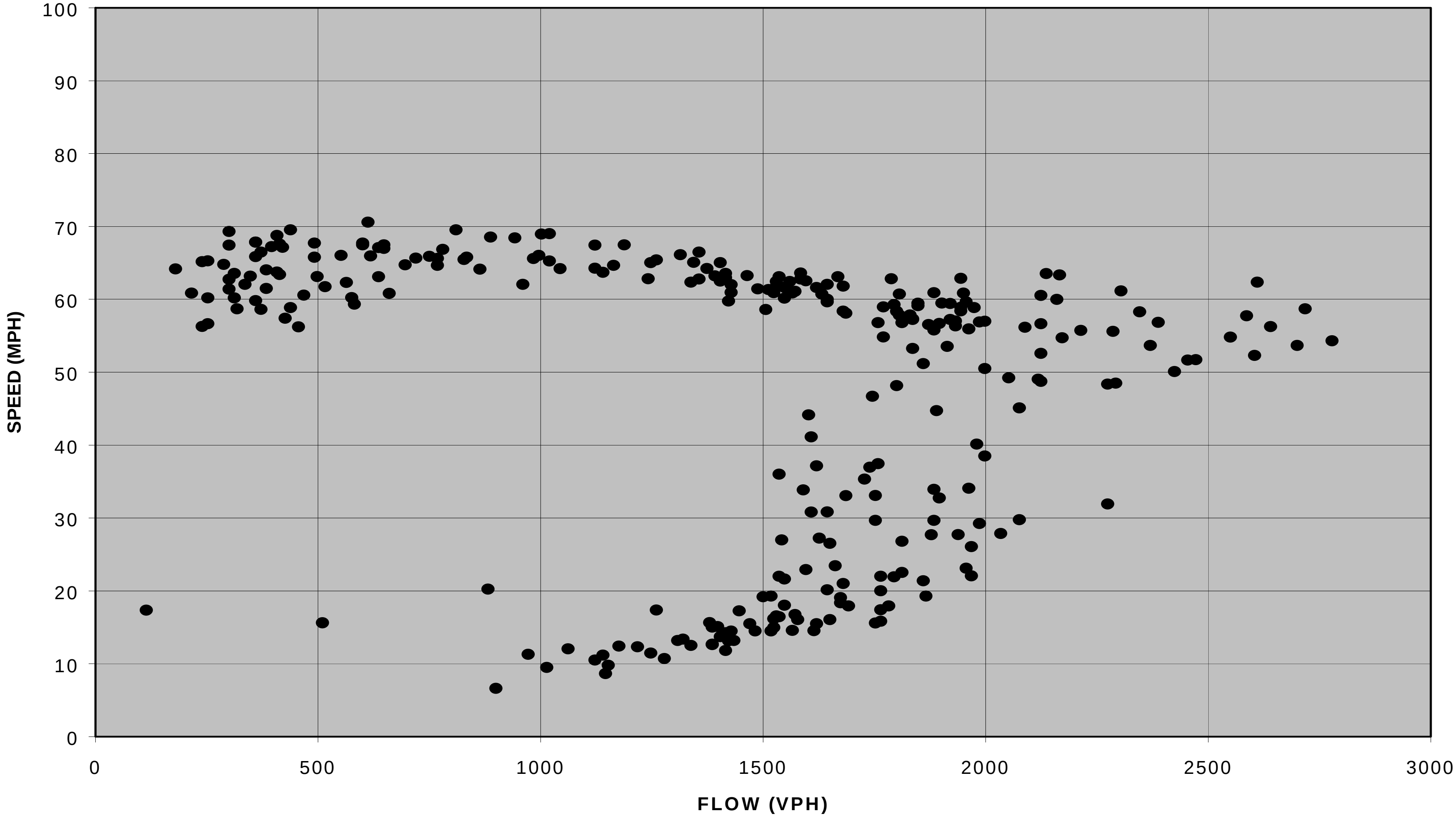


Illustration 4.40 Lane 4 Upstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

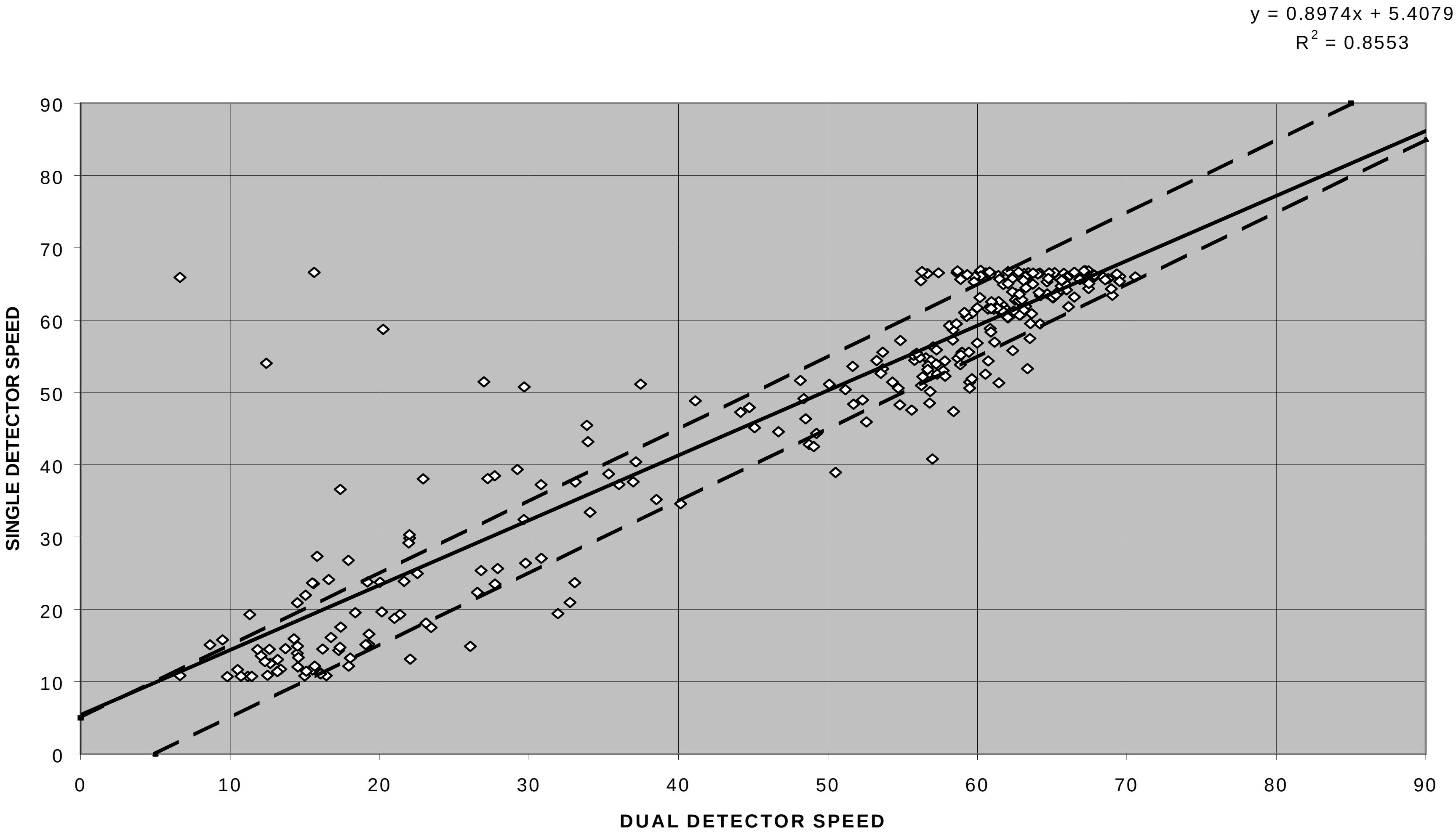


Illustration 4.41 Lane 4 Downstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

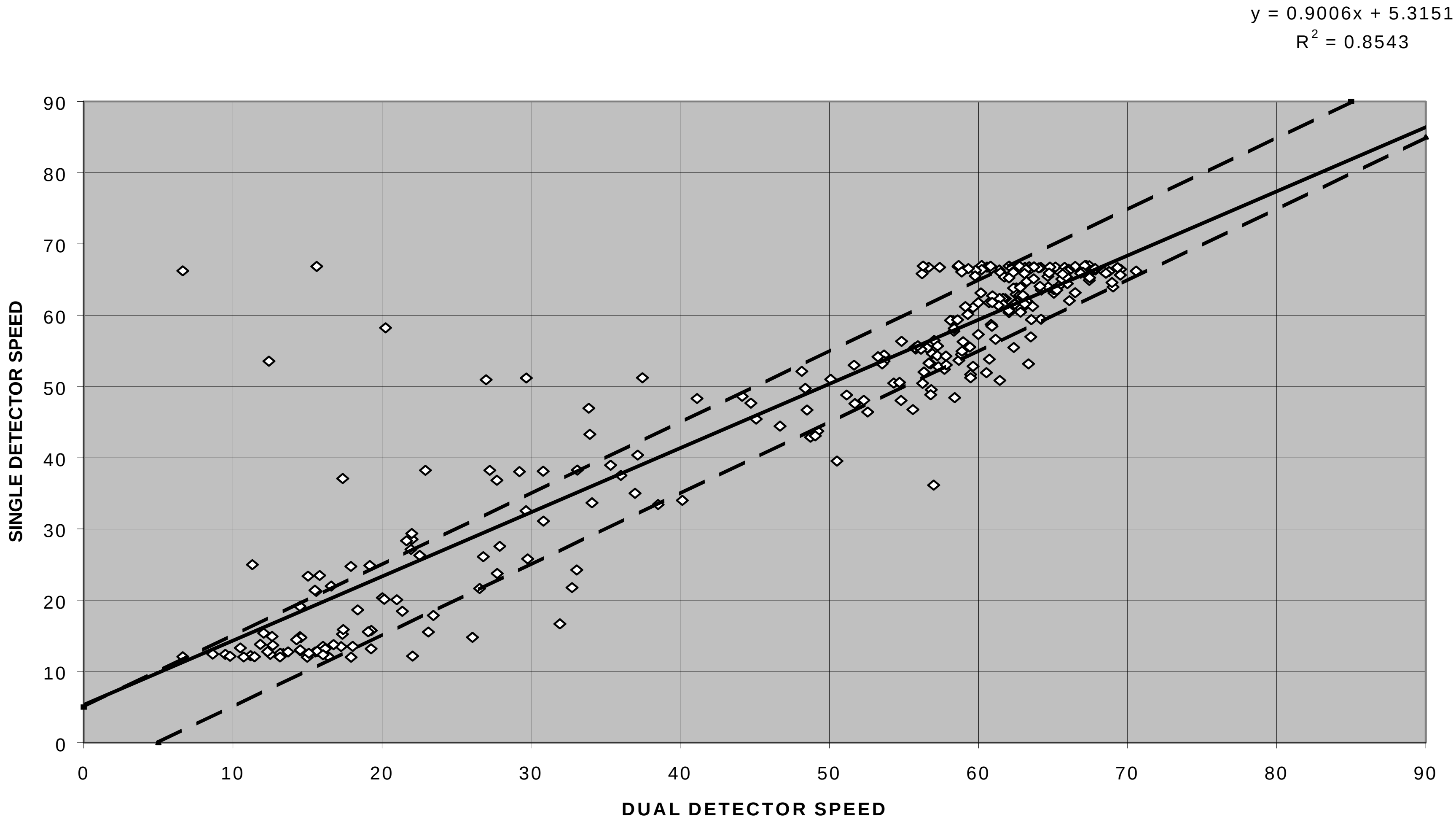


Illustration 4.42 Summary of Detector Diagnostic Results – Lane 5 at Station 8W (Tuesday 3/2/04)

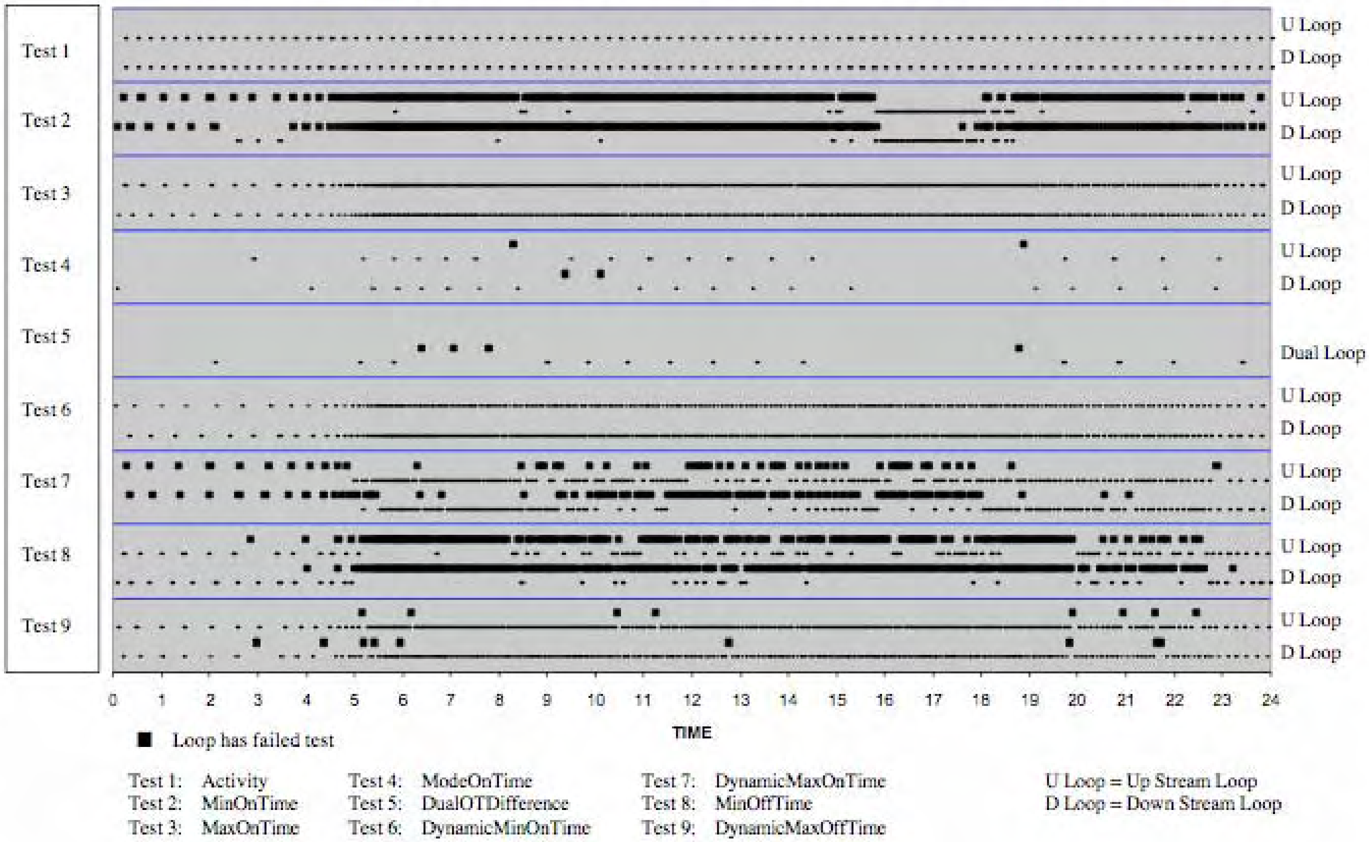


Illustration 4.43 Summary of Detector Diagnostic Results – Lane 8 at Station 8W (Thurs 3/4/04)

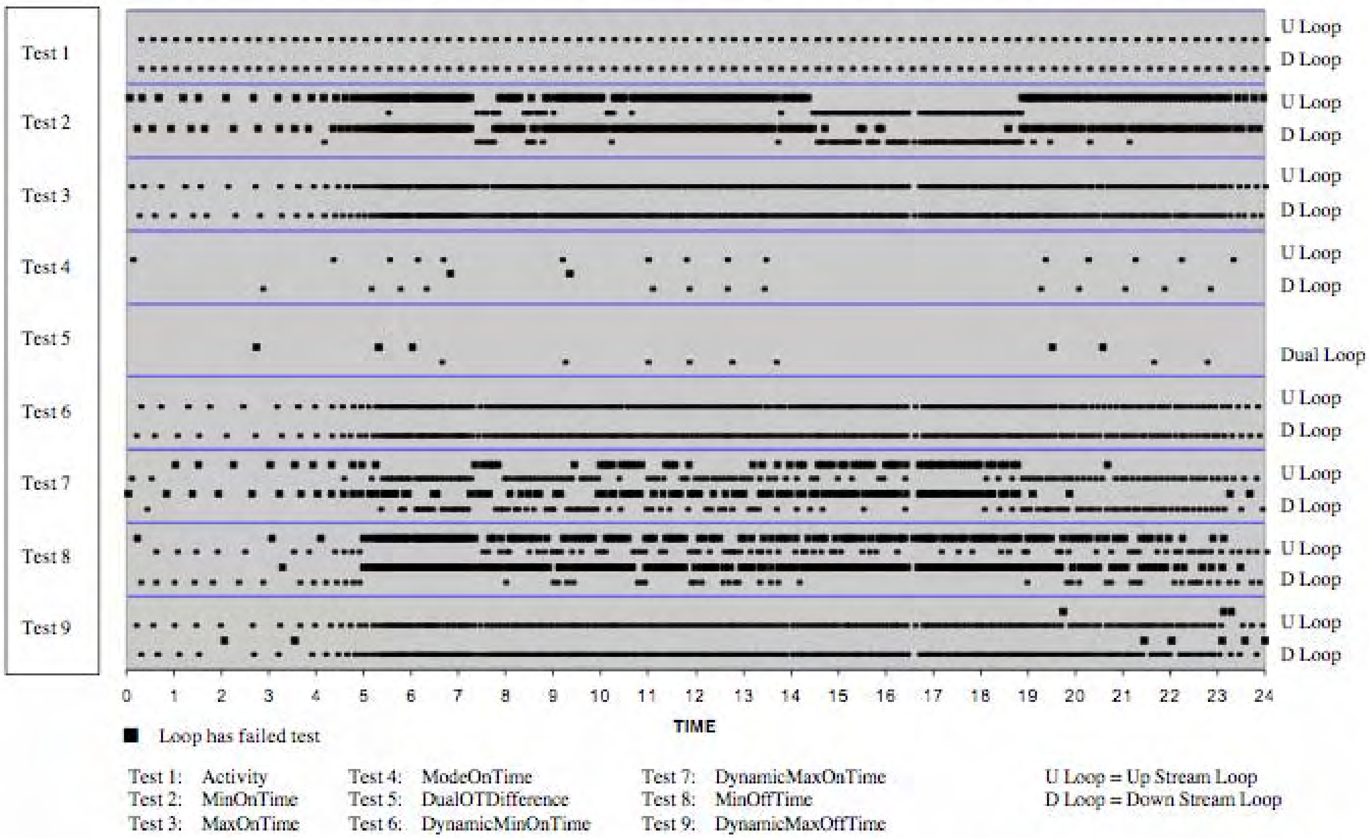


Illustration 4.44 Lane 5 Upstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

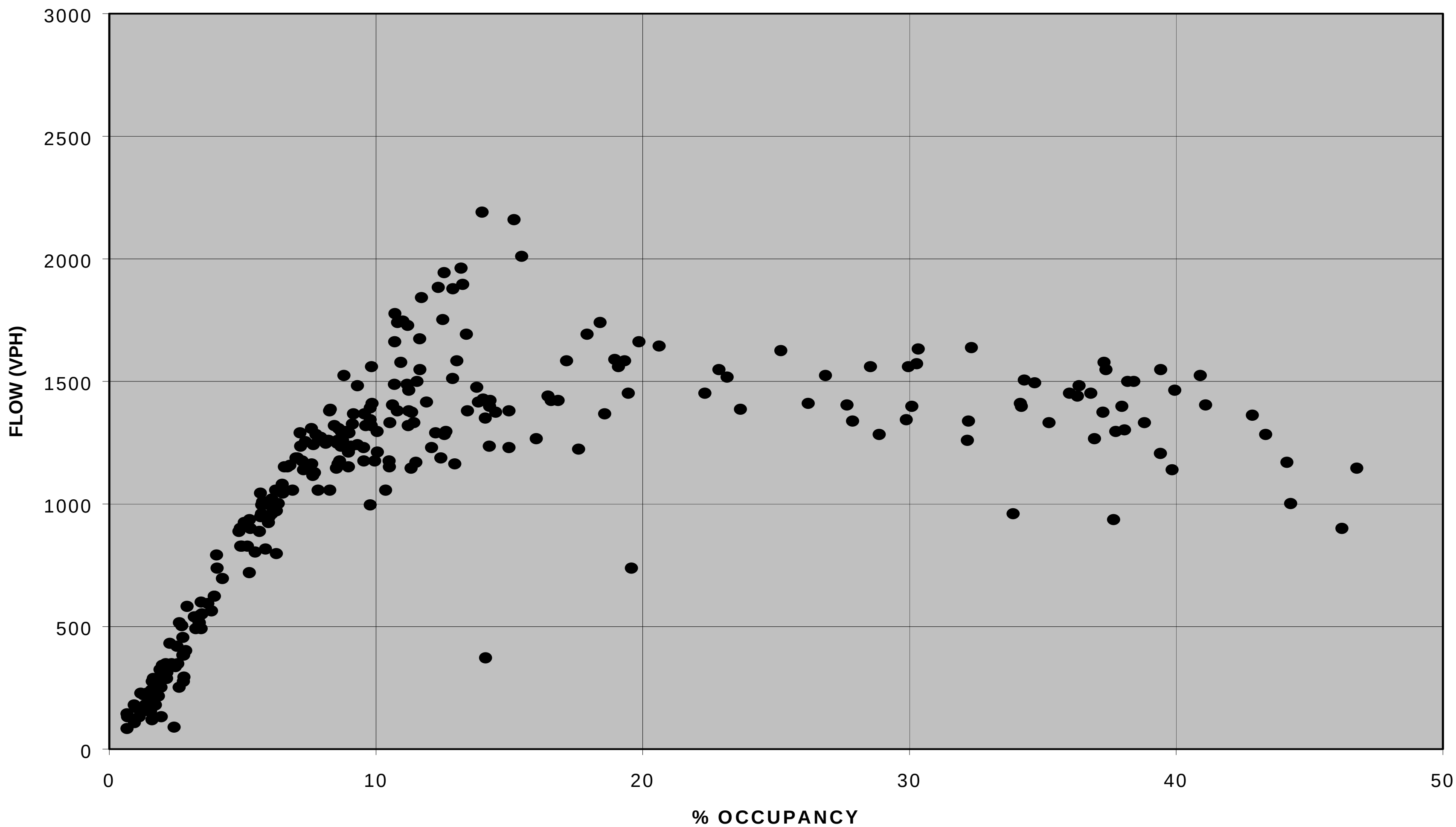


Illustration 4.45 Lane 5 Downstream Flow Rate versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

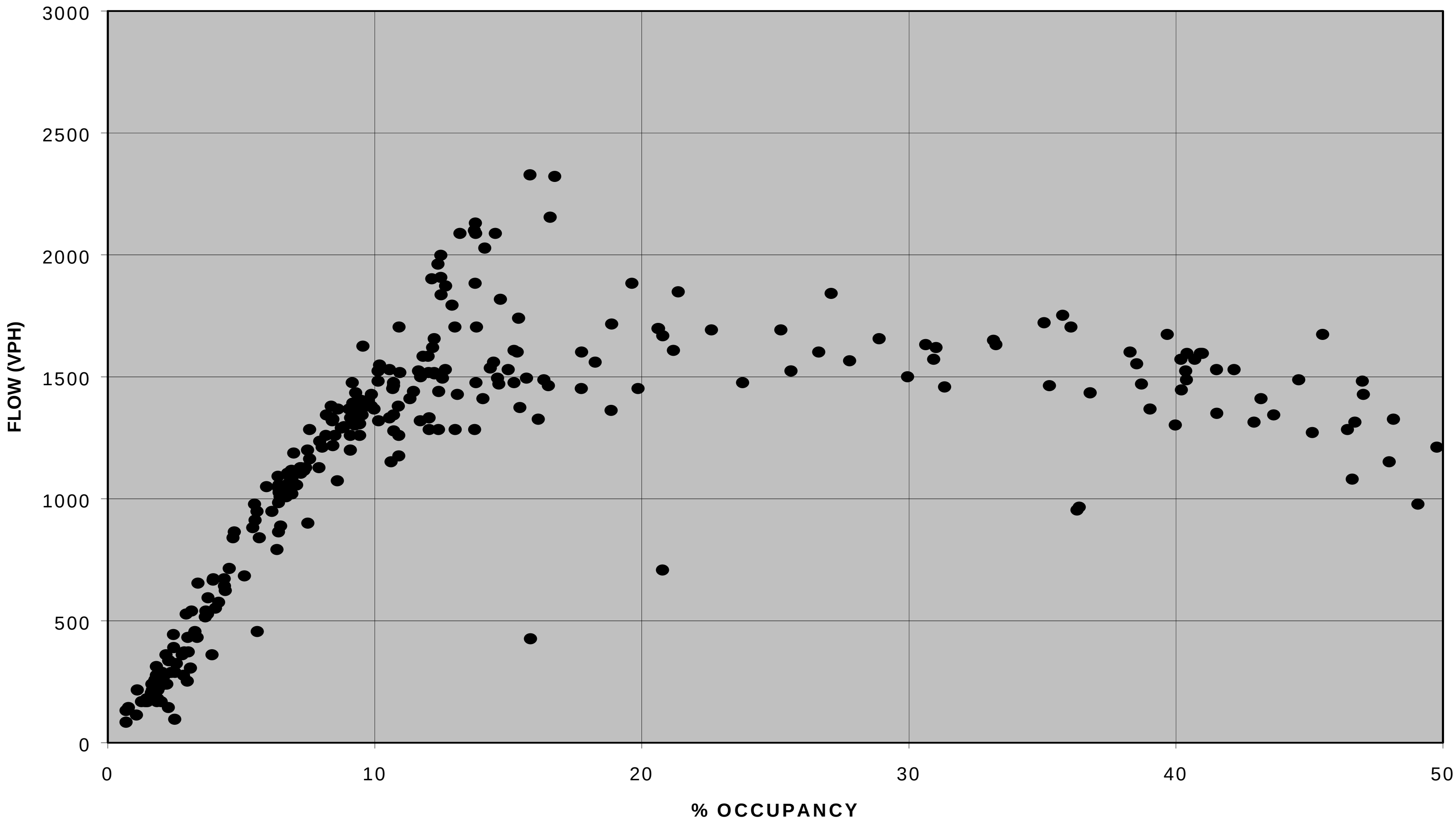


Illustration 4.46 Lane 5 Upstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

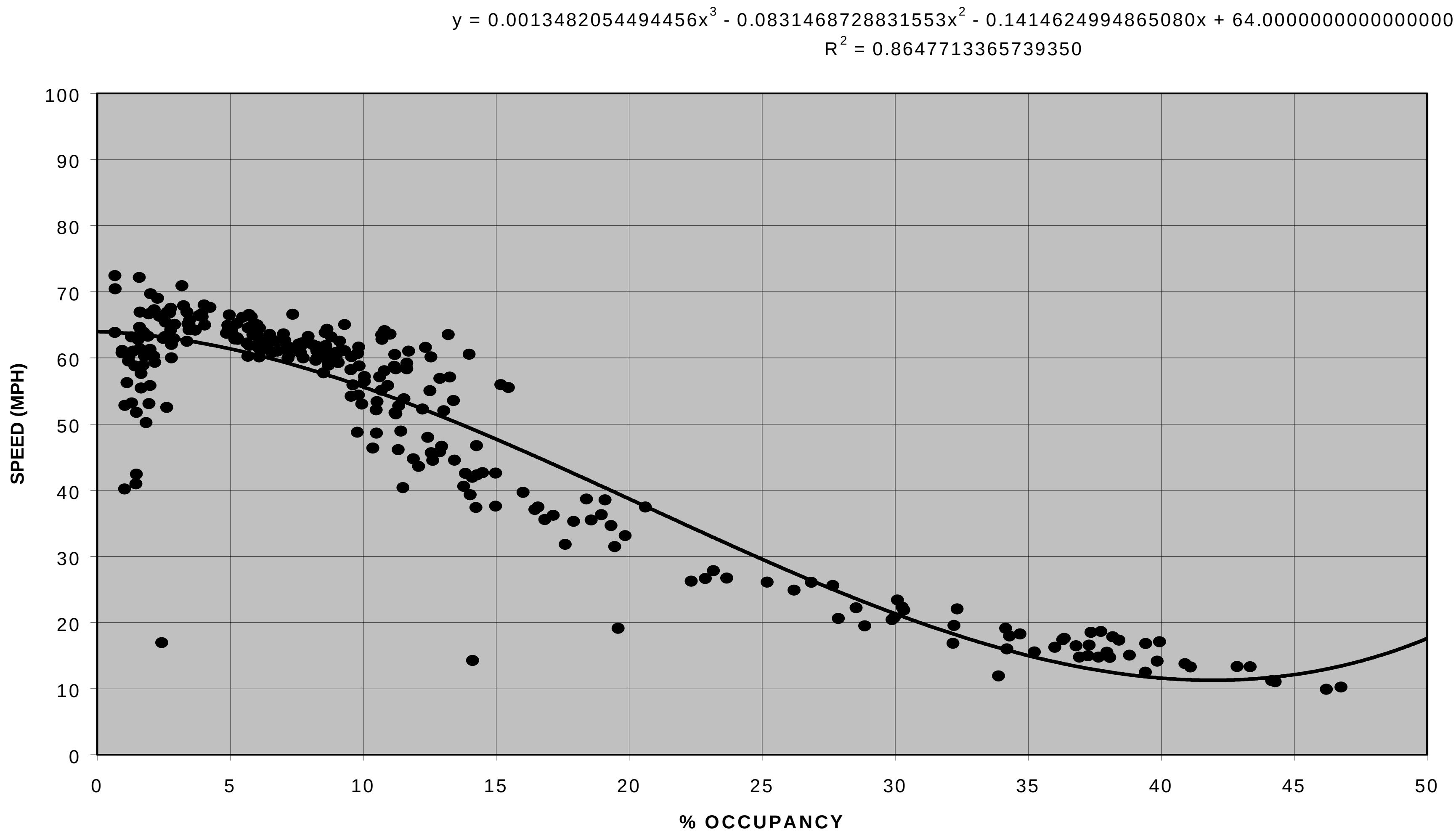


Illustration 4.47 Lane 5 Downstream Average Speed versus Percent Occupancy Relationship at Station 8W (Thurs 3/4/04)

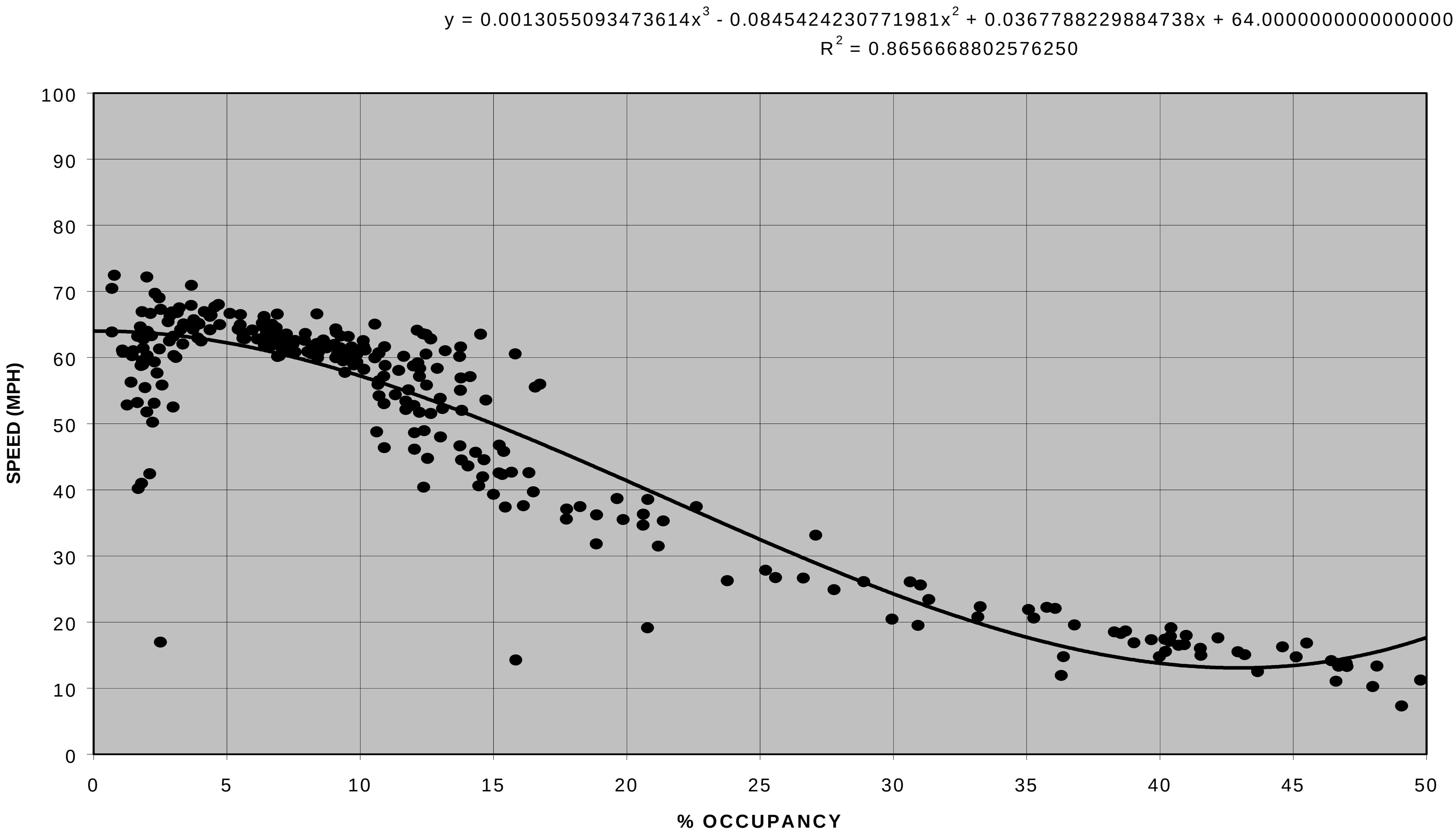


Illustration 4.48 Lane 5 Upstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

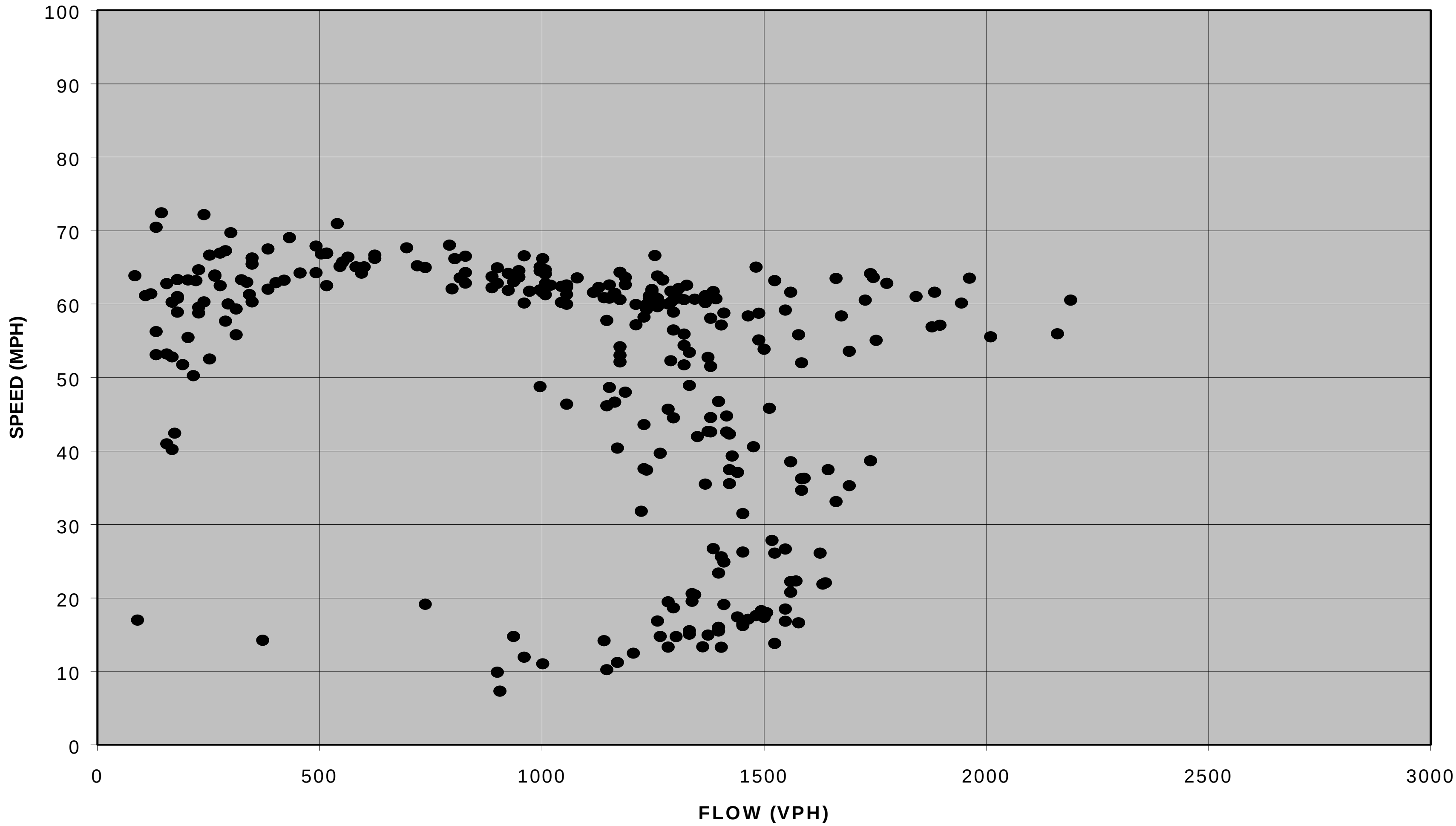


Illustration 4.49 Lane 5 Downstream Average Speed versus Flow Rate Relationship at Station 8W (Thurs 3/4/04)

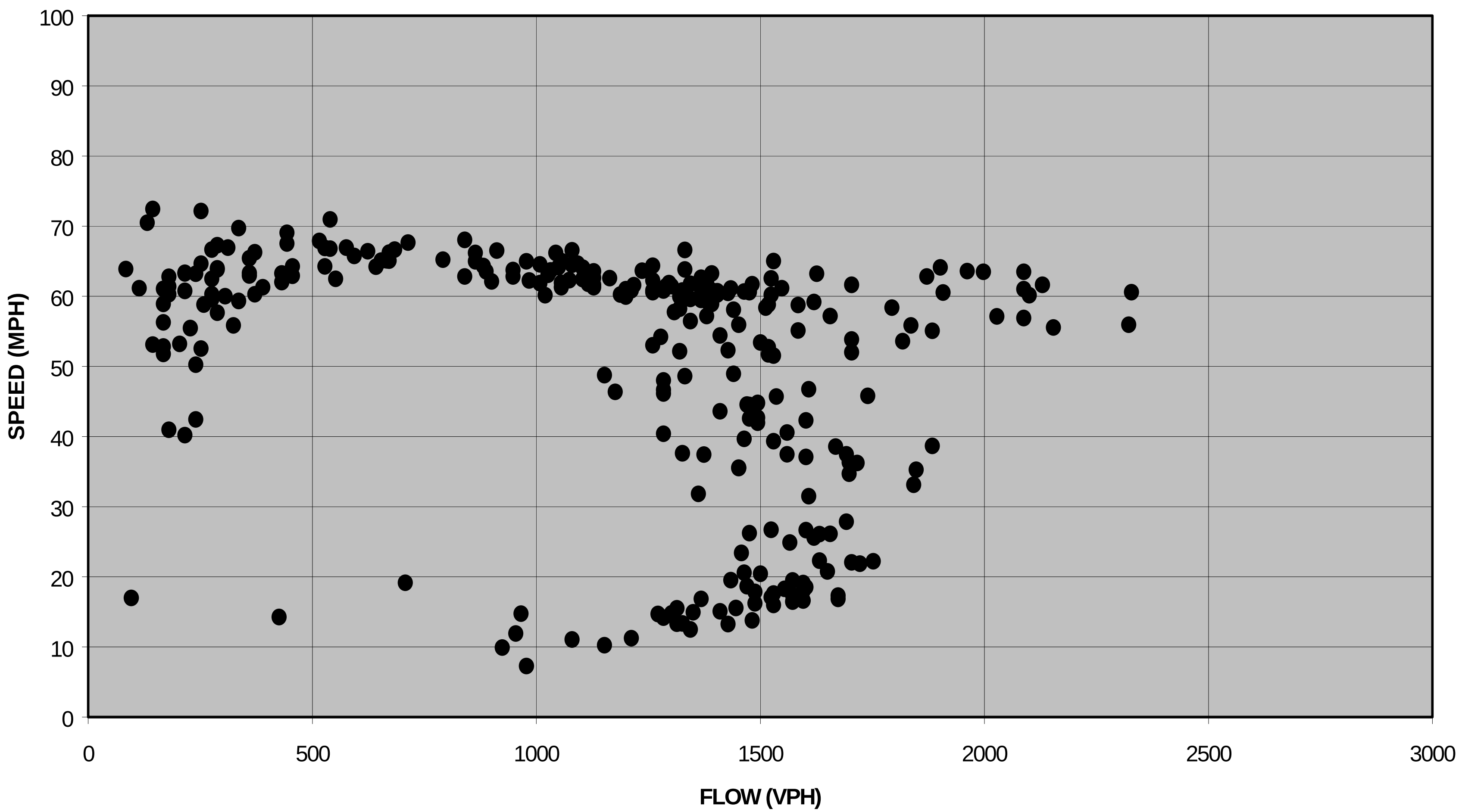


Illustration 4.50 Lane 5 Upstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

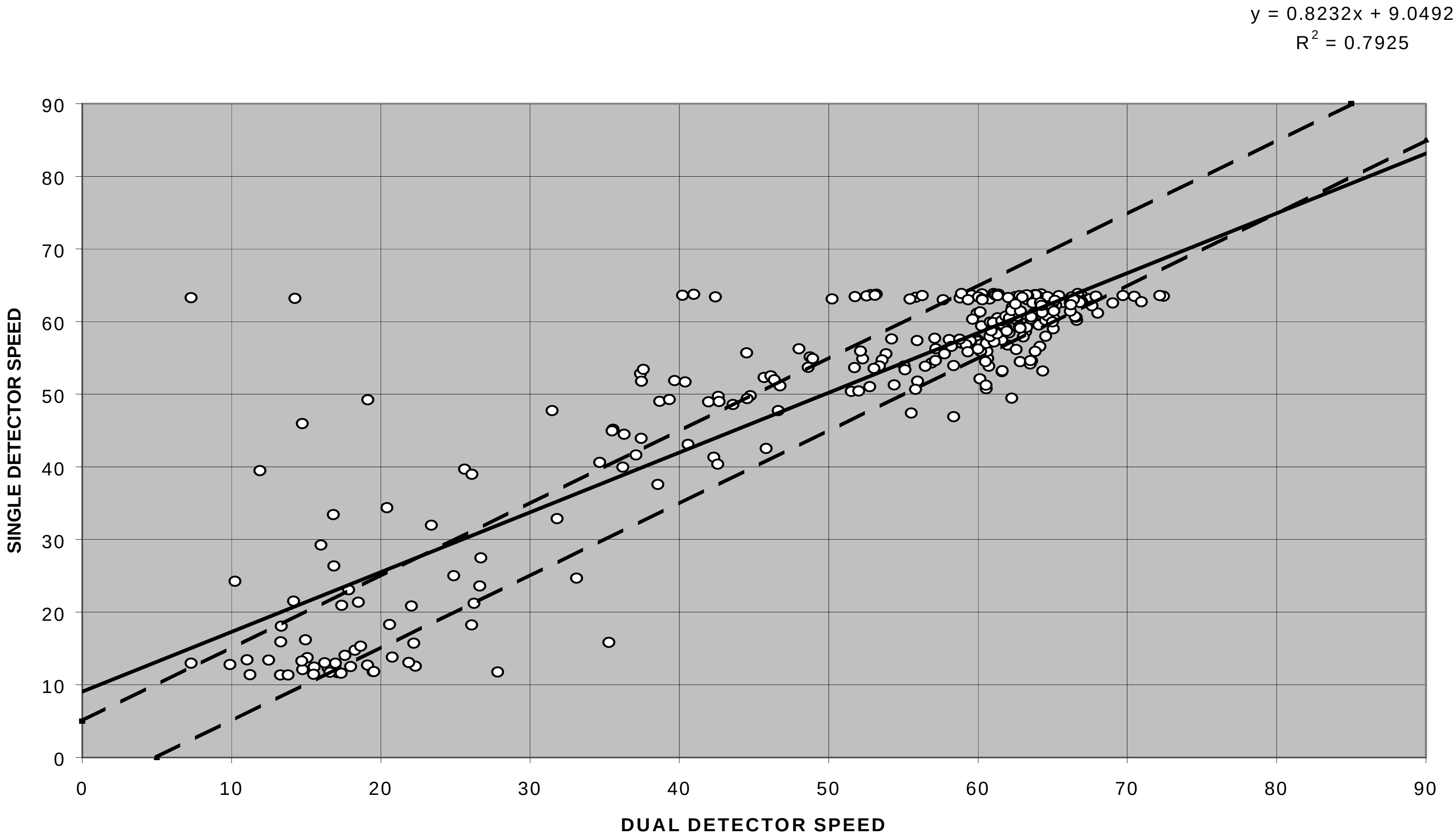


Illustration 4.51 Lane 5 Downstream Comparison of Dual-Detector and Single-Detector Estimated Average Speed at Station 8W (Thurs 3/4/04)

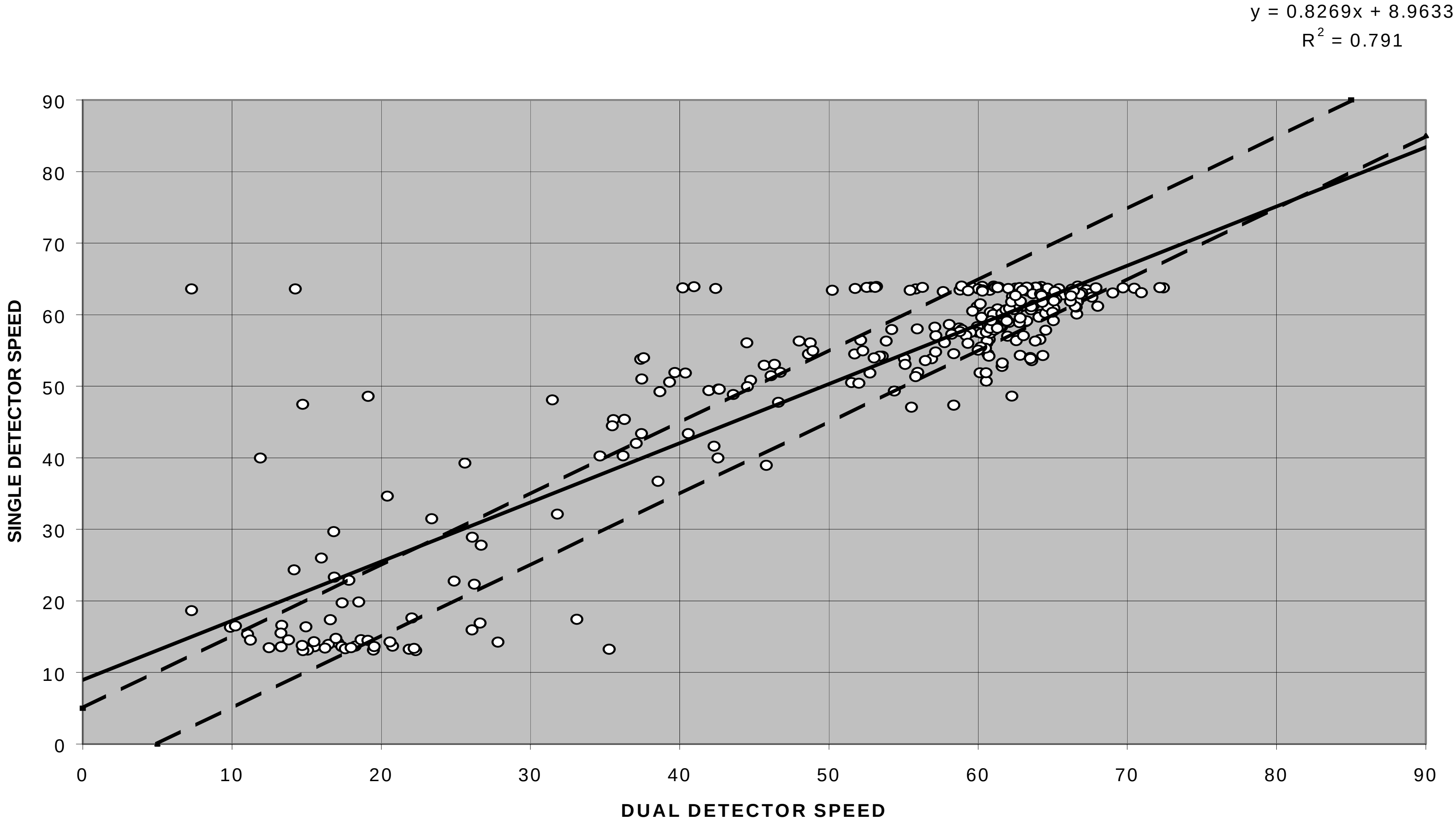


Illustration 4.52 Total Flow over All Lanes (vph) at Station 8W (Thurs 3/4/04)

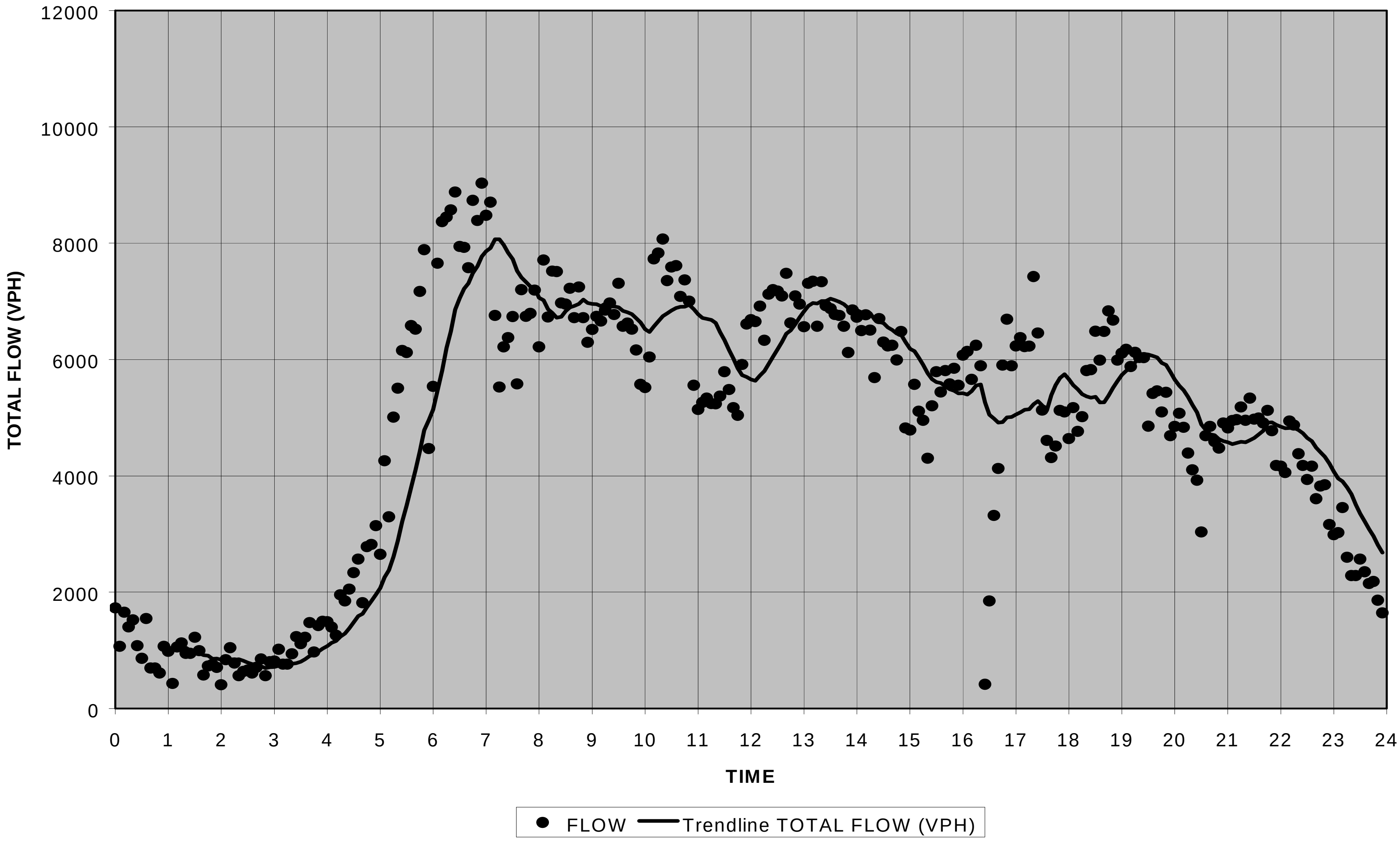
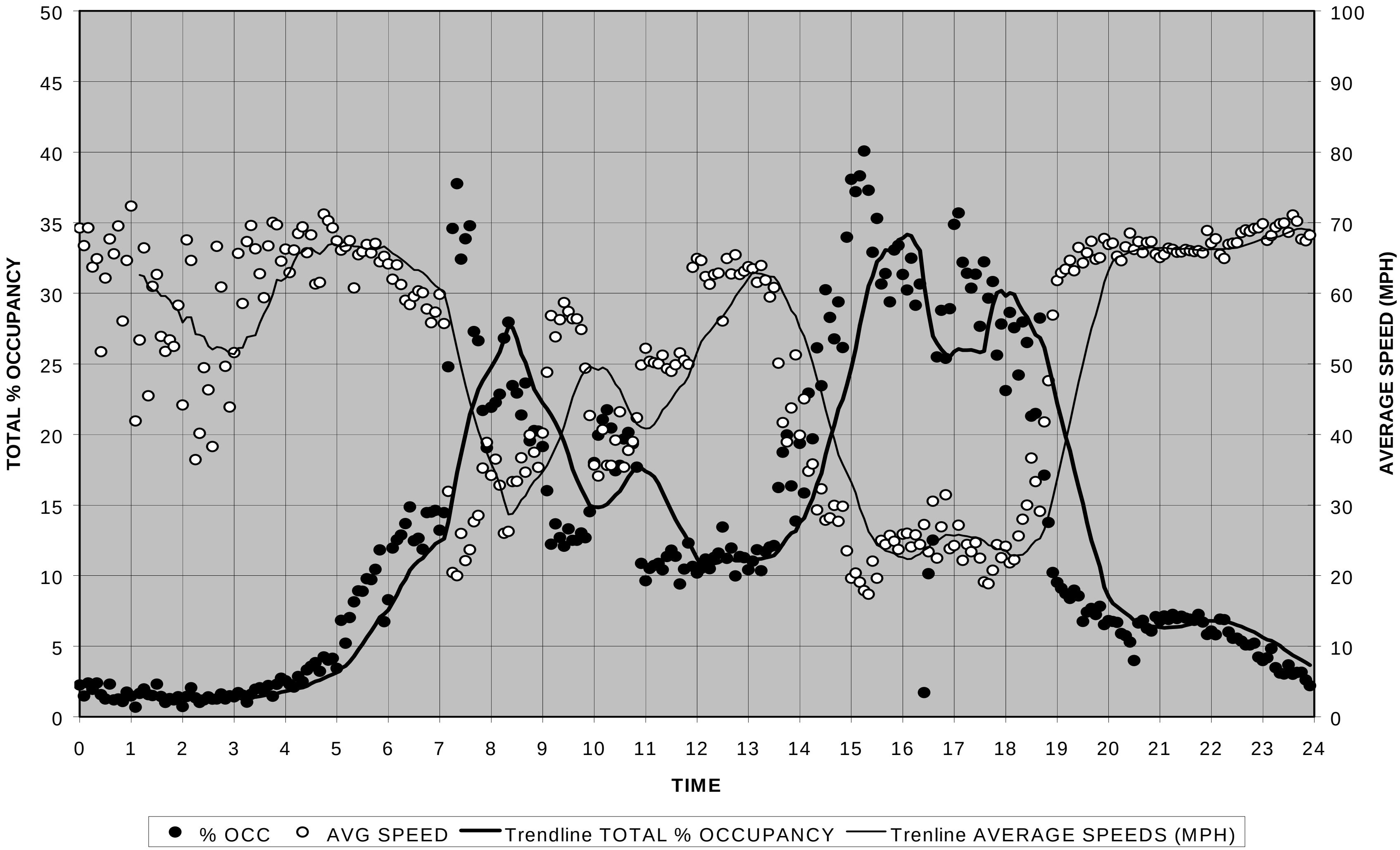


Illustration 4.53 Average percent Occupancy and Average Speed at Station 8W (Thurs 3/4/04)



APPENDIX D - Excel Macro to Calculate 5-Minute Aggregate Data from 30-Second Summary Data for Direction Station

Excel Macro to Calculate 5-Minute Aggregate Data from 30-Second Summary Data for Direction Station

Note Num_of_Lanes should be set to 5 or 6 depending on lane configuration at station.

```
Sub FiveMinAgg()

Dim i As Integer

Dim VolUp(10) As Single
Dim VolDwn(10) As Single
Dim OccUp(10) As Single
Dim OccDwn(10) As Single
Dim Speed(10) As Single
Dim VolSum(10) As Long

Dim Convert_To_MPH As Single
Dim Counter As Integer
Dim AvgVol As Single
Dim Next_Time As Double
Dim Delta_Time As Single
Dim Num_of_Lanes As Single

Dim Current_Row As Long
Dim Last_Row As Long
Dim Paste_Row As Long

'initialize variables
Counter = 0
Next_Time = 1078214700000#
Delta_Time = 300000     '(five minutes)
Current_Row = 2
Num_of_Lanes = 5
Convert_To_MPH = 3600000 / Delta_Time '(milisecs per hour)

For i = 1 To Num_of_Lanes
  VolUp(i) = 0
  VolDwn(i) = 0
  OccUp(i) = 0
  OccDwn(i) = 0
  Speed(i) = 0
```

```
  VolSum(i) = 0
Next i

'set active sheet
Sheets("30_SEC_DATA").Select

'Count rows
Cells(1, 1).Select
ActiveCell.CurrentRegion.Select
Last_Row = Selection.Rows.Count

'loop over all rows
Do Until Current_Row = Last_Row + 1
  If Cells(Current_Row, 1) < Next_Time Then
    For i = 1 To Num_of_Lanes
      VolUp(i) = VolUp(i) + Cells(Current_Row, (i - 1) * 5 + 3)
      VolDwn(i) = VolDwn(i) + Cells(Current_Row, (i - 1) * 5 + 4)
      OccUp(i) = OccUp(i) + Cells(Current_Row, (i - 1) * 5 + 5)
      OccDwn(i) = OccDwn(i) + Cells(Current_Row, (i - 1) * 5 + 6)

      If (Cells(Current_Row, (i - 1) * 5 + 3) = 0) Then
        AvgVol = Cells(Current_Row, (i - 1) * 5 + 4)
      ElseIf (Cells(Current_Row, (i - 1) * 5 + 4) = 0) Then
        AvgVol = Cells(Current_Row, (i - 1) * 5 + 3)
      Else
        AvgVol = (Cells(Current_Row, (i - 1) * 5 + 3) + Cells(Current_Row, (i - 1)
* 5 + 4)) / 2
      End If

      Speed(i) = Speed(i) + Cells(Current_Row, (i - 1) * 5 + 7) * AvgVol
      VolSum(i) = VolSum(i) + AvgVol
    Next i

    Counter = Counter + 1
    Current_Row = Current_Row + 1
  Else
    If Counter <> 0 Then

      'calculate 5 min aggretates and paste in 5_MIN_AGG
      Sheets("5_MIN_AGG").Select
      Cells(1, 1).Select
      ActiveCell.CurrentRegion.Select
      Paste_Row = Selection.Rows.Count + 1
      Cells(Paste_Row, 1) = Next_Time – 300000
```

```
      For i = 1 To Num_of_Lanes
        Cells(Paste_Row, (i - 1) * 5 + 2) = VolUp(i) * Convert_To_MPH
        Cells(Paste_Row, (i - 1) * 5 + 3) = VolDwn(i) * Convert_To_MPH
        Cells(Paste_Row, (i - 1) * 5 + 4) = OccUp(i) / Counter
        Cells(Paste_Row, (i - 1) * 5 + 5) = OccDwn(i) / Counter
        If (VolSum(i) <> 0) Then
          Cells(Paste_Row, (i - 1) * 5 + 6) = Speed(i) / VolSum(i)
        Else
          Cells(Paste_Row, (i - 1) * 5 + 6) = 0
        End If
      Next i

      'Return to original sheet
      Sheets("30_SEC_DATA").Select
      Next_Time = Next_Time + 300000

      'initialize variables
      For i = 1 To Num_of_Lanes
        VolUp(i) = 0
        VolDwn(i) = 0
        OccUp(i) = 0
        OccDwn(i) = 0
        Speed(i) = 0
        VolSum(i) = 0
      Next i
      Counter = 0
    Else
      Next_Time = Next_Time + Delta_Time
    End If 'counter <> 0
  End If   'time < next time

Loop

'Store last aggregate
If Counter <> 0 Then
  'calculate and paste 5 min aggregates in 5_MIN_AGG
  Sheets("5_MIN_AGG").Select
  Cells(1, 1).Select
  ActiveCell.CurrentRegion.Select
  Paste_Row = Selection.Rows.Count + 1

  'Paste_Row = Application.Worksheet.Function.CountA(Range("A:A")) + 1
  Cells(Paste_Row, 1) = Next_Time – 300000
```

```
    For i = 1 To Num_of_Lanes
      Cells(Paste_Row, (i - 1) * 5 + 2) = VolUp(i) * Convert_To_MPH
      Cells(Paste_Row, (i - 1) * 5 + 3) = VolDwn(i) * Convert_To_MPH
      Cells(Paste_Row, (i - 1) * 5 + 4) = OccUp(i) / Counter
      Cells(Paste_Row, (i - 1) * 5 + 5) = OccDwn(i) / Counter
      If (VolSum(i) <> 0) Then
        Cells(Paste_Row, (i - 1) * 5 + 6) = Speed(i) / VolSum(i)
      Else
        Cells(Paste_Row, (i - 1) * 5 + 6) = 0
      End If
    Next i
    Counter = 0

    'Return to original sheet
    Sheets("30_SEC_DATA").Select
  End If

  End Sub
```

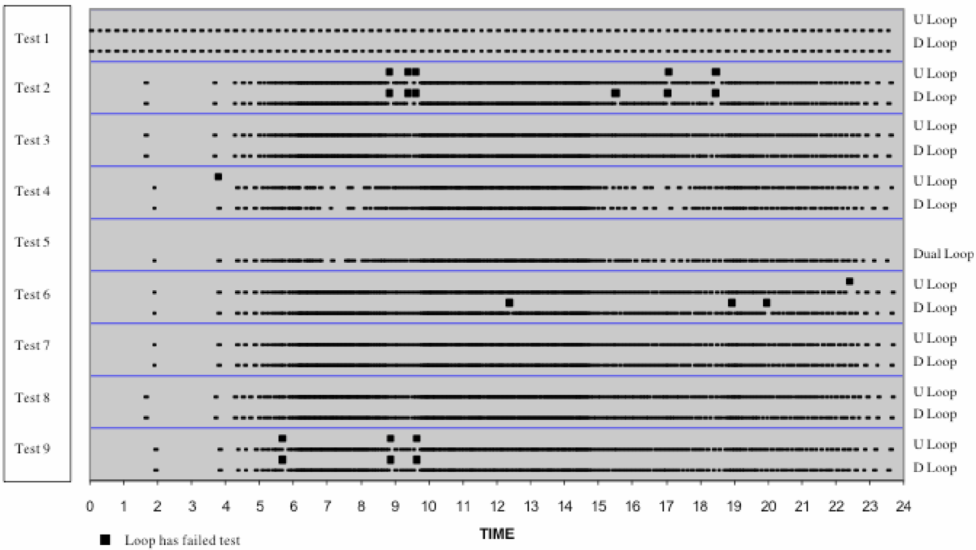
APPENDIX E – Illustrations for Chapter 6

Illustration 6.1 Initial and Final Detector Diagnostic Test Failures for Tuesday, March 2, 2004

STATION	LANE	LOOP	TEST 1		TEST 2		TEST 3		TEST 4		TEST 5		TEST 6		TEST 7		TEST 8		TEST 9	
4W	1	UP	0	0	7	5	0	0	1	1	0	0	0	1	0	0	9	0	25	3
4W	1	DOWN	0	0	10	6	0	0	0	0			0	3	0	0	8	0	25	3
4W	2	UP	0	0	0	0	0	0	1	0	0	0	0	2	12	0	5	0	2	3
4W	2	DOWN	0	0	0	0	0	0	1	0			0	1	8	0	4	0	2	4
4W	3	UP	0	0	0	0	0	0	1	0	0	0	0	0	>45	0	2	0	0	0
4W	3	DOWN	0	0	0	0	0	0	1	0			0	0	>45	1	3	0	0	0
4W	4	UP	0	0	0	0	0	0	1	0	0	0	0	0	>55	4	6	0	0	0
4W	4	DOWN	0	0	0	0	0	0	1	0			0	0	>55	5	4	0	1	0
4W	5	UP	0	0	0	0	0	0	1	0	0	0	0	0	6	2	4	0	1	1
4W	5	DOWN	0	0	0	0	0	0	1	0			0	0	7	2	4	0	0	2
5W	1	UP	0	0	6	6	0	0	1	1	0	0	0	3	0	0	6	0	25	1
5W	1	DOWN	0	0	3	8	0	0	0	1			0	1	0	0	2	0	25	2
5W	2	UP	0	0	0	0	0	0	2	0	0	0	0	1	9	0	11	0	2	1
5W	2	DOWN	0	0	0	0	0	0	2	0			0	3	10	0	10	0	2	1
5W	3	UP	0	0	0	0	0	0	1	0	0	0	0	0	>60	1	2	0	0	0
5W	3	DOWN	0	0	0	0	0	0	1	0			0	0	>60	1	1	0	0	0
5W	4	UP	0	0	0	0	0	0	1	0	0	0	0	0	>55	3	6	0	1	1
5W	4	DOWN	0	0	0	0	0	0	1	0			0	0	>55	3	8	1	1	3
5W	5	UP	0	0	0	0	0	0	2	0	0	0	0	0	7	2	6	0	0	3
5W	5	DOWN	0	0	0	0	0	0	2	0			0	0	5	1	5	0	2	4
8W	1	UP	0	0	11	12	0	0	0	0	0	0	0	0	2	0	2	0	20	1
8W	1	DOWN	0	0	10	10	0	0	1	0			0	0	2	0	2	0	24	2
8W	2	UP	4	4	50	50	1	1	10	>65	11	10	0	0	11	9	20	13	10	7
8W	2	DOWN	0	0	10	10	0	0	1	0			0	0	0	0	17	2	8	10
8W	3	UP	0	0	31	34	0	0	3	0	0	0	0	0	9	0	>60	15	4	4
8W	3	DOWN	0	0	45	45	0	0	3	0			0	0	10	0	>60	26	6	5
8W	4	UP	0	0	80	80	0	0	1	10	10	8	0	0	>70	13	>60	>80	8	4
8W	4	DOWN	0	0	80	80	0	0	10	>30			0	0	>70	22	>90	>95	8	5
8W	5	UP	0	0	80	80	0	0	2	2	4	8	0	0	0	0	>85	>65	8	5
8W	5	DOWN	0	0	80	80	0	0	2	19			0	0	2	3	>90	>80	9	7
8W	6	UP	*	*																
8W	6	DOWN	*	*																

* Detectors at station 8W lane 6 are dead

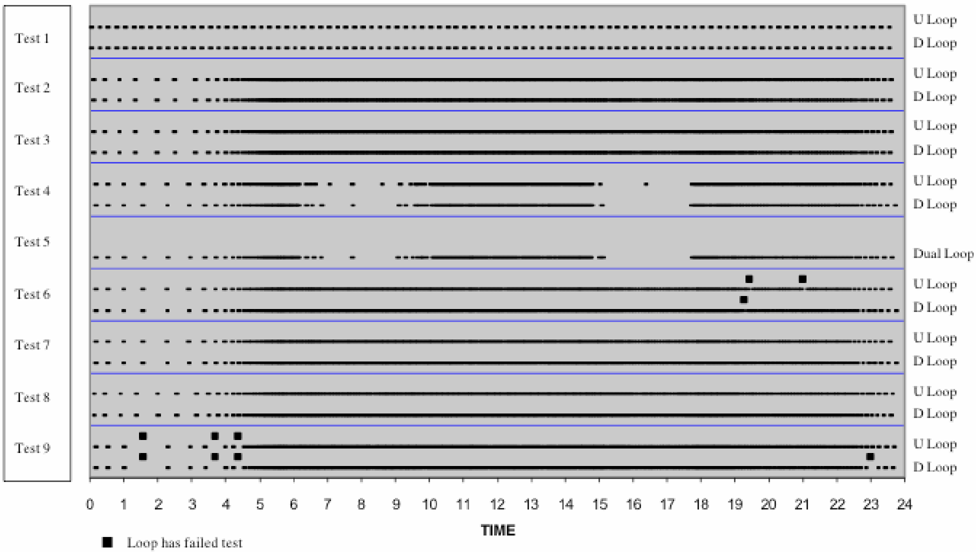
Illustration 6.2 Summary of Refined Detector Diagnostic Results – Lane 1 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

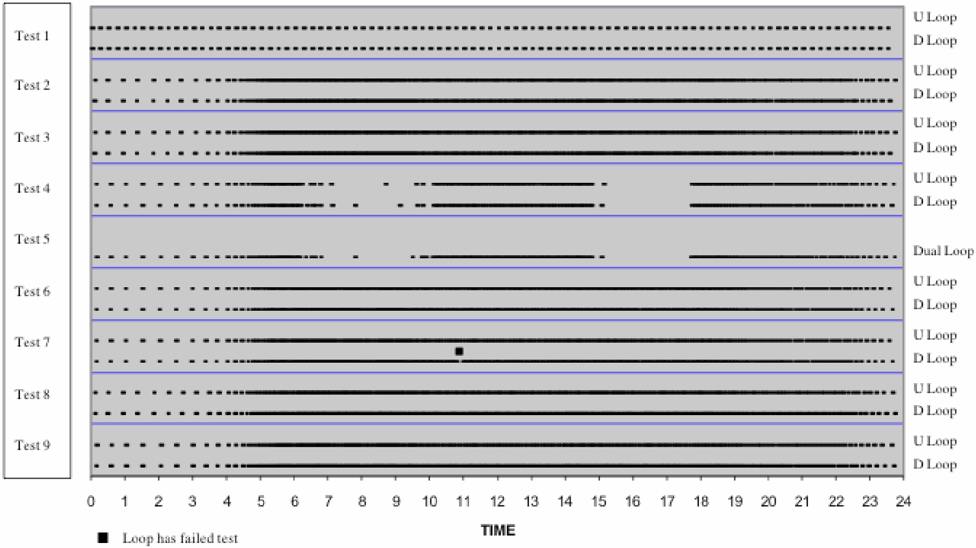
Illustration 6.3 Summary of Refined Detector Diagnostic Results – Lane 2 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

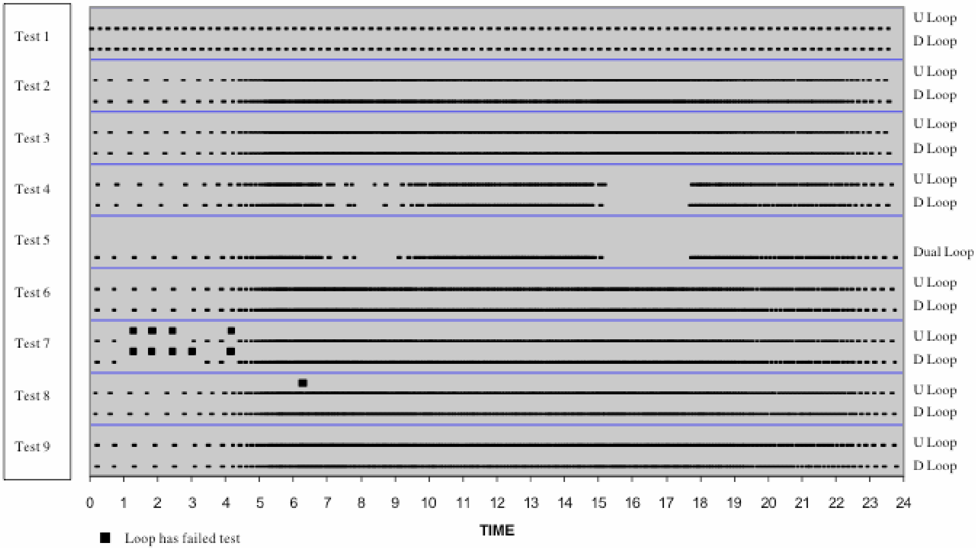
Illustration 6.4 Summary of Refined Detector Diagnostic Results – Lane 3 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

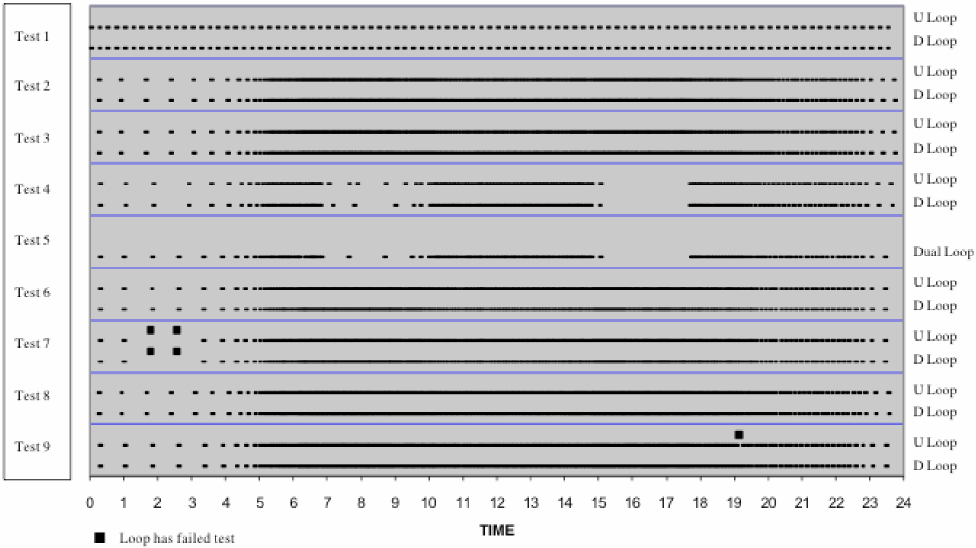
U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 6.5 Summary of Refined Detector Diagnostic Results – Lane 4 at Station 4W (Tuesday 3/2/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime	U Loop = Up Stream Loop
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime	D Loop = Down Stream Loop
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime	

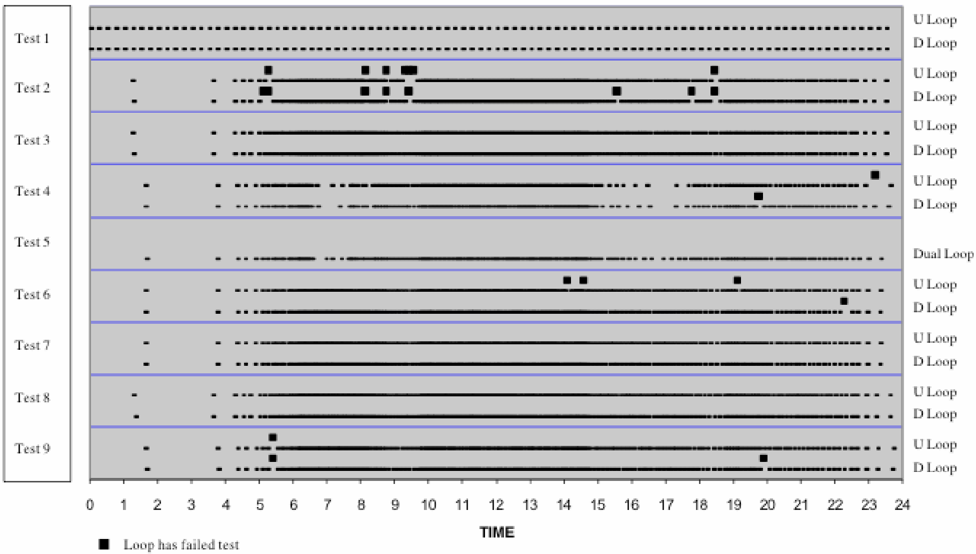
Illustration 6.6 Summary of Refined Detector Diagnostic Results – Lane 5 at Station 4W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

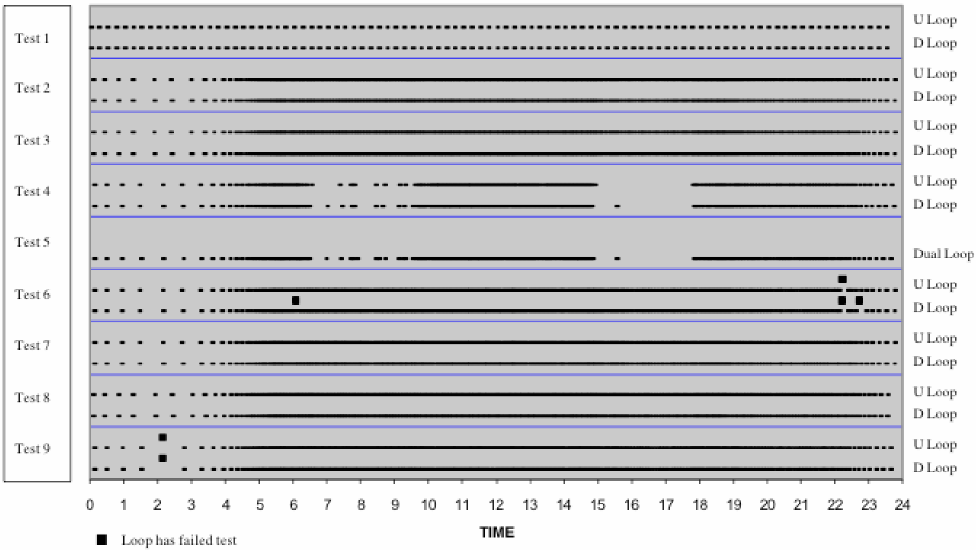
Illustration 6.7 Summary of Refined Detector Diagnostic Results – Lane 1 at Station 5W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

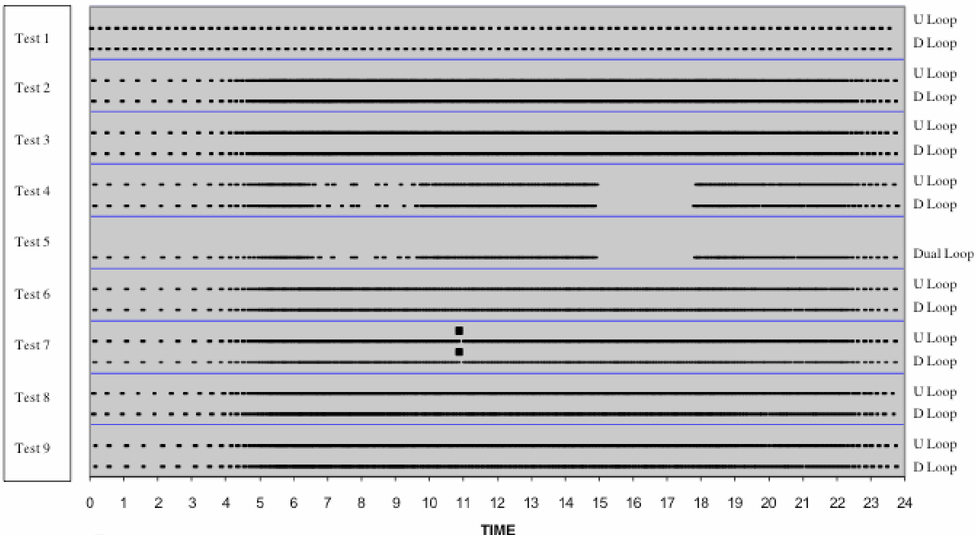
Illustration 6.8 Summary of Refined Detector Diagnostic Results – Lane 2 at Station 5W (Tuesday 3/2/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 6.9 Summary of Refined Detector Diagnostic Results – Lane 3 at Station 5W (Tuesday 3/2/04)



■ Loop has failed test

Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime	U Loop = Up Stream Loop
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime	D Loop = Down Stream Loop
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime	

Illustration 6.10 Summary of Refined Detector Diagnostic Results – Lane 4 at Station 5W (Tuesday 3/2/04)

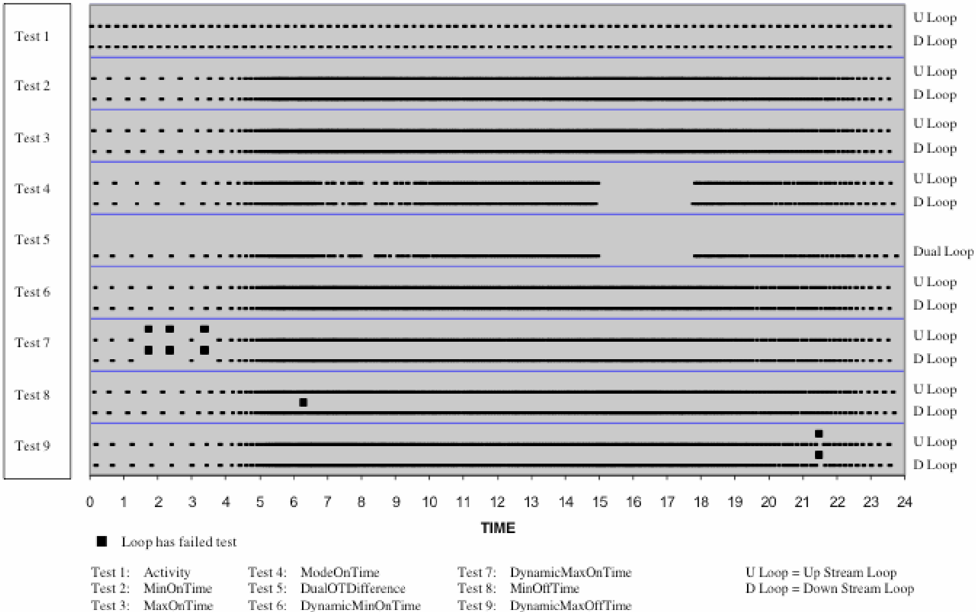
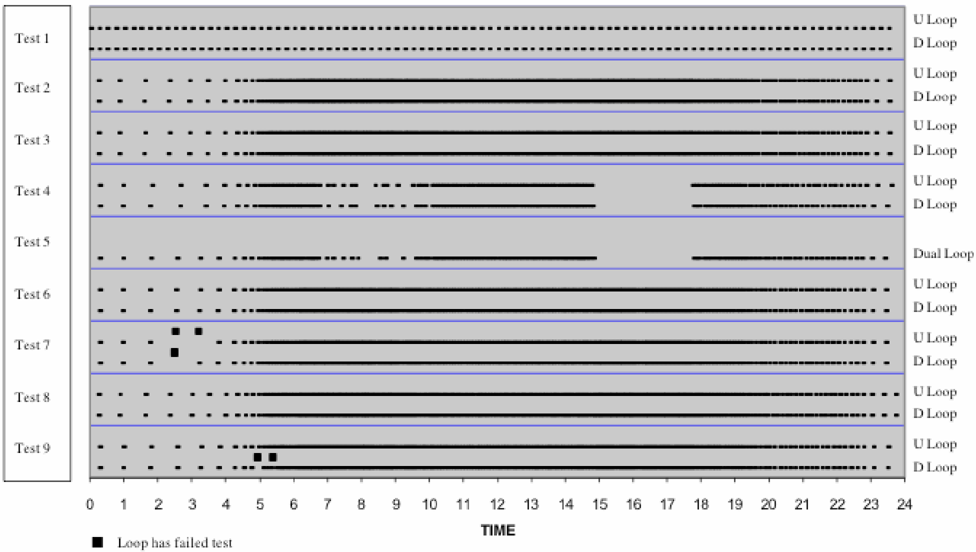


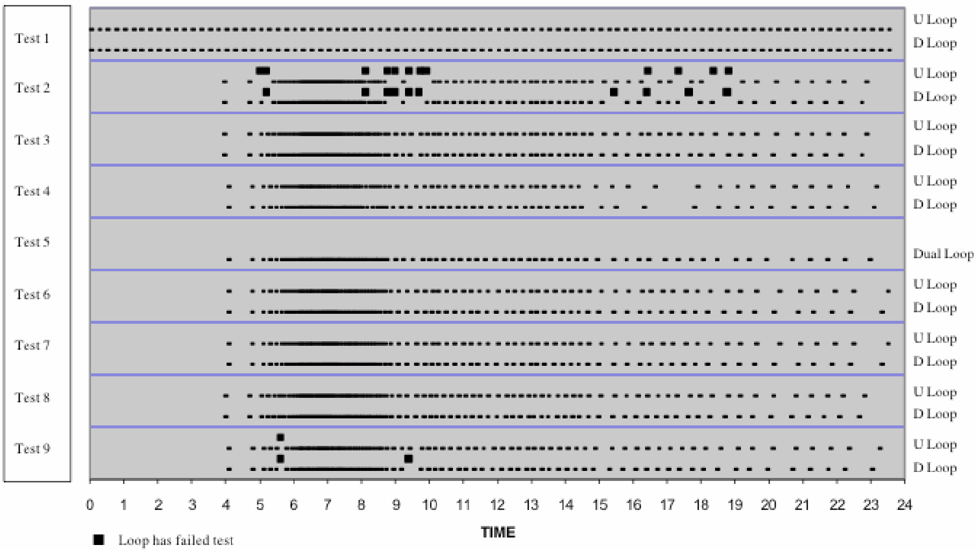
Illustration 6.11 Summary of Refined Detector Diagnostic Results – Lane 5 at Station 5W (Tuesday 3/2/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

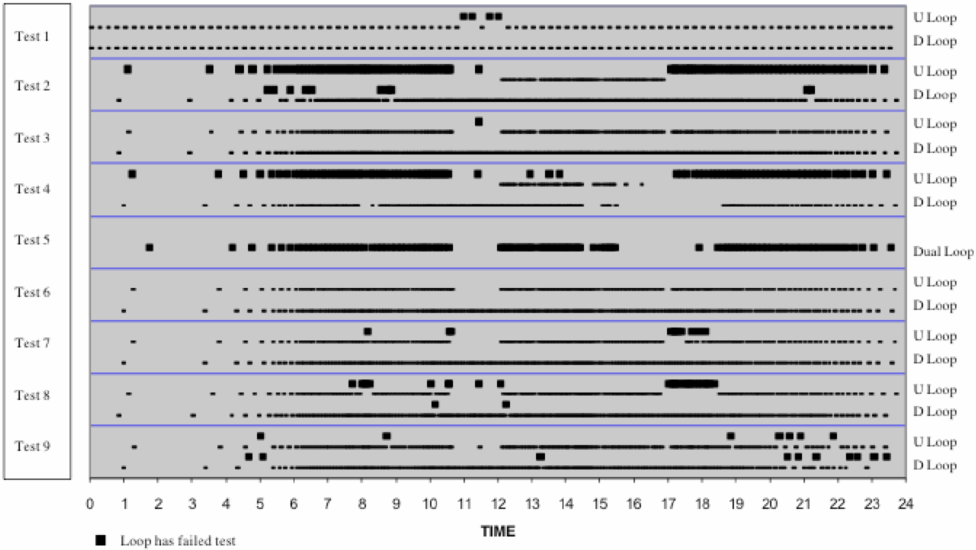
Illustration 6.12 Summary of Refined Detector Diagnostic Results – Lane 1 at Station 8W (Tuesday 3/2/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime

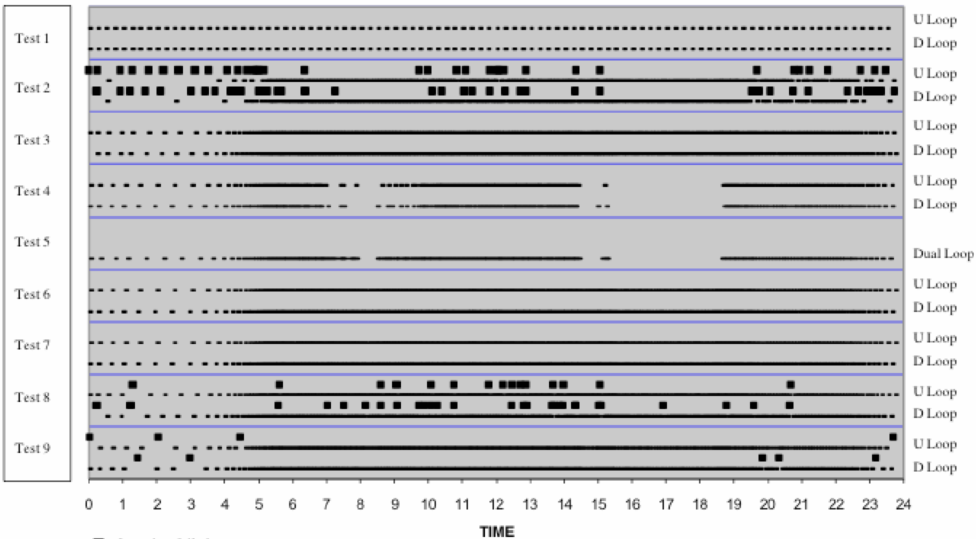
U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 6.13 Summary of Refined Detector Diagnostic Results – Lane 2 at Station 8W (Tuesday 3/2/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime	U Loop = Up Stream Loop
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime	D Loop = Down Stream Loop
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime	

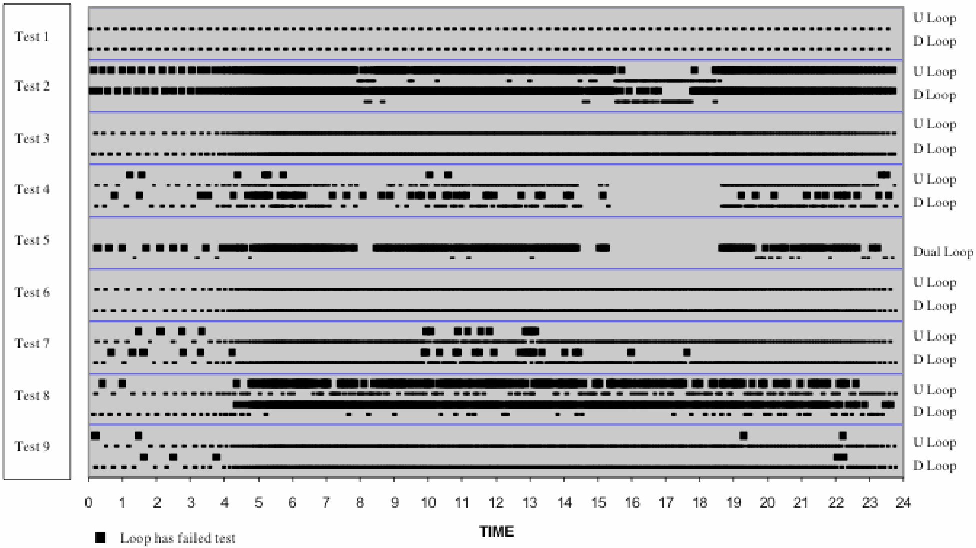
Illustration 6.14 Summary of Refined Detector Diagnostic Results – Lane 3 at Station 8W (Tuesday 3/2/04)



■ Loop has failed test

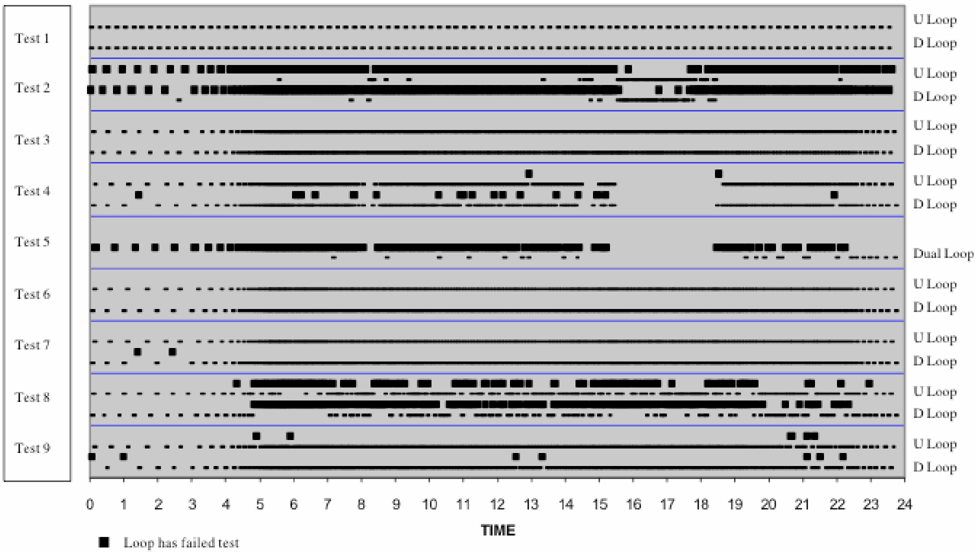
Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime	U Loop = Up Stream Loop
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime	D Loop = Down Stream Loop
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime	

Illustration 6.15 Summary of Refined Detector Diagnostic Results – Lane 4 at Station 8W (Tuesday 3/2/04)



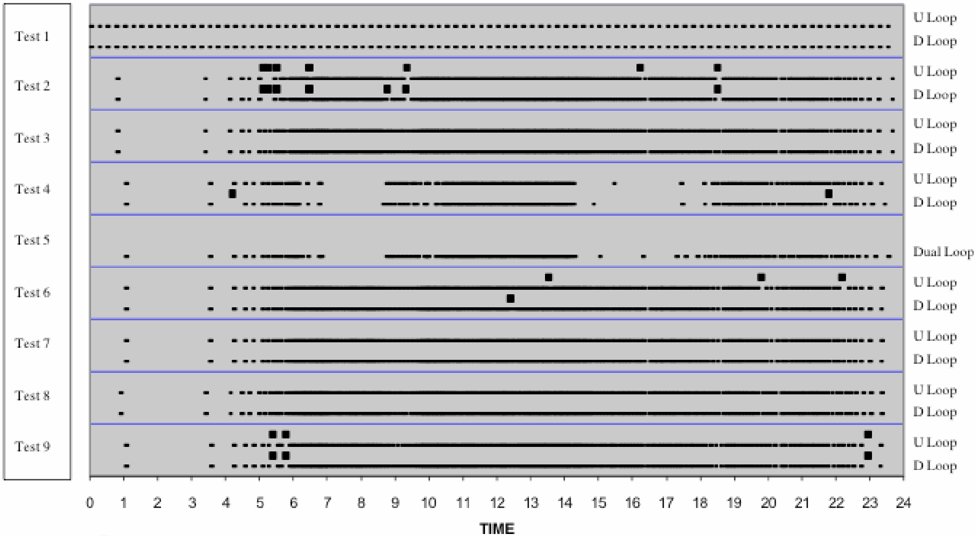
Test 1: Activity	Test 4: ModeOnTime	Test 7: DynamicMaxOnTime	U Loop = Up Stream Loop
Test 2: MinOnTime	Test 5: DualOTDifference	Test 8: MinOffTime	D Loop = Down Stream Loop
Test 3: MaxOnTime	Test 6: DynamicMinOnTime	Test 9: DynamicMaxOffTime	

Illustration 6.16 Summary of Refined Detector Diagnostic Results – Lane 5 at Station 8W (Tuesday 3/2/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime	U Loop = Up Stream Loop
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime	D Loop = Down Stream Loop
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime	

Illustration 6.17 Summary of Refined Detector Diagnostic Results – Lane 1 at Station 4W (Thursday 3/4/04)



■ Loop has failed test

Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 6.18 Summary of Refined Detector Diagnostic Results – Lane 2 at Station 4W (Thursday 3/4/04)

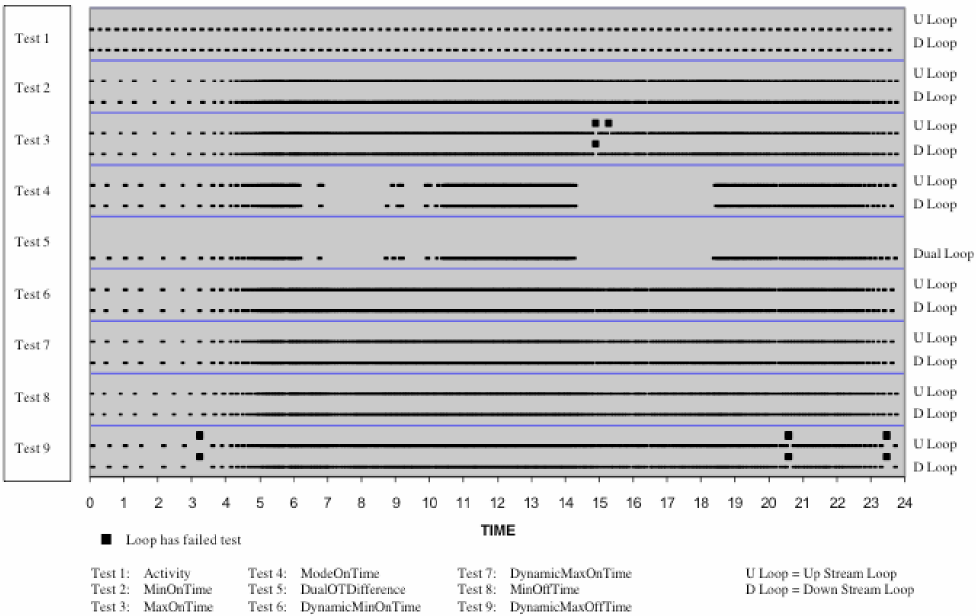
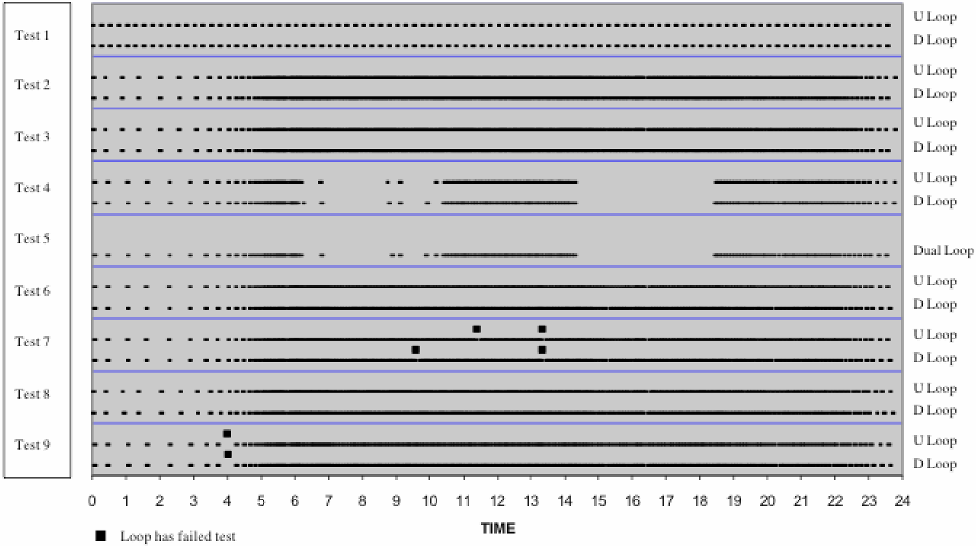


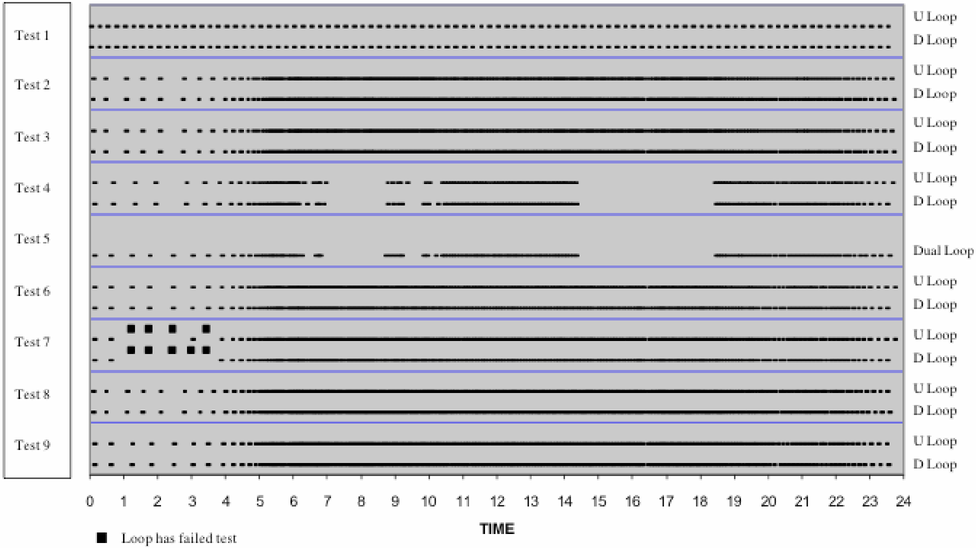
Illustration 6.19 Summary of Refined Detector Diagnostic Results – Lane 3 at Station 4W (Thursday 3/4/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

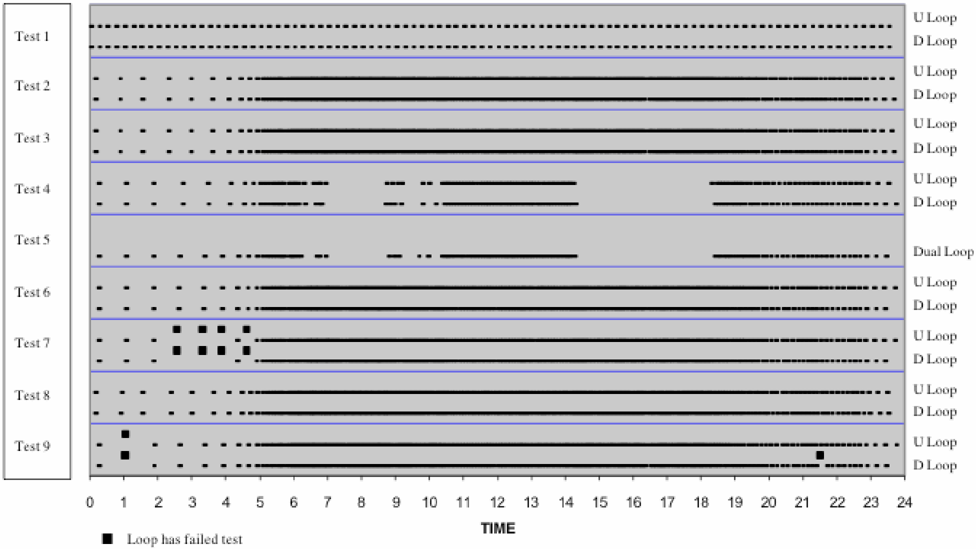
Illustration 6.20 Summary of Refined Detector Diagnostic Results – Lane 4 at Station 4W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

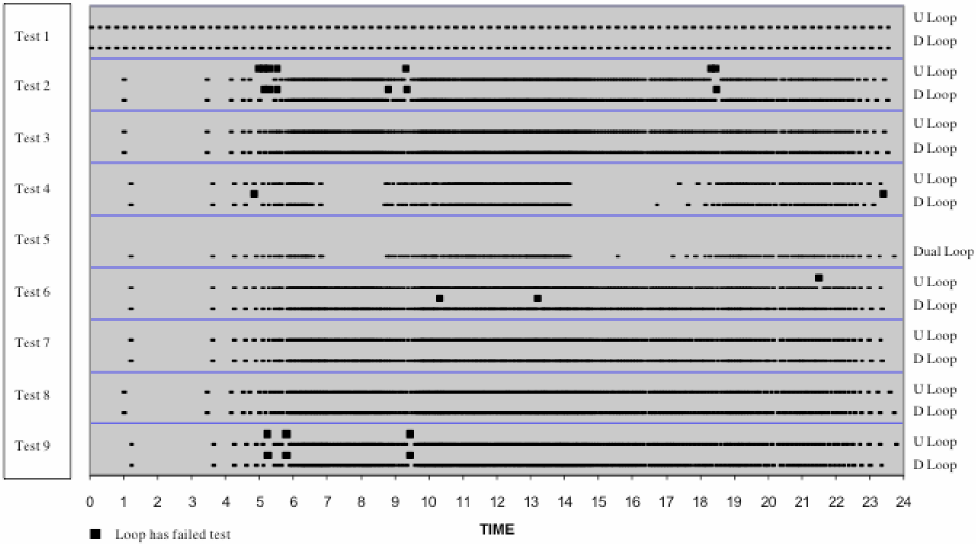
Illustration 6.21 Summary of Refined Detector Diagnostic Results – Lane 5 at Station 4W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

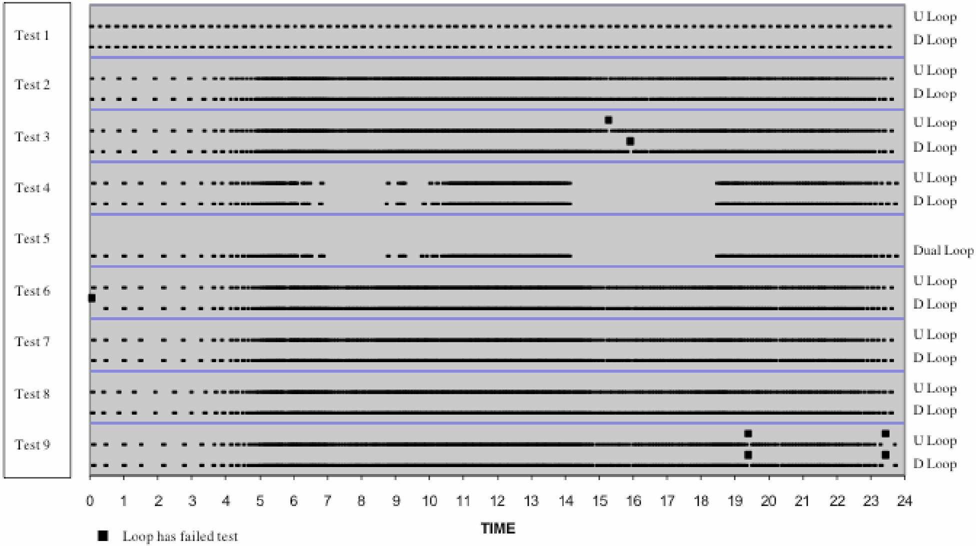
Illustration 6.22 Summary of Refined Detector Diagnostic Results – Lane 1 at Station 5W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

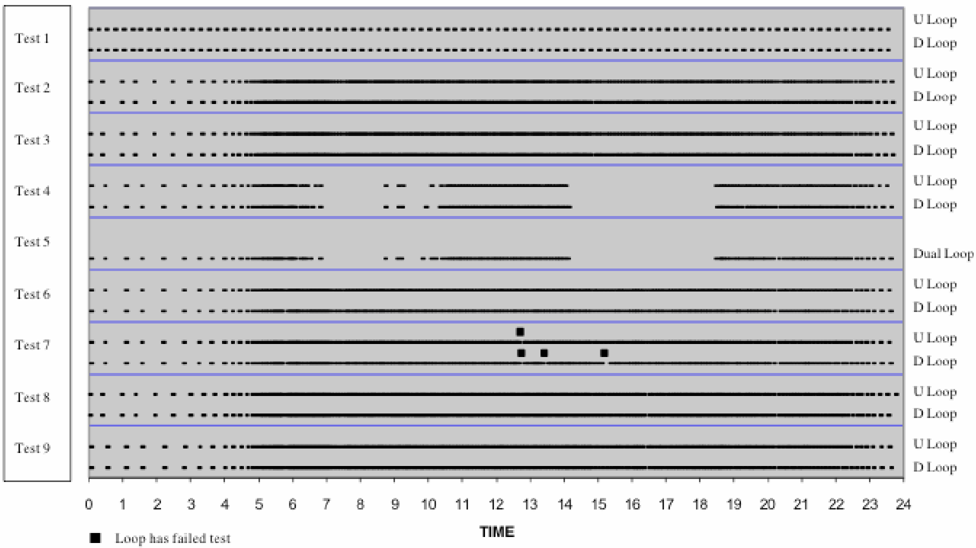
Illustration 6.23 Summary of Refined Detector Diagnostic Results – Lane 2 at Station 5W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

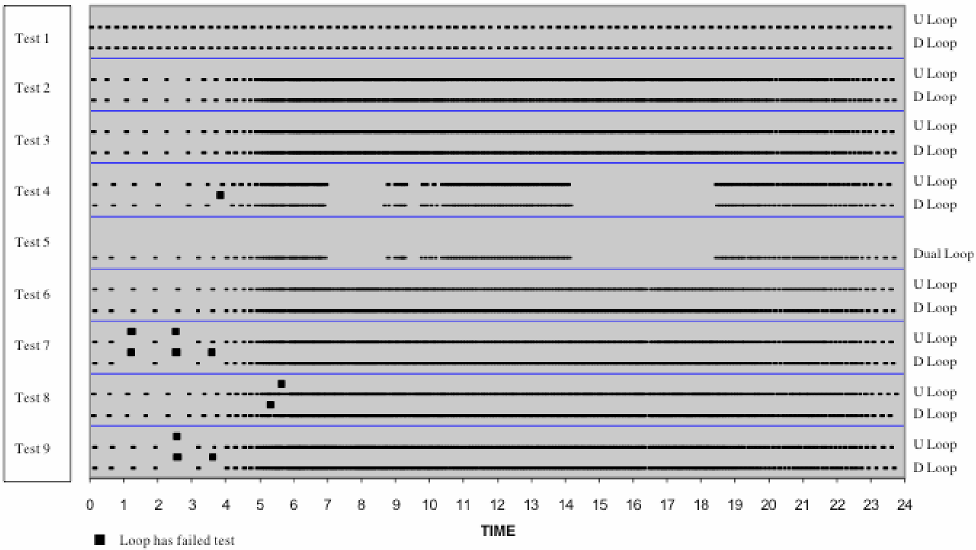
Illustration 6.24 Summary of Refined Detector Diagnostic Results – Lane 3 at Station 5W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

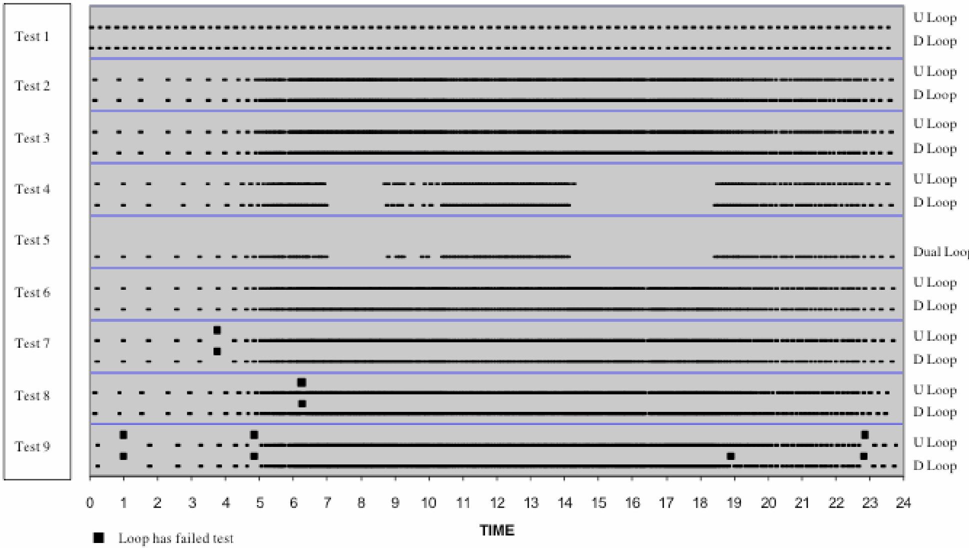
Illustration 6.25 Summary of Refined Detector Diagnostic Results – Lane 4 at Station 5W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

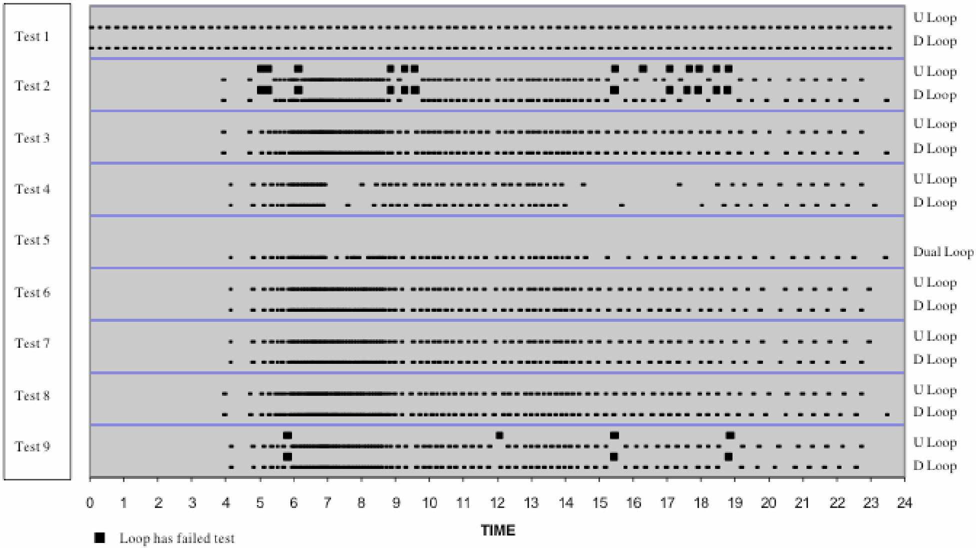
U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 6.26 Summary of Refined Detector Diagnostic Results – Lane 5 at Station 5W (Thursday 3/4/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime	U Loop = Up Stream Loop
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime	D Loop = Down Stream Loop
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime	

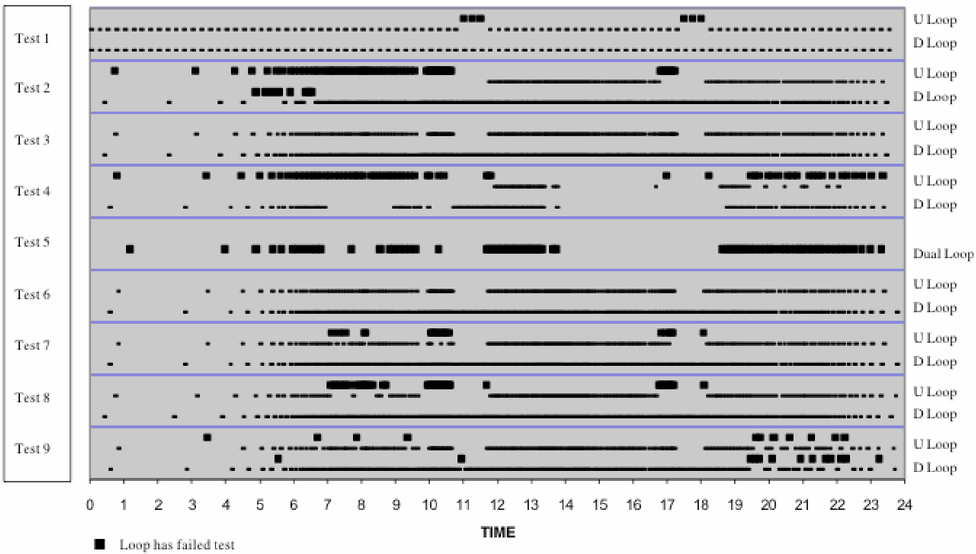
Illustration 6.27 Summary of Refined Detector Diagnostic Results – Lane 1 at Station 8W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

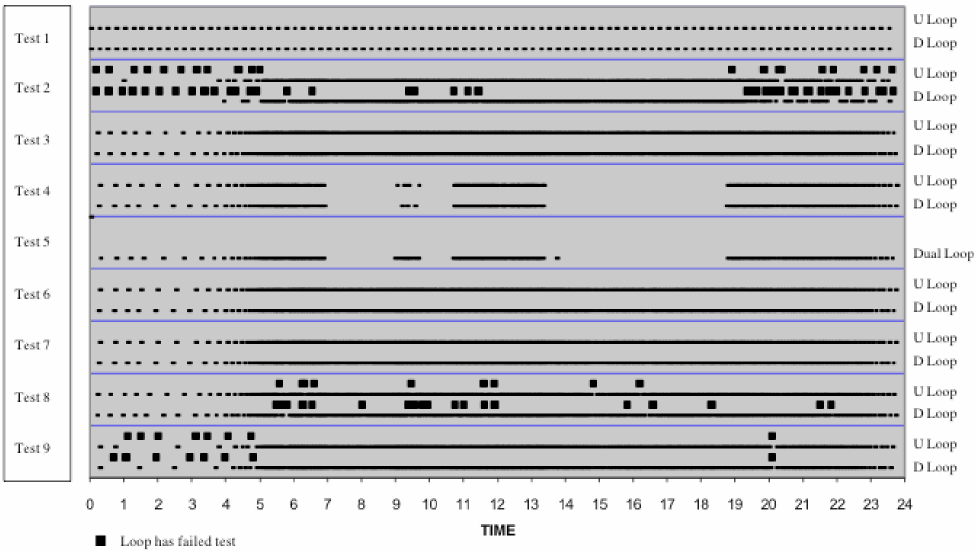
Illustration 6.28 Summary of Refined Detector Diagnostic Results – Lane 2 at Station 8W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

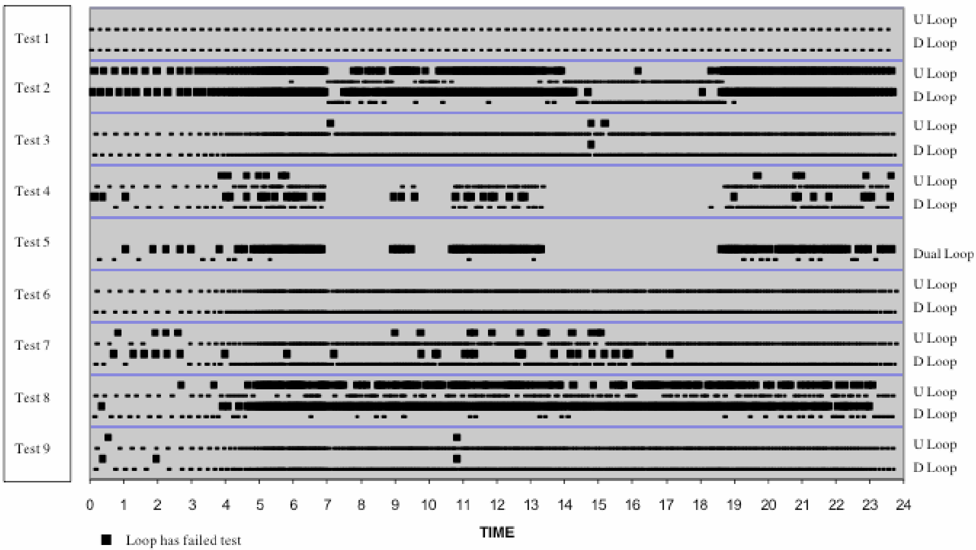
Illustration 6.29 Summary of Refined Detector Diagnostic Results – Lane 3 at Station 8W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

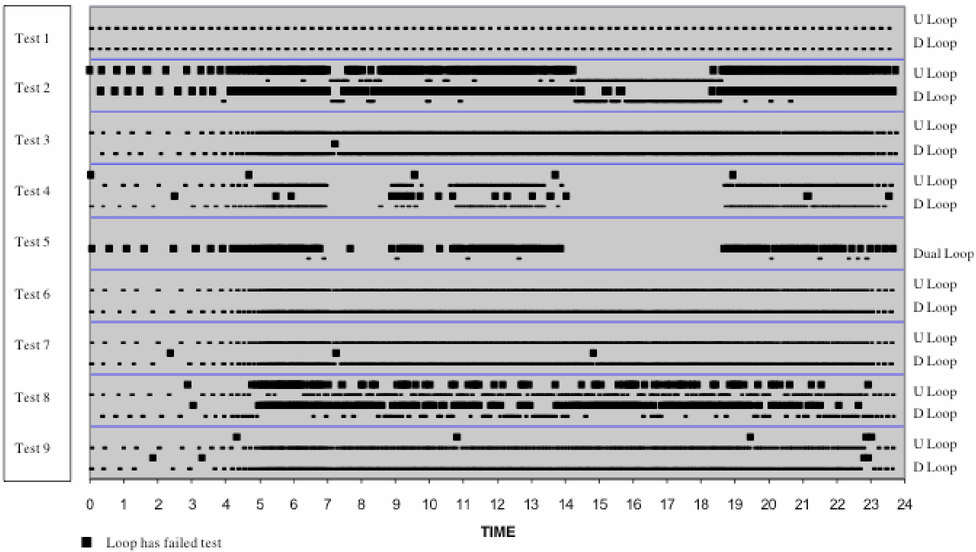
Illustration 6.30 Summary of Refined Detector Diagnostic Results – Lane 4 at Station 8W (Thursday 3/4/04)



Test 1: Activity
Test 2: MinOnTime
Test 3: MaxOnTime
Test 4: ModeOnTime
Test 5: DualOTDifference
Test 6: DynamicMinOnTime
Test 7: DynamicMaxOnTime
Test 8: MinOffTime
Test 9: DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop

Illustration 6.31 Summary of Refined Detector Diagnostic Results – Lane 5 at Station 8W (Thursday 3/4/04)



Test 1:	Activity	Test 4:	ModeOnTime	Test 7:	DynamicMaxOnTime
Test 2:	MinOnTime	Test 5:	DualOTDifference	Test 8:	MinOffTime
Test 3:	MaxOnTime	Test 6:	DynamicMinOnTime	Test 9:	DynamicMaxOffTime

U Loop = Up Stream Loop
D Loop = Down Stream Loop