Intelligent Cruise Control System Impact Analysis

Angela K. Patterson

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

Dr. Michel Van Aerde, Chair

Dr. Wei Lin
Dr. Antonio Trani

August 6, 1998
Blacksburg, Virginia

Keywords: Intelligent Cruise Control, Roadway Safety, Car-Following

Copyright 1998, Angela K. Patterson
Intelligent Cruise Control System Impact Analysis

Angela K. Patterson

(ABSTRACT)

Intelligent cruise control (ICC) has the potential to impact both roadway throughput and safety by assisting drivers in maintaining safe headways. This thesis explores this potential through comparisons of ICC to conventional cruise control (CCC) and manual driving. Accordingly, descriptions are given of both CCC and ICC systems. Furthermore, descriptions of ICC evaluation studies and car-following models are presented.

The evaluation of ICC is conducted using data collected as part of the Field Operational Test (FOT) performed in Ann Arbor, Michigan. Two levels of analysis are presented in this thesis. The first level of analysis compares the usage of ICC to CCC from a macro level. This study demonstrated that ICC was used more along similar trips. In addition, it was shown that there was no difference in usage of the ON, SET, CANCEL and RESUME buttons. ICC resulted in a higher usage of the ACCEL button and a lower usage of the COAST button compared to CCC. Furthermore, the number of brake interventions while ICC was engaged was higher than CCC. Lastly, the macro-level analysis indicated that there was no difference in the number of near encounters for ICC and CCC. The second analysis makes comparisons at a micro level. The most probable speed, acceleration and headway for each driving mode as well as the probability of using cruise control (based on speed) were determined. The probability of ICC use exceeded CCC use for every freeway speed bin and all but two high-speed arterial speed bins. Finally, a car-following behavior comparison was performed. Manual driving resulted in larger headway values for speeds less than 80 km/h. The ICC speed-headway curve was similar to the CCC speed-headway curve created from high-speed arterial data. The mean headway-speed charts, however, indicated that ICC was more similar to manual driving. Exploration into the specific differences is needed in order to determine the impact of ICC on system safety.
ACKNOWLEDGEMENTS

This thesis exists due to the wonderful support I have had throughout this past year. I would like to thank the following for their contributions:

• Dr. Michel Van Aerde, my supervisor, for his support and the opportunities that he has presented me with.

• Dr. Hesham Rakha, for direction and continued support.

• The Center for Transportation Research and MAUTC for their financial support.

• My family, comfort from the Great White North. I am especially grateful for the numerous road trips to and from Virginia.

• Josh, my best friend, for his encouragement, inspiration and computer problem solving techniques.
# TABLE OF CONTENTS

## CHAPTER 1 INTRODUCTION

1.1 THE PROBLEM: ROADWAY SAFETY

1.2 THESIS OBJECTIVE

1.3 METHODOLOGY

1.4 THESIS ORGANIZATION

## CHAPTER 2 LITERATURE REVIEW

2.1 INTELLIGENT/ADAPTIVE CRUISE CONTROL SYSTEMS

2.1.1 Intelligent and Conventional Cruise Control Operation

2.1.2 Intelligent Cruise Control System Configuration

2.1.3 Description of Intelligent Cruise Control Sub-Systems

2.2 EVALUATIONS OF ICC SYSTEMS

2.2.1 Mitsubishi Vehicle Tests

2.2.2 University of Michigan Transportation Research Institute Autonomous Cruise Control Baseline System Test Study

2.2.3 Swedish Road and Transport Research Institute VTI Simulator Study

2.2.4 Accident Analysis using a Hypothetical ICC System

2.2.5 Platoon Simulation

2.3 CAR FOLLOWING MODELS

2.3.1 Pipes’ Model

2.3.2 Forbes’ Model

2.3.3 The Driver Model

2.3.4 The General Motors’ Models

2.3.5 Five Driving Zones Model

2.3.6 Linear Acceleration Model

2.4 INTELLIGENT CRUISE CONTROL SAFETY ISSUES

2.4.1 Seat-Belt Usage

2.4.2 Foot Placement

2.5 SUMMARY
APPENDIX E SIMILAR TRIP CHARTS ...............................................................................................193

E.1 DRIVER 43 ROAD CLASS VERSUS CUMULATIVE DISTANCE FIGURES.................................193
E.2 DRIVER 53 ROAD CLASS VERSUS CUMULATIVE DISTANCE CHARTS ...................................198
E.3 DRIVER 43 SPEED VERSUS CUMULATIVE DISTANCE CHARTS ..............................................200
E.4 DRIVER 53 SPEED VERSUS CUMULATIVE DISTANCE CHARTS ..............................................205
E.5 DRIVER 43 ACCELERATION VERSUS CUMULATIVE DISTANCE CHARTS ...............................207
E.6 DRIVER 53 ACCELERATION VERSUS CUMULATIVE DISTANCE CHARTS ...............................212
E.7 DRIVER 43 RANGE VERSUS CUMULATIVE DISTANCE CHARTS ..............................................214
E.8 DRIVER 53 HEADWAY VERSUS CUMULATIVE DISTANCE CHARTS .......................................219

APPENDIX F CORRELATION PLOTS..............................................................................................222

F.1 DRIVER 43 CORRELATION PLOTS .........................................................................................222
F.2 DRIVER 53 CORRELATION PLOTS .........................................................................................227

APPENDIX G SPEED-FLOW-DENSITY RELATIONSHIPS ................................................................232

G.1 HIGH SPEED ARTERIAL SPEED-FLOW-DENSITY RELATIONSHIPS ......................................232
G.2 FREEWAY SPEED-FLOW-DENSITY RELATIONSHIPS ............................................................237
LIST OF TABLES

Table 2-1 Mitsubishi Driving Load Test Results ................................................................. 12
Table 2-2 Minimum Time Headway (seconds) for Critical Traffic Situations ................. 17
Table 2-3 Time Headway (seconds) at Start of Braking for Critical Traffic Situations ....... 17
Table 2-4 Maximum Braking Forces Applied (Newton) for Critical Traffic Situations ...... 18
Table 2-5 Deceleration (m/s²) at Maximum Braking Forces for Critical Traffic Situations ... 18
Table 2-6 Time Headway at Maximum Braking Forces for Critical Traffic Situations ...... 19
Table 3-1 Trip Summary Parameters Collected as Part of the ICC FOT ......................... 49
Table 3-2 Variation in Parameters across Similar Trip Sets by Type of Control ............... 50
Table 3-3 Example Illustration of Similar Trip Sets .......................................................... 51
Table 3-4 Trip Summary Derived Parameters ..................................................................... 52
Table 3-5 Variation in Derived Parameters across Similar Trip Sets by Type of Control .... 53
Table 3-6 Descriptive and Normality Statistics for Dependent Variables ....................... 55
Table 3-7 ANOVA Variables and Degrees of Freedom ..................................................... 61
Table 3-8 ANOVA Results Using “Set” as a Factor .......................................................... 62
Table 3-9 ANOVA Results Using “Driver” as a Factor ..................................................... 63
Table A-1 Conventional Cruise Control Similar Trip Set Summary Data ....................... 133
Table A-2 Intelligent Cruise Control Similar Trip Set Summary Data .............................. 135
Table D-1 Output Format for SENSIV.DAT ................................................................. 152
Table D-2 Sample Scenarios 40 through 50 .............................................................. 152
Table D-3 Output Format for TRIP_TAB.TXT .......................................................... 153
Table D-4 Format for SCEN_##.DAT ........................................................................ 153
Table D-5 Trip Pairs for Driver Three (TRIPTLR4.EXE) .......................................... 154
Table D-6 Spreadsheet Trip Pair Analysis ............................................................... 155
Table D-7 Trip Pairs for Driver Three by Spreadsheet .......................................... 155
Table D-8 Format of SCEN_##.OUT ................................................................. 156
Table D-9 SCEN_49.OUT Output (Driver Three) ................................................. 156
Table D-10 Output Format of ANALYSIS.OUT ...................................................... 159
Table D-11 J-Values of ANALYSIS.OUT .............................................................. 160
Table D-12 Output Format of LENGTH.OUT ....................................................... 160
Table D-13 J-Values of LENGTH.OUT ................................................................. 160
Table D-14 SETICC.OUT ...................................................................................... 161
Table D-15 SETS.OUT ......................................................................................... 161
Table D-16 TRIPS43.OUT ..................................................................................... 161
LIST OF FIGURES

Figure 2-1 Chrysler Autonomous Cruise Control System Interface ................................................. 8
Figure 2-2 Range Versus Range Rate Illustration of the Five Driving Zones Model ......................... 30
Figure 3-1 Stratification of ICC field operational test participants .................................................... 41
Figure 3-2 Determination of Like Trip Pairs ..................................................................................... 42
Figure 3-3 Trip Stratification with Trip Tolerance of 0.1 km .............................................................. 43
Figure 3-4 Trip Stratification with Trip Tolerance of 1.0 km .............................................................. 44
Figure 3-5 Trip Stratification with Trip Tolerance of 10 km ............................................................. 44
Figure 3-6 Trip Stratification with Trip Tolerance of 1000 km .......................................................... 45
Figure 3-7 Stratification of Like Trip Driver Sample ........................................................................ 46
Figure 3-8 Trip Time Distribution .................................................................................................... 50
Figure 3-9 Trip Length Distribution .................................................................................................. 51
Figure 3-10 Probability Distribution of Variable “Coast” .................................................................. 56
Figure 3-11 Probability Distribution of Variable “CoastP” ............................................................... 56
Figure 3-12 Probability Distribution of Variable “RCoastP” ............................................................ 57
Figure 3-13 Variation in Trip Time for Like Trip Sets ....................................................................... 63
Figure 3-14 Variation in “TimeP” as a Function of Set Number ....................................................... 64
Figure 3-15 Variation in “Engage” as a Function of Set Number ...................................................... 64
Figure 3-16 Variation in “AccOnP” as a Function of Set Number ..................................................... 65
Figure 3-17 Variation in “SetP” as a Function of Set Number ............................................................ 65
Figure 3-18 Variation in “CoastP” as a Function of Set Number ...................................................... 66
Figure 3-19 Variation in “ResumeP” as a Function of Set Number .................................................. 66
Figure 3-20 Variation in “AccelP” as a Function of Set Number ...................................................... 67
Figure 3-21 Variation in “CancelP” as a Function of Set Number .................................................... 67
Figure 3-22 Variation in “BrakeP” as a Function of Set Number ...................................................... 68
Figure 3-23 Variation in “CCBiP” as a Function of Set Number ....................................................... 68
Figure 3-24 Variation in “CCNeP” as a Function of Set Number ....................................................... 69
Figure 4-1 Road Class Determination for Week 1 Trip (Driver 43) ................................................... 74
Figure 4-2 Road Class Determination for Week 2 Trip (Driver 43) ................................................... 74
Figure 4-3 Road Class Determination for Week 1 Trip (Driver 53) ................................................... 75
Figure 4-4 Road Class Determination for Week 2 Trip (Driver 53) ................................................... 75
Figure 4-5 Road Class Determination for all Week 1 Trips (Driver 43) ........................................... 76
Figure 4-6 Road Class Determination for all Week 2 Trips (Driver 43)................................. 77
Figure 4-7 Road Class Determination for Weeks One and Two (Driver 53) ......................... 78
Figure 4-8 Speed versus Cumulative Distance (Driver 43, Trip 1-2)........................................ 79
Figure 4-9 Speed versus Cumulative Distance (Driver 43, Trip 1-3)........................................ 80
Figure 4-10 Acceleration versus Cumulative Distance (Driver 43, Trip 2-1)............................ 81
Figure 4-11 Acceleration versus Cumulative Distance (Driver 43, Trip 2-3)............................ 81
Figure 4-12 Range versus Cumulative Distance (Driver 43, Trip 2-3)................................. 82
Figure 4-13 Range versus Cumulative Distance (Driver 43, Trip 2-5)................................. 83
Figure 4-14 Speed versus Cumulative Distance (Driver 53, Trip 2-1)........................................ 84
Figure 4-15 Speed versus Cumulative Distance (Driver 53, Trip 2-2)........................................ 84
Figure 4-16 Acceleration versus Cumulative Distance (Driver 53, Trip 1-1)............................ 85
Figure 4-17 Acceleration versus Cumulative Distance (Driver 53, Trip 1-2)............................ 85
Figure 4-18 Headway versus Cumulative Distance (Driver 53, Trip 2-1)............................... 86
Figure 4-19 Headway versus Cumulative Distance (Driver 53, Trip 2-2)............................... 86
Figure 4-20 Headway Correlation (High Speed Arterial)....................................................... 89
Figure 4-21 Headway Correlation (Freeway)................................................................. 90
Figure 4-22 Speed Correlation (High Speed Arterial)...................................................... 92
Figure 4-23 Speed Correlation (Freeway)................................................................. 93
Figure 4-24 Acceleration Correlation (High Speed Arterial)............................................... 94
Figure 4-25 Acceleration Correlation (Freeway)............................................................. 95
Figure 4-26 High Speed Arterial Speed Distributions..................................................... 97
Figure 4-27 Freeway Speed Distributions........................................................................ 98
Figure 4-28 High Speed Arterial Acceleration Distributions.............................................. 99
Figure 4-29 Freeway Acceleration Distributions............................................................. 99
Figure 4-30 High Speed Arterial Distance Headway Distributions................................. 100
Figure 4-31 Freeway Distance Headway Distributions.................................................... 101
Figure 4-32 High Speed Arterial Time Headway Distances (With 50 second data)........ 102
Figure 4-33 High Speed Arterial Time Headway Distributions (Without 50 second data)..... 102
Figure 4-34 Freeway Time Headway Distributions (with 50 second data)......................... 103
Figure 4-35 Freeway Time Headway Distributions (without 50 second data).................... 104
Figure 4-36 Probability of Using Cruise Control on the High Speed Arterial Facility ....... 105
Figure 4-37 Cumulative Probability of using Cruise Control on
High Speed Arterial Facility............................................................................. 106
| Figure D- 7 | Trip Length Distribution for Drivers 31 through 40 | .............................................. | 165 |
| Figure D- 8 | Sets by driver and ICC usage – drivers 40 through 50 | .............................................. | 166 |
| Figure D- 9 | Like Trips Based on Driver and Set Number - Drivers 34 to 43 | .............................................. | 167 |
| Figure D- 10 | Number of Similar Trips Per Driver (Drivers 1 through 30) | .............................................. | 168 |
| Figure D- 11 | Number of Similar Trips Per Driver (Drivers 31 through 60) | .............................................. | 168 |
| Figure D- 12 | Number of Similar Trips Per Driver (Drivers 61 through 90) | .............................................. | 169 |
| Figure D- 13 | Number of Similar Trips Per Driver (Drivers 91 through 117) | .............................................. | 169 |
| Figure D- 14 | ICC and Non-ICC Similar Trips (Drivers 1 through 30) | .............................................. | 170 |
| Figure D- 15 | ICC and Non-ICC Similar Trips (Drivers 31 through 60) | .............................................. | 170 |
| Figure D- 16 | ICC and Non-ICC Similar Trips (Drivers 61 through 90) | .............................................. | 171 |
| Figure D- 17 | ICC and Non-ICC Similar Trips (Drivers 91 through 117) | .............................................. | 171 |
| Figure D- 18 | Trip Length Distribution (Drivers 1 through 10) | .............................................. | 172 |
| Figure D- 19 | Trip Length Distribution (Drivers 11 through 20) | .............................................. | 172 |
| Figure D- 20 | Trip Length Distribution (Drivers 21 through 30) | .............................................. | 173 |
| Figure D- 21 | Trip Length Distribution (Drivers 31 through 40) | .............................................. | 173 |
| Figure D- 22 | Trip Length Distribution (Drivers 41 through 50) | .............................................. | 174 |
| Figure D- 23 | Trip Length Distribution (Drivers 51 through 60) | .............................................. | 174 |
| Figure D- 24 | Trip Length Distribution (Drivers 61 through 70) | .............................................. | 175 |
| Figure D- 25 | Trip Length Distribution (Drivers 71 through 80) | .............................................. | 175 |
| Figure D- 26 | Trip Length Distribution (Drivers 81 through 90) | .............................................. | 176 |
| Figure D- 27 | Trip Length Distribution (Drivers 91 through 100) | .............................................. | 176 |
| Figure D- 28 | Trip Length Distribution (Drivers 101 through 110) | .............................................. | 177 |
| Figure D- 29 | Trip Length Distribution (Drivers 111 through 117) | .............................................. | 177 |
| Figure D- 30 | Trip Sets by ICC Usage (Drivers 1 through 10) | .............................................. | 178 |
| Figure D- 31 | Trip Sets by ICC Usage (Drivers 11 through 20) | .............................................. | 178 |
| Figure D- 32 | Trip Sets by ICC Usage (Drivers 21 through 30) | .............................................. | 179 |
| Figure D- 33 | Trip Sets by ICC Usage (Drivers 31 through 40) | .............................................. | 179 |
| Figure D- 34 | Trip Sets by ICC Usage (Drivers 41 through 50) | .............................................. | 180 |
| Figure D- 35 | Trip Sets by ICC Usage (Drivers 51 through 60) | .............................................. | 180 |
| Figure D- 36 | Trip Sets by ICC Usage (Drivers 61 through 70) | .............................................. | 181 |
| Figure D- 37 | Trip Sets by ICC Usage (Drivers 71 through 80) | .............................................. | 181 |
| Figure D- 38 | Trip Sets by ICC Usage (Drivers 81 through 90) | .............................................. | 182 |
| Figure D- 39 | Trip Sets by ICC Usage (Drivers 91 through 100) | .............................................. | 182 |

xiii
Figure D- 40 Trip Sets by ICC Usage (Drivers 101 through 110) ............................................. 183
Figure D- 41 Trip Sets by ICC Usage (Drivers 111 through 117) ............................................. 183
Figure D- 42 Similar Trips by Set Number (Drivers 1 through 10) ......................................... 184
Figure D- 43 Similar Trips by Set Number (Drivers 11 through 19) ......................................... 185
Figure D- 44 Similar Trips by Set Number (Drivers 20 through 25) ......................................... 185
Figure D- 45 Similar Trips by Set Number (Drivers 26 through 33) ......................................... 186
Figure D- 46 Similar Trips by Set Number (Drivers 34 through 43) ......................................... 186
Figure D- 47 Similar Trips by Set Number (Drivers 45 through 53) ......................................... 187
Figure D- 48 Similar Trips by Set Number (Drivers 55 and 56) ............................................. 187
Figure D- 49 Similar Trips by Set Number (Drivers 59 through 62) ......................................... 188
Figure D- 50 Similar Trips by Set Number (Drivers 63 through 67) ......................................... 188
Figure D- 51 Similar Trips by Set Number (Drivers 68 through 75) ......................................... 189
Figure D- 52 Similar Trips by Set Number (Drivers 76 through 78) ......................................... 189
Figure D- 53 Similar Trips by Set Number (Drivers 79 through 81) ......................................... 190
Figure D- 54 Similar Trips by Set Number (Drivers 84 through 87) ......................................... 190
Figure D- 55 Similar Trips by Set Number (Drivers 88 and 89) ............................................ 191
Figure D- 56 Similar Trips by Set Number (Drivers 90 through 96) ......................................... 191
Figure D- 57 Similar Trips by Set Number (Drivers 97 through 104) ....................................... 192
Figure D- 58 Similar Trips by Set Number (Drivers 105 through 117) .................................... 192
Figure E- 1 Driver 43 Road Class versus Cumulative Distance (Trip 1-1) ............................... 193
Figure E- 2 Driver 43 Road Class versus Cumulative Distance (Trip 1-2) ............................... 194
Figure E- 3 Driver 43 Road Class versus Cumulative Distance (Trip 1-3) ............................... 194
Figure E- 4 Driver 43 Road Class versus Cumulative Distance (Trip 1-4) ............................... 195
Figure E- 5 Driver 43 Road Class versus Cumulative Distance (Trip 1-5) ............................... 195
Figure E- 6 Driver 43 Road Class versus Cumulative Distance (Trip 2-1) ............................... 196
Figure E- 7 Driver 43 Road Class versus Cumulative Distance (Trip 2-2) ............................... 196
Figure E- 8 Driver 43 Road Class versus Cumulative Distance (Trip 2-3) ............................... 197
Figure E- 9 Driver 43 Road Class versus Cumulative Distance (Trip 2-4) ............................... 197
Figure E- 10 Driver 43 Road Class versus Cumulative Distance (Trip 2-5) ............................. 198
Figure E- 11 Driver 53 Road Class versus Cumulative Distance (Trip 1-1) ............................. 198
Figure E- 12 Driver 53 Road Class versus Cumulative Distance (Trip 1-2) ............................. 199
Figure E- 13 Driver 53 Road Class versus Cumulative Distance (Trip 2-1) ............................. 199
Figure E- 14 Driver 53 Road Class versus Cumulative Distance (Trip 2-2) ............................. 200
Figure E-15 Driver 43 Speed versus Cumulative Distance (Trip 1-1) ..................................... 200
Figure E-16 Driver 43 Speed versus Cumulative Distance (Trip 1-2) ..................................... 201
Figure E-17 Driver 43 Speed versus Cumulative Distance (Trip 1-3) ..................................... 201
Figure E-18 Driver 43 Speed versus Cumulative Distance (Trip 1-4) ..................................... 202
Figure E-19 Driver 43 Speed versus Cumulative Distance (Trip 1-5) ..................................... 202
Figure E-20 Driver 43 Speed versus Cumulative Distance (Trip 2-1) ..................................... 203
Figure E-21 Driver 43 Speed versus Cumulative Distance (Trip 2-2) ..................................... 203
Figure E-22 Driver 43 Speed versus Cumulative Distance (Trip 2-3) ..................................... 204
Figure E-23 Driver 43 Speed versus Cumulative Distance (Trip 2-4) ..................................... 204
Figure E-24 Driver 43 Speed versus Cumulative Distance (Trip 2-5) ..................................... 205
Figure E-25 Driver 53 Speed versus Cumulative Distance (Trip 1-1) ..................................... 205
Figure E-26 Driver 53 Speed versus Cumulative Distance (Trip 1-2) ..................................... 206
Figure E-27 Driver 53 Speed versus Cumulative Distance (Trip 2-1) ..................................... 206
Figure E-28 Driver 53 Speed versus Cumulative Distance (Trip 2-2) ..................................... 207
Figure E-29 Driver 43 Acceleration versus Cumulative Distance (Trip 1-1) .......................... 207
Figure E-30 Driver 43 Acceleration versus Cumulative Distance (Trip 1-2) .......................... 208
Figure E-31 Driver 43 Acceleration versus Cumulative Distance (Trip 1-3) .......................... 208
Figure E-32 Driver 43 Acceleration versus Cumulative Distance (Trip 1-4) .......................... 209
Figure E-33 Driver 43 Acceleration versus Cumulative Distance (Trip 1-5) .......................... 209
Figure E-34 Driver 43 Acceleration versus Cumulative Distance (Trip 2-1) .......................... 210
Figure E-35 Driver 43 Acceleration versus Cumulative Distance (Trip 2-2) .......................... 210
Figure E-36 Driver 43 Acceleration versus Cumulative Distance (Trip 2-3) .......................... 211
Figure E-37 Driver 43 Acceleration versus Cumulative Distance (Trip 2-4) .......................... 211
Figure E-38 Driver 43 Acceleration versus Cumulative Distance (Trip 2-5) .......................... 212
Figure E-39 Driver 53 Acceleration versus Cumulative Distance (Trip 1-1) .......................... 212
Figure E-40 Driver 53 Acceleration versus Cumulative Distance (Trip 1-2) .......................... 213
Figure E-41 Driver 53 Acceleration versus Cumulative Distance (Trip 2-1) .......................... 213
Figure E-42 Driver 53 Acceleration versus Cumulative Distance (Trip 2-2) .......................... 214
Figure E-43 Driver 43 Range versus Cumulative Distance (Trip 1-1) ................................. 214
Figure E-44 Driver 43 Range versus Cumulative Distance (Trip 1-2) ................................. 215
Figure E-45 Driver 43 Range versus Cumulative Distance (Trip 1-3) ................................. 215
Figure E-46 Driver 43 Range versus Cumulative Distance (Trip 1-4) ................................. 216
Figure E-47 Driver 43 Range versus Cumulative Distance (Trip 1-5) ................................. 216
Figure G- 7 High Speed Arterial ICC Speed-Headway Relationship ................................. 235
Figure G- 8 High Speed Arterial ICC Speed-Density Relationship .................................... 236
Figure G- 9 High Speed Arterial ICC Speed-Flow Relationship ........................................ 236
Figure G- 10 Freeway Manual Speed-Headway Relationship ........................................... 237
Figure G- 11 Freeway Manual Speed-Density Relationship .................................................. 237
Figure G- 12 Freeway Manual Speed-Flow Relationship ...................................................... 238
Figure G- 13 Freeway CCC Speed-Headway Relationship .................................................... 238
Figure G- 14 Freeway CCC Speed-Density Relationship ....................................................... 239
Figure G- 15 Freeway CCC Speed-Flow Relationship .......................................................... 239
Figure G- 16 Freeway ICC Speed-Headway Relationship .................................................... 240
Figure G- 17 Freeway ICC Speed-Density Relationship ....................................................... 240
Figure G- 18 Freeway ICC Speed-Flow Relationship .......................................................... 241