

1. Report No. FHWA/TX-05/0-4745-1	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle <b>INCIDENT CHARACTERISTICS AND IMPACT ON FREEWAY TRAFFIC</b>		5. Report Date <b>October 2004</b>	6. Performing Organization Code
7. Author(s) Cesar Quiroga, Edgar Kraus, Robert Pina, Khaled Hamad, and Eun Sug Park		8. Performing Organization Report No. <b>Report 0-4745-1</b>	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)	11. Contract or Grant No. <b>Project 0-4745</b>
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered <b>Technical Report: September 2003 – August 2004</b>	
14. Sponsoring Agency Code			
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration. Project Title: Using Archived ITS Data and Spatial Statistics for Optimizing Incident Response at Transportation Management Centers URL: <a href="http://tti.tamu.edu/documents/0-4745-1.pdf">http://tti.tamu.edu/documents/0-4745-1.pdf</a>			
16. Abstract Transportation management centers (TMCs) generate and archive enormous amounts of data. Many applications of archived intelligent transportation system (ITS) data nationwide, including Texas, address transportation planning needs. As the number of applications of archived ITS data increases, interest is growing in identifying areas where archived ITS data could result in more effective TMC operations.  One area of interest is how to use archived ITS data to help improve incident management practices. Using geographic information system (GIS), traffic engineering, and statistical analysis techniques, this report describes procedures to determine patterns in the spatial and temporal distribution of incidents along freeway corridors. The report describes current incident detection and data archival at several Texas TMCs, a process to develop a data model and geodatabase of ITS equipment and archived ITS data using a variety of data sources at TransGuide, a process to determine patterns in the spatial and temporal distribution of freeway incidents in San Antonio, a procedure to calculate the impact of incidents on traffic conditions, and recommendations for implementation of the research findings.			
17. Key Words Intelligent Transportation Systems, Incidents, GIS, Transportation Management Centers, Archived ITS Data		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 <a href="http://www.ntis.gov">http://www.ntis.gov</a>	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 208	22. Price



# **INCIDENT CHARACTERISTICS AND IMPACT ON FREEWAY TRAFFIC**

by

Cesar Quiroga, P.E.  
Associate Research Engineer  
Texas Transportation Institute

Edgar Kraus  
Associate Transportation Researcher  
Texas Transportation Institute

Robert Pina  
Programmer/Analyst I  
Texas Transportation Institute

Khaled Hamad  
Assistant Research Scientist  
Texas Transportation Institute

and

Eun Sug Park  
Assistant Research Scientist  
Texas Transportation Institute

Report 0-4745-1  
Project 0-4745

Project Title: Using Archived ITS Data and Spatial Statistics for Optimizing Incident Response  
at Transportation Management Centers

Performed in cooperation with the  
Texas Department of Transportation  
and the  
Federal Highway Administration

October 2004

TEXAS TRANSPORTATION INSTITUTE  
The Texas A&M University System  
College Station, Texas 77843-3135



## **DISCLAIMER**

The contents of this document reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This document does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Cesar Quiroga, P.E. (Texas Registration #84274).

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

## **ACKNOWLEDGMENTS**

This project was conducted in cooperation with TxDOT and FHWA. The researchers would like to gratefully acknowledge the assistance provided by TxDOT officials, in particular the following:

- Bill Jurczyn – San Antonio District (project director),
- Brian Burk – Austin District,
- Steve Connell – Fort Worth District,
- Guillermo Dougherty – Laredo District,
- Brian Fariello – San Antonio District,
- David Fink – Houston District,
- Ron Holtz – San Antonio District,
- Pat Irwin – San Antonio District,
- Tai Nguyen – Fort Worth District, and
- David Rodrigues – San Antonio District.

The researchers would also like to acknowledge Robert Bacon (formerly at the TxDOT Dallas District), Southwest Research Institute's Glenn Regner and Dedaimia Kozlovsky, as well as TTI's Bryan Miller and Mike Vickich, for providing timely information and assistance. The work completed by the students was critical, in particular that of Charles Shultz and Eros Bertoni, who built most of the geodatabase; Doyle Dennis, who wrote the code to process raw archived ITS data; and Mia-Andrea Veliz, who assisted with the completion of the data model.

## TABLE OF CONTENTS

	Page
LIST OF FIGURES .....	ix
LIST OF TABLES.....	xiii
LIST OF ACRONYMS, ABBREVIATIONS, AND TERMS .....	xv
CHAPTER 1. INTRODUCTION .....	1
CHAPTER 2. ARCHIVED TRAFFIC AND INCIDENT DATA IN TEXAS .....	3
AUSTIN'S CTECC .....	3
Configuration .....	3
Incident Detection and Response.....	3
Archived Traffic and Incident Data .....	7
DALLAS' DALTRANS .....	8
Configuration .....	8
Incident Detection and Response.....	8
Archived Traffic and Incident Data .....	9
FORT WORTH'S TRANVISION .....	10
Configuration .....	10
Incident Detection and Response.....	11
Archived Traffic and Incident Data .....	11
HOUSTON'S TRANSTAR.....	11
Configuration .....	11
Incident Detection and Response.....	12
Archived Traffic and Incident Data .....	13
SAN ANTONIO'S TRANSGUIDE SYSTEM .....	16
Configuration .....	16
Incident Detection and Response.....	18
Archived Traffic and Incident Data .....	21
CHAPTER 3. GEODATABASE DEVELOPMENT .....	23
DATA SOURCES .....	23
Road Base Maps .....	23
Flight Data Files and Aerial Photography .....	26
ITS Equipment Schematics.....	29
GEODATABASE DEVELOPMENT .....	31
GIS Feature Classes .....	31
Transformations .....	33
ITS Features .....	35
DATA MODEL .....	37
CHAPTER 4. EVALUATION OF INCIDENT CHARACTERISTICS.....	49
INCIDENT DATA MINING.....	49

TEMPORAL AND SPATIAL DISTRIBUTION OF INCIDENTS.....	52
Distribution of Incidents by Month and Season .....	52
Distribution of Incidents by Day of Week.....	57
Effect of Traffic Volume on the Distribution of Incidents .....	59
Distribution of Incidents by Corridor .....	65
Distribution of Incidents by Time of Day.....	68
Distribution of Incidents by Scenario Duration.....	70
Distribution of Incidents by Lane and Shoulder Blockage .....	71
Weather Impact on Incidents .....	73
 CHAPTER 5. INCIDENT IMPACTS ON TRAFFIC.....	75
DEFINITIONS OF DELAY .....	75
CALCULATION OF DELAY .....	76
CALCULATION OF REFERENCE SPEED.....	80
DATA IMPUTATION.....	84
INCIDENT DURATION.....	85
CASE STUDIES.....	87
Sample Incident No. 1 .....	87
Sample Incident No. 2.....	101
DETECTOR DATA QUALITY CONTROL.....	114
 CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS .....	119
SUMMARY OF FINDINGS .....	119
Traffic and Incident Data Archival Practices.....	119
Geodatabase Development.....	119
Incident Characteristics.....	120
Incident Delay .....	122
STEPS/RECOMMENDATIONS FOR IMPLEMENTATION.....	124
RECOMMENDATIONS FOR FURTHER RESEARCH WORK.....	127
 REFERENCES .....	129
 APPENDIX A. SPATIAL DISTRIBUTION OF INCIDENTS BY SEASON .....	133
 APPENDIX B. SPATIAL DISTRIBUTION OF INCIDENTS BY DAY OF WEEK.....	155
 APPENDIX C. SPATIAL DISTRIBUTION OF INCIDENTS BY TIME OF DAY .....	169

## LIST OF FIGURES

	Page
Figure 1. ATMS Incident List Window (7) .....	4
Figure 2. ATMS Incident Report Page 1 (7).....	5
Figure 3. ATMS Incident Report Page 2 (7).....	5
Figure 4. ATMS LCS Control Page (7).....	6
Figure 5. ATMS DMS Control Page (7).....	6
Figure 6. Current DalTrans ITS Data Archive Model.....	10
Figure 7. TranStar RIMS Interface.....	14
Figure 8. Sample Query View of TranStar Archived Traffic and Incident Data.....	16
Figure 9. TransGuide Incident Assignment Screen.....	19
Figure 10. TransGuide Operator Console Screen.....	20
Figure 11. TransGuide Scenario Search Screen.....	20
Figure 12. Sample 20-Second Archived Detector Data at TransGuide.....	21
Figure 13. Sample Archived Event Data at TransGuide.....	22
Figure 14. Sample Archived Scenario Data at TransGuide.....	22
Figure 15. TransGuide Map Display Application (16).....	23
Figure 16. Sample GIS-Based Road Base Maps in San Antonio (IH-35 at Judson).....	24
Figure 17. Sample Flight Data File and Aerial Photography.....	27
Figure 18. Sample ITS Microstation Schematic and Paper Roll (IH-35 at Judson).....	30
Figure 19. Typical TransGuide Loop Detector Configuration.....	33
Figure 20. Application of Scale Transformation to “English System” Files.....	34
Figure 21. ITS Features in the GIS.....	36
Figure 22. TransGuide CCTV Cameras Overlaying Main Corridors and City Limits.....	38
Figure 23. Data Model “A”—Logical Model.....	39
Figure 24. Data Model “A”—Physical Model.....	41
Figure 25. Data Model “B”—Logical Model.....	43
Figure 26. Data Model “B”—Physical Model.....	45
Figure 27. Distribution of Incidents According to the Scenario Header Table.....	50
Figure 28. Number of Incidents by Incident Type.....	52
Figure 29. Average Number of Incidents per Month (Expressed for Convenience as Number of Incidents per 3 Months).....	55
Figure 30. Year 2002 Average Daily Traffic for San Antonio.....	60
Figure 31. Average Number of Incidents per Sector (Expressed as Number of Incidents per 100 Weekdays).....	61
Figure 32. Average Number of Weekday Incidents per 10 Million Vehicles.....	62
Figure 33. Average Number of Weekday Incidents per 10 Million Vehicles (Color Coded Map).....	63
Figure 34. Corridor Sections.....	66
Figure 35. Cumulative Scenario Durations by Incident Type.....	70
Figure 36. Typical Incident Lane Speed Profile.....	76
Figure 37. Sample Incident Location on Freeway.....	77
Figure 38. Schematic Representation of a $q$ -Nearest Neighborhood Using $\pm 2$ Minutes and Merged Speed Data from Three Archived Weekdays.....	82

Figure 39. Speed Time Series Imputation.....	85
Figure 40. Incident Time Stamps.....	86
Figure 41. Sample Incident 1 Detector and Sector Locations. ....	87
Figure 42. Speed Time Series by Sector and Lane for March 8, 2002 (Day of Incident). ....	89
Figure 43. Speed Time Series by Sector and Lane for March 1, 2002.....	91
Figure 44. Speed Time Series by Sector and Lane for March 15, 2002.....	93
Figure 45. Speed Time Series by Sector and Lane for March 22, 2002.....	95
Figure 46. Sample Incident 2 Detector and Sector Locations. ....	102
Figure 47. Speed Time Series by Sector and Lane for March 21, 2002 (Day of Incident). ....	103
Figure 48. Speed Time Series by Sector and Lane for March 7, 2002.....	105
Figure 49. Speed Time Series by Sector and Lane for March 14, 2002.....	107
Figure 50. Speed Time Series by Sector and Lane for March 28, 2002.....	109
Figure 51. Detectors Controlled by Naztec LCUs and TRF LCUs. ....	117
Figure 52. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months).....	135
Figure 53. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002. ....	136
Figure 54. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.....	137
Figure 55. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003. ....	138
Figure 56. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.....	139
Figure 57. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months). ....	140
Figure 58. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002. ....	141
Figure 59. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.....	142
Figure 60. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003. ....	143
Figure 61. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.....	144
Figure 62. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months). ....	145
Figure 63. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002.....	146
Figure 64. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.....	147
Figure 65. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003.....	148
Figure 66. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.....	149
Figure 67. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months). ....	150

Figure 68. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002.....	151
Figure 69. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.....	152
Figure 70. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003.....	153
Figure 71. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.....	154
Figure 72. Average Number of Major Accidents per Day (Expressed as Number of Incidents per 100 Days).....	157
Figure 73. Average Number of Major Accidents per Weekday (Expressed as Number of Incidents per 100 Days).....	158
Figure 74. Average Number of Major Accidents per Weekend Day (Expressed as Number of Incidents per 100 Days).....	159
Figure 75. Average Number of Minor Accidents per Day (Expressed as Number of Incidents per 100 Days).....	160
Figure 76. Average Number of Minor Accidents per Weekday (Expressed as Number of Incidents per 100 Days).....	161
Figure 77. Average Number of Minor Accidents per Weekend Day (Expressed as Number of Incidents per 100 Days).....	162
Figure 78. Average Number of Stalled Vehicle Incidents per Day (Expressed as Number of Incidents per 100 Days).....	163
Figure 79. Average Number of Stalled Vehicle Incidents per Weekday (Expressed as Number of Incidents per 100 Days).....	164
Figure 80. Average Number of Stalled Vehicle Incidents per Weekend Day (Expressed as Number of Incidents per 100 Days).....	165
Figure 81. Average Number of Debris Incidents per Day (Expressed as Number of Incidents per 100 Days).....	166
Figure 82. Average Number of Debris Incidents per Weekday (Expressed as Number of Incidents per 100 Days).....	167
Figure 83. Average Number of Debris Incidents per Weekend Day (Expressed as Number of Incidents per 100 Days).....	168
Figure 84. Average Number of Major Accident Incidents per 1000 Hours.....	171
Figure 85. Average Number of Major Accident Incidents per 1000 Hours during AM Peak Hours (7-9 AM).....	172
Figure 86. Average Number of Major Accident Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).....	173
Figure 87. Average Number of Major Accident Incidents per 1000 Hours during PM Peak Hours (4-7 PM).....	174
Figure 88. Average Number of Major Accident Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).....	175
Figure 89. Average Number of Minor Accident Incidents per 1000 Hours.....	176
Figure 90. Average Number of Minor Accident Incidents per 1000 Hours during AM Peak Hours (7-9 AM).....	177
Figure 91. Average Number of Minor Accident Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).....	178

Figure 92. Average Number of Minor Accident Incidents per 1000 Hours during PM Peak Hours (4-7 PM).....	179
Figure 93. Average Number of Minor Accident Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).....	180
Figure 94. Average Number of Stalled Vehicle Incidents per 1000 Hours.....	181
Figure 95. Average Number of Stalled Vehicle Incidents per 1000 Hours during AM Peak Hours (7-9 AM).....	182
Figure 96. Average Number of Stalled Vehicle Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).....	183
Figure 97. Average Number of Stalled Vehicle Incidents per 1000 Hours during PM Peak Hours (4-7 PM).....	184
Figure 98. Average Number of Stalled Vehicle Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).....	185
Figure 99. Average Number of Debris Incidents per 1000 Hours.....	186
Figure 100. Average Number of Debris Incidents per 1000 Hours during AM Peak Hours (7-9 AM).....	187
Figure 101. Average Number of Debris Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).....	188
Figure 102. Average Number of Debris Incidents per 1000 Hours during PM Peak Hours (4-7 PM).....	189
Figure 103. Average Number of Debris Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).....	190

## LIST OF TABLES

	Page
Table 1. ATMS Archived Incident Report Table (Adapted from 8). ....	7
Table 2. TransGuide Subsystems.....	17
Table 3. Sample of Relevant ITS Data TransGuide Subsystem Components.....	18
Table 4. Road Base Map Characteristics. ....	25
Table 5. Flight Data File Characteristics. ....	28
Table 6. Aerial Photography Characteristics. ....	29
Table 7. GIS Feature Class Conceptual Description. ....	32
Table 8. Geodatabase Coordinate System Characteristics.....	34
Table 9. Data Model “A”—Entity Description.....	47
Table 10. Data Model “B”—Entity Description.....	48
Table 11. Distribution of Original and Reclassified Scenario Records by Scenario Type.....	51
Table 12. Frequency of Incidents per Month.....	53
Table 13. Average Number of Incidents per Month. ....	54
Table 14. Distribution of Incidents per Month and Season. ....	54
Table 15. Average Number of Incidents per Day of Week, Weekdays, and Weekends. ....	57
Table 16. Distribution of Incidents by Day of Week, Weekdays, and Weekends.....	57
Table 17. Sectors with the Highest Average Number of Incidents per Weekday (Expressed as Number of Incidents per 100 Weekdays). ....	58
Table 18. Sectors with the Highest Number of Weekday Incidents per 10 Million Vehicles....	64
Table 19. Average Incident Statistics per Corridor Section. ....	65
Table 20. Corridor Section Ranking by Measure. ....	65
Table 21. Comparison between TxDPS Crash Data and TransGuide Incident Data (Major and Minor Accidents). ....	68
Table 22. Average Number of Incidents per 10-Hour Period by Time of Day. ....	68
Table 23. Distribution of Incidents by Time of Day.....	69
Table 24. Summary Statistics of Scenario Durations. ....	70
Table 25. Distribution of Incidents by Main Lane Blockage.....	72
Table 26. Distribution of Incidents by Shoulder Blockage.....	72
Table 27. Cross-Distribution of Incidents by Main Lane and Shoulder Blockages (Excluding Zero-Duration Scenarios).....	72
Table 28. Distribution of Scenario Durations in Minutes by Main lane and Shoulder Blockages (Excluding Zero-Duration Scenarios).....	72
Table 29. Average Number of Incidents per Day for Each Rainfall and Incident Category.....	74
Table 30. Distribution of Incidents per Rainfall and Incident Category.....	74
Table 31. Length and Number of Lanes per Sector for Sample Incident 1 Calculations. ....	88
Table 32. Incident Delay Using Disaggregate Lane-by-Lane Data <i>without</i> Data Imputation....	97
Table 33. Incident Delay Using Disaggregate Lane-by-Lane Data <i>with</i> Data Imputation. ....	97
Table 34. Incident Delay Using Sector Data <i>without</i> Data Imputation. ....	98
Table 35. Incident Delay Using Sector Data <i>with</i> Data Imputation. ....	98
Table 36. Incident Delay Using Disaggregate Lane-by-Lane Data <i>without</i> Data Imputation (Assuming Incident Duration = 41 minutes). ....	100

Table 37. Incident Delay Using Disaggregate Lane-by-Lane Data <i>with</i> Data Imputation (Assuming Incident Duration = 41 minutes). ....	100
Table 38. Incident Delay Using Sector Data <i>without</i> Data Imputation (Assuming Incident Duration = 41 minutes). ....	101
Table 39. Incident Delay Using Sector Data <i>with</i> Data Imputation (Assuming Incident Duration = 41 minutes). ....	101
Table 40. Length and Number of Lanes per Sector for Sample Incident 2. ....	102
Table 41. Incident Delay Using Disaggregate Lane-by-Lane Data <i>without</i> Data Imputation... ....	111
Table 42. Incident Delay Using Disaggregate Lane-by-Lane Data <i>with</i> Data Imputation. ....	111
Table 43. Incident Delay Using Sector Data <i>without</i> Data Imputation. ....	111
Table 44. Incident Delay Using Sector Data <i>with</i> Data Imputation. ....	112
Table 45. Incident Delay Using Disaggregate Lane-by-Lane Data <i>without</i> Data Imputation (Assuming Incident Duration = 90 minutes). ....	113
Table 46. Incident Delay Using Disaggregate Lane-by-Lane Data <i>with</i> Data Imputation (Assuming Incident Duration = 90 minutes). ....	113
Table 47. Incident Delay Using Sector Data <i>without</i> Data Imputation (Assuming Incident Duration = 90 minutes). ....	114
Table 48. Incident Delay Using Sector Data <i>with</i> Data Imputation (Assuming Incident Duration = 90 minutes). ....	114
Table 49. Draft Speed, Volume, and Occupancy Quality Control Tests. ....	116
Table 50. Summary of 20-Second Records Flagged from March 1 to September 30, 2002....	118

## **LIST OF ACRONYMS, ABBREVIATIONS, AND TERMS**

911-RDMT	911 Radio Dispatch and Mobile Transportation
AADT	Annual average daily traffic
ADM	Administrative
AIH	Alarm incident handler
ArcIMS	Arc Internet Map Server
ArcSDE	Arc Spatial Data Engine
ARIMA	Autoregressive integrated moving averages
ATIS	Advanced traveler information system
ATMS	Advanced traffic management system
ATR	Automatic traffic recorder
AVI	Automated vehicle identification
AWARD	Advanced warning to avoid railroad delays
C2C	Center to Center
CAD	Computer-assisted design
CCTV	Closed caption television
CET	Calculation end time
CMS	Changeable message sign
CSF	Combined scale factor
CST	Calculation start time
CSV	Comma-separated value
CTECC	Combined Transportation and Emergency Communications Center
CTMS	Computerized Transportation Management System

DACS	Digital access cross-connect system
DART	Dallas Area Rapid Transit
DDD	Dynamic data distribution
DMS	Dynamic message sign
DOQ	Digital orthophoto quadrangle
ESRI	Environmental Systems Research Institute
ETT	Estimated travel time
FHWA	Federal Highway Administration
GIS	Geographic information systems
GUI	Graphical user interface
HAR	Highway advisory radio
HCTRA	Harris County Toll Road Authority
HOV	High occupancy vehicle
HTTP	Hypertext transfer protocol
GRS	Geodetic Reference System
IET	Incident end time
ISDN	Integrated service digital network
IST	Incident start time
ITS	Intelligent transportation systems
LCS	Lane control signal
LCU	Local control unit
MAP	Motorist Assistance Program
METRO	Metropolitan Transit Authority of Harris County

MrSID	Multi-resolution seamless image database
NAD	North American Datum
NTCIP	National Transportation Communications for ITS Protocol
PLAN	Personalized assistance and notification
RCTSS	Regional computerized traffic signal system
RIMS	Regional Incident Management System
SCM	Scenario management
SCU	System control unit
SCT	Scenario cancelled time
SET	Scenario execution time
SOAP	Simple object access protocol
StratMap	Texas Strategic Mapping Program
TMC	Transportation management center
TNRIS	Texas Natural Resource Information System
TP&P	Transportation Planning & Programming Division
TRF	Traffic Operations Division
TSMS	Texas Statewide Mapping System
TTI	Texas Transportation Institute
TxDPS	Texas Department of Public Safety
TxDOT	Texas Department of Transportation
USGS	United States Geological Survey
XML	Extensible markup language



## CHAPTER 1. INTRODUCTION

Transportation management centers (TMCs) generate and archive enormous amounts of data. Many applications of archived intelligent transportation system (ITS) data nationwide, including Texas, address transportation planning needs. As the number of applications of archived ITS data increases, interest is growing in identifying areas where archived ITS data could result in more effective TMC operations.

One area that has attracted the attention of practitioners and researchers alike is the use of archived ITS data to help improve incident management practices. The body of knowledge in this area is increasing and includes topics ranging from development of procedures to estimate incident delay ([1](#), [2](#)) to evaluation of incident management program benefits ([3](#)) to incident duration forecasting ([4](#)). A common denominator of most applications is the recognition that the roadway environment plays a role in the way drivers react to that environment, which, in turn, plays a role in the type and frequency of incidents on the road. It follows that a good understanding of the correlation between system performance indicators, the roadway environment, and the frequency of incidents is important for the development and implementation of incident management strategies.

This report contains products 0-4745-P1 (incident evaluation procedures: [Chapters 3, 4, and 5](#)) and 0-4745-P2 (steps for implementing the incident evaluation procedures: listed in [Chapter 6](#)). It describes a process to determine patterns in the spatial and temporal distribution of incidents along freeway corridors using geographic information system (GIS), traffic engineering, and statistical analysis techniques. The report illustrates current incident detection and data archival at several Texas Department of Transportation (TxDOT) TMCs, a process to develop a data model and geodatabase of ITS equipment and archived ITS data using a variety of data sources at the San Antonio TMC (TransGuide), a process to determine patterns in the spatial and temporal distribution of freeway incidents in San Antonio, a process to calculate the impact of incidents on traffic delay, and recommendations for implementation and further work.

This report is organized into chapters as follows:

- [Chapter 1](#) is this introductory chapter.
- [Chapter 2](#) summarizes a characterization of incident data archival practices in Texas.
- [Chapter 3](#) describes the process to develop a geodatabase of ITS features.
- [Chapter 4](#) summarizes the evaluation of spatial and temporal patterns in the distribution of incidents in San Antonio.
- [Chapter 5](#) describes the process to calculate incident delay using archived ITS data.
- [Chapter 6](#) summarizes conclusions and recommendations for implementation and further work.



## CHAPTER 2. ARCHIVED TRAFFIC AND INCIDENT DATA IN TEXAS

This chapter summarizes the ITS data collection process, existing and planned archived ITS data activities, and the incident detection and incident data management process at several TMCs in Texas, namely Austin's Combined Transportation and Emergency Communications Center (CTECC), Dallas' DalTrans, Fort Worth's TransVISION, Houston's TranStar, and San Antonio's TransGuide. The discussion is general for the first four TMCs but becomes more detailed for TransGuide because of the analyses the researchers completed using archived traffic and incident data from that TMC. To the extent possible, the researchers examined system database design documents, sample traffic ITS data, incident logs, and other related information. The researchers also interviewed system analysts and operators to understand the incident detection and incident management processes that lead to the production and archival of the data.

### AUSTIN'S CTECC

#### Configuration

CTECC is part of a multi-agency (City of Austin, Travis County, TxDOT, and the Capital Metropolitan Transportation Authority) emergency communications project called the 911 Radio Dispatch and Mobile Transportation (911-RDMT) project (5). In addition to CTECC, the project includes seven other initiatives (5, 6): 911 network upgrade; a multipurpose GIS-based database; a new computer-aided dispatch system; a new regional 800 MHz trunk radio system; a new police, fire, and emergency medical record management system; mobile data communications; and an automatic vehicle location system.

The current CTECC ITS deployment includes loop detector stations on some 30 freeway centerline miles, with loop detectors located roughly every half a mile. Main lanes and frontage road lanes have dual (speed-trap) loop detectors. Entrance and exit ramps have single (non-speed-trap) loop detectors. In total, the system has 504 speed-trap and 120 non-speed-trap detector stations, 92 closed caption television (CCTV) cameras, 16 dynamic message signs (DMSs), and 44 lane control signals (LCSs). LCSs are installed under sign bridges and are located roughly every 3 miles. CCTV camera spacing is irregular, with most cameras located at intersections and congestion-prone locations. The system pulls data from 81 local control units (LCUs). A courtesy patrol covers about 69 miles of freeway, and four highway advisory radio (HAR) stations transmit advisory information to the traveling public.

CTECC uses TxDOT's Advanced Traffic Management System (ATMS) software (7, 8) and relies on Sybase as the main data repository. The system stores ITS equipment locations using data from as-built schematics in state plane coordinates. As of March 2004, the database contained 30 to 50 percent of all installed detectors. ATMS uses Environmental Systems Research Institute (ESRI) MapObjects components to display ITS equipment locations on the same geo-referenced map used by the local emergency dispatch.

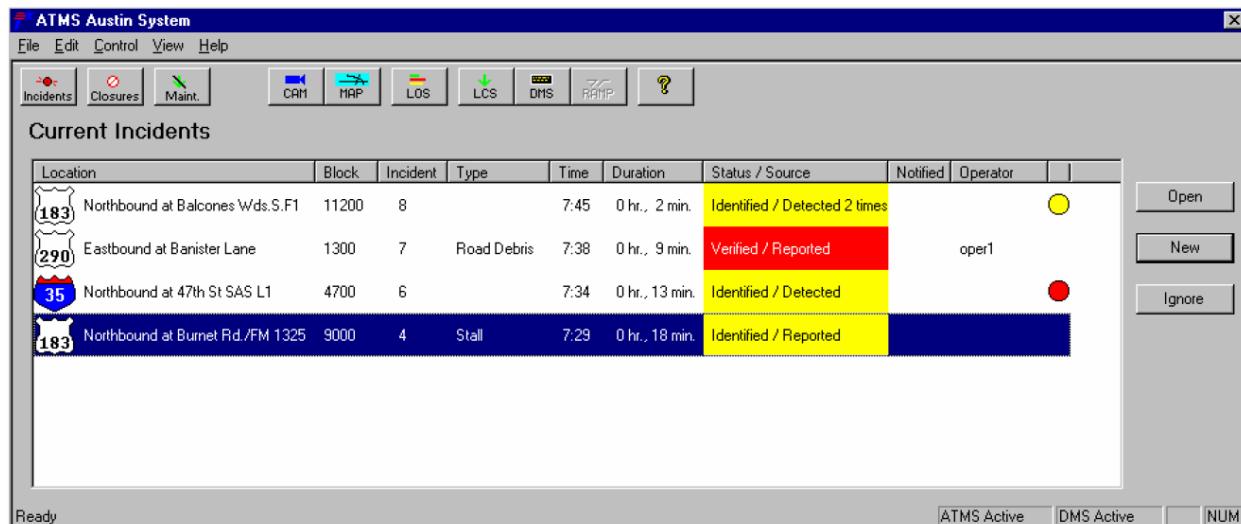
#### Incident Detection and Response

Incident detection relies mostly on a combination of loop detector-based incident alarms, CCTV camera scanning, police radio scanning, and courtesy patrols. The loop detector-based incident

detection algorithm compares a 3-minute moving average of percent occupancy values against a threshold and generates an alarm if the moving average exceeds the threshold. The 3-minute moving average is based on 1-minute aggregated data at the system control unit (SCU) level, which in turn relies on 20-second loop detector data. Each day can have up to six periods with different alarm thresholds depending on typical daily occupancy values that are stored in a profile. The system supports different profiles for weekdays, weekends, special events, and weather. For each sector, operators enter occupancy thresholds manually for the outermost lanes. For practical purposes, the system typically uses the same calibration parameters for all other lanes. If emergency 911 dispatchers on the operations floor detect a traffic incident first, they verbally relay this information to TxDOT operators. In general, TxDOT operators confirm incidents with the CCTV cameras and enter incident data into the system.

Incidents detected by the loop detector-based incident detection algorithm appear automatically in the ATMS incident list window ([Figure 1](#)) on the operator's screen. ATMS associates those incident locations with cross street, entrance ramp, or exit ramp data and shows the locations, along with a relative location indicator (before, at, or after) and block and/or mile marker values, on the first incident report page ([Figure 2](#)). The system also selects a primary camera, which operators use to confirm incidents and enter relevant incident-related data, such as incident type, number of lanes blocked, detection source, and status. As needed, operators also enter comments to more fully describe the incident and its evolution. For incidents detected by means other than the loop detector-based incident detection algorithm, ATMS provides operators with the ability to define the location of such incidents through the use of an interactive map. Based on the location identified by the operator, the system automatically determines coordinates, roadway name and direction, and mile marker location.

Once there is an incident record in the system, operators can select additional screens. Operators seldom use the second incident report page ([Figure 3](#)), which includes fields to enter additional information about the incident. The LCS and DMS control pages ([Figure 4](#) and [Figure 5](#)) automatically suggest LCS locations and DMS predefined messages to display in the vicinity of the incident, but operators can change the default settings as needed.



**Figure 1. ATMS Incident List Window (7).**

**Incident Evaluation of: US 0183 Northbound after LP 0001 NB / MoPac : Incident Number: 26**

Incident Report Page 1 | Incident Report Page 2 | LCS Control: NB | LCS Control: SB | DMS Control: NB | DMS Control: SB |

<b>Roadway</b> US 0183 Northbound	<b>REQUIRED FIELDS IN BLUE</b>	<b>Incident Type</b>	<b>Notify</b>
<b>Location</b> <input type="radio"/> Before <input type="radio"/> At <input checked="" type="radio"/> After Cross Street LP 0001 NB / MoPac Entrance Ramp Exit Ramp Detector Station	<b>Lanes Blocked</b> <input checked="" type="radio"/> Freeway / 2 Way Traffic <input type="radio"/> Frontage <b>Lanes</b> <input type="checkbox"/> All Lanes  <input type="checkbox"/> Entrance Ramp <input type="checkbox"/> Exit Ramp <input type="checkbox"/> Connector <input type="checkbox"/> Turn Around <input type="checkbox"/> Interchange <input type="checkbox"/> Detour	<input type="radio"/> Collision <input type="radio"/> Abnormal Congestion <input type="radio"/> Overturn <input checked="" type="radio"/> Stall <input type="radio"/> Abandonment <input type="radio"/> Vehicle on Fire <input type="radio"/> Road Debris <input type="radio"/> HAZMAT Spill <input type="radio"/> Public Emergency	<input type="checkbox"/> City Police Department <input type="checkbox"/> County Sheriff <input type="checkbox"/> County Constable <input type="checkbox"/> City EMS <input type="checkbox"/> County EMS <input type="checkbox"/> City Fire Department <input type="checkbox"/> County Fire Department <input type="checkbox"/> Traffic Signal Operations <input type="checkbox"/> TxDOT Maintenance <input type="checkbox"/> TxDOT ATMS Operations <input type="checkbox"/> TxDOT Courtesy Patrol <input type="checkbox"/> Media
Coordinates Block 9300	TxRef Marker 510+0.523	Incident Source <input type="radio"/> Detected <input checked="" type="radio"/> Reported	PAGING ENABLED
Latitude, Y 10111340.37237192	Longitude, X 3115000.38680531	Incident Status <input type="radio"/> FALSE ALARM <input checked="" type="radio"/> VERIFIED <input type="radio"/> MOVED <input type="radio"/> CLEARED	<b>Comments</b>  <input type="button" value="Send Page"/>
Primary Camera	Logged: 12 / 18 / 2002 13 : 23	Cleared: 0 / 0 / 0 0 : 0	<input type="button" value="OK"/> <input type="button" value="Cancel"/>

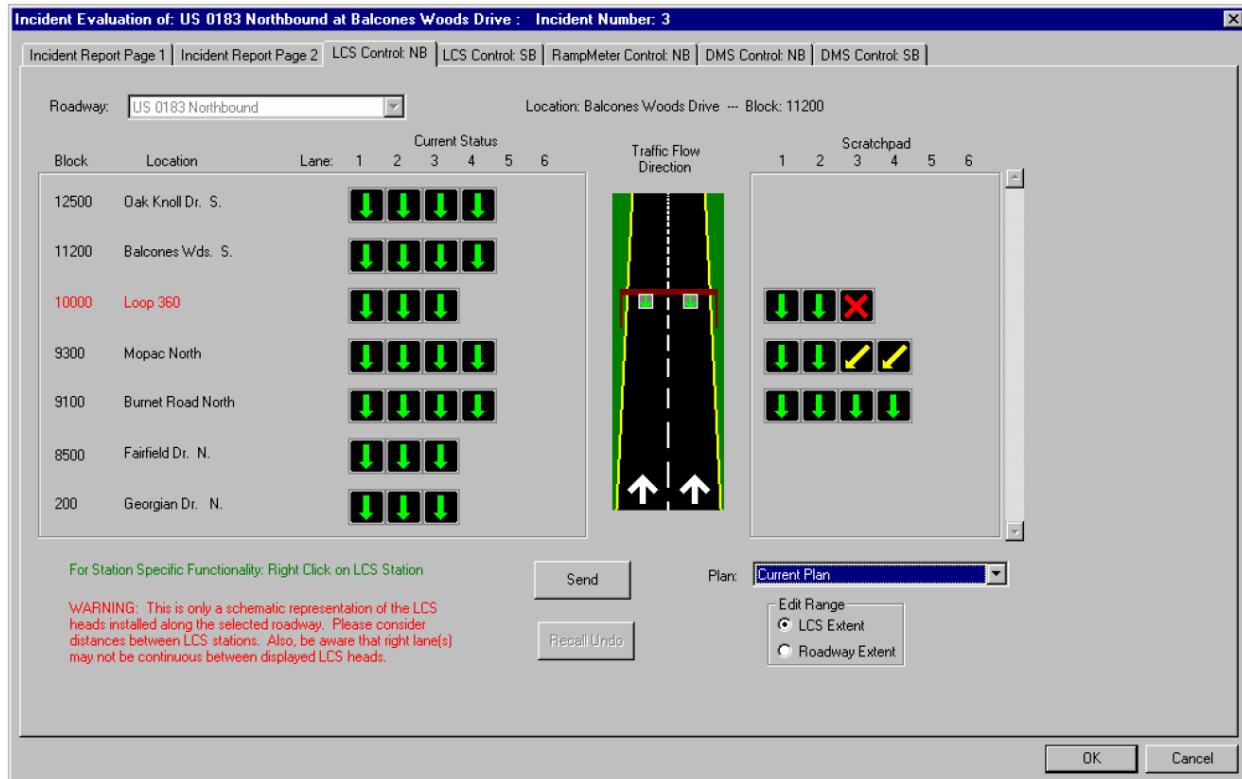
Figure 2. ATMS Incident Report Page 1 (7).

**Incident Entry and Evaluation**

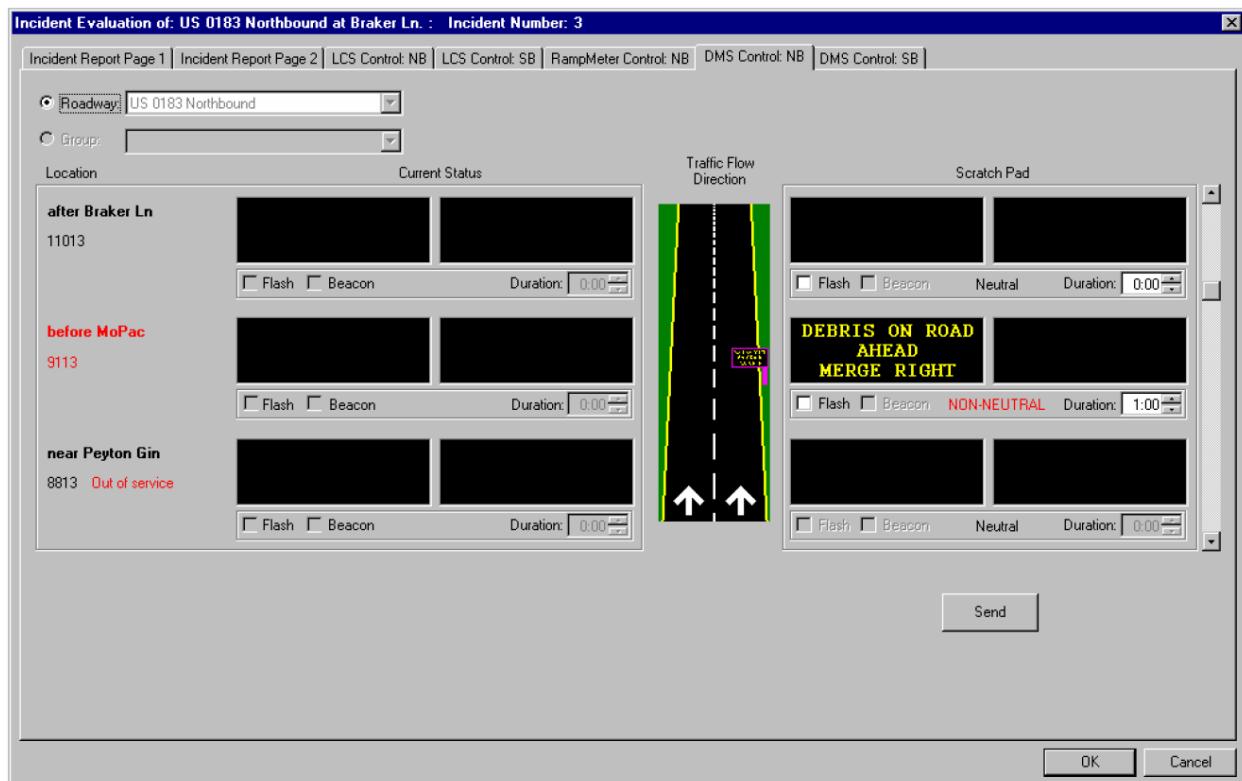
Report Page 1 | Report Page 2 | LCS Control: NB | LCS Control: SB | RampMeter Control: NB |

<b>Surface Condition</b> <input type="radio"/> Dry <input type="radio"/> Snowy <input type="radio"/> Wet <input type="radio"/> Icy <input type="radio"/> Muddy	<b>Light Conditions</b> <input type="radio"/> Daylight <input type="radio"/> Dawn <input type="radio"/> Darkness - no street lights <input type="radio"/> Darkness - street lights <input type="radio"/> Dusk	<b>Injuries</b> <input type="radio"/> None <input type="radio"/> Possible Injuries <input type="radio"/> Confirmed Fatality
<b>Road Condition</b> <input type="radio"/> No defects <input type="radio"/> Holes/ruts in surface <input type="radio"/> Foreign material on surface <input type="radio"/> High water or flood debris <input type="radio"/> Obstruction in road (night) <input type="radio"/> Obstruction in road (day) <input type="radio"/> Narrow bridge/over/underpass <input type="radio"/> Road under construction <input type="radio"/> Road under repair	<b>Weather Conditions</b> <input type="radio"/> Clear/Cloudy <input type="radio"/> Raining <input type="radio"/> Snowing <input type="radio"/> Fog <input type="radio"/> Blowing dust <input type="radio"/> Smoke <input type="radio"/> Sleet	<b>Vehicles Involved</b> <input type="radio"/> 1 <input type="radio"/> 2 <input checked="" type="radio"/> 3 or more <input type="checkbox"/> Passenger car <input type="checkbox"/> Truck <input type="checkbox"/> Trailer <input type="checkbox"/> House trailer <input type="checkbox"/> Farm tractor <input type="checkbox"/> Road machinery <input type="checkbox"/> Bus <input type="checkbox"/> School bus <input type="checkbox"/> Motorcycle <input type="checkbox"/> Emergency vehicle <b>Other Collisions:</b> <input type="checkbox"/> Vehicle (in transport) <input type="checkbox"/> Parked Vehicle <input type="checkbox"/> RR train <input type="checkbox"/> Pedestrian <input type="checkbox"/> Bicycle/other <input type="checkbox"/> Animal <input type="checkbox"/> Fixed object <input type="checkbox"/> Other object
<b>Detection</b> <input type="radio"/> Courtesy Patrol <input type="radio"/> Law Enforcement <input type="radio"/> Fleet Operators <input type="radio"/> CCTV <input type="radio"/> Automated Detection <input type="radio"/> Other Public Agencies <input type="radio"/> Citizen <input type="radio"/> Maintenance <input type="radio"/> Other	<b>Verification</b> <input type="checkbox"/> Courtesy Patrol <input type="checkbox"/> Law Enforcement <input type="checkbox"/> CCTV <input type="checkbox"/> Other Public Agencies <input type="checkbox"/> Maintenance	<input type="button" value="OK"/> <input type="button" value="Cancel"/>

Figure 3. ATMS Incident Report Page 2 (7).



**Figure 4. ATMS LCS Control Page (7).**



**Figure 5. ATMS DMS Control Page (7).**

## Archived Traffic and Incident Data

CTECC archives 1-minute aggregated volume, occupancy, speed, and truck percentage data by lane along freeway main lanes and at selected locations along frontage road lanes. Archived data also include volume and occupancy on most entrance and exit ramps.

CTECC has been archiving incident data since 1999. CTECC also has the capability, although rarely used, to record weather data and work zone data. ATMS stores archived incident data in a stand-alone archive incident report table ([Table 1](#)) that does not contain links to other tables in the Sybase database. This table is a snapshot of the system at the time the operator resolves the incident. Incident data archiving does not include LCS data. A separate log in the database records DMS messages, which the system keeps until deleted or permanently archived. CTECC keeps the last complete year on-line.

**Table 1. ATMS Archived Incident Report Table (Adapted from 8).**

Column Name	Datatype	Column Description
single_lanes_str	varchar(30)	Represents the lane numbers affected in ascii format.
nof_lanes_right	int	
nof_lanes_left	int	
surface_condition_str	varchar(30)	One surface condition in string format.
road_condition_str	varchar(30)	One road condition in string format.
detection_str	varchar(30)	One detection in string format.
light_conditions_str	varchar(30)	One light condition in string format.
weather_conditions_str	varchar(30)	One weather condition in string format.
verification_str	varchar(255)	All verification agencies in string format.
injuries_str	varchar(30)	One inquiry in string type format.
nof_vehicles_involved	tinyint	Number is 1, 2, or 3.
type_vehicles_involved_str	varchar(255)	All vehicles involved chosen in string format.
repeat_detections	int	Number of times an alarm has occurred, prior to being verified by an operator.
user_name	varchar(20)	Name of responsible traffic management operator.
latitude	numeric(16,8)	
longitude	numeric(16,8)	
TxRef_marker	int	Texas Reference Marker.
TxRef_suffix	varchar(8)	Texas Reference Marker suffix is appended to indicate a move from the original location.
TxRef_displacement	numeric(6,3)	Texas Reference Marker displacement.
location_description	varchar(30)	Location of an incident NOT in the Cross Street table.
entr_ramp_str	varchar(30)	Entrance ramp string.
detector_location_str	varchar(30)	Detector station string.
cross_street_str	varchar(30)	Cross street string.
off_roadway_str	varchar(30)	Indicates whether this incident was off the instrumented roadway.
roadway_str	varchar(30)	Roadway string.
direction_str	varchar(12)	One direction string.
incident_number	int	Incident was identified by this number on a daily basis in the ACTIVE INCIDENT REPORT.
lanes_affected_str	varchar(225)	One lane type affected in string format.
block	int	Block number.
exit_ramp_str	varchar(30)	Exit ramp string.
last_detected_datetime	smalldatetime	Date and time when this incident was last reported. Logged date and time in Sybase smalldatetime format.
cleared_datetime	smalldatetime	Cleared date and time in Sybase smalldatetime format.
logged_datetime	smalldatetime	Logged date and time in Sybase smalldatetime format.
notified_str	varchar(255)	All notified agencies chosen in string format.
incident_type_str	varchar(30)	One incident type in string format.
comment_str	varchar(255)	Comment in string format.
before_or_after_str	varchar(30)	"Before" or "after" string.
archive_number	numeric(7,0)	Unique system number that is generated when the incident is archived to this table.

## DALLAS' DALTRANS

### Configuration

As of November 2003, DalTrans covered some 70 miles of freeway. The ITS deployment includes 97 CCTV cameras, 32 Autoscope cameras (located roughly every 1.5 miles covering some 26 miles of freeway), loop detector stations (covering some 10 miles of freeway, although a large percentage of loop detectors are currently not working mostly due to highway reconstruction), 66 microwave sensors organized into 54 stations throughout Dallas County, and 28 DMSs. Each Autoscope camera uses up to six “virtual” detectors that continuously capture volume, occupancy, speed, and vehicle classification data. The system polls camera data every 10 seconds.

Coverage also includes the infrastructure associated with the high occupancy vehicle (HOV) Dallas Area Rapid Transit (DART) network on IH-30, IH-635, IH-35E, and US 67 ([9](#)). In addition, DalTrans has interfaces for a number of external systems to enable data exchange with other centers such as Fort Worth’s TransVISION, City of Dallas, City of Richardson, City of Plano, and Dallas County. DalTrans was the first system to implement a standard Center-to-Center (C2C) interface to enable system status data exchange and system device control ([10](#)).

Currently, a temporary facility houses the DalTrans TMC. The current DalTrans ITS management software is a prototype system developed incrementally to support DalTrans’ initial and short-term ITS deployment needs. Plans for a permanent facility close to the TxDOT Dallas District office and a new ITS management software are currently under way ([9](#)). The current DalTrans software supports incident management, lane closure management, DMS monitoring and control, camera control and snapshots, video control, and detector management. The software displays ITS equipment and incident locations on an interactive map that relies on Microsoft MapPoint components. The interface enables operators to pan, zoom, look up addresses, query road segments, and obtain information about the current status of ITS features.

### Incident Detection and Response

In areas covered by Autoscope cameras, the system polls field cameras every 10 seconds and can generate alarms by detecting changes in speed. Because of difficulties with the camera detection process, this part of the system is currently not operational. To detect incidents, operators rely on police dispatch, police radio monitoring, courtesy patrol calls, and 911. Every 5 minutes, DalTrans receives an updated list of incidents from the City of Dallas 911 system. The software then filters out incidents that are not freeway related. Typically, incident data include latitude/longitude data, as well as roadway/cross street or street/block number. DalTrans only uses roadway/cross street and street/block number data because latitude/longitude data are expressed in decimal degrees with only one decimal digit, which makes these data unsuitable for locating incidents. Unfortunately, roadway names are often inconsistent. For example, instead of “US 75,” a 911 incident record might refer to the same corridor as “US75,” “US-75,” “75,” “North Central Expressway,” or “North Central.” Over time, DalTrans has built a look-up table that contains previously used roadway name designations for 16 widely used corridors. A similar table for cross streets does not exist at this time.

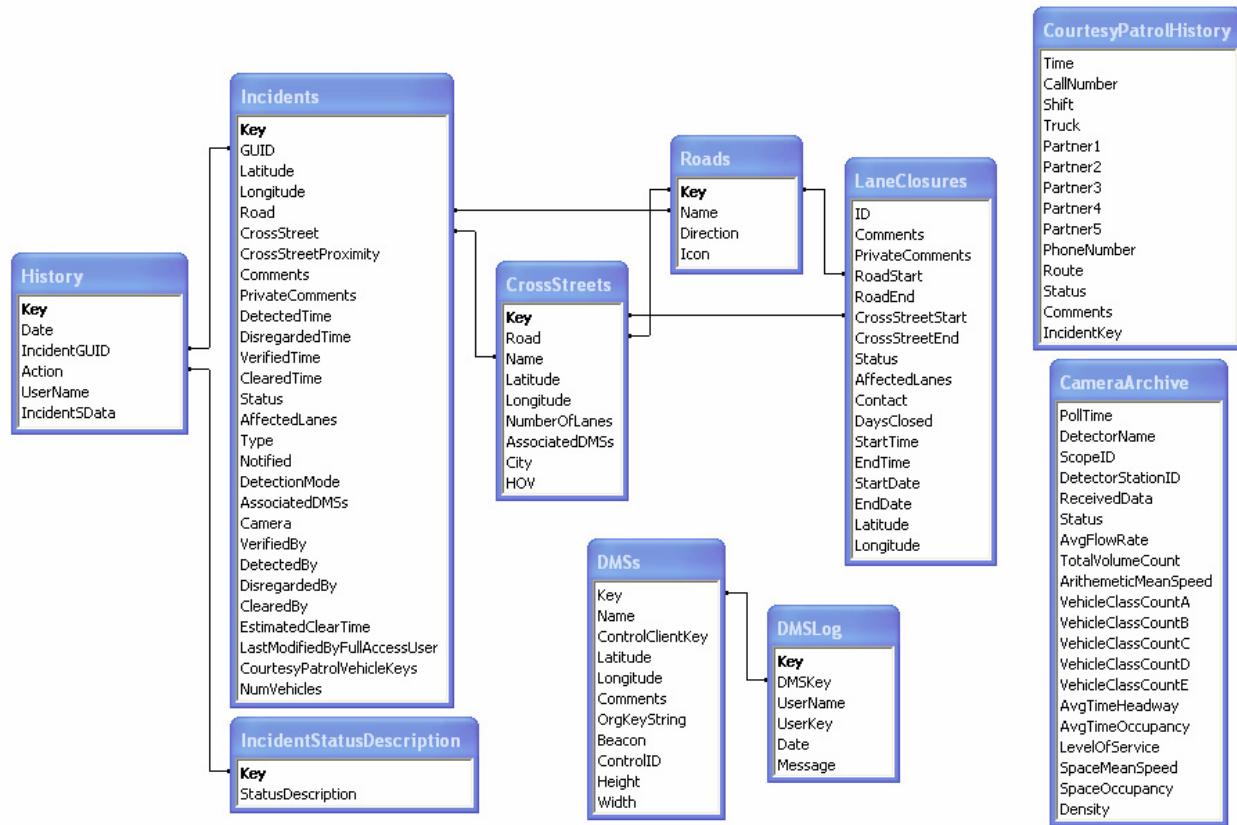
The software displays new traffic-related incidents as icons on the upper left corner of the operator's console. The operator then checks the intersecting street data against a list of streets that cross the freeway system monitored by DalTrans. If the incident is within the DalTrans area of authority, the operator manually relocates the incident icon so that it displays correctly on the screen and verifies the incident location using the closest available CCTV camera. After confirming the incident, the operator generates incident messages and delivers those messages to the appropriate DMSs. The system also publishes this information on the website that DalTrans shares with TransVISION ([11](#)). The system includes a subscriber-based incident alert system that forwards incident alerts to e-mail addresses of subscribed users. An incident remains active in the system until the operator confirms with the cameras that emergency services have cleared the incident. Incident status options include detected (when TxDOT received notice of the incident), verified, cleared, and disregarded (if the operator cancels an incident).

## Archived Traffic and Incident Data

Daltrans keeps an ITS data archive in Microsoft Access format ([Figure 6](#)) that includes four separate archived data types:

- Autoscope camera data. DalTrans archives 5-minute aggregated flow rate, volume, speed, vehicle classification, headway, occupancy, and density. Autoscope camera data archiving started in January 2003.
- Incident data. Three main tables make up the incident data archive: Incidents, History, and LaneClosures. The Incidents table contains basic incident data, including location, incident type, comments, affected lanes, associated DMSs, as well as time stamps for detection, disregard, verification, and clearance. The History table contains a record of changes in incident status and includes incident ID, date, action, user name, and incident data, which is a serialized extensible markup language (XML) representation of the incident data. The LaneClosures table contains data about planned lane closures. Incident data archiving started in 1999.
- DMS data. The DMS data archive contains a record of displayed DMS messages. DMS data archiving started in May 2000.
- Courtesy patrol data. The courtesy patrol data archive contains a record of courtesy patrol responses to incidents. Although this table includes an incident identification field, all archived entries in this field are currently blank, thus limiting the possibility of linking the table to the incident data archive. Courtesy patrol data archiving started in 1999.

Recently, DalTrans developed a prototype Universal Detector Data Archive to include data from Autoscope video detectors, inductive loop detectors, and microwave detectors ([12](#)). The intent of the development was to provide wide data access and the ability to archive data from disparate sources and multiple centers into a single repository with a simple common interface. The new archive transfers data from multiple sources using hypertext transfer protocol (HTTP) and simple object access protocol (SOAP) to access a web service that writes to the archive. Users can access the archived data using an Internet browser. The archived data are in comma-delimited text format and include 5-minute aggregated speed, volume, and occupancy data.



**Figure 6. Current DalTrans ITS Data Archive Model.**

## FORT WORTH'S TRANSVISION

### Configuration

As of September 2003, the TransVISION ITS deployment included 50 miles of fiber-optic cable, 1,523 loop detector stations roughly every half a mile, 93 radar detectors, 111 CCTV cameras, 56 DMSs, 265 LCSs, and five ramp-metering systems. Radar detectors are located roughly every half a mile in areas with fiber-optic cable coverage and every 1 to 3 miles in areas without fiber-optic cable coverage (transmission is wireless in those areas). TransVISION also includes courtesy patrols and a weather alert system. TransVISION uses three types of video transmission: uncompressed over optical fiber, compressed over integrated service digital network (ISDN) (128 kbytes/s), and compressed over telephone line (56 kbytes/s). ISDN provides lower resolution and a lower refresh rate than fiber although, according to TransVISION officials, it is adequate to satisfy their current needs. Cameras that use a telephone line connection generally transmit about two compressed images per second.

Loop arrangement in the field is an alternate speed-trap (which can measure volume, speed, occupancy, and density) and non-speed-trap (which only measures volume and occupancy) configuration. Radar detectors do not measure speed. In general, LCUs report 20-second data. SCUs poll LCUs every 20 seconds but only report data every minute. The system polls SCUs

every minute and produces 5-minute moving averages, i.e., every minute the system produces an average that represents aggregated data over the previous 5 minutes.

The TransVISION management software relies on a database structure in Sybase that is a modification of Houston's TranStar system ([13](#)). The database structure includes data submodels for a variety of data categories, including loop detector characteristics and data, DMS characteristics and data, LCSs, SCUs, CCTV cameras, incident detection and logs, ramp metering, and road closures. Even though the data model includes loop detector data, problems with the Sybase implementation have severely limited the use of loop detector data at TransVISION. TransVISION has also not implemented the DMS data model at this point. Currently, operators can make use of a library of DMS messages, but in practice they edit old or create new messages as needed. The library contains incident and special event messages as well as public education and public service messages. TransVISION normally does not display congestion-related messages unless the congestion is due to an incident on the road or related to a special event.

### **Incident Detection and Response**

Incident detection relies mostly on police dispatch monitoring, courtesy patrol calls, and commercial traffic services. CCTV camera scanning is also used but to a lesser degree. Fort Worth 911 is in the planning stage. In addition to the above, TransVISION uses a trunk radio scanner that is compatible with the trunk radio systems used by the City of Fort Worth and some local police departments. When the radio reports an incident, operators use the cameras to confirm its existence/location. Once confirmed, the operator fills an incident report form and posts messages on the appropriate DMSs. The system also publishes this information on a website that TransVISION shares with DalTrans ([11](#)). According to TransVISION officials, there is usually a 3- to 4-minute incident response time after the operators first hear about an incident on the freeway. This time includes locating the incident with the cameras, filling out the report, and posting the messages on the DMSs. A main constraint for quick incident detection and/or confirmation is the camera pan, tilt, and zoom speed.

### **Archived Traffic and Incident Data**

Although TransVISION started archiving incident data in 1995 and 5-minute aggregated traffic data in June 2000, these activities have been sporadic. TransVISION has also collected and archived incident report logs, operator logs, and planned construction lane closures since June 2000.

## **HOUSTON'S TRANSTAR**

### **Configuration**

TranStar is a partnership of TxDOT, the Metropolitan Transit Authority of Harris County (METRO), City of Houston, and Harris County ([14](#)). TranStar's ITS deployment is one of the largest in the country. Among other features, it includes automated vehicle identification (AVI) infrastructure covering 260 directional freeway miles and 94 reversible HOV lane miles, 128

entrance ramp flow signals, 316 CCTV cameras, 154 DMSs, a regional computerized traffic signal system (RCTSS) for 2,800 planned signals, a motorist assistance patrol, emergency management, flood alert/roadway weather information with 41 TxDOT-owned sensors and 100 county-owned sensors, METRO's bus dispatch, railroad monitoring, and highway advisory radio (12 fixed sites and one portable site). AVI reader spacing varies widely between 1 and 5 miles. The current AVI tag market penetration is over one million tags issued by Harris County Toll Road Authority (HCTRA). CCTV cameras are located roughly every mile. DMSs are located roughly every 3 miles.

TranStar's transportation management software, the Computerized Transportation Management System (CTMS), operates on an Oracle database. Incident management is one of the main system functions. A recent development in CTMS is the Regional Incident Management System (RIMS), which enables web-based incident data entry and management. It includes a web application server that drives the data entry forms and some 100 Oracle tables located on the main TranStar database server. The RIMS database schema accesses data from other TranStar subsystems as well.

### **Incident Detection and Response**

Incident detection relies mostly on police dispatch monitoring, Motorist Assistance Program (MAP) calls, commercial traffic services, and CCTV camera scanning. Operators use a police radio scanner to assist in the incident detection process. However, because several local law enforcement agencies also use consoles and have personnel on the TranStar operations floor, it is more common for operators to receive direct incident feedback from police agency representatives on the floor. A significant percentage of incident detection occurs through the TranStar MAP dispatch. In the event of an incident on the road, drivers can dial a “\*MAP” shortcut on their cell phones to report the incident to the MAP dispatch. Only one cell phone provider, Cingular, currently supports the shortcut, although any cell phone can call the dispatch using MAP's 10-digit number. The MAP dispatcher—who is located on the TranStar operations floor—compiles and screens cell phone calls, makes a judgment call as to the nearest cross street, and generates an incident record in the database. A second operator then takes over and manages the incident as appropriate. MAP is on duty only on weekdays.

Other sources of information for incident detection are two private traffic services that provide traffic information to the public (METRO Networks/Westwood One and Mobility Technologies). Occasionally, these services receive information about incidents on the road and forward that information to TranStar operators.

TranStar does not rely on the 911 system or on the AVI subsystem for incident detection. In the case of 911, this is not likely to change in the short term, particularly after the recent merge of the Police 911 and Fire Department 911 databases, which resulted in the elimination of a critical field that documented whether incidents were traffic related. In the case of the AVI subsystem, TranStar has an incident detection algorithm that checks for changes in segment speed data. In general, speed data are only as old as it takes vehicles to traverse the distance between consecutive AVI readers. Operators see rolling 30-second average speed data on their speed maps. However, little incident detection takes place this way, mainly because distances between consecutive AVI readers are relatively long, which increases the time it takes for incident

“signals” to reach the AVI readers. In practice, other incident detection processes usually detect incidents earlier than the incident detection algorithm.

Operators confirm all incidents using CCTV cameras. After verification, operators decide on the appropriate response, which might include posting messages on the DMSs. The operator can change pre-defined messages as needed. Two operators often handle one incident, with one operator taking care of the incident verification and the other operator taking care of the DMS messages. TranStar follows a hierarchical procedure for posting messages, and operators typically display messages only for major incidents, e.g., major accidents or flooding. After the incident has cleared, operators usually leave DMS messages until traffic returns to normal flow patterns. TranStar no longer displays recurrent congestion-related messages following negative feedback received from the public about displaying such messages on the DMSs.

Operators enter all incident-related information into the database through the RIMS interface ([Figure 7](#)). Each time the operator changes the status of an incident, the system adds a new record to the database. There are four main time stamps to document the evolution of an incident: detected, verified, moved, and cleared. “Detected” refers to the time an operator, including the MAP dispatcher, creates a record for the incident in the database (which may or may not coincide with the actual detection time depending on the procedure that led to the identification of the incident). “Verified” refers to the time the operator confirmed the incident with the CCTV camera. “Moved” refers to the time when emergency services moved a lane-blocking vehicle to the shoulder. “Cleared” refers to the time the appropriate response agency cleared the incident.

### **Archived Traffic and Incident Data**

TranStar has been archiving 15-minute aggregated AVI travel time and speed data since October 1993, freeway incident data since May 1996, emergency road closure data since August 2001, and construction lane closure data since May 2002. Archived data are stored in an Oracle database, which enables the production of a variety of queries and reports. As an illustration, [Figure 8](#) shows a query view that includes incident data, a listing of DMSs used to respond to the incident, and archived AVI data. Notice the AVI data archive allows the identification of segment data by roadway, cross street, and latitude/longitude. The incident data archive also allows the identification of incident locations by roadway, cross street, and latitude/longitude, which would enable the linking between the AVI data archive and the incident data archive.

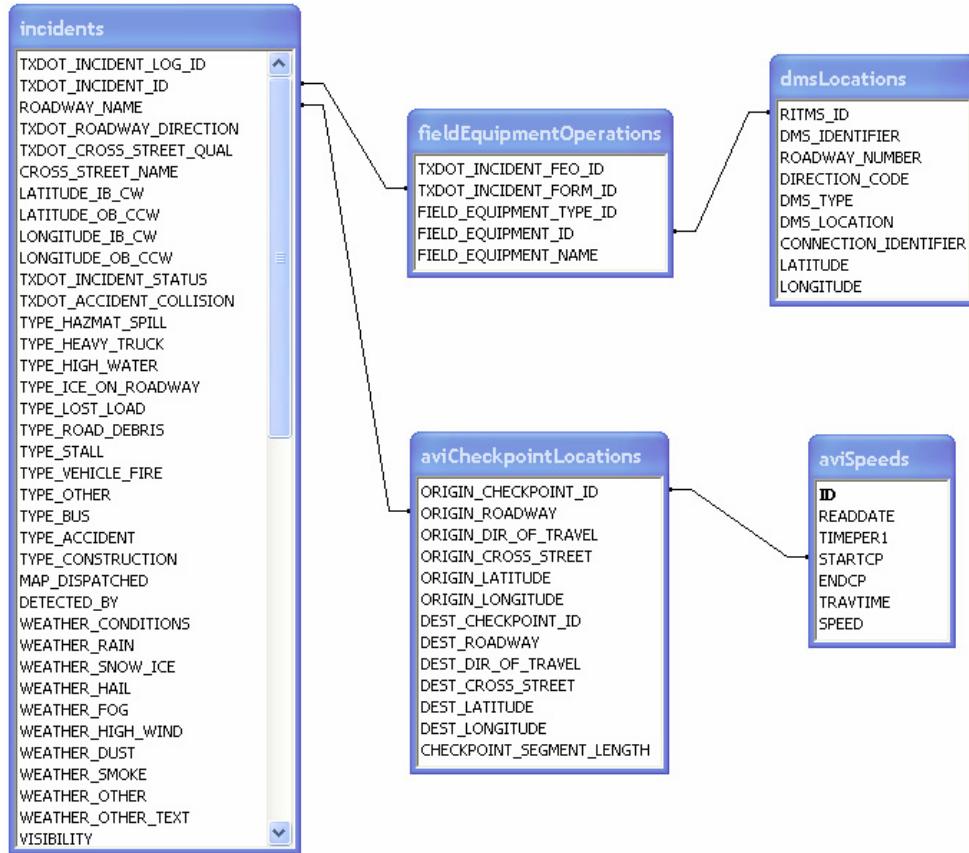
TranStar has developed an interactive web-based application that displays average archived speeds for corridor sections with AVI coverage ([14](#)). The system dynamically generates speed charts representing freeway segment speed averages every 15 minutes from 5 AM to 8 PM. Currently, the charts show historical averages for 2000, 2001, 2002, 2003, and the current day. The system also shows averages for each day of the week.

General Information										
Status:	<input type="checkbox"/> Detected	<input type="checkbox"/> Verified	<input type="checkbox"/> Moved	<input type="checkbox"/> Cleared						
Roadway Information										
*										
<input type="checkbox"/> Freeway <input type="checkbox"/> Street		<input type="button" value="Search"/>	1) I-10 Katy <input type="checkbox"/> *							
<input type="checkbox"/> Eastbound <input type="checkbox"/> Westbound			<input type="checkbox"/> Before <input type="checkbox"/> After <input type="checkbox"/> At							
Sort By:	<input type="checkbox"/> Name(Seq) <input type="checkbox"/> Block Number	<input checked="" type="checkbox"/> Condense Consecutive	Cross Street:							
		<input type="checkbox"/> Show Unique		<input type="checkbox"/> 55) 7900 ANTOINE DR <input type="checkbox"/> *						
Latitude:	0.0	Longitude:	0.0	<a href="#">See Map At These Coordinates</a>						
Lanes Affected Information										
<input type="checkbox"/> All Main Lanes <input type="checkbox"/> Single Lanes		<input type="checkbox"/> LS <input checked="" type="checkbox"/> #1 <input type="checkbox"/> #2 <input type="checkbox"/> #3 <input type="checkbox"/> #4 <input type="checkbox"/> #5 <input type="checkbox"/> #6 <input type="checkbox"/> #7 <input type="checkbox"/> #8 <input type="checkbox"/> RS								
Frontage Road	<input type="checkbox"/> #1	<input type="checkbox"/> #2	<input type="checkbox"/> #3	<input type="checkbox"/> U-Turn						
Ramp	<input type="checkbox"/> Exit	<input type="checkbox"/> Entrance	<input type="checkbox"/> Left Interchange	<input type="checkbox"/> Right Interchange						
HOV	<input type="checkbox"/> Main	<input type="checkbox"/> Entrance	<input type="checkbox"/> Exit	<input type="checkbox"/> Ramp						
Opposing Direction	<input type="checkbox"/> LS	<input type="checkbox"/> #1	<input type="checkbox"/> #2	<input type="checkbox"/> #3	<input type="checkbox"/> #4	<input type="checkbox"/> #5	<input type="checkbox"/> #6	<input type="checkbox"/> #7	<input type="checkbox"/> #8	<input type="checkbox"/> RS
Classification:										
Vehicles Involved:	2 <input type="checkbox"/>									
Type:	<input checked="" type="checkbox"/> Accident/Collision <input type="checkbox"/> Minor <input type="checkbox"/> Major <input type="checkbox"/> Fatalities <input type="checkbox"/> Accident/Collision <input type="checkbox"/> Accident/Collision <input type="checkbox"/> Accident/Collision <input type="checkbox"/> HAZMAT_Spill <input type="checkbox"/> Heavy_Truck <input type="checkbox"/> High_Water <input type="checkbox"/> Ice_On_Roadway <input type="checkbox"/> Lost_Load <input type="checkbox"/> Road_Debris <input type="checkbox"/> Stall <input type="checkbox"/> Vehicle_On_Fire <input type="checkbox"/> Other <input type="checkbox"/> Bus 0									
Construction:	<input type="checkbox"/> Construction									
Field Equipment Operated										
use < CTRL > - LMB to select more than 1 item. use < CTRL > - LMB to un-select a selected item.										
When button pressed, items selected under "All" REPLACE items under "Selected".										
All	Select	Selected								
2011-10 East EB @ Lathrop 2012-10 East EB @ Market 2060-10 East EB @ Monmouth 2061-10 East WB @ John Raleston	<input type="checkbox"/> DMS->		2046-10 Katy EB @ Antoine 2102-10 Katy EB @ Dairy Ashford 2077-10 Katy EB @ Kirkwood 2047-10 Katy EB @ SH 6							
418-45NB 610 N. Loop 412-45NB 610 S. Loop 415-45NB Broadmoor 411-45NB Broadway	<input type="checkbox"/> LCS->									
	<input type="checkbox"/> HAR->									
54965-I-10 Katy @ Barker Cypress Entanc 54966-I-10 Katy @ Fry Entrance EB 54967-I-10 Katy @ Mason Entrance EB 54968-I-10 Katy @ SH-99 Entrance EB	<input type="checkbox"/> Flow Signal->									
1825-101 E. 4th St.@Center 1826-1015 E. 13th St. @Flasher 1827-118 Queens@Flasher 3768-11th St. @Hempstead Rd.	<input type="checkbox"/> Traffic Signal->									

Figure 7. TranStar RIMS Interface.

<input type="button" value="Other--&gt;"/>				
<b>Heavy Duty Wrecker</b>				
<input type="button" value="JIMO"/>				
<b>Weather:</b>				
Conditions:	<input checked="" type="checkbox"/> OK <input checked="" type="checkbox"/> Inclement  <input type="text" value="Other text:"/>			
Visibility:	<input checked="" type="checkbox"/> Good <input type="checkbox"/> Limited			
<b>Detection:</b>				
Date(MM/DD/YYYY):	01/29/2004	Time(HH:MM:SS):	11:59:28	<input type="button" value="Insert"/>
<input checked="" type="checkbox"/> Aerial_Surveillance <input type="checkbox"/> Automated_Detection <input type="checkbox"/> CCTV <input type="checkbox"/> Citizen <input checked="" type="checkbox"/> Commercial_Traffic_Services <input type="checkbox"/> Fleet_Operators <input type="checkbox"/> MAP <input type="checkbox"/> METRO <input checked="" type="checkbox"/> Police <input type="checkbox"/> Other_Public_Agencies <input type="checkbox"/> Other				
<b>Verification:</b>				
Verification Date(MM/DD/YYYY):	01/29/2004	Verification Time(HH:MM:SS):	11:59:32	<input type="button" value="Insert"/>
<input checked="" type="checkbox"/> CCTV <input type="checkbox"/> Commercial_Traffic_Services <input type="checkbox"/> MAP <input type="checkbox"/> METRO <input type="checkbox"/> Police_Dept._City <input type="checkbox"/> Police_Dept._County <input type="checkbox"/> Police_Dept._METRO <input type="checkbox"/> Police_Dept._State <input type="checkbox"/> Other_Public_Agencies				
<b>Response By:</b>				
<input type="checkbox"/> City <input type="checkbox"/> Coroner/ME <input type="checkbox"/> County <input type="checkbox"/> EMS <input type="checkbox"/> Fire_Dept. <input type="checkbox"/> HAZMAT <input type="checkbox"/> HCFCD <input type="checkbox"/> MAP <input type="checkbox"/> METRO <input type="checkbox"/> Police_Dept._City <input type="checkbox"/> Police_Dept._County <input type="checkbox"/> Police_Dept._METRO <input type="checkbox"/> Police_Dept._State <input type="checkbox"/> TXDOT <input checked="" type="checkbox"/> Wrecker				
Moved Date(MM/DD/YYYY):	<input type="text"/>	Moved Time(HH:MM:SS):	<input type="text"/>	<input type="button" value="Insert"/>
Cleared Date(MM/DD/YYYY):	01/29/2004	Cleared Time(HH:MM:SS):	12:10:08	<input type="button" value="Insert"/>
<b>Comments:</b>				
Type	Date Created ▾	Operator	Comment	EDIT
Operators	1/29/2004 11:59:28 AM	hdunn	/// HAR/// SYNC AND BROOKSIRE	<a href="#">[Edit]</a>
<input type="text"/>				
Date (MM/DD/YYYY) <input type="text" value="01/29/2004"/> Time (HH:MM:SS) <input type="text" value="12:18:00"/> <input type="button" value="Insert"/>				
<input type="button" value="Operators"/> <input type="button" value="Add"/>				
<b>RIMS Notification</b>				
use < CTRL > - LMB to select more than 1 item.				
use < CTRL > - LMB to un-select a selected item.				
Users		Groups		
abowdoi () adavis2 () adicks2 () administrator ()		<input type="checkbox"/> Everyone		
Message: <input type="text"/>				

**Figure 7. TranStar RIMS Interface (Continued).**



**Figure 8. Sample Query View of TranStar Archived Traffic and Incident Data.**

## SAN ANTONIO'S TRANSGUIDE SYSTEM

### Configuration

TransGuide's ITS deployment covers some 87 miles of freeway. It includes 1,463 loop detector units (both speed-trap and non-speed-trap) and sonic detectors organized in 325 sensor locations located roughly every half a mile, 140 CCTV cameras located roughly every mile, 80 main lane DMSs located roughly every 3 miles, 121 frontage road DMSs, and 236 LCSs located roughly every mile. No longer operational is an AVI subsystem that TransGuide used to collect travel time and speed data on corridors that did not have loop detector coverage. Currently, TransGuide is deploying Autoscope cameras to collect speed, volume, and occupancy data on several periphery corridors.

TransGuide's transportation management software operates as a client/server-based system that runs on Sun workstations in a Unix Solaris environment (15, 16). The system includes several subsystems (Table 2), each with a number of components, including menu bars, processes, services, and servers. Table 3 describes subsystem components that are most relevant for understanding the ITS data archival process.

**Table 2. TransGuide Subsystems.**

<b>Subsystem</b>	<b>Description</b>
Administrative (ADM) Subsystem	It accomplishes basic administrative tasks and contains the main user interface—called the ATMS Menu Bar—that sends requests to all other graphical user interface (GUI) servers in the system.
Alarm Incident Handler (AIH) Subsystem	It handles incident alarms using data from four subsystems: LCU, Advanced Warning to Avoid Railroad Delays (AWARD), AIH 911, and Pump Station. It also executes incident responses.
Advanced Traveler Information System (ATIS) Subsystem	It distributes travel information managed by the ATIS data server process.
AVI Subsystem	No longer operational, it handled real-time speed and travel time data using field data collected from vehicle AVI tags.
AWARD Subsystem	It provides railroad crossing information to motorist and emergency response vehicles. Using loop detector sensors, it calculates and predicts the arrival and duration of closures along the Union Pacific Kerrville Line.
CCTV Subsystem	It controls the operation of the CCTV cameras in the TransGuide ATMS.
Changeable Message Sign (CMS) or DMS Subsystem	It manages and controls DMSs through interaction with the Map Application and Scenario Management (SCM) subsystems.
Data Server Subsystem	It is the main centerpoint of access for all data in the TransGuide ATMS. It collects stores and distributes data to the TransGuide ATMS.
Dynamic Data Distribution (DDD) Subsystem	It distributes real-time ATMS data to the appropriate collection point. It interacts with all ATMS master processes and collects and sends equipment and incident data every 20 seconds to the Data Server Subsystem.
Estimated Travel Time (ETT) Subsystem	It provides current traffic and estimated travel time data to drivers through field equipment such as the DMSs.
Lane Closure GUI Subsystem	It allows operators to manually edit information about lane closures in a database table.
LCS Subsystem	It manages and controls LCS units. This subsystem interacts with the SCM and map display subsystems.
LCU Subsystem	It manages and controls LCUs in the TransGuide ATMS.
Map Application Subsystem	It is a set of map application tools (Real-Time Map Display, Real-Time Map Generation Tool, and World Wide Web Real-Time Map Display) that display TransGuide ATMS data using a map interface.
SCM Subsystem	It manages scenarios in the TransGuide ATMS.
Paging Subsystem	It sends alphanumeric pages from ATMS operators.
Personalized Assistance and Notification (PLAN) Subsystem	No longer operational, it enabled users to select routes for which they wanted to receive incident information from the TransGuide ATMS via e-mail.
Pump Station Subsystem	It handles alarms from the drainage pumps.

**Table 3. Sample of Relevant ITS Data TransGuide Subsystem Components.**

Component	Function
AIH Background Process	It handles alarm requests from all subsystems that produce incident events.
AIH Management Process	It manages all ATMS alarms and incidents.
AIH 911 Process	It reads current San Antonio Police Department incidents and updates the AIH background process.
AIH GUI Server	It displays ATMS incident alarms and messages on the screen.
CCTV Master	It manages all connection, disconnection, and control command requests.
CCTV GUI	It makes requests for connection and control commands to cameras.
CCTV digital access cross-connect system (DACS)-III Arbiter	It connects and disconnects cameras and monitors to the DACS-III video switch.
CCTV ATM Arbiter	It connects and disconnects cameras and monitors to the ATM video switch.
CMS Master	It manages the interactions of all DMSs in the TransGuide ATMS.
CMS GUI Server	It manages the screens for the CMS interface.
TransGuide CMS Poll Server	It establishes connections to DMSs and polls DMSs once per polling cycle.
National Transportation Communications for ITS Protocol (NTCIP) CMS Poll Server	It is similar to the TransGuide CMS Poll Server, except it uses the statewide driver client library that supports the NTCIP to communicate with DMSs.
LCS Master	It manages lane control signal interactions.
LCS GUI Server	It manages the screens for the LCS interface.
TransGuide LCS Poll Server	It establishes connections to LCSs and polls LCSs once per polling cycle.
LCU Master	It manages LCU interactions.
LCU GUI Server	It manages screens for the LCU interface.
LCU Driver	It pushes commands from the LCU Master to the LCU poll servers.
Austin LCU Poll Server	It establishes connections to Austin LCUs and polls those LCUs once per polling cycle.
NazTech LCU Poll Server	It establishes connections to Naztech LCUs and polls those LCUs once per polling cycle.
Map WWW Application	It provides access to current ATMS data using a map interface.
Map Display Application	It provides access to real-time speed data, status data about road segments and traffic equipment, incident data, and lane closure data.
Map Generation Application	It creates a geographic representation of roadway segments and ITS equipment.
Scenario Master	It manages scenarios along with interactions with the field equipment.
Scenario GUI Server	It manages screens for the scenario interface.

## Incident Detection and Response

Incident detection relies on a combination of detector-based alarms and 911-based alarms (through the AIH subsystem), CCTV camera scanning, police radio scanning, and courtesy patrols. Detector-based alarms rely on speed for speed-trap detectors (installed on main lanes and some ramps) and percent occupancy for non-speed-trap detectors (mostly installed on entrance and exit ramps). LCUs continuously poll data from the detectors and relay 20-second aggregated data to the AIH subsystem. For speed-trap detectors, if a moving 2-minute average speed drops below 25 mph, the AIH subsystem automatically triggers a minor (yellow) alarm. If the moving 2-minute average speed drops below 20 mph, the AIH subsystem triggers a major (red) alarm. For non-speed-trap detectors, the default minor and major alarm thresholds are 25 percent occupancy and 35 percent occupancy, respectively.

TransGuide has a connection to the San Antonio Police Department 911 dispatch that enables TransGuide to receive 911 alarms in real time. The AIH subsystem processes 911 alarms only if the alarms are on or near TransGuide LCU-instrumented roadways. In these cases, the AIH subsystem generates an incident alarm that appears on the operators' consoles.

The manager on duty receives all alarms, decides what further action is necessary, and assigns alarms to operators ([Figure 9](#)). After the manager assigns an alarm to an operator, the alarm becomes an incident. In practice, operators are responsible for specific corridors and tend to handle most incidents that happen on those corridors. However, if a corridor is experiencing too many alarms, the system manager can forward alarms to other operators to distribute the work load. At the operator's desk, all incidents on the network appear both on the system map and in the form of icons that identify the process that gave origin to the alarm (e.g., "LA" for lane alarm, "PD" for police department alarm, "RR" for railroad alarm, and "PS" for pumping station alarm) and a color code to indicate the alarm condition (green, yellow, or red).



**Figure 9. TransGuide Incident Assignment Screen.**

After an operator acknowledges an incident, the system displays a modified version of the incident assignment screen and the CCTV subsystem attempts to display the primary incident camera listed on the incident screen ([Figure 10](#)). After verifying the incident with the CCTV camera, the operator has the option to execute a scenario ([Figure 11](#)). A scenario is a pre-defined set of messages that operators can apply to a pre-selected set of DMSs and/or LCSs, depending on incident type, extent, and location. In practice, operators also have the option to create new scenarios or modify existing scenarios to fit the needs of the specific incidents the operators are managing. The system displays all active scenarios on the operator's main console using "S" icons ([Figure 10](#)).

The original TransGuide ATMS design allowed operators to load scenarios only if an incident record already existed in the system. After a system design change several years ago, operators were able to load scenarios even if an incident record did not previously exist. This resulted in added flexibility because operators could display DMS and LCS messages to manage incidents detected by processes such as CCTV camera scanning and courtesy patrols, i.e., incidents not handled by the AIH subsystem. In practice, the system design change did not include an alternate procedure to generate an incident record for those incidents, leaving the scenario record as the only data repository for incidents not handled by the AIH subsystem.

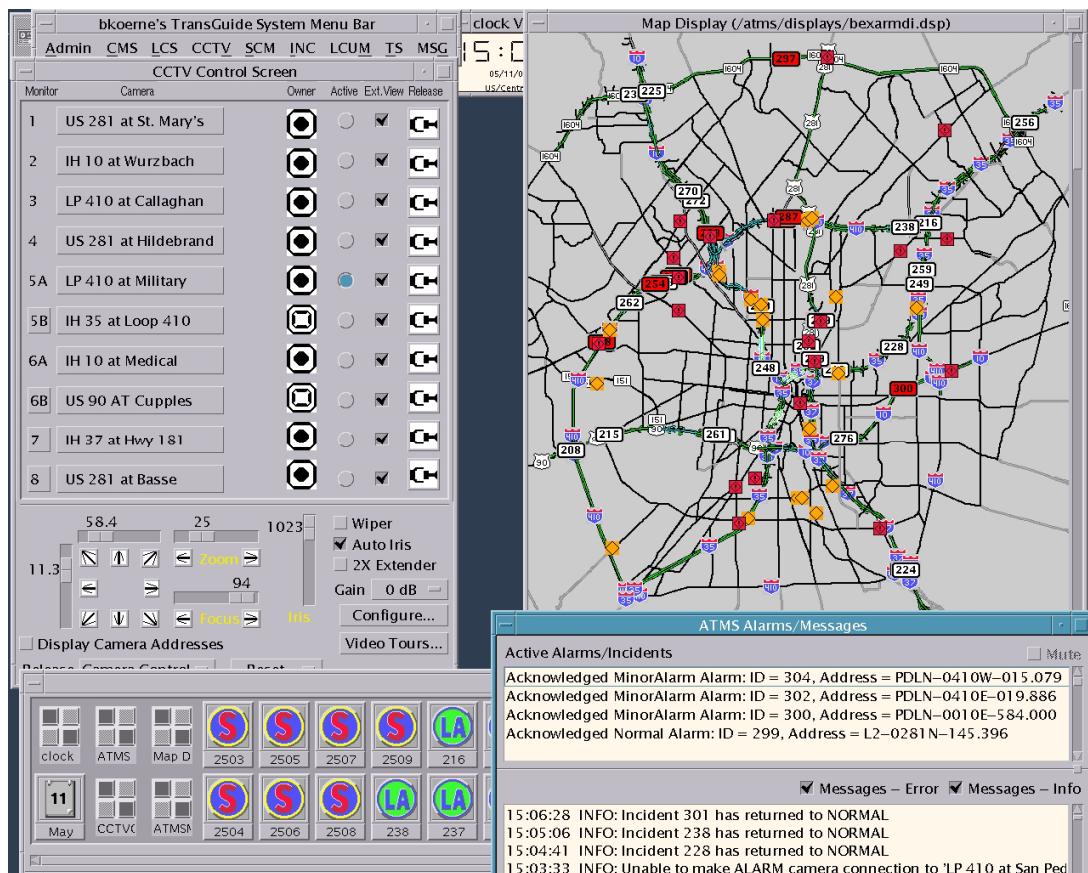


Figure 10. TransGuide Operator Console Screen.

**Scenario Search Screen – ID #2566**

Incident Address:	SECT-0090E-569.166
Scenario Time: ASAP or MM/DD/YY HH:MM	ASAP
Identify type of incident <input checked="" type="radio"/> Major Accident <input type="radio"/> Minor Accident <input type="radio"/> Congestion <input type="radio"/> Debris <input type="radio"/> Construction/Maintenance <input type="radio"/> Weather Condition <input type="radio"/> Stalled Vehicle <input type="radio"/> RR Crossing Delay <input type="radio"/> Special Scenarios	
<input type="checkbox"/> Lanes Closed <input type="checkbox"/> Left Shoulder <input type="checkbox"/> Lane 1 <input type="checkbox"/> Lane 2 <input type="checkbox"/> Lane 3 <input type="checkbox"/> Lane 4 <input type="checkbox"/> Lane 5 <input type="checkbox"/> Lane 6 <input type="checkbox"/> Right Shoulder	
<input type="checkbox"/> Demand Exceeds Capacity <input type="checkbox"/> Page	
Special Scenarios	Travel Times: IH 10
<input type="button" value="Search"/>	<input type="button" value="Cancel"/>

Figure 11. TransGuide Scenario Search Screen.

Because of the current structure of the detector-based incident detection algorithm, which relies on speed for main lanes and percent occupancy for ramps, many alarms are actually the result of recurrent roadway congestion. TransGuide has a policy of displaying congestion-related DMS messages to alert motorists about congested traffic conditions. Experienced operators are aware of the locations where the system usually triggers congestion-related alarms and prepare scenarios accordingly ahead of time. Typically, operators watch camera feeds for specific corridors to monitor congestion build up. When the system begins to generate congestion-related alarms, or at the discretion of the operator, the operator may execute the scenario prepared in advance. In theory, operators could cancel congestion-related alarms at any time. In practice, they typically “iconize” congestion-related alarms and wait until speeds increase again to prevent new alarm triggers at the same locations within a short period of time.

### **Archived Traffic and Incident Data**

TransGuide uses a Sybase database environment to store data describing ITS equipment characteristics and data needed to support day-to-day operational activities at the center. TransGuide maintains a long-term data repository in compressed file format, including 20-second detector data (since July 1997), AVI data (from June 1998 to June 2003), and event data (since January 1998) ([17](#)). TransGuide also maintains a scenario log in Sybase, which includes a scenario header table and a scenario execution table (since February 2002).

The current 20-second detector data archive includes speed, volume, and percent occupancy. As [Figure 12](#) shows, each record contains a date and time stamp, the detector address, and the corresponding average speed (in mph), volume, and percent occupancy values. The detector address has three components separated by a dash: detector location and designation (where “L” represents main lane, “EN” represents entrance ramp, “EX” represents exit lane, and the number represents the lane number beginning with the lane closest to the median), freeway number and direction, and mile marker. The system reports speeds on non-speed-trap detectors as -1.

02/04/2003 00:30:35 L3-0035N-165.409	Speed=56 Vol=000 Occ=000
02/04/2003 00:30:35 L3-0035S-165.409	Speed=55 Vol=002 Occ=002
02/04/2003 00:30:36 EN1-0035S-166.340	Speed=-1 Vol=001 Occ=001
02/04/2003 00:30:36 EX1-0035S-166.239	Speed=-1 Vol=000 Occ=000
02/04/2003 00:30:36 EX2-0035S-166.239	Speed=-1 Vol=001 Occ=001
02/04/2003 00:30:36 L1-0035N-166.450	Speed=61 Vol=001 Occ=001
02/04/2003 00:30:36 L2-0035N-166.450	Speed=54 Vol=001 Occ=001
02/04/2003 00:30:36 L2-0035S-166.450	Speed=60 Vol=004 Occ=005
02/04/2003 00:30:36 L3-0035N-166.450	Speed=54 Vol=004 Occ=005
02/04/2003 00:30:36 L3-0035S-166.450	Speed=57 Vol=004 Occ=005
02/04/2003 00:30:36 L4-0035N-166.450	Speed=57 Vol=003 Occ=010
02/04/2003 00:30:36 L4-0035S-166.450	Speed=70 Vol=004 Occ=005

**Figure 12. Sample 20-Second Archived Detector Data at TransGuide.**

The current event data archive includes 30 different major record types (such as 2301, 2303, and 8354), with several record types including more than one record subtype ([Figure 13](#)). The original intent of the event data archive was to serve as a debugging tool for ATMS, but over time, the archive has grown to become a very extensive data repository. Of particular interest in this research are record types 5301, 5302, and 5303, which contain incident data records, and record type 8352, which contains DMS and LCS scenario data records.

8337 lcu\_driver5 2003/05/20 16:00:10 1053464410 L2-1604W-032.121 1 61 5 15 25 144  
2301 cms\_master 2003/05/20 15:57:00 1053464220 CMS CMS2-0410W-025.558 Display Return: msgID=2643  
text='TRAVEL TIME TO|US281 4-6 MINS|IH10 9-11 MINS|||'  
2301 cms\_master 2003/05/20 15:57:12 1053464232 CMS CMS2-0090W-568.933 Display Return: msgID=2646  
text='TRAVEL TIME TO|LP410 5-7 MINS|HUNT LN 6-8 MINS|||'  
5304 aih\_back 2003/05/20 16:00:33 1053464433 258 'L2-0035S-164.412' 'SECT-0035S-164.412' 3 28 23  
'Normal' 'CCTV-0035N-163.955'.1 'ToBeAssigned' 'blopez' '' '' 1053461876 0 0 0  
5302 aih\_back 2003/05/20 16:00:33 1053464433 258 'L2-0035S-164.412' 'SECT-0035S-164.412' 3 23 25  
'MinorAlarm' 'CCTV-0035N-163.955'.1 'ToBeAssigned' 'blopez' '' '' 1053461876 0 0 0  
5301 aih\_back 2003/05/20 16:00:33 1053464433 274 'L3-0035N-164.412' 'SECT-0035N-164.412' 3 20 16  
'MinorAlarm' 'CCTV-0035N-164.835'.1 'ToBeAssigned' 'blopez' '' '' 1053464433 0 0 0  
8341 aih\_mgmt 2003/05/20 16:00:33 1053464433 274 SECT-0035N-164.412 blopez 3 0  
2301 cms\_master 2003/05/20 15:57:21 1053464241 CMS CMS3-0035N-164.308 Display Return: msgID=2805  
text='CONGESTION|ON FREEWAY|ENTER WITH|CAUTION|'  
2301 cms\_master 2003/05/20 15:57:21 1053464241 CMS CMS2-0035N-168.672 Display Return: msgID=2645  
text='TRAVEL TIME TO|LOOP 1604|UNDER 5 MINS|||'  
5302 aih\_back 2003/05/20 16:00:49 1053464449 267 'EN2-0035S-153.608' 'SECT-0035S-153.608' 2 -1 35  
'MinorAlarm' 'CCTV-0035N-153.619'.1 'ToBeAssigned' 'blopez' '' '' 1053463712 0 0 0  
2301 cms\_master 2003/05/20 15:57:42 1053464262 CMS CMS2-0035S-168.645 Display Return: msgID=2645  
text='TRAVEL TIME TO|LP410 UNDER 5 MINS|US281 12-14 MINS|||'  
2301 cms\_master 2003/05/20 15:57:45 1053464265 CMS CMS2-0090W-570.580 Display Return: msgID=2646  
text='TRAVEL TIME TO|LP410 7-9 MINS|HUNT LN 8-10 MINS|||'  
5302 aih\_back 2003/05/20 16:01:30 1053464490 267 'EN2-0035S-153.608' 'SECT-0035S-153.608' 2 -1 37  
'MajorAlarm' 'CCTV-0035N-153.619'.1 'ToBeAssigned' 'blopez' '' '' 1053463712 0 0 0  
8352 scm\_master 2003/05/20 16:01:41 1053464501 2805 None 0 CMS3-0035N-164.308 CONGESTION|ON  
FREEWAY| ENTER WITH|CAUTION|

**Figure 13.** Sample Archived Event Data at TransGuide.

[Figure 14](#) shows sample records from the archived scenario database. Each record includes a header that summarizes basic data from the scenario loaded by the operator and a linked table that contains the actual DMS and LCS messages displayed in the field.

**Figure 14.** Sample Archived Scenario Data at TransGuide.

## CHAPTER 3. GEODATABASE DEVELOPMENT

This chapter describes the process to develop geographically referenced traffic and incident ITS data sets in preparation for the incident evaluation phase. As the previous chapter showed, CTECC, DalTrans, TransVISION, TranStar, and TransGuide follow very different approaches for generating and archiving ITS traffic and incident data. Data archives range from limited, e.g., TransVISION, to comprehensive, e.g., TranStar, or comprehensive but without a formal data model, e.g., TransGuide. Temporal archived data resolution ranges from aggregate, e.g., TranStar's 15-minute travel time and speed data, to disaggregate, e.g., TransGuide's 20-second loop detector data. Archived data types range from basic incident data descriptions at most TMCs to actual displayed message data, e.g., DalTrans and TransGuide.

ITS hardware and software systems are also quite different across TMCs, making the process to develop standardized procedures difficult. Nonetheless, there are common elements to most TMCs, e.g., they all follow procedures to associate incident data with roadway locations or segments. TMCs are increasingly using GIS in their ATMS implementations to map ITS infrastructure and incidents, and, consequently, it makes sense to conduct the analysis in a geo-referenced environment. To ensure the generalization of the research results, it was important to focus on TMCs with substantial ITS traffic and incident data archives at relatively disaggregate levels. For this reason, and in agreement with the project director and the project advisors, the researchers focused on developing an ITS geodatabase for TransGuide.

### DATA SOURCES

#### Road Base Maps

The TransGuide ATMS map application subsystem provides a graphical interface that enables operators to view, query, and edit highway lane segments and ITS equipment. [Figure 15](#) shows a sample of map displays at two locations on IH-10: IH-10 at Colorado and IH-10 at IH-35.

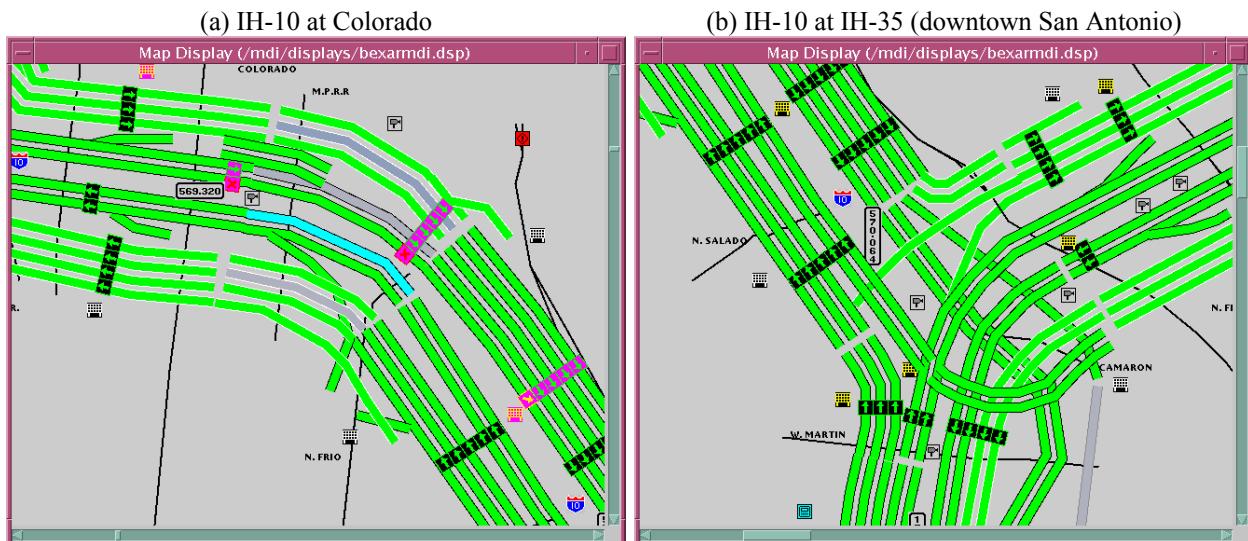
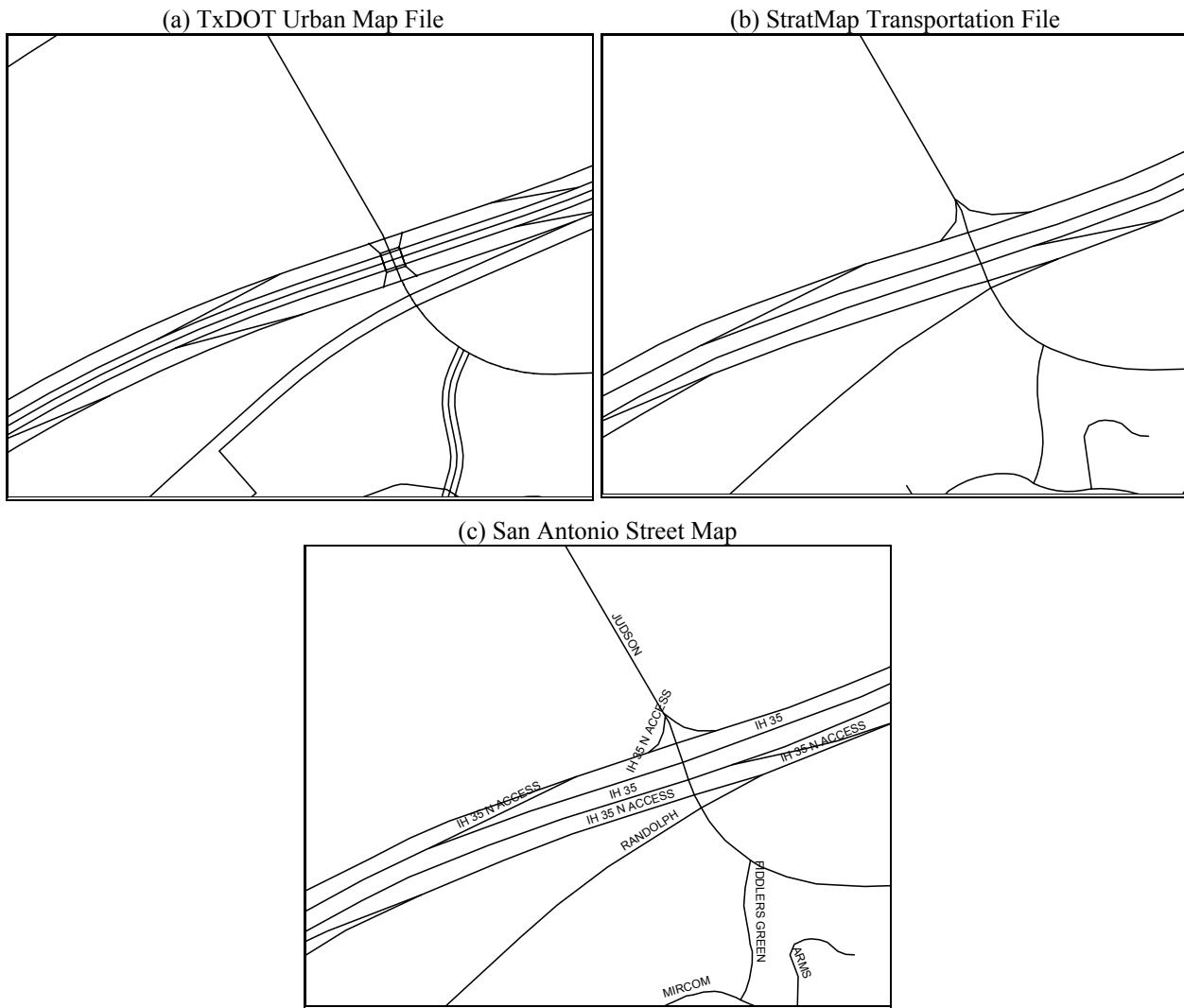


Figure 15. TransGuide Map Display Application ([16](#)).

The mapping application can only be used within the TransGuide ATMS and is limited in its capability to reference and query geospatial data. Although the coordinates associated with the map lane segments are in latitude and longitude, the linear features are only sketches that do not correspond to the actual location of the lane segments in the field. This makes it difficult to use the lane segments in a standardized, platform-independent geo-referenced GIS environment.

To address this limitation, the researchers examined a number of road base map alternatives, including the TxDOT urban map file, the StratMap transportation file, and a street map from the City of San Antonio. [Figure 16](#) shows sample views from these files, and [Table 4](#) summarizes relevant file characteristics. The urban map file is part of a series of maps developed by TxDOT in the mid-1990s and distributed by the Texas Natural Resource Information System (TNRIS) ([18](#)). This file contains many of the features found on 7.5-minute United States Geological Survey (USGS) quadrangle maps, except for contour lines, fence lines, jeep trails, electrical transmission lines, oil and gas pipelines, and control data monuments.



**Figure 16. Sample GIS-Based Road Base Maps in San Antonio (IH-35 at Judson).**

**Table 4. Road Base Map Characteristics.**

File	Format	Basic Metadata	
		Parameter	Description
TxDOT Urban Map File	Arcinfo coverage (originally in Microstation format)	Source	TxDOT, TNRIS
		Coordinate system	Texas Statewide Mapping System (TSMS)
		Projection	Lambert Conformal Conic
		Ellipsoid	Clarke 1866
		Surface adjustment	None; referenced to ellipsoid
		Datum	North American Datum 1927 (NAD 27)
		Longitude of origin	100 degrees west (-100)
		Latitude of origin	31 degrees 10 minutes north
		Standard parallel # 1	27 degrees 25 minutes north
		Standard parallel # 2	34 degrees 55 minutes north
		False easting	3,000,000 feet
		False northing	3,000,000 feet
		Unit of measure	Feet (international)
		Data source	USGS 7.5 minute quadrangles
StratMap File	Arcinfo coverage	Source	TxDOT, TNRIS
		Coordinate system	Geographic
		Ellipsoid	Geodetic Reference System 80
		Datum	North American Datum 1983 (NAD 83)
		Unit of measure	Decimal degrees
		Data source	USGS 7.5-minute quadrangles
		Nominal scale	1:24,000
San Antonio Street Map	ESRI shape file	Source	City of San Antonio, Public Works
		Coordinate system	State Plane Texas South Central
		Projection	Lambert Conformal Conic
		Ellipsoid	Geodetic Reference System 80
		Surface adjustment	None; referenced to ellipsoid
		Datum	North American Datum 1983 (NAD 83)
		Longitude of origin	-99.000000
		Latitude of origin	27.833333
		Standard parallel # 1	28.383333
		Standard parallel # 2	30.283333
		False easting	1,968,500 feet
		False northing	13,123,333.333333 feet
		Unit of measure	Survey feet
		Data source	Aerial photography, other sources

The StratMap transportation file is part of the Texas Strategic Mapping Program (StratMap) (19). TxDOT is responsible for the development and maintenance of this map. The transportation file contains updated, digital versions of transportation features found on 7.5-minute, 1:24,000 scale USGS quadrangle maps, including city streets, county roads, state and federal highways, interstates, selected private streets, railroads, trails, and pipelines.

The San Antonio street map is a file in an ESRI shape format that contains roadway features in and around San Antonio, including city streets and state-maintained roads. Local agencies in the San Antonio area are responsible for the development and maintenance of the map.

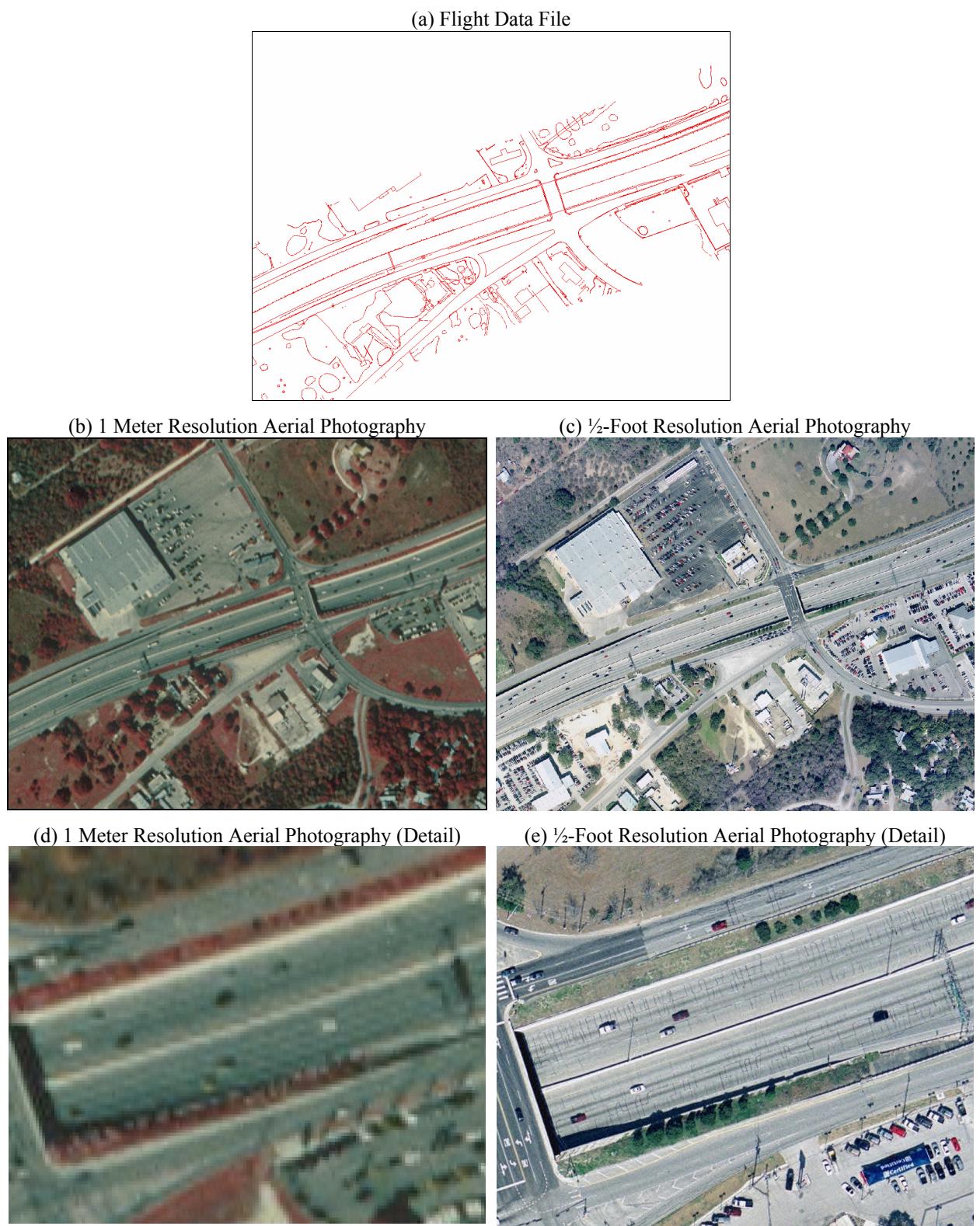
## Flight Data Files and Aerial Photography

The researchers also examined flight data files and aerial photography. In principle, the idea behind using these data sources was to provide context to the vector road base map data rather than providing a numerical data source for engineering analysis. [Figure 17](#) shows sample views from these data sources, and [Table 5](#) and [Table 6](#) summarize relevant file characteristics.

Flight data files are Microstation-format files that contain vector features normally visible on low-altitude rectified aerial photographs such as roadbeds, poles, drainage structures, traffic barriers, and topographic controls. Flight data files typically do not include pavement markings or lane configurations. They constitute the basis for most highway design, construction, and maintenance activities at TxDOT. As [Table 5](#) shows, there were three types of flight data files along TransGuide corridors according to their associated coordinate system and projection information: “English system” files, “metric system” files, and “unknown system” files.

Two types of aerial photography were available: high-altitude (1 meter or 3.281 foot) resolution digital orthophoto quadrangle (DOQ) aerial photography and low-altitude ( $\frac{1}{2}$  foot) resolution aerial photography. The 1 meter aerial photography is high-altitude aerial photography collected in the 1990s and managed by TNRIS ([19](#)). The  $\frac{1}{2}$ -foot aerial photography is low-altitude aerial photography that the Bexar County Appraisal District collected in early 2003. Through an interagency cooperation agreement, other agencies in the San Antonio area—such as TxDOT—may use this imagery free of charge.

In general, as [Figure 17](#) shows, the  $\frac{1}{2}$ -foot aerial photography provides a much finer level of resolution than the 1 meter photography, making it possible to identify features that would be very difficult, if not impossible, to distinguish otherwise. Examples include pavement markings, lane configurations, utility poles, ITS and signal cabinets, and traffic support structures. In some cases, depending on lighting, contrast, and other environmental factors, the  $\frac{1}{2}$ -foot aerial photography even shows the outlines of loop detectors on the pavement. It may be worth noting that the Bexar County Appraisal District is planning the collection of  $\frac{1}{4}$ -foot resolution aerial photography in the near future, increasing even more the potential of that type of data source.



**Figure 17. Sample Flight Data File and Aerial Photography.**

**Table 5. Flight Data File Characteristics.**

Flight File Type	Format	Basic Metadata	
		Parameter	Description
“English system” file	Microstation	Source	TxDOT San Antonio District Office
		Coordinate system	State Plane Texas South Central
		Projection	Lambert Conformal Conic
		Ellipsoid	Geodetic Reference System 80
		Surface adjustment	1/0.99983 = 1.00017003
		Datum	North American Datum 1983 (NAD 83)
		Longitude of origin	-99.000000
		Latitude of origin	27.833333
		Standard parallel # 1	28.383333
		Standard parallel # 2	30.283333
		False easting	1,968,500 feet
		False northing	13,123,333.333333 feet
		Unit of measure	Survey feet
		Data source	Low-altitude aerial photography
“Metric system” file	Microstation	Source	TxDOT San Antonio District Office
		Coordinate system	State Plane Texas South Central
		Projection	Lambert Conformal Conic
		Ellipsoid	Geodetic Reference System 80
		Surface adjustment	1/0.99983 = 1.00017003
		Datum	North American Datum 1983 (NAD 83)
		Longitude of origin	-99.000000
		Latitude of origin	27.833333
		Standard parallel # 1	28.383333
		Standard parallel # 2	30.283333
		False easting	600,000 meters
		False northing	4,000,000 meters
		Unit of measure	Meters
		Data source	Low-altitude aerial photography
“Unknown system” file	Microstation	Source	TxDOT
		Surface adjustment	1/0.99983 = 1.00017003
		Unit of measure	Survey feet
		Data source	Low-altitude aerial photography

**Table 6. Aerial Photography Characteristics.**

File Name(s)	Format	Basic Metadata	
		Parameter	Description
1 Meter Resolution Aerial Photography	Multi-resolution Seamless Image Database (MrSID)	Source	TNRIS
		Coordinate system	Universal Transverse Mercator Zone 14
		Projection	Transverse Mercator
		Ellipsoid	Geodetic Reference System 80
		Surface adjustment	None; referenced to ellipsoid
		Datum	North American Datum 1983 (NAD 83)
		Longitude of origin	-99.000000
		Latitude of origin	0.000000
		False easting	500000.000000
		False northing	0.000000
		Unit of measure	Meters
		Resolution	1 meter
½-Foot Resolution Aerial Photography	MrSID	Source	Bexar County Appraisal District
		Coordinate system	State Plane Texas South Central*
		Projection	Lambert Conformal Conic
		Ellipsoid	Geodetic Reference System 80
		Surface adjustment	None; referenced to ellipsoid
		Datum	North American Datum 1983 (NAD 83)
		Longitude of origin	-99.000000
		Latitude of origin	27.833333
		Standard parallel # 1	28.383333
		Standard parallel # 2	30.283333
		False easting	1,968,500 feet
		False northing	13,123,333.333333 feet
		Unit of measure	Survey feet
		Resolution	1 foot

\* Assumed. It was not possible to confirm.

## ITS Equipment Schematics

There were two types of ITS equipment schematics available to obtain ITS equipment addresses: ITS schematics in Microstation format and schematics on long paper rolls (typically 6–8 feet long by 17–24 inches wide) that TransGuide operators use to manually mark the address of individual pieces of ITS equipment (Figure 18). The Microstation schematics show the location of ITS features on the ground. They represent as-built conditions, and, as such, they should provide the most reliable information about ITS feature locations in the field. The foundation for ITS equipment schematics are flight data files that TransGuide personnel use to generate the schematics. This means the coordinate system and projection associated with these schematics should also be either “English system,” “metric system,” or “unknown system,” as described previously. Until recently, however, operators typically extracted and rotated specific flight data file sections to generate and print ITS equipment schematics on 11 inch by 7 inch paper. The disadvantage of this process is that many schematics lost all references to their underlying coordinate system, whereas under normal circumstances all schematics would be geo-referenced or at least compatible with the underlying flight data files.

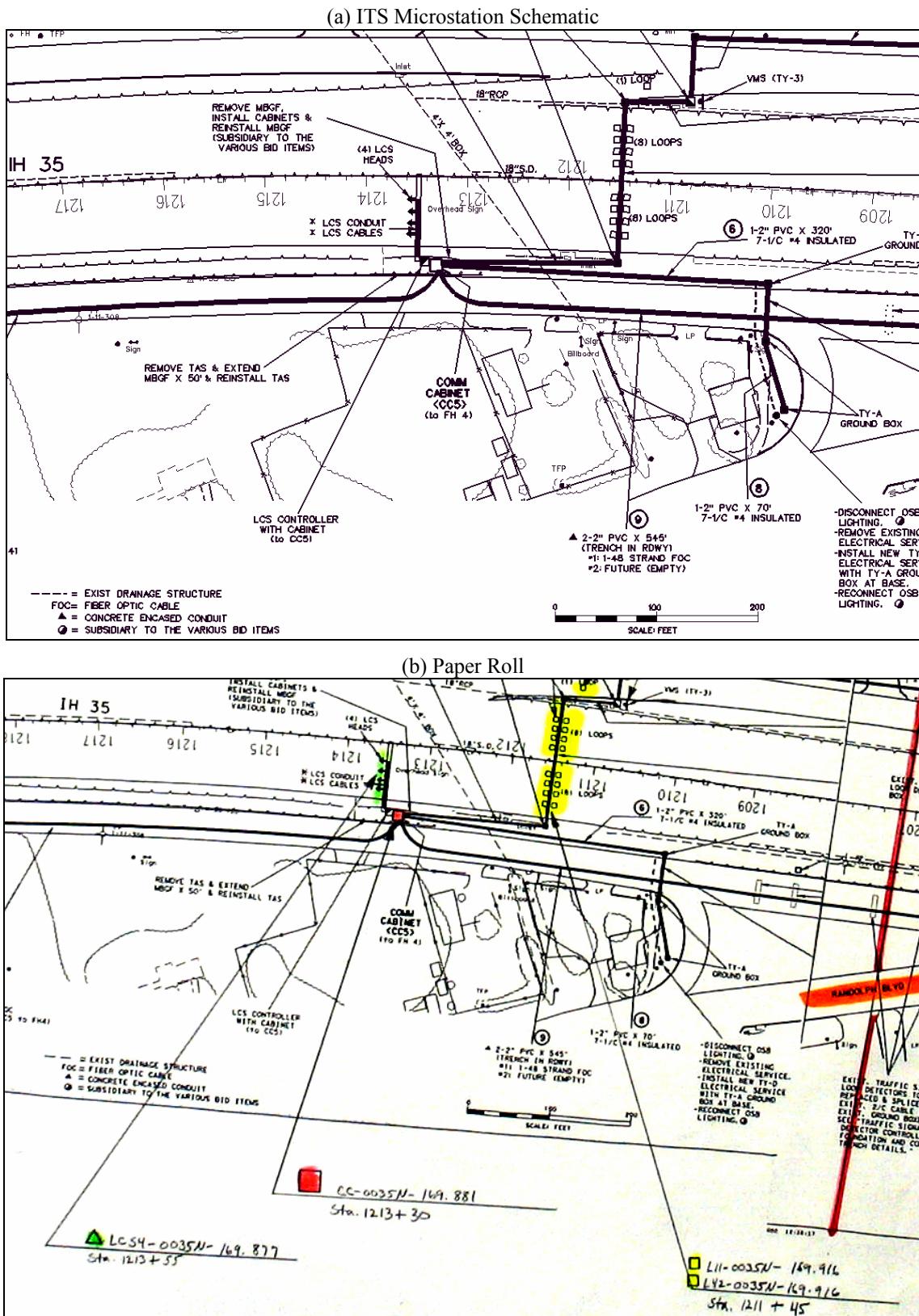


Figure 18. Sample ITS Microstation Schematic and Paper Roll (IH-35 at Judson).

The ITS schematics do not show ITS feature names or addresses. In most cases, the shape of a feature in the drawing is an indication of the type of ITS equipment it represents since TransGuide personnel frequently use shape cells to draw ITS features, e.g., squares (cell “loop”) for loop detectors and hexagons (cell “CCTV”) for camera towers. To generate ITS equipment addresses, TransGuide operators normally use the 100-foot stations shown on the ITS schematics ([Figure 18b](#)). For example, the numerical address of the loop detectors located at station 1211+45 (on northbound IH-35) is 169.916. This value results from converting the distance associated with the station value (121,145 feet) to miles (22.944 miles) and then applying an offset to make the distance consistent (in theory) with the TxDOT route/mile marker linear referencing system. For some corridors, stations grow in the opposite direction as the TxDOT routes. In those cases, the operators first had to generate station numbers that were compatible with the TxDOT route system and then generate address values for the ITS equipment located on the affected corridors.

## GEODATABASE DEVELOPMENT

With the data sources described in the previous section, the researchers developed a geodatabase of ITS features. The researchers also developed a data model—described in the following section—that includes both GIS features and archived ITS traffic and incident data. The researchers developed the geodatabase in ArcGIS 8.3, which is part of TxDOT’s core GIS architecture. The geodatabase is physically stored in Microsoft Access. It may be worth noting that ArcGIS includes tools that make it possible to export geodatabases to a variety of file and database formats, including ESRI coverage, shape, and Arc Spatial Data Engine (ArcSDE). With the upcoming ArcGIS Data Interoperability Extension, the number of export file formats is expected to increase to include AutoCAD, comma-separated value (CSV), dBase, Microstation, Oracle Spatial, MapInfo, and XML ([20](#)).

### GIS Feature Classes

Following the TransGuide ITS architecture, the researchers modeled roadway detectors, LCUs, LCSs, DMSs, CCTV cameras, and highway sectors. The researchers also modeled the San Antonio street database. [Table 7](#) provides a summarized conceptual description of each one of these feature classes. [Figure 19](#) shows the typical configuration of TransGuide detectors on the field. It may be worth noting that TransGuide operators do not see icons representing roadway detectors on their consoles. Rather, as Figure 15 shows, they see non-geo-referenced linear sketches representing lane segments between consecutive detectors. Those linear sketches change color when the AIH subsystem triggers an alarm (to yellow in the case of a minor alarm or red in the case of a major alarm). By definition, a lane segment address is the same as that of the detector unit located at its upstream end ([Figure 19](#)). Because incident detection happens at the detector unit level, not at the lane segment level and because there was high-resolution geo-referenced aerial photography the researchers could use to easily locate individual lanes, the researchers decided not to generate linear features to represent lane segments. Instead, they generated features to represent detectors and detector units. They also generated linear features to represent sectors, which TransGuide operators use to load and execute scenarios.

**Table 7. GIS Feature Class Conceptual Description.**

Feature Class	Shape	Address	Description
GIS-Detector	Polyline (square)	Lx1-yyyyy-zzz.zzz Lx2-yyyyy-zzz.zzz	Individual detector on the ground (e.g., loop detector, radar detector, or sonic detector). Dual loop detectors are represented by two individual loop detector features (the upstream loop detector is Lx1, and the downstream loop detector is Lx2).
GIS-Detector Unit	Polygon (square or square pair)	Lx-yyyyy-zzz.zzz	Minimum unit that captures speed, volume, and occupancy data on main lanes. The GIS treats each unit as a polygon feature (in the case of dual loop detectors, the polygon treats both loop detectors as a single unit). The address name matches the sector that begins at the detector unit and ends at the detector unit immediately downstream.
		ENx-yyyyy-zzz.zzz EXx-yyyyy-zzz.zzz	Minimum unit that captures volume and occupancy data on entrance or exit ramp lanes (note: the TransGuide system treats direct connectors either as entrance ramps or exit ramps). The address name matches the sector that represents each entrance or exit ramp.
GIS-Detector Group	Polygon (multiple square)	L-yyyyy-zzz.zzz	Group associated with all the detectors at the same main location (per direction). This feature class is not part of the TransGuide architecture. It is just a convenient mechanism for displaying aggregated ITS data in a GIS environment. L-groups are located at the upstream end of main lane sectors (see below).
		EN-yyyyy-zzz.zzz EX-yyyyy-zzz.zzz	Group associated with all the detectors at the same entrance or exit ramp location. This feature class is not part of the TransGuide architecture. It is just a convenient mechanism for displaying aggregated ITS data in a GIS environment. The highway name and direction (yyyyy) and mile marker location (zzz.zzz) coincide with that of the detector group located at the entrance or exit ramp.
GIS-Sect	Polyline	SECT-yyyyy-zzz.zzz	Directional centerline segment that connects two consecutive main lane detector groups. The highway name and direction (yyyyy) and mile marker location (zzz.zzz) coincide with that of the upstream detector group.
		NSECT-yyyyy-zzz.zzz XSECT-yyyyy-zzz.zzz	Directional centerline associated with an entrance or exit ramp. The highway name and direction (yyyyy) and mile marker location (zzz.zzz) coincide with that of the detector group located at the entrance or exit ramp.
GIS-LCU	Polyline	LCU-yyyyy-zzz.zzz	LCU location.
GIS-CCTV	Polyline (hexagon)	CCTV-yyyyy-zzz.zzz	CCTV camera location.
GIS-CMS	Polyline	CMSa-yyyyy-zzz.zzz	CMS location.
GIS-LCS	Polyline (arrow set)	LCSb-yyyyy-zzz.zzz	LCS location. The GIS shows individual heads associated with an LCS (one per lane); however, it treats all the heads as a single unit.

Note: The TransGuide ITS equipment naming convention is as follows:

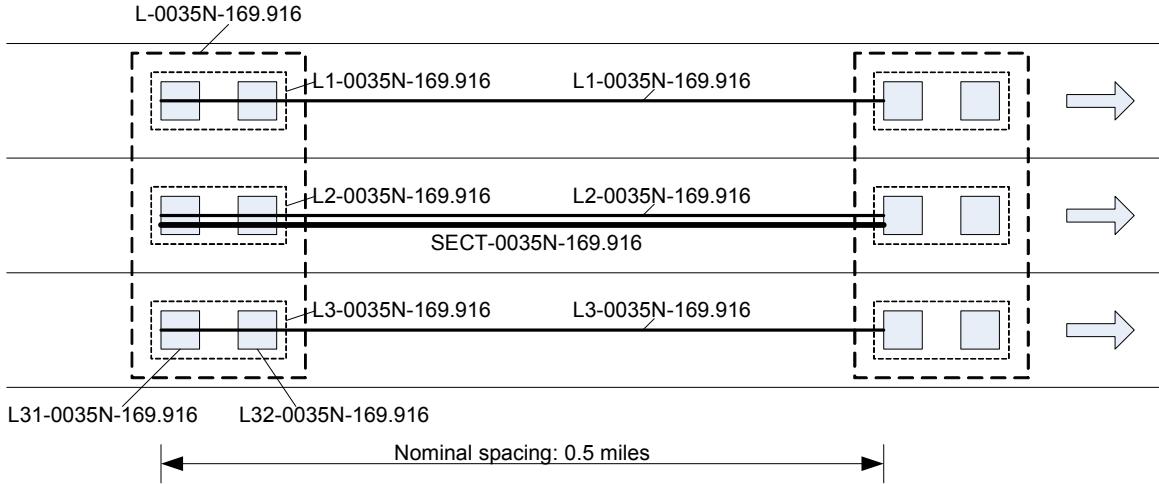
x Lane number (1, 2, 3, and so on), beginning with the left-most lane

yyyyy Highway name and direction (e.g., 0035S, where 0035 represents IH-35 and S represents southbound)

zzz.zzz Mile marker (three decimal digits)

a Number of message lines (normally two or three)

b Number of LCS heads (normally one for every main lane)



**Figure 19. Typical TransGuide Loop Detector Configuration.**

## Transformations

The data set coordinate system is State Plane Texas South Central (Table 8). The ellipsoid for this spatial reference is the Geodetic Reference System (GRS) 80 ellipsoid. As a result, it was necessary to apply a scale transformation to convert all “surface” level sources, e.g., ITS Microstation schematics and flight data files, so they could display correctly in the GIS (21, 22). In the San Antonio area, TxDOT uses a combined scale factor (CSF) of  $1/1.00017003 = 0.99983$  to convert from “surface” to state plane coordinates. To apply the transformation, the researchers created a companion world file with the same name as the corresponding “English system” file processed, except the world file had a .wld extension. Each world file contains the following information:

$$\begin{aligned} X_{1a}, Y_{1a} & X_{1b}, Y_{1b} \\ X_{2a}, Y_{2a} & X_{2b}, Y_{2b} \end{aligned}$$

where

- $X_{1a}, Y_{1a}$  = point No. 1 coordinates (“surface”),
- $X_{1b}, Y_{1b}$  = point No. 1 coordinates (“ellipsoid”),
- $X_{2a}, Y_{1a}$  = point No. 2 coordinates (“surface”), and
- $X_{2b}, Y_{2b}$  = point No. 2 coordinates (“ellipsoid”).

The researchers normalized the process by creating a generic world file that contained the following information:

$$\begin{aligned} 0,0 & 0,0 \\ 1,1 & 0.99983,0.99983 \end{aligned}$$

**Table 8. Geodatabase Coordinate System Characteristics.**

File Name	Format	Basic Metadata	
		Parameter	Description
4745_GIS.mdb	Personal geodatabase	Source	Texas Transportation Institute (TTI)
		Coordinate system	State Plane Texas South Central
		Projection	Lambert Conformal Conic
		Ellipsoid	Geodetic Reference System 80
		Surface adjustment	None; referenced to ellipsoid
		Datum	North American Datum 1983 (NAD 83)
		Longitude of origin	-99.000000
		Latitude of origin	27.833333
		Standard parallel # 1	28.383333
		Standard parallel # 2	30.283333
		False easting	1,968,500 feet
		False northing	13,123,333.333333 feet
		Unit of measure	Survey feet

As an illustration, [Figure 20](#) shows the result of applying the scale transformation to a sample Microstation file on IH-35. It may be worth noting that the transformed file is still in its native format (Microstation) and that all the world file does is provide the necessary scale transformation data for ArcGIS to correctly display the file on the screen.



**Figure 20. Application of Scale Transformation to “English System” Files.**

In the case of “metric system” files, it was necessary to generate temporary shape files, convert these files from meters to feet, and then save the resulting files in shape format in addition to the scale transformation described previously. This process resulted in ArcGIS shape files, but the “metric system” files were no longer applicable. However, this is not likely to be a severe limitation of the procedure. TxDOT switched back to the English unit system after only a short period in the metric unit system, and therefore only a limited number of schematics in the metric system exist. In general, the procedure to geo-reference “metric system” files was as follows:

- open an ArcGIS project and set the data frame coordinate system to State Plane South Central Texas 4204 (meters);
- apply world file and add “metric system” Microstation file to the project;
- export file to a temporary shape file, using the “metric” data frame coordinate system;
- open a new ArcGIS project and set the data frame coordinate system to State Plane South Central Texas 4204 (feet);
- add the newly created shape file to the project; and
- export data to a new shape file, using the “feet” data frame coordinate system.

In the case of “unknown system” files, the only parameter known was that the distance units were in feet. This made it necessary to manually geo-reference the files. To facilitate the process, the researchers downloaded and used an interactive computer-assisted design (CAD) transformation tool within the GIS (23). This tool made it considerably easier to translate, scale, and rotate Microstation files to their correct location using the San Antonio street map as a reference and then generate a world file for those files. In general, the procedure to geo-reference “unknown system” files was as follows:

- determine the correct location of the flight data in reference to the centerlines and existing flight data;
- use the CAD transformation tool to translate, rotate, and scale the file so that it displays correctly in the GIS; and
- save the world file.

Strictly speaking, this process did not geo-reference files. What it accomplished was to produce world files that enabled a linear transformation of the data—made possible because the files were already projected to a rectangular grid to begin with—that, in turn, enabled the correct display of the Microstation data in the GIS environment. The linear transformation was the result of combining three independent transformations—translation, scaling, and rotation—into one single transformation. (Note: internally, the CAD transformation tool first scales and rotates data with respect to its own local origin—located in the middle of the data extent—and then it translates the data to its correct final location.)

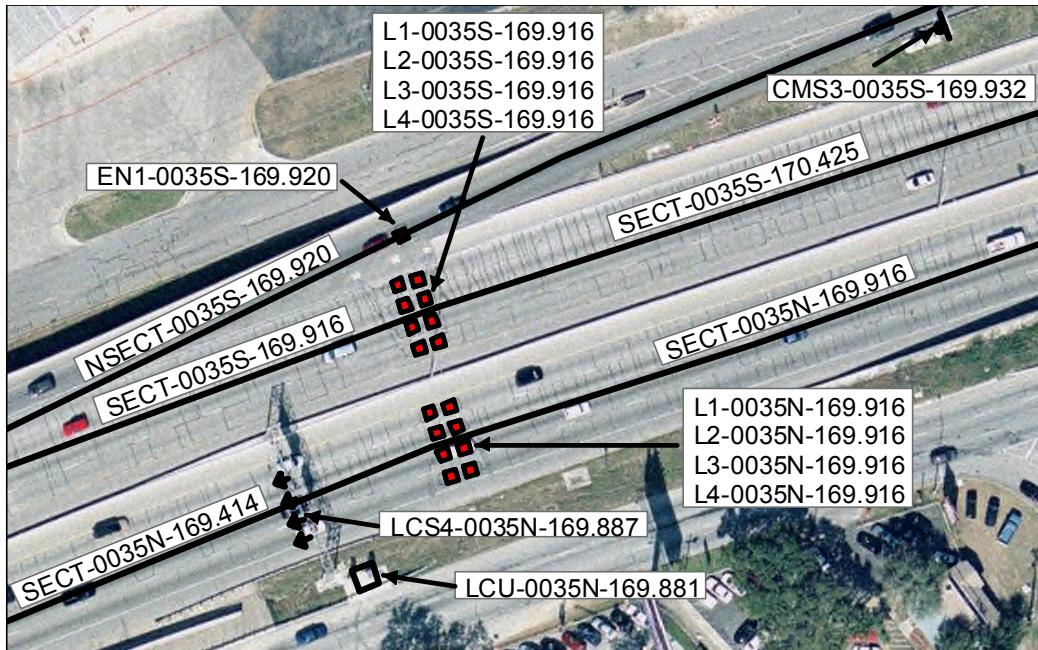
The researchers also geo-referenced scanned “paper roll” images to keep a record of the original data source that contained handwritten annotations of individual ITS feature addresses. As mentioned previously, the paper rolls were critical because the Microstation ITS equipment schematics contained no references to ITS equipment addresses. To geo-reference scanned “paper roll” images, the researchers used standard geo-referencing tools in the GIS.

## **ITS Features**

After geo-referencing the data source files, the researchers generated ITS features in the GIS ([Figure 21](#)). This process involved selecting geo-referenced data source features and transferring those features to the geodatabase. The general procedure was as follows:

- start an editing session in ArcGIS;
- set the task to “Create New Feature” on the editor tool bar;

- on the map, select the desired feature(s) to copy;
- on the editor tool bar, set the target layer to the appropriate geodatabase feature class;
- copy and paste the feature(s) to the appropriate target layer;
- verify location against geo-referenced flight data file and aerial photograph background; and
- populate a GIS attribute table.



**Figure 21. ITS Features in the GIS.**

The researchers applied additional operations to ensure the imported features were in the correct format. For example, it was necessary to merge individual LCS arrow features to generate a single LCS feature. Likewise, it was necessary to create and merge polygon features from the GIS detector feature class to generate GIS detector unit features. To automate this process, the researchers implemented a script to automatically generate polygons from polylines.

It may be worth noting that copying ITS features from the Microstation files resulted in GIS features that had the same look as those in Microstation (Figure 21). This had two advantages: (a) easy recognition of individual features, and (b) correct feature orientation with respect to the roadway alignment on the map (this is doable with point features in ArcGIS but normally with great difficulty). The main disadvantage of using polylines and polygons to represent relatively small, closed-shape features is that the relative scale of the features does not change as the screen zoom level changes. A similar problem happens when creating and printing maps. As a result, these features tend to disappear on smaller scale maps (i.e., maps covering larger extensions). For this reason, the researchers generated a second data set by using simple GIS scripts to convert all polyline and polygon features to point features, which can be very easily represented by icons and other graphical symbols that do not change size as the map scale or screen zoom level changes.

In all cases, the researchers used the aerial photography layers, in particular the ½-foot layer, to verify and, as needed, edit the location of individual ITS features. As mentioned previously, using ½-foot aerial photography made it possible to identify the correct location of a wide range of features, including pavement markings, lane configurations, utility poles, cabinets, traffic support structures, and even in some cases loop detectors. While using Microstation schematic files facilitated the generation of features in the GIS, using high-resolution aerial photography made a significant difference in the ability to correctly identify the location of those features. It also made it possible to identify a few cases where the Microstation schematics did not correctly represent as-built locations in the field.

An ITS feature geodatabase makes it possible to generate a wide range of maps displaying ITS feature locations as well as archived ITS data for visualization and analysis. For example, the following chapter describes several uses of the geodatabase to assist in the process of identifying spatial and temporal patterns in the distribution of incidents along TransGuide-instrumented freeways. Adding other layers of geographic data to the map, e.g., city limits or agency jurisdictional boundaries, which are critical pieces of information for coordinating emergency response activities, is also straightforward. As an illustration, [Figure 22](#) shows a map of TransGuide CCTV cameras overlaying the roadway network and city limits in the San Antonio area. Another example is the use of relevant TxDOT layers such as routes, reference markers, and control sections to automate the process to select names and addresses for new ITS features or, as in the case of TxDOT’s ATMS software ([7](#)), to provide geo-referencing measures to incident locations. The use of standard online mapping tools such as Arc Internet Map Server (ArcIMS)—which is part of TxDOT’s GIS architecture—would further enhance the production of a wide range of interactive maps that TMC personnel and other users could access using platform-independent browsers. Several TMCs are already beginning to use these tools, which only emphasizes the advantages of using a geodatabase approach for managing ITS locations and data.

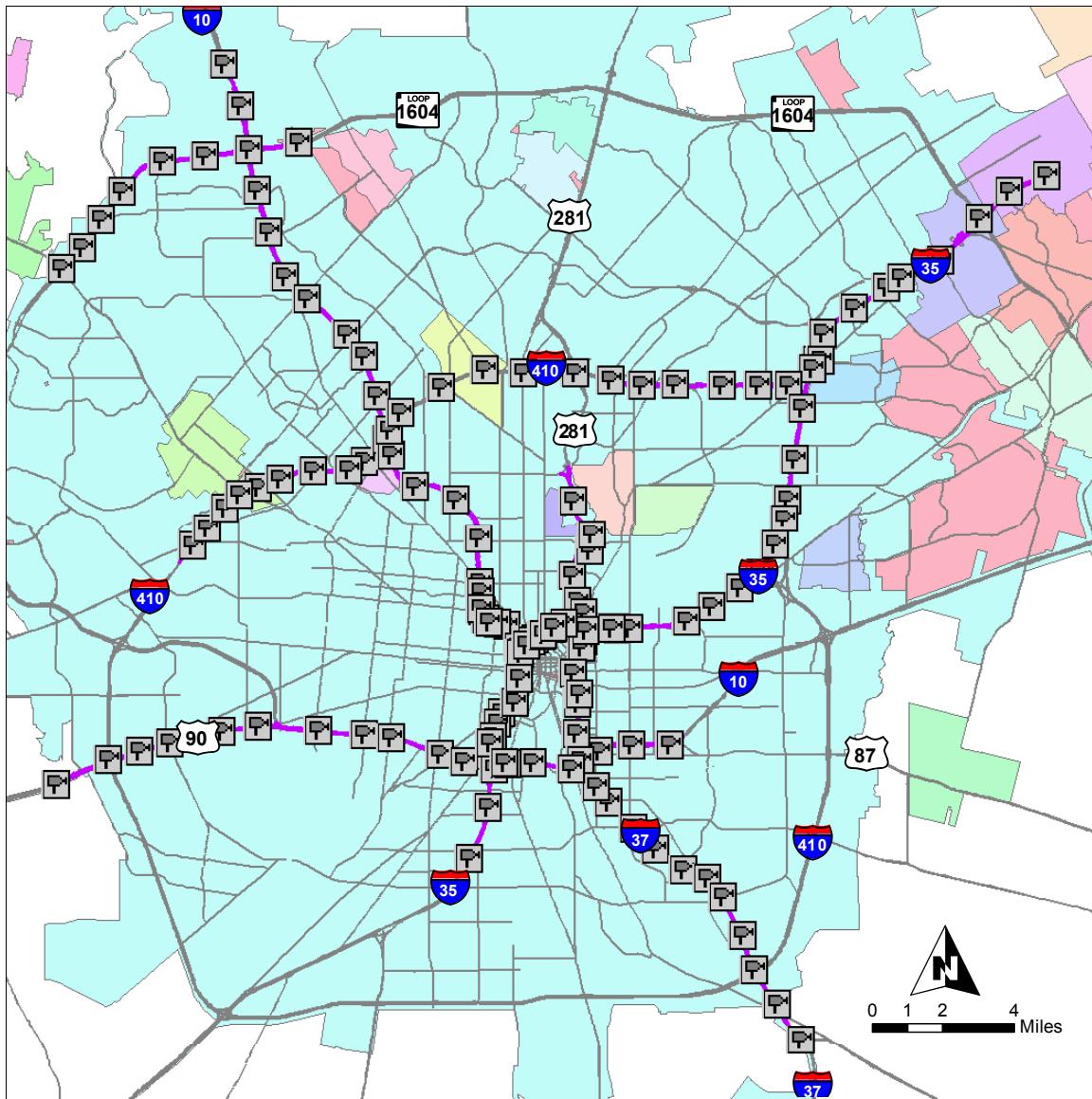
## DATA MODEL

As mentioned previously, the researchers developed a data model that includes both GIS features and archived ITS traffic and incident data. The researchers actually developed two data models: one data model (called data model “A”) that represents current data archival practices at TransGuide and a second data model (called data model “B”) that addresses several structural limitations of the current data archive. Both models are in a Sybase PowerDesigner format, although they could easily be exported to other database environments such as Oracle, SQL Server, and Access to facilitate implementation at other TMCs.

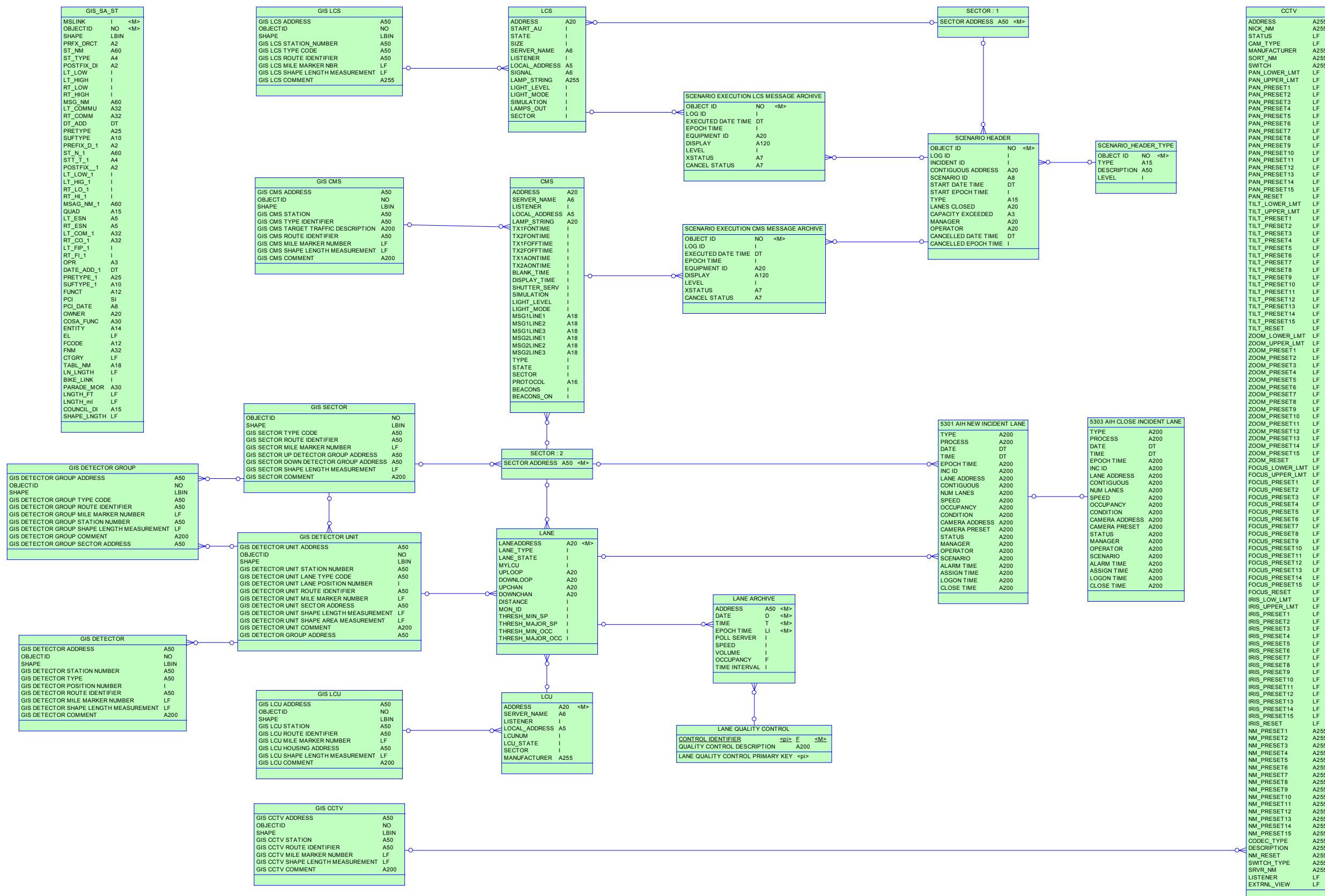
Data model “A” represents current data archival practices at TransGuide. This is the model the researchers used for the incident data analysis in subsequent chapters. [Figure 23](#) shows the logical model, [Figure 24](#) shows the physical model, and [Table 9](#) provides summary table descriptions. In addition to geodatabase tables (GIS-series tables), the model includes TransGuide equipment data tables and archived data tables. The archived data tables rely on data the researchers extracted from the long-term data repository saved in compressed file format, namely 20-second detector data ([Figure 12](#)), event data ([Figure 13](#)), and scenario data

from the scenario log database ([Figure 14](#)). In particular, the researchers used record types 5301 and 5303 from the event data archive.

Data model “B” is a modified version of data model “A” that addresses a few structural limitations of the existing data archive, such as data redundancy, lack of connectivity between archived incident data and archived scenario data, and lack of quality control information. It may also be worth noting that data model “B” contains a number of elements included in the current version of the C2C data model ([10](#)), which should facilitate the implementation of both data archive and C2C interfaces. [Figure 25](#) shows the logical model, [Figure 26](#) shows the physical model, and [Table 10](#) provides summary table descriptions.



**Figure 22. TransGuide CCTV Cameras Overlaying Main Corridors and City Limits.**



**Figure 23. Data Model “A”—Logical Model**



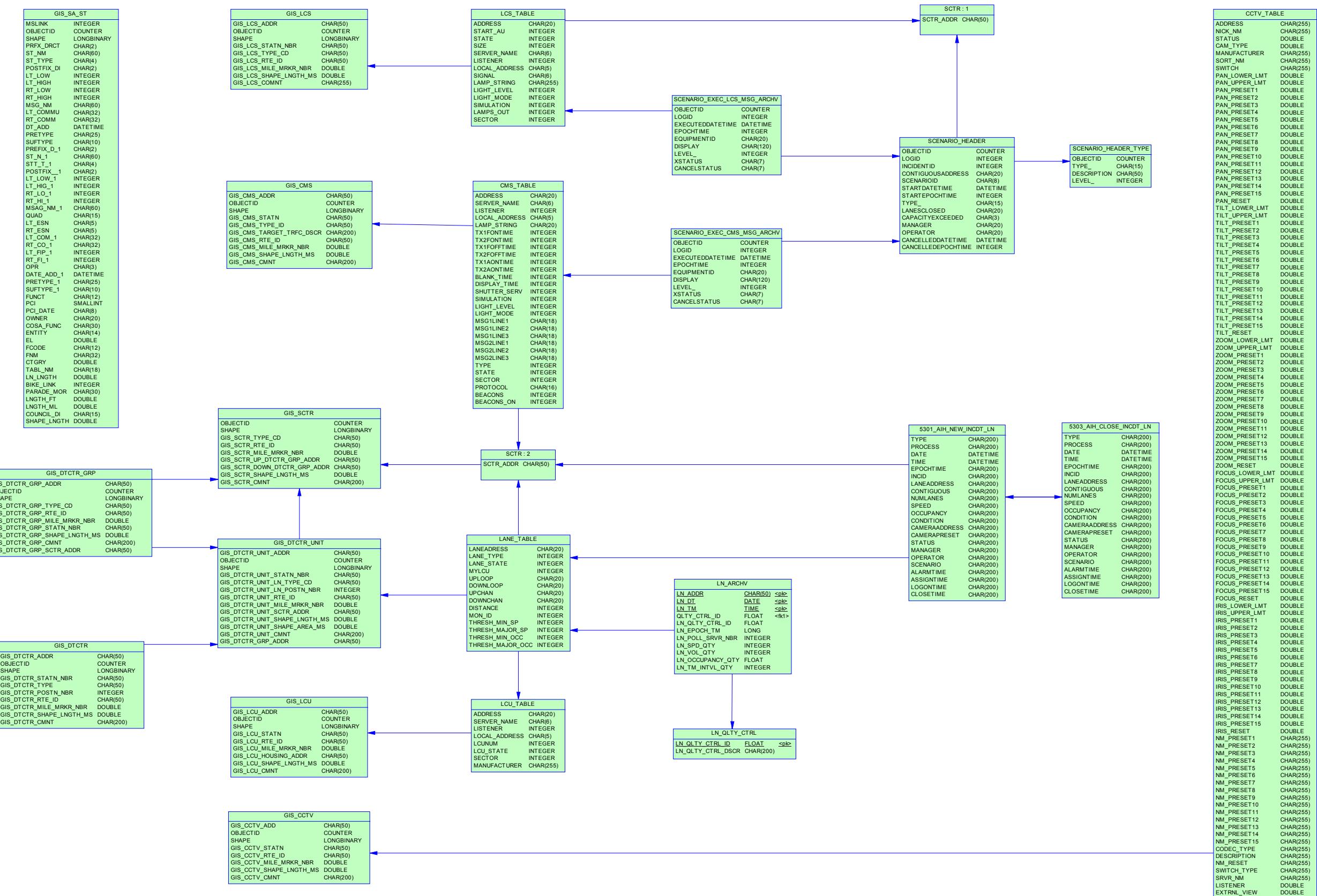


Figure 24. Data Model “A”—Physical Model.



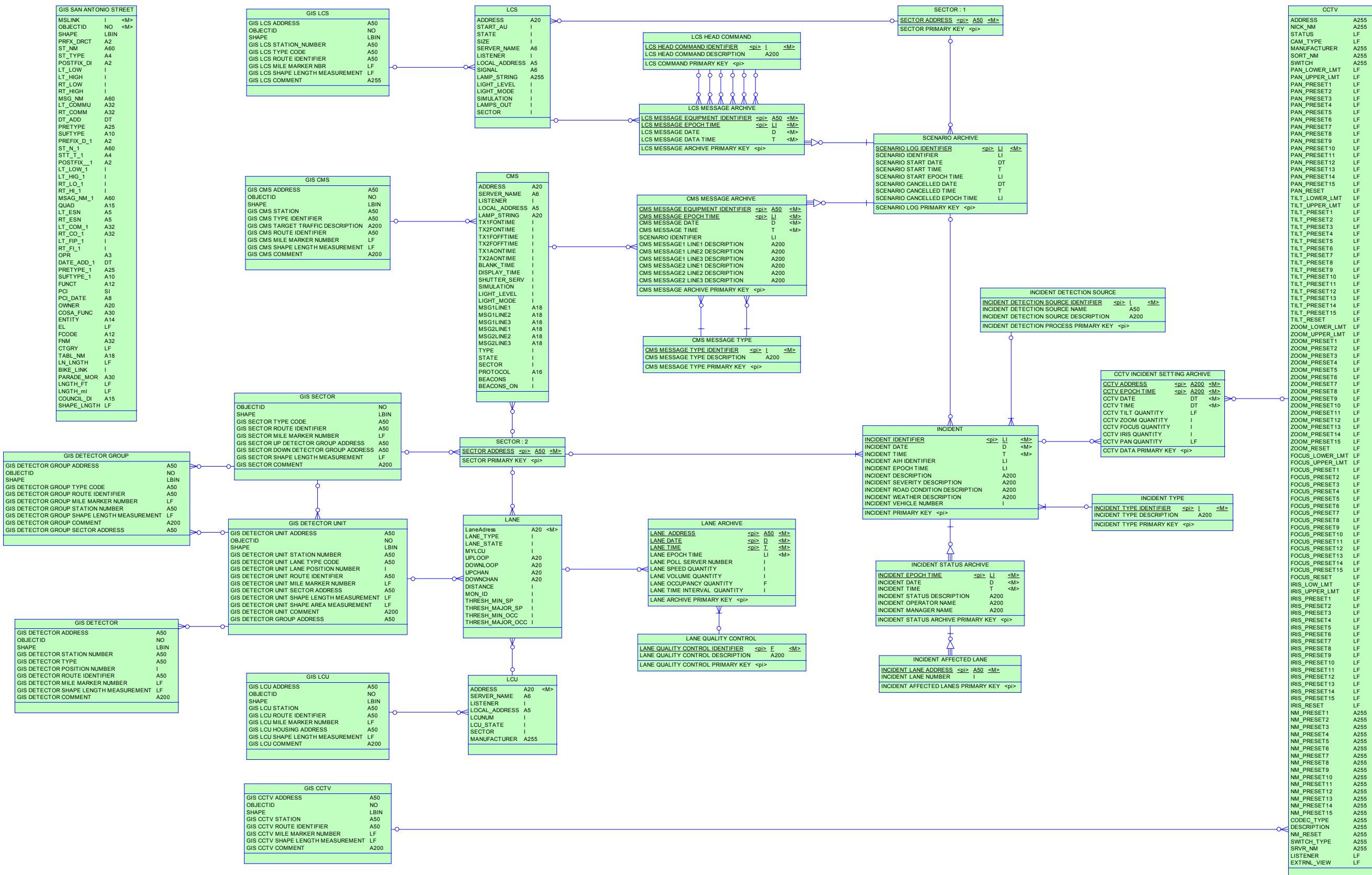


Figure 25. Data Model "B"—Logical Model.



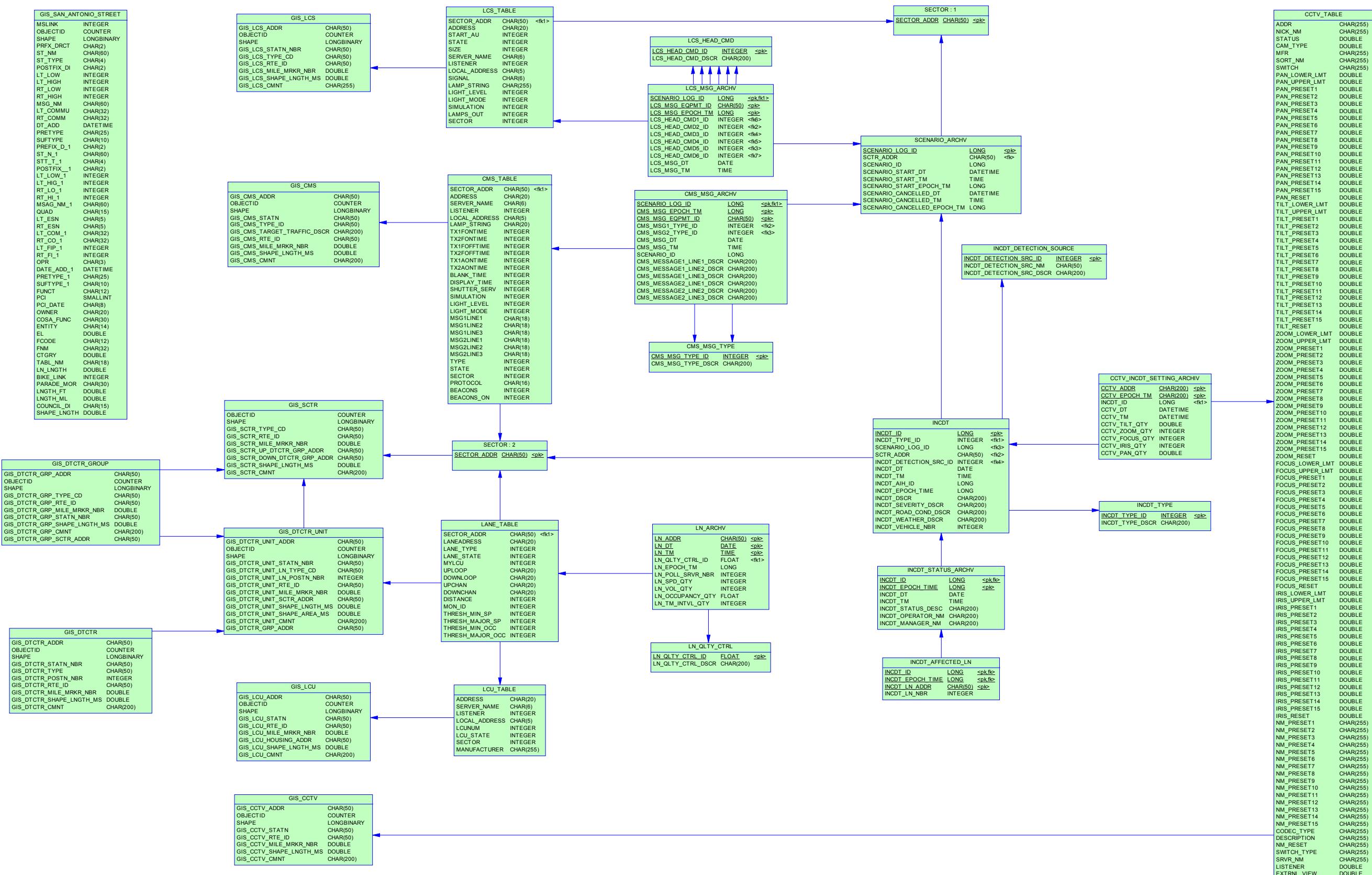


Figure 26. Data Model “B”—Physical Model.



**Table 9. Data Model “A”—Entity Description.**

<b>Entity</b>	<b>Definition</b>
GIS DETECTOR	A GIS DETECTOR is the GIS representation of an individual detector on the ground. Dual loop detectors are represented by two individual loop detector features.
GIS DETECTOR UNIT	A GIS DETECTOR UNIT is the GIS representation of the minimum unit that captures speed, volume, and occupancy data in the field.
GIS DETECTOR GROUP	A GIS DETECTOR GROUP is the GIS representation of a GIS DETECTOR UNIT group. It is not part of the TransGuide architecture. It is just a convenient mechanism for displaying aggregated ITS data in a GIS environment.
GIS SECTOR	A GIS SECTOR is the GIS representation of the directional centerline segment that connects two consecutive main lane detector groups.
GIS LCU	A GIS LCU is the GIS representation of an LCU.
GIS CCTV	A GIS CCTV is the GIS representation of a CCTV camera.
GIS CMS	A GIS CMS is the GIS representation of a CMS (or DMS) unit.
GIS LCS	A GIS LCS is the GIS representation of an LCS.
GIS SAN ANTONIO STREET	A GIS SAN ANTONIO STREET is a GIS representation of a roadway in the San Antonio area.
LANE	A LANE is the TransGuide database representation of the minimum detector unit that captures speed, volume, and occupancy data in the field.
SECTOR	A SECTOR is a directional centerline segment that connects two consecutive main lane detector groups.
LCU	An LCU is the TransGuide database representation of a local control unit that polls detector units.
CCTV	A CCTV is the TransGuide database representation of a CCTV camera.
CMS	A CMS is the TransGuide database representation of a changeable (or dynamic) message sign.
LCS	An LCS is the TransGuide database representation of a local control signal.
LANE ARCHIVE	A LANE ARCHIVE is a record of archived 20-second speed, volume, and occupancy from a LANE unit.
LANE QUALITY CONTROL	A LANE QUALITY CONTROL is a description of a quality control indicator associated with each LANE ARCHIVE record.
5301 AIH NEW INCIDENT LANE	A 5301 AIH NEW INCIDENT LANE is a record of the beginning of a new LANE-related incident handled through the AIH subsystem.
5303 AIH CLOSE INCIDENT LANE	A 5303 AIH CLOSE INCIDENT LANE is a record of the end of a new LANE-related incident handled through the AIH subsystem.
SCENARIO HEADER	A SCENARIO HEADER is a record of the scenario loaded or modified by an operator in response to a roadway incident, regardless of whether or not a 5301 AIH NEW INCIDENT LANE record exists.
SCENARIO HEADER TYPE	A SCENARIO HEADER TYPE is a description of the type of scenario loaded or modified by an operator.
SCENARIO EXECUTION CMS MESSAGE ARCHIVE	A SCENARIO EXECUTION CMS MESSAGE ARCHIVE is a record of CMS messages displayed during the execution of a scenario.
SCENARIO EXECUTION LCS MESSAGE ARCHIVE	A SCENARIO EXECUTION MESSAGE ARCHIVE is a record of LCS messages displayed during the execution of a scenario.

**Table 10. Data Model “B”—Entity Description.**

<b>Entity</b>	<b>Definition</b>
GIS DETECTOR	A GIS DETECTOR is the GIS representation of an individual detector on the ground. Dual loop detectors are represented by two individual loop detector features.
GIS DETECTOR UNIT	A GIS DETECTOR UNIT is the GIS representation of the minimum unit that captures speed, volume, and occupancy data in the field.
GIS DETECTOR GROUP	A GIS DETECTOR GROUP is the GIS representation of a GIS DETECTOR UNIT group. It is not part of the TransGuide architecture. It is just a convenient mechanism for displaying aggregated ITS data in a GIS environment.
GIS SECTOR	A GIS SECTOR is the GIS representation of the directional centerline segment that connects two consecutive main lane detector groups.
GIS LCU	A GIS LCU is the GIS representation of an LCU.
GIS CCTV	A GIS CCTV is the GIS representation of a CCTV camera.
GIS CMS	A GIS CMS is the GIS representation of a CMS (or DMS) unit.
GIS LCS	A GIS LCS is the GIS representation of an LCS.
GIS SAN ANTONIO STREET	A GIS SAN ANTONIO STREET is a GIS representation of a roadway in the San Antonio area.
LANE	A LANE is the TransGuide database representation of the minimum detector unit that captures speed, volume, and occupancy data in the field.
SECTOR	A SECTOR is a directional centerline segment that connects two consecutive main lane detector groups.
LCU	An LCU is the TransGuide database representation of a local control unit that polls detector units.
CCTV	A CCTV is the TransGuide database representation of a CCTV camera.
CMS	A CMS is the TransGuide database representation of a changeable (or dynamic) message sign.
LCS	An LCS is the TransGuide database representation of a local control signal.
LANE ARCHIVE	A LANE ARCHIVE is a record of archived 20-second speed, volume, and occupancy from a LANE unit.
LANE QUALITY CONTROL	A LANE QUALITY CONTROL is a description of a quality control indicator associated with each LANE ARCHIVE record.
INCIDENT	An INCIDENT is a non-recurring event on the TransGuide-instrumented freeway network.
INCIDENT STATUS ARCHIVE	An INCIDENT STATUS ARCHIVE is a record of changes that take place during the life of an INCIDENT.
INCIDENT AFFECTED LANE	An INCIDENT AFFECTED LANE is a record of lanes affected associated with each INCIDENT STATUS ARCHIVE record.
INCIDENT TYPE	An INCIDENT TYPE is a description of the type of INCIDENT.
INCIDENT DETECTION SOURCE	An INCIDENT DETECTION SOURCE is a description of the process that enabled the detection of an INCIDENT.
CCTV INCIDENT SETTING LOG	A CCTV INCIDENT SETTING LOG is a record of the tilt, zoom, focus, iris, and pan of a CCTV camera at the time the operator confirmed an INCIDENT.
SCENARIO ARCHIVE	A SCENARIO ARCHIVE is a record of the scenario loaded or modified by an operator in response to an INCIDENT.
CMS MESSAGE ARCHIVE	A CMS MESSAGE ARCHIVE is a record of messages displayed by one or more CMS units during the execution of a SCENARIO LOG.
CMS MESSAGE TYPE	A CMS MESSAGE TYPE is a description of the type of message displayed by a CMS unit.
LCS MESSAGE ARCHIVE	An LCS MESSAGE ARCHIVE is a record of messages displayed by one or more LCS units during the execution of a loaded or modified SCENARIO.
LCS HEAD COMMAND	An LCS HEAD COMMAND is a description of the type of message displayed by an LCS unit.

## CHAPTER 4. EVALUATION OF INCIDENT CHARACTERISTICS

This chapter summarizes the work completed to evaluate spatial and temporal patterns in the distribution of incidents along TransGuide's instrumented freeway network. It includes a description of the data-mining process that resulted in a data set suitable for the analysis as well as results from the statistical analysis. The purpose of this analysis was to derive basic descriptive statistics and to determine whether there was evidence of spatial and temporal effects in the distribution of incidents in San Antonio. For the analysis, the researchers grouped incident data according to several categories such as incident type, month, season (schools in session versus schools not in session), day of week, weekdays versus weekend days, traffic volume, time of day, number of lanes blocked, and weather (rainy days versus non-rainy days).

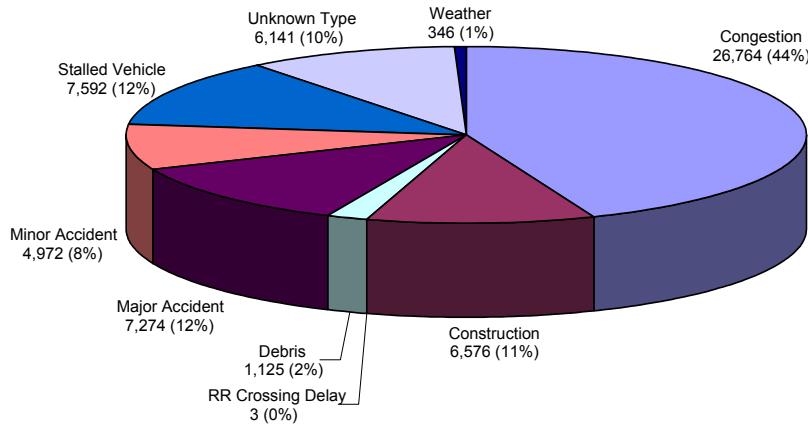
### INCIDENT DATA MINING

As mentioned in the previous chapter, the researchers relied on archived incident data extracted from the long-term data repository, namely record types 5301 and 5303 from the event data archive, and scenario data from the scenario database. Both event data and scenario data included incident identification fields the researchers used in an attempt to join the event data archive and the DMS and LCS message archive. Unfortunately, this effort was largely unsuccessful because incident identification values in the scenario data, which were mostly blank ([Figure 14](#)), rarely matched incident identification values in the event data. The researchers also developed queries using the sector address field and time stamp ranges to join the tables since the sector address field appeared on both event data tables and scenario data tables. However, the success rate of this operation was extremely low—3 to 7 percent depending on the size of the time stamp window. Reasons that could explain the low matching rate include the following:

- Operators load scenarios even if an incident record did not previously exist. As a result, many scenario data records do not contain incident identification values.
- The event data only include records for alarms handled by the AIH subsystem, more specifically, detector-based alarms and 911-based alarms. The event data do not include records for incidents detected using other protocols, e.g., CCTV camera scanning or courtesy patrols.
- Operators sometimes associate scenarios with sectors different from those where the algorithm detects the incident. If the CCTV camera verification determines a different incident location, operators sometimes execute a scenario on the verified sector.
- Operators sometimes modify existing scenarios instead of loading new ones. For example, this could happen if there is an accident on a sector that already has an active congestion-related scenario. In this case, the operator would simply modify the congestion scenario to display accident-related messages on the DMSs and LCSs.

Between event data tables and scenario data tables, the latter ones contain information the researchers considered to be more useful for characterizing incidents, in particular the type of scenario loaded (major accident, minor accident, debris, and so on) and the messages the operators displayed in the field. For this reason, the researchers decided to conduct the analysis using data from the scenario data tables. TransGuide has been archiving scenario data since February 2002. The archive includes a header table, which keeps a log of all scenarios loaded,

and an execution table, which keeps a log of all DMS and LCS messages displayed in the field. For the analysis, the researchers used data from March 2002 through May 2004. During this period, the database included 60,793 scenario records, distributed among nine scenario categories (Figure 27): congestion, construction, weather, railroad crossing delay, major accident, minor accident, stalled vehicle, debris, and unknown type.



**Figure 27. Distribution of Incidents According to the Scenario Header Table.**

Of interest here are four scenario types that pertain to nonrecurring, unplanned incidents: major accident, minor accident, stalled vehicle, and debris. Although compiling scenario data for these four scenario types seems straightforward, it was necessary to make several adjustments to the original data. First, an evaluation of scenario execution messages revealed cases where the DMS or LCS messages displayed in the field were inconsistent with the scenario type in the header table. For example, a DMS message would indicate the presence of a stalled vehicle ahead, even though the scenario type referred to something different, e.g., congestion or minor accident. In several cases, there were scenario execution records that began with a message of a certain type, e.g., congestion—which matched the scenario type in the header table—but then changed to a message of a different type, e.g., major accident.

The researchers hypothesized that messages in the execution table reflected more accurately how operators responded to incidents on the freeway. For this reason, the scenario type adjustment process involved extracting scenario type data from the messages displayed and updating the corresponding scenario type value in the header table (actually, the researchers created a new field for the updated scenario type to maintain the integrity of the original table). The general procedure for adjusting scenario types was as follows:

- From the execution table, query all records that displayed a DMS message containing at least one of the following keywords: “accident,” “major,” “minor,” “stalled,” or “debris.” For those cases where the query found more than one record per scenario, the algorithm selected the worst type, e.g., if it found “stalled vehicle” and “major accident,” it selected “major accident.”
- Update the scenario type in the header table based on the information collected from the execution table.

- From the header table, query all scenario records for which the updated scenario type was major accident, minor accident, stalled vehicle, or debris.

**Table 11** shows the results of the adjustment process. In total, there were 23,349 scenario records from March 2002 to May 2004 that originally fell under one of eight scenario type classifications and that were either correctly classified as (or required reclassification as) major accident, minor accident, stalled vehicle, or debris. In total, 20,664 (or 89 percent) scenario records were correctly classified and did not require adjustment: 6,937 for major accidents, 4,836 for minor accidents, 7,713 for stalled vehicles, and 1,178 for debris. The remaining 2,685 records (or 11 percent) required reclassification.

**Table 11. Distribution of Original and Reclassified Scenario Records by Scenario Type.**

Scenario Type	Original No. of Scenario Records *		Reclassified Scenario Records by Scenario Type							
			Major Accident		Minor Accident		Stalled Vehicle		Debris	
Major Accident	7,567	32%	6,937	87%	360	6%	247	3%	23	2%
Minor Accident	5,180	22%	83	1%	4,836	87%	255	3%	6	0%
Stalled Vehicle	7,866	34%	68	1%	68	1%	7,713	90%	17	1%
Debris	1,182	5%	1	<1%	0	0%	3	0%	1,178	93%
Congestion	1,314	6%	724	9%	249	4%	313	4%	28	2%
Construction	182	1%	103	1%	19	0%	48	1%	12	1%
Unknown Type	36	0%	24	0%	5	0%	6	0%	1	0%
Weather	22	0%	15	0%	5	0%	2	0%	0	0%
Total	23,349	100%	7,955	100%	5,542	100%	8,587	100%	1,265	100%
Total Percentage	100%		34%		24%		37%		5%	

\* Records that were correctly classified as (or required reclassification as) major accident, minor accident, stalled vehicle, or debris.

Second, an evaluation of scenario start and end times revealed a substantial percentage of records, 27 percent, without a cancellation time stamp. In addition, there were a few records for which the executed message time stamps were either before the scenario header start time or after the scenario end time. This made it necessary to make an adjustment of scenario time stamps in general. As with the scenario type adjustment, the researchers queried the earliest and latest times associated with each incident from the execution table, and then used these time stamps to update the scenario header start and end times.

Third, an evaluation of sector address values revealed that scenarios associated with entrance or exit ramps truncated the first character of the sector address, making the sector address appear as if it belonged to a main lane sector. For example, instead of displaying “XSECT-0035N-160.625,” the scenario header table displayed “SECT-0035N-160.625.” This made it necessary to run a query to update the sector address field so that it displayed correct sector addresses for all scenario records.

Fourth, an evaluation of closed lane field entries revealed that this field displayed which lanes were affected but not the total number of lanes affected. For the analysis of lane blockage impacts, the researchers ran a query to determine the number of main lanes and shoulder lanes affected by all incidents listed in the scenario database.

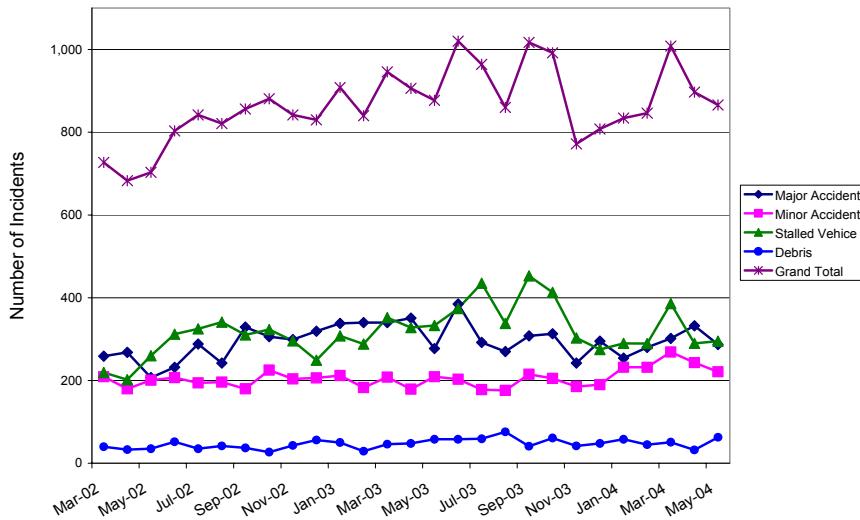
## TEMPORAL AND SPATIAL DISTRIBUTION OF INCIDENTS

With the updated scenario database in place, the researchers conducted a series of analyses to determine any evidence of spatial and/or temporal clustering in the occurrence of incidents along TransGuide-instrumented freeways. The analyses focused on the following categories:

- distribution of incidents by month and season,
- distribution of incidents by day of week,
- effect of traffic volume on the distribution of incidents,
- distribution of incidents by corridor,
- distribution of incidents by time of day,
- distribution of incidents by scenario duration,
- distribution of incidents by number of lanes/shoulders blocked, and
- distribution of incidents by weather conditions.

### Distribution of Incidents by Month and Season

This analysis focuses on the distribution of incidents by month and by season. For simplicity, the researchers considered two seasons: summer season, which includes June, July, and August; and academic year (or school-in-session) season, which includes the remaining nine months. Figure 28 shows the number of incidents per month for each incident type from March 2002 to May 2004. [Table 12](#) shows the corresponding data. [Table 13](#) shows average monthly values, as well as monthly averages for the summer and academic year seasons. [Table 14](#) shows the distribution of incidents per month. The map in [Figure 29](#) shows the average number of incidents per month (expressed for convenience as number of incidents per 3 months) per sector regardless of incident type. [Appendix A](#) includes similar maps that show the average number of incidents per month for each incident type and season.



**Figure 28. Number of Incidents by Incident Type.**

**Table 12. Frequency of Incidents per Month.**

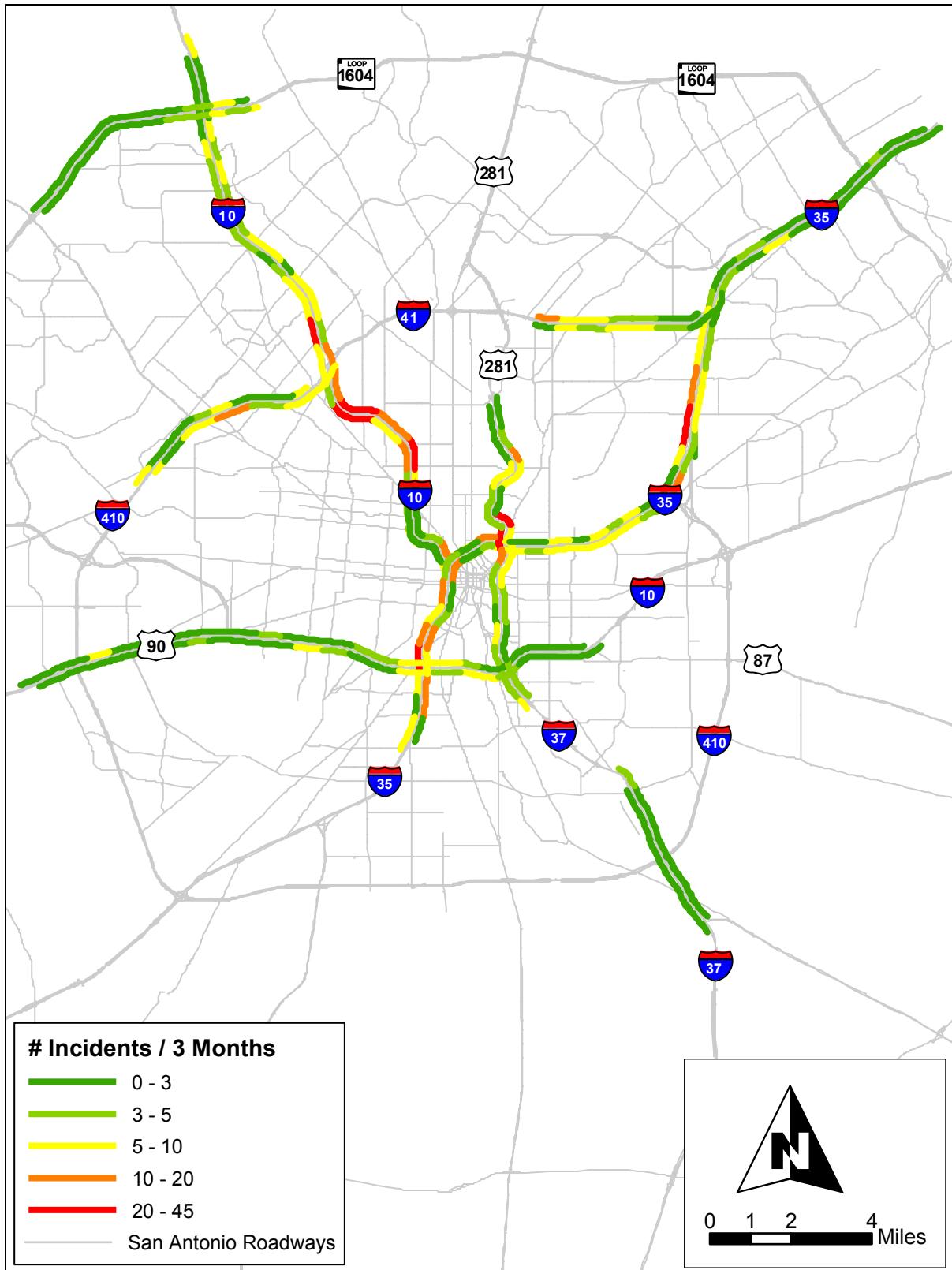
<b>Season</b>	<b>Month</b>	<b>Major Accident</b>	<b>Minor Accident</b>	<b>Stalled Vehicle</b>	<b>Debris</b>	<b>Total</b>
	Mar-02	259	209	219	40	727
	Apr-02	268	180	202	33	683
	May-02	207	201	260	35	703
Summer 02	Jun-02	232	207	312	52	803
	Jul-02	288	194	325	35	842
	Aug-02	242	196	341	42	821
Academic 02-03	Sep-02	329	180	310	37	856
	Oct-02	306	225	323	27	881
	Nov-02	299	204	296	43	842
	Dec-02	319	206	249	56	830
	Jan-03	338	212	308	50	908
	Feb-03	340	183	288	29	840
	Mar-03	340	208	352	46	946
	Apr-03	351	179	328	48	906
	May-03	277	209	333	58	877
	Jun-03	385	203	374	58	1,020
Summer 03	Jul-03	292	178	435	59	964
	Aug-03	270	176	338	76	860
	Sep-03	308	215	453	41	1,017
Academic 03-04	Oct-03	313	205	413	61	992
	Nov-03	242	185	303	42	772
	Dec-03	295	190	275	48	808
	Jan-04	254	232	290	58	834
	Feb-04	280	232	289	45	846
	Mar-04	302	269	386	51	1,008
	Apr-04	332	243	290	32	897
	May-04	287	221	295	63	866
Grand Total		7,955	5,542	8,587	1,265	23,349

**Table 13. Average Number of Incidents per Month.**

	Major Accident	Minor Accident	Stalled Vehicle	Debris	Average Total
January	296	222	299	54	871
February	310	208	289	37	843
March	300	229	319	46	894
April	317	201	273	38	829
May	257	210	296	52	815
June	309	205	343	55	912
July	290	186	380	47	903
August	256	186	340	59	841
September	319	198	382	39	937
October	310	215	368	44	937
November	271	195	300	43	807
December	307	198	262	52	819
Yearly Total	3,540	2,451	3,849	565	10,406
Monthly Average	295	204	321	47	867
Summer 02	254	199	326	43	822
Academic 02-03	322	201	310	44	876
Summer 03	316	186	382	64	948
Academic 03-04	290	221	333	49	893
Summer Average	285	192	354	54	885
Academic Year Average	306	211	321	46	885

**Table 14. Distribution of Incidents per Month and Season.**

	Major Accident	Minor Accident	Stalled Vehicle	Debris		Total	
January	34%	8%	25%	9%	34%	8%	6% 10% 100% 8%
February	37%	9%	25%	8%	34%	7%	4% 7% 100% 8%
March	34%	8%	26%	9%	36%	8%	5% 8% 100% 9%
April	38%	9%	24%	8%	33%	7%	5% 7% 100% 8%
May	32%	7%	26%	9%	36%	8%	6% 9% 100% 8%
June	34%	9%	22%	8%	38%	9%	6% 10% 100% 9%
July	32%	8%	21%	8%	42%	10%	5% 8% 100% 9%
August	30%	7%	22%	8%	40%	9%	7% 10% 100% 8%
September	34%	9%	21%	8%	41%	10%	4% 7% 100% 9%
October	33%	9%	23%	9%	39%	10%	5% 8% 100% 9%
November	34%	8%	24%	8%	37%	8%	5% 8% 100% 8%
December	37%	9%	24%	8%	32%	7%	6% 9% 100% 8%
Monthly Average	34%	100%	24%	100%	37%	100%	5% 100% 100% 100%
Summer 02	31%	21%	24%	25%	40%	26%	5% 25% 100% 24%
Academic 02-03	37%	79%	23%	75%	35%	74%	5% 75% 100% 76%
Summer 03	33%	27%	20%	22%	40%	28%	7% 30% 100% 26%
Academic 03-04	33%	73%	25%	78%	37%	72%	5% 70% 100% 74%
Summer Average	32%	24%	22%	24%	40%	27%	6% 28% 100% 25%
Academic Year Average	35%	76%	24%	77%	36%	73%	5% 73% 100% 75%



**Figure 29. Average Number of Incidents per Month (Expressed for Convenience as Number of Incidents per 3 Months).**

An analysis of the data yields the following observations:

- The number of incidents per month increased from 727 in March 2002 to 866 in May 2004, with monthly variations that included a maximum of 1,020 incidents in June 2003 and a minimum of 683 incidents in April 2002. While the record shows that the number of incidents increased, the length of the record—only 27 months—is not enough to determine whether the increasing trend is part of a long-term trend or just part of the cyclical oscillations that are normal in any time series.
- On average, some 867 incidents occur every month throughout TransGuide's coverage area. Out of the 867 incidents, 295 (or 34 percent) are major accidents, 204 (or 24 percent) are minor accidents, 321 (or 37 percent) are stalled vehicles, and 47 (or 5 percent) are debris. There are monthly variations in these percentages, which are statistically significant, although it is not clear to what extent those variations could have a significant impact on TMC operations. Nonetheless, it may be worth mentioning certain trends, e.g., that the percentage of accidents (major and minor combined) is higher than average from December to April while the percentage of stalled vehicles is higher than average from June to October.
- There are monthly variations in the average number of incidents, but the behavior is different according to incident type. In the case of major accidents, minor accidents, and debris, the monthly variations are small, suggesting that seasonal effects have no impact on the frequency of these types of incidents. In the case of stalled vehicles, an analysis shows that monthly variations in the number of incidents are statistically significant. In particular, there was a sudden drop in the number of incidents from September to November 2003, due mostly to a reduction in the number of stalled vehicle incidents. At this point, it is not clear why this happened. A more detailed analysis of the archived data would be necessary to clarify the trend.
- The average number of incidents per month while schools are in session (academic year) is roughly the same as the number of incidents per month when schools are not in session (summer). There are differences in the distribution by incident type, e.g., more major accidents happen per month during the academic year than in the summer (306 versus 285, or a 52/48 percent split), but an analysis shows that such differences are not statistically significant.
- The average number of incidents per month varies considerably from sector to sector, but the behavior is different according to incident type. An analysis shows that there are statistically significant spatial variations in the rates of major accidents, minor accidents, and stalled vehicles. The analysis also shows no statistically significant spatial variations in the rate of debris incidents.
- Sectors with the highest incident rates tend to be concentrated along certain corridors. There are differences in incident rate according to season and also according to incident type (except for debris, where the spatial distribution is essentially uniform regardless of season). For example, sectors with at least five incidents per 3-month period are concentrated along three corridors: IH-10 from Hildebrand Avenue to Medical Drive, IH-35 from Southcross to IH-37/US 281, and IH-35 between the two Loop 410 interchanges in northeast San Antonio.

## Distribution of Incidents by Day of Week

This analysis focuses on the distribution of incidents by day of week. It also includes the distribution of incidents per weekday and per weekend day. [Table 15](#) shows the average number of incidents of each type per day of week, as well as per weekday and weekend days. [Table 16](#) shows the corresponding distribution percentages, by incident type. [Table 17](#) shows a listing of sectors with the highest frequency of incidents. [Appendix B](#) includes maps showing the number of incidents per day for each incident type (expressed for convenience as number of incidents per 100 days), separately for weekdays and weekend days.

**Table 15. Average Number of Incidents per Day of Week, Weekdays, and Weekends.**

	Major Accident	Minor Accident	Stalled Vehicle	Debris	Average Total
Monday	10	8	12	2	32
Tuesday	11	8	13	2	34
Wednesday	10	8	13	2	32
Thursday	11	8	14	2	34
Friday	13	9	15	2	38
Saturday	8	4	3	1	16
Sunday	6	2	3	1	13
Weekly Total	68	47	73	11	199
Daily Average	10	7	10	2	28
Weekday	11	8	13	2	34
Weekend Day	7	3	3	1	14

**Table 16. Distribution of Incidents by Day of Week, Weekdays, and Weekends.**

	Major Accident		Minor Accident		Stalled Vehicle		Debris		Grand Total	
Monday	31%	15%	26%	17%	38%	17%	6%	16%	100%	16%
Tuesday	32%	16%	23%	16%	40%	18%	5%	16%	100%	17%
Wednesday	30%	14%	24%	16%	41%	18%	5%	14%	100%	16%
Thursday	32%	16%	24%	17%	40%	19%	5%	15%	100%	17%
Friday	33%	18%	25%	20%	39%	20%	4%	14%	100%	19%
Saturday	47%	11%	24%	8%	21%	5%	8%	12%	100%	8%
Sunday	50%	9%	19%	5%	21%	4%	10%	11%	100%	6%
Daily Average	34%	100%	24%	100%	37%	100%	5%	100%	100%	100%
Weekday Average	32%	80%*	24%	87%	39%	92%	5%	76%	100%	86%
Weekend Average	48%	20%*	22%	13%	21%	8%	9%	24%	100%	14%

\* Percentages represent proportion of total number of incidents per week that happen on a weekday or a weekend day.

**Table 17. Sectors with the Highest Average Number of Incidents per Weekday (Expressed as Number of Incidents per 100 Weekdays).**

Sector ID	Average Number of Incidents per 100 Weekdays				
	Major Accident	Minor Accident	Stalled Vehicle	Debris	Grand Total
SECT-0035S-164.412	21.4	24.1	18.0	0.7	64.1
SECT-0010E-562.581	15.3	9.7	15.6	0.5	41.0
SECT-0035S-163.893	12.2	14.9	9.3	0.3	36.8
SECT-0010W-565.683	11.7	8.1	13.6	0.3	33.7
SECT-0010W-567.352	7.3	4.2	18.3	0.7	30.5
SECT-0035S-154.234	9.8	6.4	12.0	1.5	29.8
SECT-0281S-143.421	11.7	8.6	6.6	1.4	28.3
SECT-0010W-564.581	10.7	6.4	10.0	0.7	27.8
SECT-0010W-566.641	8.6	4.6	13.6	1.0	27.8
SECT-0035S-155.884	5.6	4.2	13.4	4.2	27.5
SECT-0035N-155.863	5.4	5.3	14.9	1.4	26.9
SECT-0010E-564.635	10.3	6.6	8.5	1.4	26.8
SECT-0281N-143.421	14.6	5.4	4.7	1.4	26.1
SECT-0410E-013.659	9.3	7.1	8.8	0.5	25.8
SECT-0010E-566.507	10.3	5.1	5.4	1.4	22.2
SECT-0035S-165.409	7.5	5.9	7.3	0.3	21.0
SECT-0035S-164.909	4.2	5.9	9.8	0.3	20.3
SECT-0035N-154.187	6.1	5.4	7.6	1.0	20.2
SECT-0410W-023.019	5.3	6.1	7.6	0.2	19.2
SECT-0035S-157.552	3.2	3.9	8.8	0.3	16.3

An analysis of the data yields the following observations:

- On average, there are 199 incidents per week (or about 28 incidents per day). Of the 199 incidents per week, about 68 (or 34 percent) are major accidents, 47 (or 24 percent) are minor accidents, 73 (or 37 percent) are stalled vehicles, and 11 (or 5 percent) are debris related. The relative distribution is similar to the yearly and monthly distributions.
- There are daily variations in the number of incidents. The day of the week with the largest number of incidents is Friday (with 38 incidents), followed by Tuesday and Thursday (with 34 incidents each). An analysis shows that, regardless of incident type, daily variations in the number of incidents are statistically significant.
- On average, there are 34 incidents per weekday and 14 incidents per weekend day. The distribution varies by incident type. More major accidents happen per weekday than per weekend day (11 versus 7). Something similar happens with minor accidents (8 versus 3), stalled vehicles (13 versus 3), and debris (2 versus 1). An analysis shows that these differences are statistically significant.
- Even though there are more incidents per weekday than per weekend day, the relative frequency of incidents by incident type is the opposite. Some 70 percent of all incidents per weekend day are either major or minor accidents. In contrast, 56 percent of all incidents per weekday are either major or minor accidents. As a result, even though the number of incidents per weekend day is lower, if an incident occurs during the weekend, it is more likely to be a major or minor accident than a stalled vehicle or debris.
- The spatial distribution of incidents tends to be much more uniform for weekend days than for weekdays, regardless of incident type. Not surprisingly, the spatial distribution

of incidents for weekdays, regardless of incident type, is very similar to the corresponding overall spatial distributions of total number of incidents per month. In the case of major accidents, even though the spatial distribution for weekend days is more uniform than for weekdays, there are still a few sectors with unusually high weekend-day major accident rates. These sectors are SECT-0281N-143.421, SECT-0281S-143.421, and SECT-0037S-142.830 on US 281/IH-37 just north of downtown; and SECT-0010E-564.635 on eastbound IH-10 around Vance Jackson Road.

- The sector with the highest frequency of weekday incidents was sector SECT-0035S-164.412, which is located on southbound IH-35 around Rittiman Road. On average, this sector had about 64 incidents per 100 weekdays. Other sectors worth mentioning include sector SECT-0010E-562.581 (eastbound IH-10 around Callaghan Road) with 41 incidents per 100 weekdays, sector SECT-0035S-163.893 (southbound IH-35 south of Rittiman Road), with about 37 incidents per 100 weekdays, and sector SECT-0010W-565.683 (westbound IH-10 around Vance Jackson Road) with about 34 incidents per 100 weekdays. The two sectors on IH-35, SECT-0035S-164.412 and SECT-0035S-163.893, are noteworthy because these two sectors are consecutive sectors characterized by large amounts of truck traffic and weaving as vehicles move to the left lane over a very short distance to continue on southbound IH-410 (24). Other sectors, e.g., SECT-0010W-565.683, are characterized by tight horizontal alignments.

### **Effect of Traffic Volume on the Distribution of Incidents**

This analysis focuses on the distribution of incidents after taking into account the effect of traffic volume. Several studies in the literature report on the positive correlation between congestion—therefore traffic volume—and the frequency of incidents (25). The assumption in this section is that normalization by traffic volume should smooth out differences in the distribution of incidents and, at the same time, should highlight outliers, namely sectors with unusually high incident frequencies in relation to the amount of traffic those sectors carry.

A number of analyses are possible using data at various levels of temporal resolution. For simplicity, the researchers normalized average weekday incident frequencies using year 2002 annual average daily traffic (AADT) data obtained from the Transportation Planning and Programming (TP&P) Division. The analysis could have used archived ITS volume data instead of AADT data. However, the archived ITS volume data set has not undergone a rigorous validity test to determine, e.g., how annual volumes derived from this data set would compare against AADT values. This test is important and should be carried out, particularly because of the increasing level of interest at TxDOT and other transportation agencies in the use of ITS data to augment traffic data gathering capabilities and because of cases where studies have found significant differences between volumes reported by ITS equipment and volumes reported by automatic traffic recorder (ATR) units (26, 27).

Figure 30 shows the spatial distribution of year 2002 AADT values on state highways in the San Antonio area. Figure 31 shows the spatial distribution of the number of incidents per 100 weekdays in the same format as the map in Figure 30 to facilitate the comparison. Figure 32 shows the average number of weekday incidents per 10 million vehicles for each sector on the TransGuide freeway network. Figure 33 shows a similar map, except that it highlights

differences between individual sectors by direction. [Table 18](#) shows a listing of sectors with the highest number of weekday incidents per 10 million vehicles.

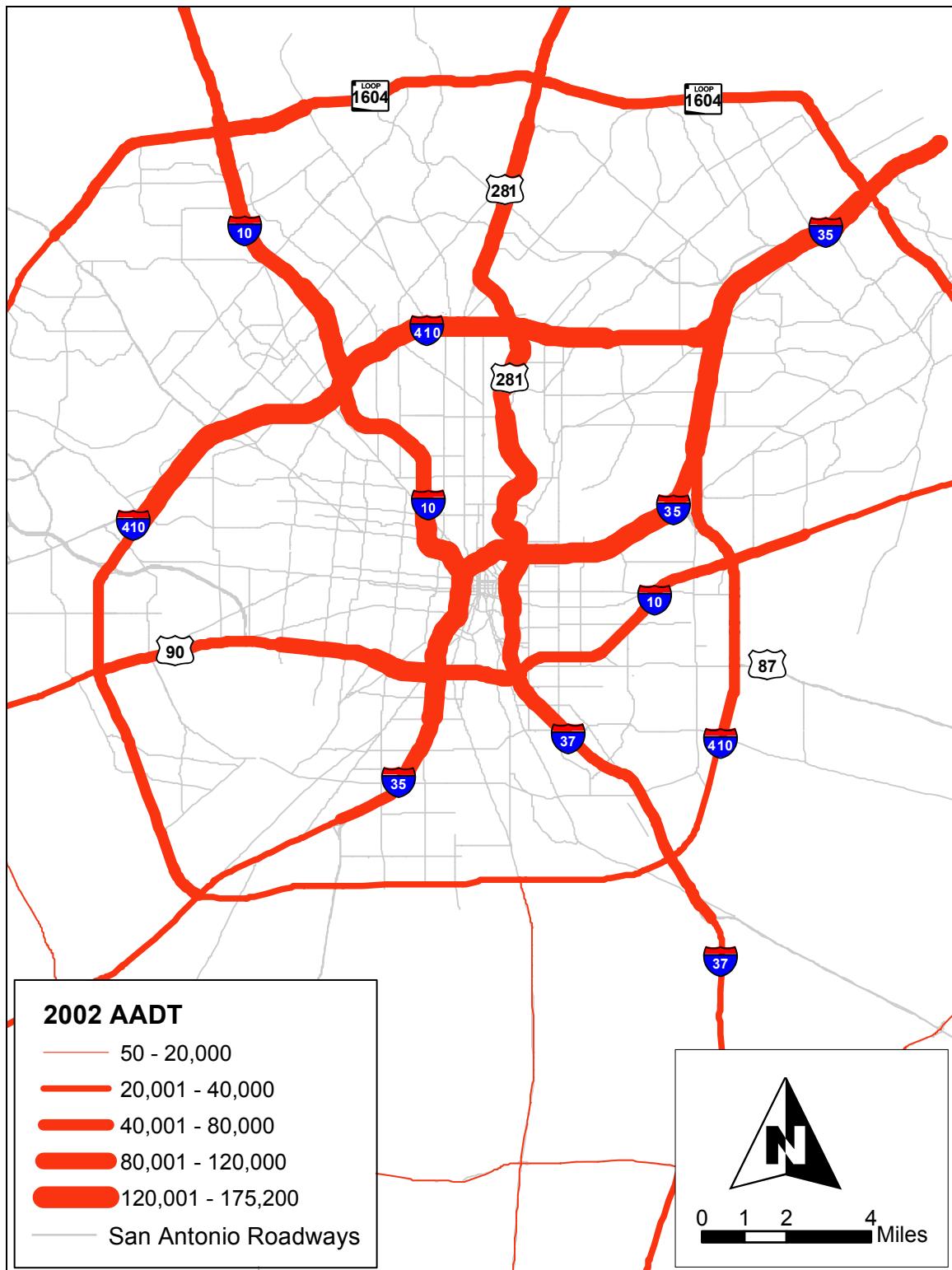


Figure 30. Year 2002 Average Daily Traffic for San Antonio.

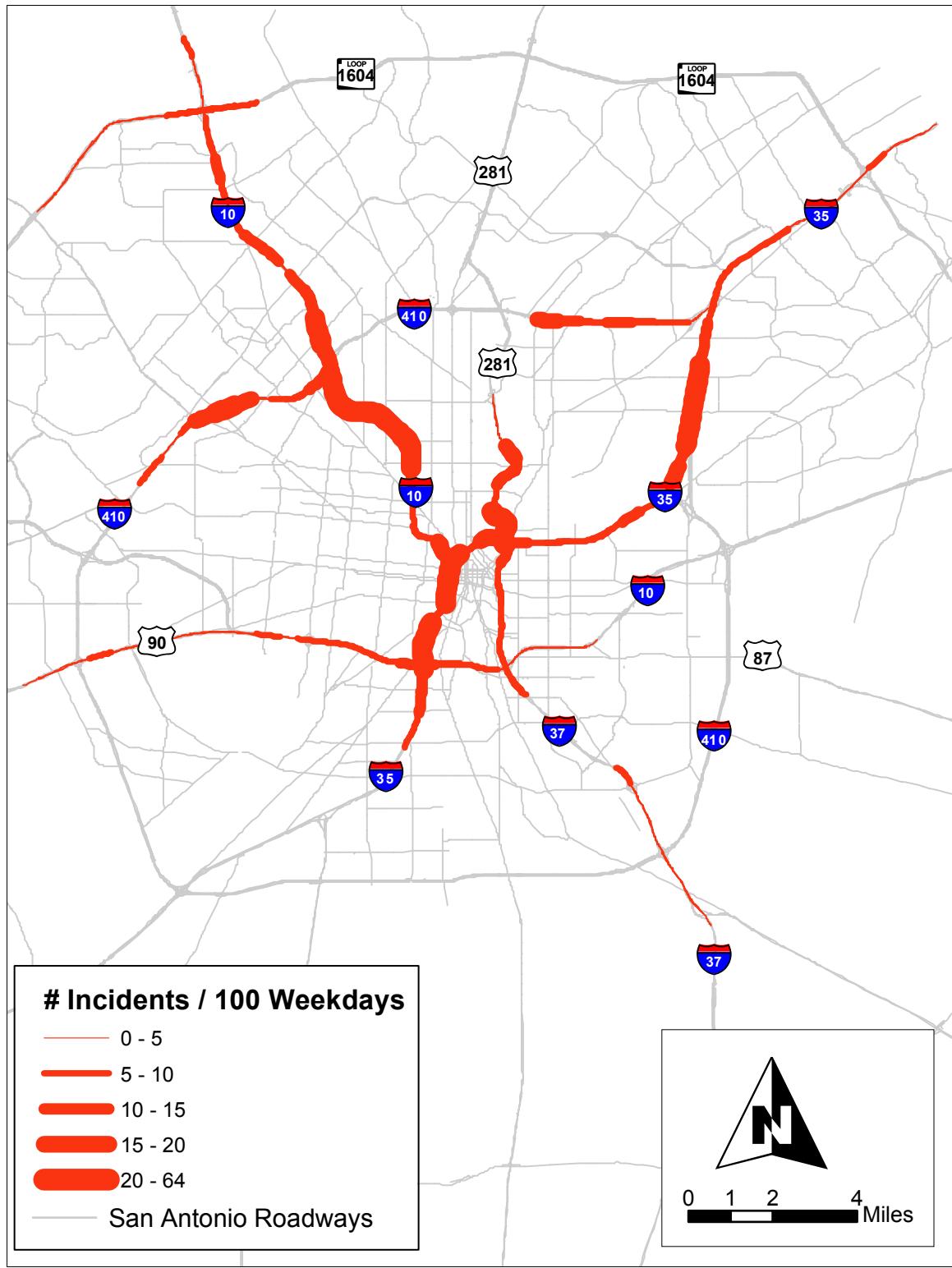


Figure 31. Average Number of Incidents per Sector (Expressed as Number of Incidents per 100 Weekdays).

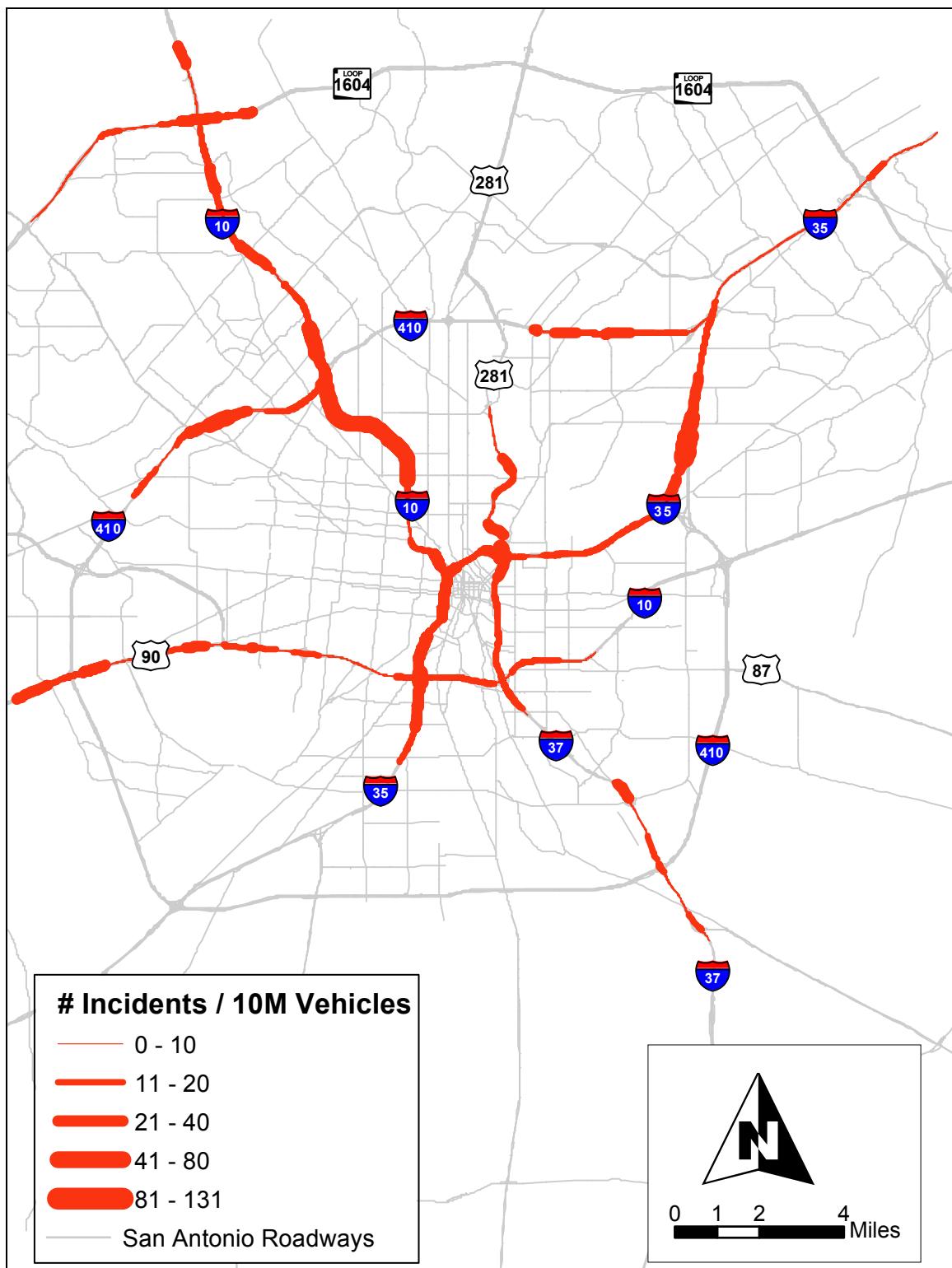


Figure 32. Average Number of Weekday Incidents per 10 Million Vehicles.

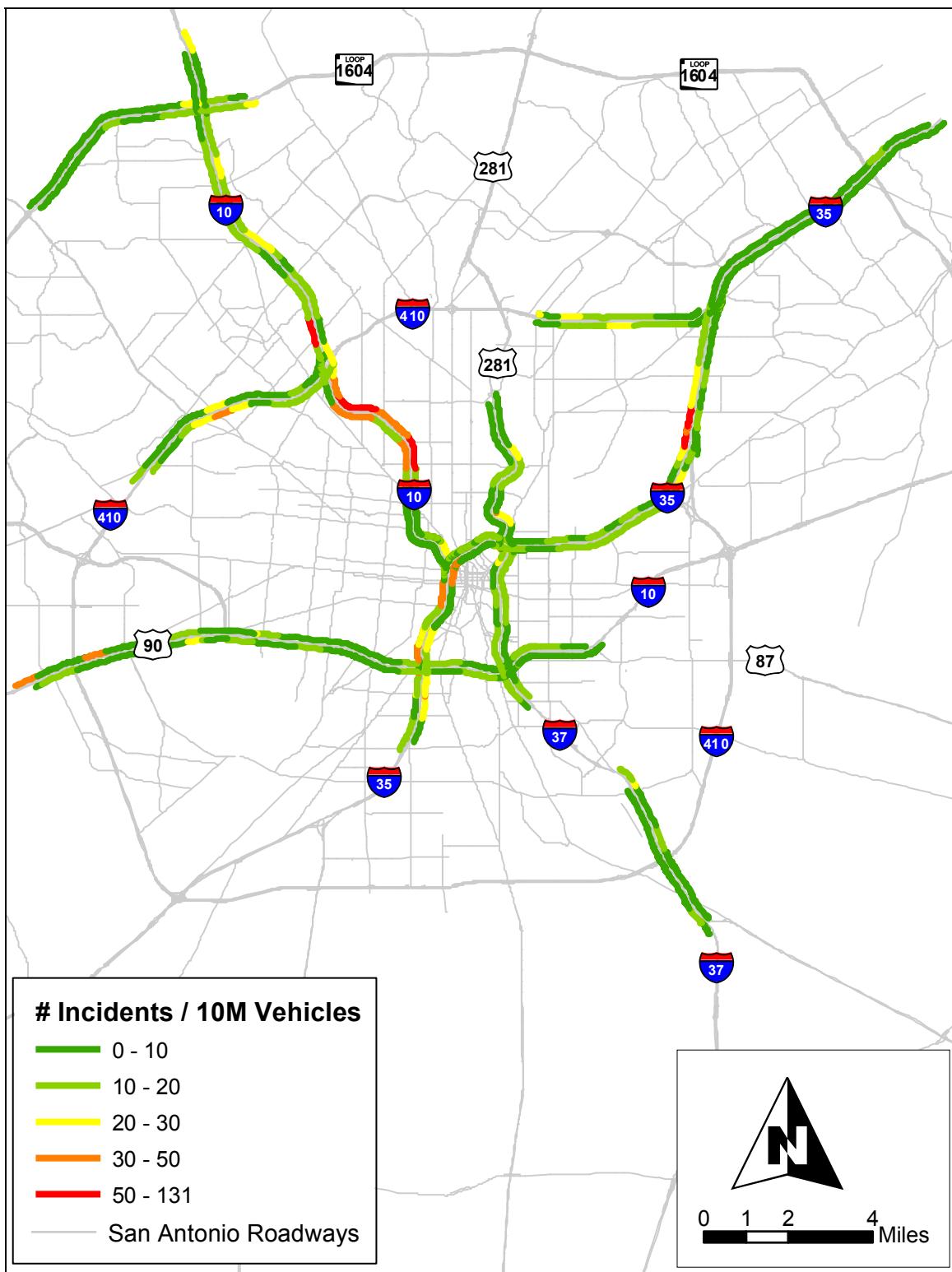


Figure 33. Average Number of Weekday Incidents per 10 Million Vehicles (Color Coded Map).

**Table 18. Sectors with the Highest Number of Weekday Incidents per 10 Million Vehicles.**

Sector Address	Number of Incidents on All Weekdays	AADT	Incidents per 10 Million Vehicles	Comment
SECT-0035S-164.412	378	98,000	131	Two AADT segments with different AADT values overlaid this sector
		165,850	77	
SECT-0035S-163.893	217	98,000	75	Two AADT segments with different AADT values overlaid this sector
		165,850	44	
SECT-0010E-562.581	242	117,180	70	Two AADT segments with different AADT values overlaid this sector
		158,400	52	
SECT-0010W-565.683	199	117,180	58	
SECT-0010W-567.352	180	117,180	52	
SECT-0010W-566.641	164	117,180	47	
SECT-0010E-564.635	158	117,180	46	
SECT-0281S-143.421	167	131,710	43	
SECT-0035S-154.234	176	141,680	42	
SECT-0410E-013.659	152	123,750	42	
SECT-0281N-143.421	154	134,920	39	Two AADT segments with different AADT values overlaid this sector
		175,200	30	
SECT-0010E-566.507	131	117,180	38	
SECT-0035S-155.884	162	160,460	34	
SECT-0035N-155.863	159	160,460	34	
SECT-0090W-564.576	43	47,070	31	
SECT-0035N-153.048	87	97,510	30	

Readers should be aware that one of the difficulties of using AADT data—which highlights the potential advantage of using ITS data for traffic volume gathering purposes—is that the spatial resolution of the AADT data is not the same as the ITS sector or ITS incident data. To normalize incident data by AADT, the researchers overlaid the AADT layer on the sector layer in the GIS. However, because these layers use linear segments of different lengths and therefore different beginning and ending points, there were sectors that ended up with more than one AADT layer segment associated with them—and therefore more than one AADT value. Nonetheless, the analysis resulted in some interesting observations, as documented below:

- After taking AADT into account, the incident rate for several sectors became more in line with the incident rate for other sectors on the same corridor. This was the case of IH-35 between US 90 and US 281/IH-37, IH-35 between SL 1604 and IH-410 on the northeast part of town, US 281 north of IH-35, and IH-10 between SL 1604 and IH-410.
- Despite the smoothing effect due to normalization, there were sectors with unusually high incident rates. These are sectors that also rank high in the total number of incidents without normalization, clearly indicating the outlier character of those sectors. The sector with the highest number of weekday incidents per 10 million vehicles was sector SECT-0035S-164.412, located on southbound IH-35 around Rittiman Road. On average, this sector had 131 weekday incidents per 10 million vehicles. Other sectors worth mentioning include sector SECT-0035S-163.893 (southbound IH-35 south of Rittiman Road), with 75 weekday incidents per 10 million vehicles, sector SECT-0010E-562.581 (eastbound IH-10 around Callaghan Road) with 70 weekday incidents per 10 million vehicles, and sector SECT-0010W-565.683 (westbound IH-10 around Vance Jackson Road) with 58 weekday incidents per 10 million vehicles.

## Distribution of Incidents by Corridor

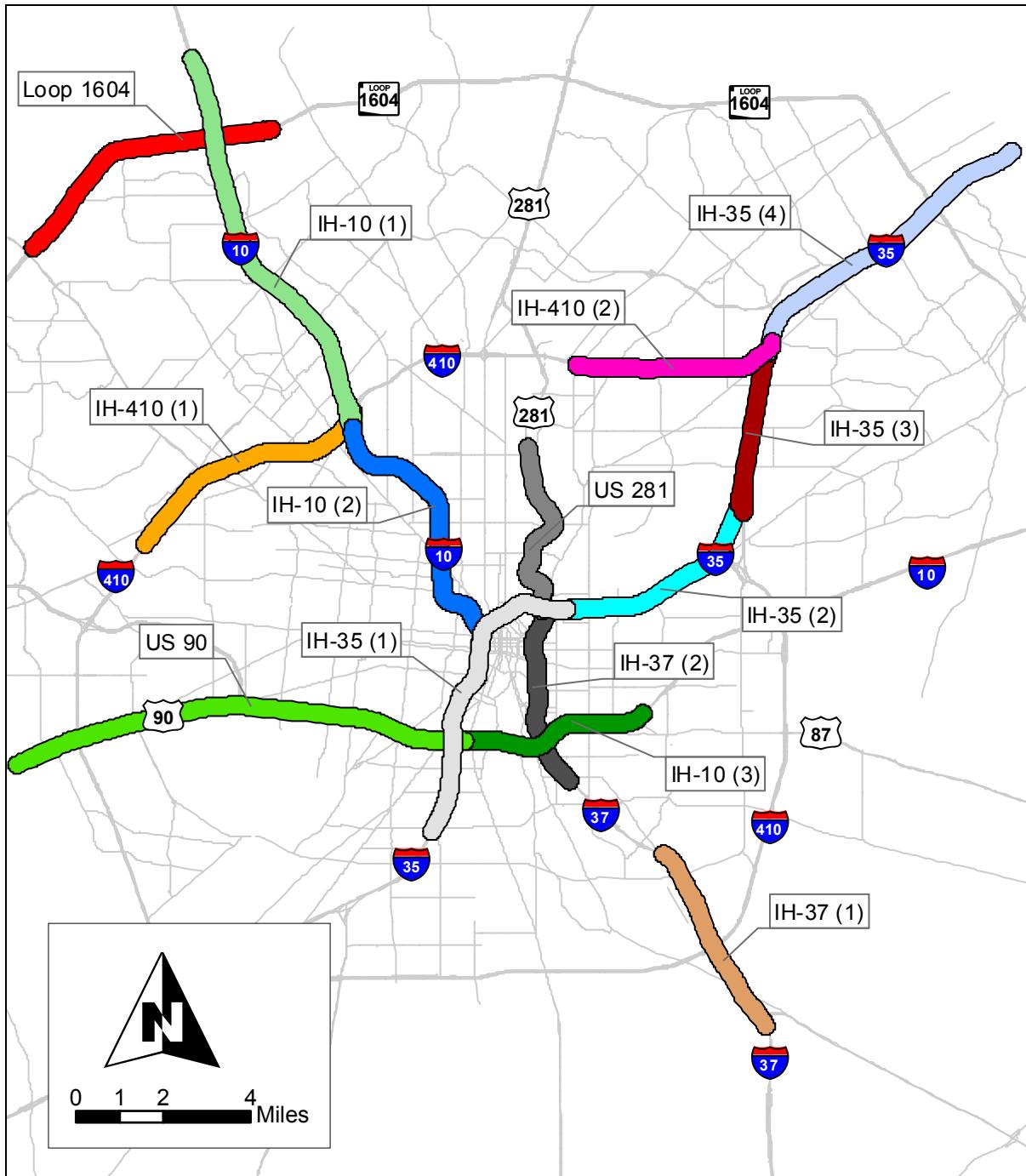
This analysis focuses on the distribution of incidents by corridor. It complements previous sections, which evaluated incidents at the individual sector level, by following a more aggregate, corridor-level approach. [Figure 34](#) shows 14 roughly homogeneous corridor sections in the TransGuide freeway network. For each corridor section, [Table 19](#) shows AADT, average number of incidents per 100 weekdays, average number of incidents per 1,000 weekdays per mile, average number of incidents per 10 million vehicles, and average number of incidents and accidents per 100 million vehicle miles traveled (VMT). [Table 20](#) shows the corresponding rankings.

**Table 19. Average Incident Statistics per Corridor Section.**

Corridor Section	Length (miles)	AADT	Number of Incidents per 100 Weekdays	Number of Incidents per 1,000 Weekdays per Mile	Number of Incidents per 10 Million Vehicles	Number of Incidents per 100 Million VMT	Number of Accidents per 100 Million VMT
IH-10 (1)	8.5	111,817	234	276	210	247	119
IH-10 (2)	6.1	132,615	288	475	217	358	185
IH-10 (3)	4.4	100,583	70	159	70	158	90
IH-35 (1)	6.9	149,091	334	486	224	326	161
IH-35 (2)	4.9	126,369	134	272	106	215	120
IH-35 (3)	3.6	137,445	219	600	159	436	285
IH-35 (4)	7.1	135,428	128	180	95	133	80
IH-37 (1)	4.1	52,880	29	70	54	133	83
IH-37 (2)	3.7	115,772	91	247	79	213	124
IH-410 (1)	5.1	138,102	152	295	110	214	142
IH-410 (2)	4.3	118,809	103	239	86	201	127
Loop 1604	6.1	60,443	77	126	128	208	133
US 281	3.9	132,226	132	343	100	260	154
US 90	9.6	79,999	110	115	138	143	83

**Table 20. Corridor Section Ranking by Measure.**

Corridor Section	Length (miles)	AADT	Number of Incidents per 100 Weekdays	Number of Incidents per 1,000 Weekdays per Mile	Number of Incidents per 10M Vehicles	Number of Incidents per 100M Vehicle Miles Traveled	Category
IH-35 (3)	14	3	4	1	4	1	1
IH-10 (2)	6	5	2	3	2	2	2
IH-35 (1)	4	1	1	2	1	3	3
US 281	12	6	7	4	9	4	3
IH-10 (1)	2	10	3	6	3	5	
IH-35 (2)	8	7	6	7	8	6	
IH-410 (1)	7	2	5	5	7	7	
IH-37 (2)	13	9	11	8	12	8	
Loop 1604	5	13	12	12	6	9	
IH-410 (2)	10	8	10	9	11	10	
IH-10 (3)	9	11	13	11	13	11	
US 90	1	12	9	13	5	12	
IH-37 (1)	11	14	14	14	14	13	
IH-35 (4)	3	4	8	10	10	14	



**Figure 34. Corridor Sections.**

An analysis of the data yields the following observations:

- Corridor section IH-35 (1) in the downtown area ranked first in the number of incidents per 100 weekdays and first in the number of incidents per 10 million vehicles. However, it ranked second in the number of incidents per 1,000 weekdays per mile and third in the number of incidents per 100 million VMT. In contrast, corridor section IH-35 (3),

located between the two IH-410 interchanges in northeast San Antonio, ranked fourth in the number of incidents per 100 weekdays, fourth in the number of incidents per 10 million vehicles, first in the number of incidents per 1,000 weekdays per mile, and first in the number of incidents per 100 million VMT. It is worth mentioning that this corridor section includes sectors SECT-0035S-164.412 and SECT-0035S-163.893, which ranked consistently at the top by almost every incident rate measure.

- [Table 20](#) groups corridor sections into five general categories, according to the ranking in the number of incidents per 100 million VMT. By and large, the rankings in [Table 20](#) are consistent with the results obtained previously at the more disaggregate sector level, i.e., they highlight the fact that IH-35 between the two IH-410 interchanges in northeast San Antonio, IH-10 between IH-410 and IH-35 in northwest San Antonio, and US 281 just north of downtown have unusually high incident rates. Although not shown in [Table 19](#) and [Table 20](#), an analysis shows the differences are statistically significant in the case of major accidents, minor accidents, and stalled vehicles, but not in the case of debris.
- Two measures, number of incidents per 1,000 weekdays per mile and number of incidents per 100 million VMT, produced very similar rankings. The second measure is a stronger indicator of risk because it includes the effect of traffic volume. However, the fact that the two measures gave similar results suggests that it might be possible to use a simpler measure that does not depend on AADT. It also validates the analysis in the previous sections, which relied on number of incidents per sector, because sectors have roughly the same length (about half a mile).
- It might be useful to compare the incident rates in [Table 19](#) with other rates reported in the literature. For example, an analysis of crash data on the northern, suburban section of the New Jersey Turnpike revealed 55 to 75 crashes per 100 million VMT ([24](#)). The same study found 55 to 105 crashes per 100 million VMT on suburban IH-5 near Los Angeles. These rates are similar to crash rates associated with suburban corridor sections in [Table 19](#) (roughly 80 to 130 crashes per 100 million VMT).
- [Table 19](#) suggests non-crash incidents (i.e., stalled vehicles and debris) account for 40 to 50 percent of all incidents. In contrast, other studies have found much higher percentages for non-crash incidents. For example, using data from urban, heavily traveled sections of IH-880 in the San Francisco area and IH-10 in Los Angeles, Skabardonis et al. ([1, 2](#)) found breakdowns were 87 to 89 percent of all incidents while crashes were 6 to 10 percent of all incidents. This raises the possibility that non-crash incident rates could be higher than those documented in this report. Interestingly, Skabardonis et al. also found 600 to 660 crashes per 100 million VMT on IH-10 and IH-880, i.e., more than twice the rate for the corridor section with the highest crash rate in [Table 19](#). Readers should notice that both IH-10 and IH-880 carry more traffic than IH-35 in San Antonio (in the case of IH-10, 249,000 AADT on four lanes per direction and one HOV lane; in the case of I-880, 160,000–200,000 AADT on three to five lanes per direction and one HOV lane). In the case of I-880, Skabardonis et al. also reported that several segments lacked shoulders. These differences make the crash rate comparison difficult.
- For completeness, the researchers also compared incidents (major and minor accidents) from the TransGuide incident database to crash data from the Texas Department of Public Safety (TxDPS) crash database. Since the latest year for which TxDPS has released official crash data is 2001, the researchers used data from 1999, 2000, and 2001. Although not ideal, the analysis produced some interesting results. [Table 21](#) summarizes

number of crashes along TransGuide's instrumented corridors, as well as average monthly, daytime, nighttime, week day, and weekend day crashes. On average, there were 453 crashes reported by TxDPS every month, compared to 500 reported by TransGuide. By itself, this difference is not meaningful because the two data sets were not synchronous, although it does suggest similar orders of magnitude. More interesting is the comparison between week day and weekend day crashes and between daytime and nighttime crashes. As [Table 21](#) shows, the percentage of crashes reported during a typical week day was similar in both data sets (74 versus 77 percent). However, the percentage of crashes reported during daytime hours was much lower for TxDPS than for TransGuide (68 versus 83 percent), suggesting the possibility of underreporting of daytime crashes by the TxDPS database. Likewise, the percentage of crashes reported during nighttime hours was much higher for TxDPS than for TransGuide (32 versus 17 percent), suggesting the possibility of underreporting of nighttime crashes by TransGuide. This is reasonable considering there are fewer TransGuide operators at night, and confirms similar trends observed by TranStar officials in Houston.

**Table 21. Comparison between TxDPS Crash Data and TransGuide Incident Data (Major and Minor Accidents).**

TxDPS Crash Database (1999 – 2001)						TransGuide Incident Database (03/2002 – 05/2004)					
Year	All	Day time	Night time	Week Days	Week end Days	Type	All	Day time	Night time	Week Days	Week end Days
<b>2001</b>	5,666	3,828	1,838	4,230	1,436	<b>Major</b>	7,955	6,332	1,623	5,883	2,072
<b>2000</b>	5,532	3,692	1,840	4,079	1,453	<b>Minor</b>	5,542	4,811	731	4,563	979
<b>1999</b>	5,109	3,549	1,560	3,828	1,281	<b>Total</b>	13,497	11,143	2,354	10,446	3,051
<b>Total</b>	16,307	11,069	5,238	12,137	4,170						
Avg per Month	<b>453</b>	<b>308</b> (68%)	<b>146</b> (32%)	<b>337</b> (74%)	<b>116</b> (26%)	Avg per Month	<b>500</b>	<b>413</b> (83%)	<b>87</b> (17%)	<b>387</b> (77%)	<b>113</b> (23%)

### Distribution of Incidents by Time of Day

This analysis focuses on the distribution of incidents by time of day. The researchers divided the day into four periods: AM peak (7 to 9 AM), midday (9 AM to 4 PM), PM peak (4 to 7 PM), and night and early morning hours (7 PM to 7 AM). Table 22 shows the average number of incidents per hour for each of these time periods (expressed for convenience as number of incidents per 10 hours). [Table 23](#) shows the corresponding relative distribution of incidents. The maps in Appendix C show the spatial distribution of the total number of incidents per hour for each incident type (expressed for convenience as number of incidents per 1,000 hours).

**Table 22. Average Number of Incidents per 10-Hour Period by Time of Day.**

Time Period	Major Accident	Minor Accident	Stalled Vehicle	Debris	Average Total	Average per Hour
AM Peak	7	6	7	1	21	2.1
Midday	5	4	7	1	18	1.8
PM Peak	7	6	9	1	23	2.3
Night	2	1	1	<1	4	0.4
Average	4	3	4	1	12	1.2

**Table 23. Distribution of Incidents by Time of Day.**

	Major Accident		Minor Accident		Stalled Vehicle		Debris		Grand Total	
AM Peak	32%	14%	31%	19%	34%	14%	3%	9%	100%	15%
Midday	31%	39%	20%	37%	42%	49%	8%	62%	100%	43%
PM Peak	30%	21%	26%	26%	39%	26%	4%	19%	100%	24%
Night	50%	26%	23%	18%	23%	11%	3%	11%	100%	18%
Hourly Average	34%	100%	24%	100%	37%	100%	5%	100%	100%	100%

An analysis of the data yields the following observations:

- On average, there are 12 incidents every 10 hours (or 1.2 incidents per hour). Of these incidents, 4 (or 34 percent) are major accidents, 3 (or 24 percent) are minor accidents, 4 (or 37 percent) are stalled vehicles, and 1 (or 5 percent) is debris. However, there are hourly variations. While there are about 2.1 incidents per hour during the AM peak and 2.3 incidents per hour during the PM peak, there are only 0.4 incidents per hour at night.
- There are differences in the number of incidents per hour according to incident type. In the case of major and minor accidents, the number of incidents per hour is highest during the AM and PM peak periods. An analysis shows these values are significantly different from other time periods. In the case of stalled vehicles, the number of incidents per hour is highest during the PM peak, followed by midday, AM peak, and night. The PM peak value is significantly different from all the other periods. In the case of debris, the number of incidents per hour is highest during midday, followed by PM peak, AM peak, and night. These values are significantly different from one another.
- Of all incidents occurring in a 24-hour period, 43 percent occur during midday hours, 24 percent during the PM peak, 18 percent at night, and 15 percent during the AM peak. This is not unexpected given the duration of these time periods is different: 7, 3, 12, and 2 hours, respectively. However, it is interesting to note that of all incidents occurring in a 24-hour period, 39 percent occur during the AM and PM peak periods, even though the total duration of these two periods is 5 hours. In contrast, 43 percent of incidents occur during midday hours (duration of 7 hours), and 18 percent of incidents occur at night (duration of 12 hours).
- The night period had the highest percentage of major accidents (50 percent) in 24 hours, AM peak had the highest percentage of minor accidents (31 percent), midday had the highest percentage of stalled-vehicle incidents (42 percent), and also midday had the highest percentage of debris incidents (8 percent).
- The spatial distribution of incidents tends to be much more uniform at night than for other time periods during the day. Not surprisingly, the spatial distribution of incidents during daytime hours, particularly during the AM and PM periods, regardless of incident type, is very similar to the corresponding overall spatial distributions of total number of incidents per month. In the case of major accidents, even though the spatial distribution of incidents at night is more uniform than during daytime hours, there are two sectors (SECT-0281N-143.421 and SECT-0281S-143.421 on US 281 just north of downtown) with unusually high nighttime major accident rates.

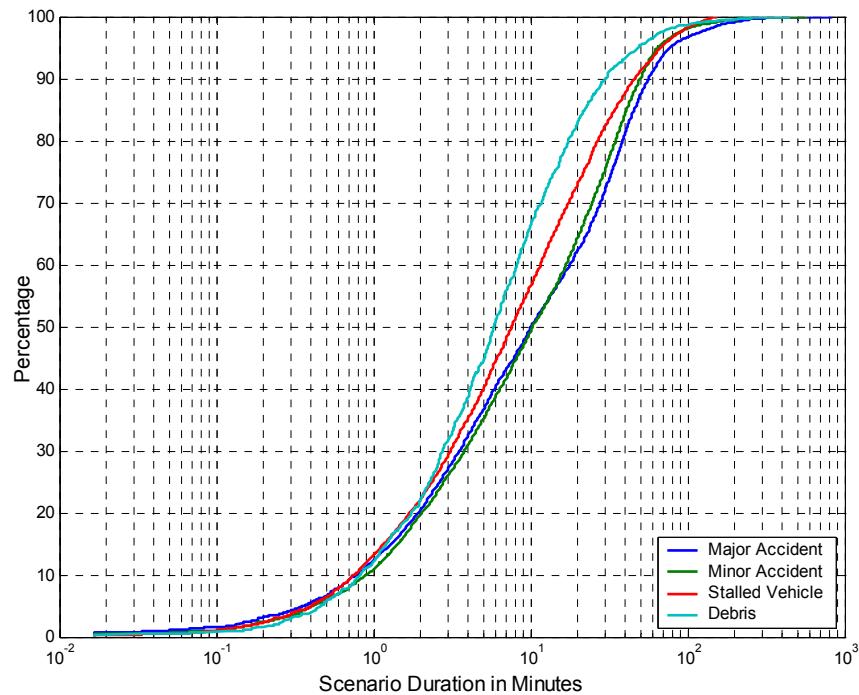
## Distribution of Incidents by Scenario Duration

This analysis focuses on the distribution of incidents by scenario duration. For the analysis, the researchers defined scenario duration to be the time elapsed between scenario start time and scenario cancellation time. As the following chapter shows, these times do not necessarily reflect the times when an incident started and ended. In fact, actual incident durations are typically longer than the corresponding total duration of the incident response time at the TMC. Nonetheless, an aggregate analysis of total scenario durations yields some interesting results.

[Table 24](#) summarizes some basic statistics of scenario durations. [Figure 35](#) shows the cumulative distribution of incident durations for each incident type.

**Table 24. Summary Statistics of Scenario Durations.**

Measure	Major Accident	Minor Accident	Stalled Vehicle	Debris	Total
Count	7,135	4,777	7,333	1,156	20,401
Mean (minutes)	23.8	20.9	20.0	13.4	21.2
Median (minutes)	10.1	10.3	7.8	5.8	8.8
Standard Deviation (minutes)	38.4	31.9	35.5	28.1	35.5
Maximum (minutes)	824.7	575.9	689.5	444.6	824.7
Minimum (minutes)	0.02	0.02	0.02	0.02	0.02
Skewness	5.5	6.0	5.2	8.3	5.6
Kurtosis	61.9	68.2	49.7	102.3	60.7



**Figure 35. Cumulative Scenario Durations by Incident Type.**

An analysis of the data yields the following observations:

- On average, scenarios last 21 minutes. Major accidents have the longest average scenario duration (24 minutes), followed by minor accidents (21 minutes), stalled vehicles (20 minutes), and debris (14 minutes). These are arithmetic mean values. Using the median (i.e., the 50th percentile) as a central tendency estimator produces very different results. In this case, minor accidents have the longest scenario duration (10.3 minutes), followed by major accidents (10.1 minutes), stalled vehicles (8 minutes), and debris (6 minutes). The overall median is 9 minutes. Because of the presence of records with unusually short and long durations in the scenario data set, the median represents a better central tendency indicator than the arithmetic mean.
- The large difference between mean and median scenario durations is an indication of skewness in the scenario duration distributions. This is particularly evident in the case of the major accident, minor accident, and stalled vehicle distributions.
- The distribution of major accident scenario durations is very similar to the distribution of minor accident scenario durations. Whether an operator classifies a scenario as a major accident or a minor accident is largely a judgment call—when loading scenarios—on whether the perceived incident duration will be longer or shorter than 15 minutes. Given that the actual duration distributions are practically identical is an indication that the current distinction between major accidents and minor accidents when loading scenarios is probably not meaningful and should be either replaced or eliminated.
- About 95 percent of scenarios last less than 30 minutes, and 98 percent last less than 1 hour. The longest scenario durations are 825 minutes (13.7 hours) for a major accident scenario, 576 minutes (9.6 hours) for a minor accident scenario, 690 minutes (11.5 hours) for a stalled vehicle scenario, and 445 minutes (7.4 hours) for a debris scenario.
- A substantial percentage of scenarios have very short durations. For example, some 12 percent of scenarios last less than a minute, which is significant considering that the percentages for all incident types are very similar. It may be worth noting that the original data set had a substantial percentage (about 13 percent) of zero-duration scenarios. A review of scenario execution entries for these scenarios revealed that, in many cases, the corresponding messages appeared to represent genuine responses to incidents. However, since there was no way to determine the actual incident response time from the scenario execution entries, the researchers decided for simplicity not to include the zero-duration scenarios in the scenario duration analysis.

## Distribution of Incidents by Lane and Shoulder Blockage

This analysis focuses on the distribution of incidents by lane and shoulder blockage. [Table 25](#) shows the distribution of incidents by main lane blockage. [Table 26](#) shows the distribution of incidents by shoulder blockage. [Table 27](#) shows the cross-distribution of incidents by both main lane and shoulder blockages. [Table 28](#) summarizes the distribution of lane/shoulder blockages and the average scenario durations in minutes, excluding zero-duration scenarios. The tables represent the number of main lanes and shoulders blocked at the time the operators confirmed the incidents and loaded scenarios, not necessarily the number of main lanes and shoulders blocked when the incidents happened. Further, the tables do not describe changes in the number of lanes blocked as incident response personnel arrived at the scene and managed the incidents.

**Table 25. Distribution of Incidents by Main Lane Blockage.**

Number of Main Lanes Blocked	Major Accident		Minor Accident		Stalled Vehicle		Debris		Grand Total
0	16%	20%	29%	55%	54%	66%	1%	9%	100% 45%
1	46%	68%	21%	44%	25%	34%	8%	72%	100% 50%
2	70%	9%	7%	1%	3%	<1%	21%	17%	100% 5%
3	85%	2%	2%	<1%	1%	<1%	11%	2%	100% <1%
4	90%	<1%	3%	<1%			7%	<1%	100% <1%
5	100%	<1%							100% <1%
Grand Total	34%	100%	24%	100%	37%	100%	5%	100%	100% 100%

**Table 26. Distribution of Incidents by Shoulder Blockage.**

Number of Shoulders Blocked	Major Accident		Minor Accident		Stalled Vehicle		Debris		Grand Total
0	49%	82%	19%	45%	23%	35%	9%	92%	100% 57%
1	14%	17%	30%	54%	56%	65%	1%	7%	100% 43%
2	47%	1%	39%	1%	13%	0%	1%	<1%	100% <1%
Grand Total	34%	100%	24%	100%	37%	100%	5%	100%	100% 100%

**Table 27. Cross-Distribution of Incidents by Main Lane and Shoulder Blockages (Excluding Zero-Duration Scenarios).**

Number of Main Lanes Blocked	Number of Shoulders Blocked			Grand Total		
	0	1	2			
0	299	1%	8,388	41%	128 1% 8,815 43%	
1	10,405	51%	35	<1%	2 <1% 10,442 51%	
2	949	5%	4	<1%		953 5%
3	173	1%	1	<1%		174 1%
4	27	<1%	1	<1%		28 <1%
5	3	<1%				3 <1%
Grand Total	11,856	58%*	8,429	41%*	130 1%* 20,415 100%	

\* These percentages are slightly different from their counterparts in Table 25 because of the exclusion of zero-duration scenarios.

**Table 28. Distribution of Scenario Durations in Minutes by Main lane and Shoulder Blockages (Excluding Zero-Duration Scenarios).**

Number of Main Lanes Blocked	Number of Shoulders Blocked			Grand Total
	0	1	2	
0	32.7	21.4	22.7	21.8
1	20.0	14.3	11.5	20.0
2	24.5	80.5		24.8
3	39.0	63.1		39.1
4	29.8	34.6		30.0
5	71.3			71.3
Average Duration	21.0	21.4	22.5	21.2

An analysis of the data yields the following observations:

- Overall, 45 percent of incidents did not have main lane blockages when operators confirmed the incidents and executed scenarios. Further, 50 percent of incidents had one

main lane blocked, and only about 5 percent of incidents had two or more main lanes blocked. Likewise, 57 percent of incidents had no shoulders blocked, 43 percent of incidents had one shoulder blocked, and less than 1 percent of incidents had both shoulders blocked. Interestingly, of the 57 percent of incidents with no shoulders blocked, the vast majority had one main lane blocked. In contrast, of the 43 percent of incidents with one shoulder blocked, the vast majority had no main lanes blocked.

- The distribution of main lane and shoulder blockage varied by incident type. For example, among incidents that had one main lane blocked, 46 percent were major accidents, 21 percent were minor accidents, 25 percent were stalled vehicle incidents, and 8 percent were debris incidents. Likewise, among incidents that had no shoulders blocked, 49 percent were major accidents, 19 percent were minor accidents, 23 percent were stalled vehicle incidents, and 9 percent were debris incidents.
- The vast majority of incidents blocking two or more main lanes were caused by major accidents: 70 percent in the case of two-lane blockages, 85 percent in the case of three-lane blockages, 90 percent in the case of four-lane blockages, and 100 percent in the case of five-lane blockages. Debris contributed to most of the remaining percentages.
- Scenarios with the longest average duration were those for incidents with two main lanes blocked and one shoulder blocked (80 minutes or 1.3 hours). Interestingly, this duration was slightly longer than the average scenario duration for incidents with five main lanes blocked but no shoulders blocked (71 minutes or 1.2 hours). Surprisingly, incidents with one main lane blocked and one shoulder blocked had the lowest average scenario duration (14 minutes). In general, the researchers expected scenario durations to increase as the number of main lanes and shoulders blocked increased. However, the data did not support this hypothesis. As the following chapter documents more clearly, scenario durations do not necessarily represent incident durations accurately. There is a possibility, therefore, that if the analysis used actual incident durations instead of scenario durations, the trends in [Table 28](#) could change.

## Weather Impact on Incidents

This analysis focuses on the evaluation of potential weather effects on the frequency of incidents throughout the study area. In the absence of detailed weather information for each sector on the TransGuide freeway network, the researchers used daily precipitation data from the weather station at the San Antonio International Airport ([28](#)). In addition to rain gage data, which—strictly speaking—only apply to the location associated with the weather station, the National Weather Service relies on radar data to produce data sets containing 6-hour rainfall estimates on a 4 kilometer (2.5-mile) grid centered over each radar site ([29](#)). For the San Antonio area, the 6-hour, 4 kilometer grid precipitation data archive goes back several years. These data provide considerably finer spatial and temporal resolution than the data from a single weather station. The downside, however, is the additional processing required to derive the data needed for the analysis, which is beyond the scope of the research. For this reason, the researchers only used daily precipitation totals.

The researchers obtained daily rainfall data for 823 days from March 2002 to May 2004. In total, there were 220 days with rain, 495 days without rain, and 108 days (or 13 percent) with no rainfall data. [Table 29](#) shows the average number of incidents per day for each rainfall and incident category. [Table 30](#) shows the corresponding distribution of incidents.

**Table 29. Average Number of Incidents per Day for Each Rainfall and Incident Category.**

Rainfall Event	Number of Days	Major Accident	Minor Accident	Stalled Vehicle	Debris	Grand Total
Rain	220	13.7	8.9	10.8	1.9	33.8
No Rain	495	8.3	6.7	10.6	2.3	26.5
No Data	108	8.5	5.8	10.4	2.4	25.8
All Days	823	9.8	7.2	10.6	2.2	28.4

**Table 30. Distribution of Incidents per Rainfall and Incident Category.**

Rainfall Event	Number of Days	Major Accident	Minor Accident	Stalled Vehicle	Debris	Grand Total
Rain	27%	41%	26%	32%	6%	100%
No Rain	60%	31%	25%	40%	9%	100%
No Data	13%	33%	23%	40%	9%	100%
All Days	100%	34%	25%	37%	8%	100%

An analysis of the data yields the following observations:

- On average, there were about 34 incidents per day during rainy days, as opposed to 27 incidents per day when it did not rain or 26 incidents per day for days with no rainfall data. Rainy days had on average 7 more incidents than days without rain. This is an indication, although circumstantial because of the aggregate nature of the rainfall data, that rain has an impact on incident frequency. Interestingly, the incident rate for days with no rainfall data was almost the same—regardless of incident type—as the incident rate for days without rain, suggesting the possibility that most days with no rainfall data could have been days in which it did not rain. However, in the absence of a positive confirmation of this hypothesis, the researchers decided not to make such an assumption.
- Major accidents account for most of the difference between rainy days and days without rain. On average, there were 14 major accidents per day during rainy days, as opposed to 8.3 major accidents per day when it did not rain. Rainy days had on average 5 more major accidents than days without rain. This difference is statistically significant, suggesting that rain has an impact on the frequency of major accidents.
- The number of minor accidents is also higher (about two more accidents) during rainy days than during days without rain. The analysis shows the difference is statistically significant. On the other hand, differences in the number of stalled vehicles and debris during rainy days versus days without rain are very small and are not statistically significant.
- On an average rainy day, 41 percent of all incidents were major accidents, 26 percent were minor accidents, 32 percent were stalled vehicles, and 6 percent were debris. Compared to an average day with no rain, this translates to about 10 percent more major accidents, 1 percent more minor incidents, 8 percent less stalled vehicles, and 3 percent less debris. It also suggests that rain increases the relative frequency of major and minor accidents and lowers the relative frequency of stalled vehicle and debris incidents.

## CHAPTER 5. INCIDENT IMPACTS ON TRAFFIC

This chapter summarizes the analysis completed to measure the impact of incidents on freeway traffic conditions using ITS traffic and incident data, mainly in the form of vehicle delay. The chapter includes a review of basic delay-related definitions and concepts, describes a methodology to calculate delay using ITS traffic and incident data, and summarizes the results of the application of the methodology to two sample case studies.

### DEFINITIONS OF DELAY

Incidents on freeways have multiple impacts, including extra delays, additional fuel consumption, higher emissions, increased driver aggressiveness, and lost worker productivity. Of particular interest in this research is the vehicle delay impact because of the possibility of using archived ITS data to measure vehicle delay.

A number of approaches are available to measure vehicle delay. The two most common approaches are the queuing diagram approach and the difference-in-travel-time approach. The queuing diagram approach relies on the identification of the reduction in freeway capacity resulting from an incident, the quantification of traffic demand, and the application of a balance equation to determine the magnitude of the delay (30, 31, 32). Difficulties with the application of this approach include: (a) measuring the reduction in capacity since capacity reduction changes dynamically throughout the duration of an incident and tends to be disproportionate to the number of lanes blocked and (b) measuring changes in traffic demand because of the possibility of traffic diversion (33).

The difference-in-travel-time approach relies on the identification of travel times under normal and incident conditions and the quantification of the amount of traffic affected by incidents (1, 2, 33, 34, 35, 36). There are several techniques to calculate incident delay depending on the level of spatial and temporal aggregation of the study in question. For example, the TTI Urban Mobility Study (25, 35, 37) calculates incident delay as a percentage of the amount of recurring delay using an incident delay factor that depends on roadway design characteristics and estimated volume patterns. For San Antonio, the factor is 0.8, which translates to incident delay accounting for some 44 percent of the total congestion delay. As a reference, using data from two urban corridors in California, Skabardonis, Varaiya, and Petty (38) obtained incident delay percentages between 13 and 30 percent (which correspond to incident delay factors of 0.15 and 0.43, respectively). More disaggregate approaches that calculate incident delay for individual incidents include those reported by Skabardonis et al. (33) and Petty (36).

By definition, delay—more exactly, moving delay—is the extra travel time required to traverse a given roadway segment of finite length compared to an ideal, reference travel time. In terms of segment length and travel speed, it may be possible to express delay as (33):

$$\text{Delay} = \text{Volume} \times \left[ \frac{\text{Segment Length}}{\text{Actual Speed}} - \frac{\text{Segment Length}}{\text{Ideal Speed}} \right] \quad (1)$$

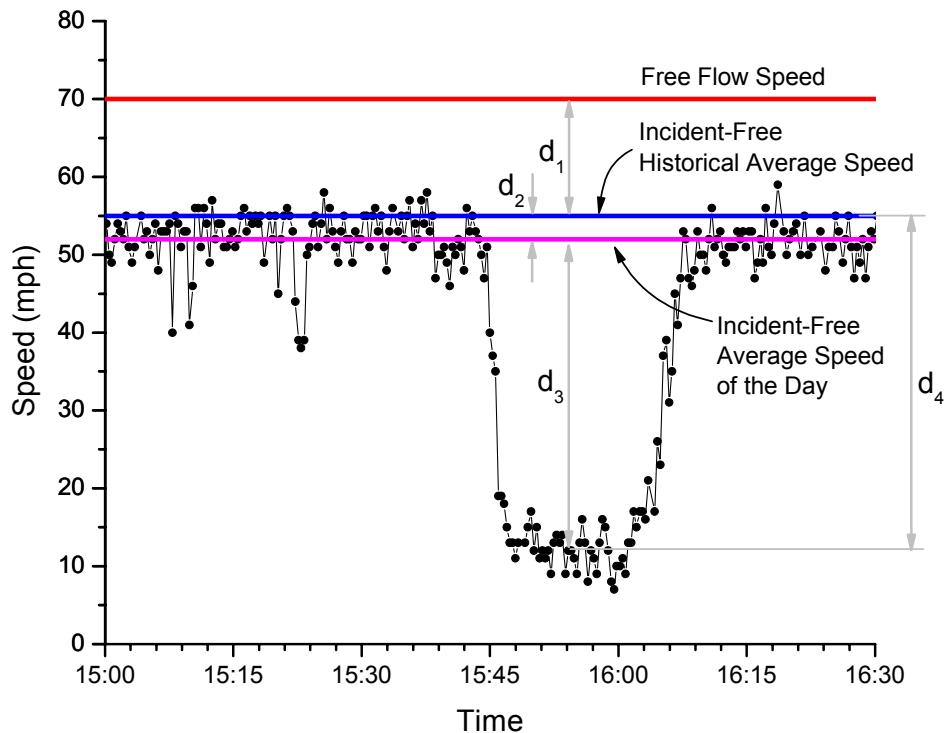
Notice that [Equation \(1\)](#) requires speeds to be different from zero. This happens most of the time. However, some incidents block lanes to the point that vehicles are either not moving or moving at such a slow speed that [Equation \(1\)](#) simply no longer applies. Further, [Equation \(1\)](#) assumes that all vehicles within the segment are able to traverse the segment within the period of time associated with the traffic volume. However, particularly in the case of major incidents, some vehicles might remain “stored” in the system at the end of the calculation time interval. [Equation \(1\)](#) does not account for these vehicles. A more comprehensive formulation, therefore, would include both moving delay and storage delay, expressed as:

$$\text{Total Delay} = \text{Moving Delay} + \text{Storage Delay} \quad (2)$$

Calculating storage delay is conceptually simple. However, there are challenges because of the practical difficulty to locate vehicles that remain “stored” in the system at the end of each time period which are not “caught” by the detection system. For simplicity, the analysis that follows only calculates moving delay.

## CALCULATION OF DELAY

[Figure 36](#) shows sample 20-second speed data on a freeway segment impacted by an incident. [Figure 36](#) also shows three conceptual reference speed profiles that enable the calculation of moving delay: free flow speed, incident-free historical average speed, and a hypothetical “incident-free” average speed for the day of the incident.



**Figure 36. Typical Incident Lane Speed Profile.**

In Figure 36,

- $d_1$  = delay due to the difference between free flow speed and incident-free historical average speed,
- $d_2$  = delay due to the difference between incident-free historical average speed and the “hypothetical” incident-free average speed for the day of the incident,
- $d_3$  = delay due to the difference between the “hypothetical” incident-free average speed for the day of the incident and speed during the incident, and
- $d_4$  =  $d_2 + d_3$  = delay due to the difference between incident-free historical average speed and speed during the incident.

Delays  $d_1$  and  $d_2$  are due to factors other than the incident, such as recurring congestion or construction. Only  $d_3$  is the delay as a result of the incident. Unfortunately, it is not possible to calculate  $d_3$  (or  $d_2$  for that matter) because the “hypothetical” incident-free historical average speed for the day of the incident does not exist. However, the incident-free historical average speed data include data for the same location on the same weekday at the same time of the incident. Under normal circumstances, this incident-free historical average speed should be very close to the “hypothetical” incident-free average speed for the day of the incident, making  $d_3$  very close to  $d_4$ . The following equations determine incident delay by calculating component  $d_4$ .

Figure 37 shows a location where an incident occurred. Of interest here is the speed  $S$  and volume  $V$  data collected by each detector unit and recorded by the corresponding LCU every 20 seconds.

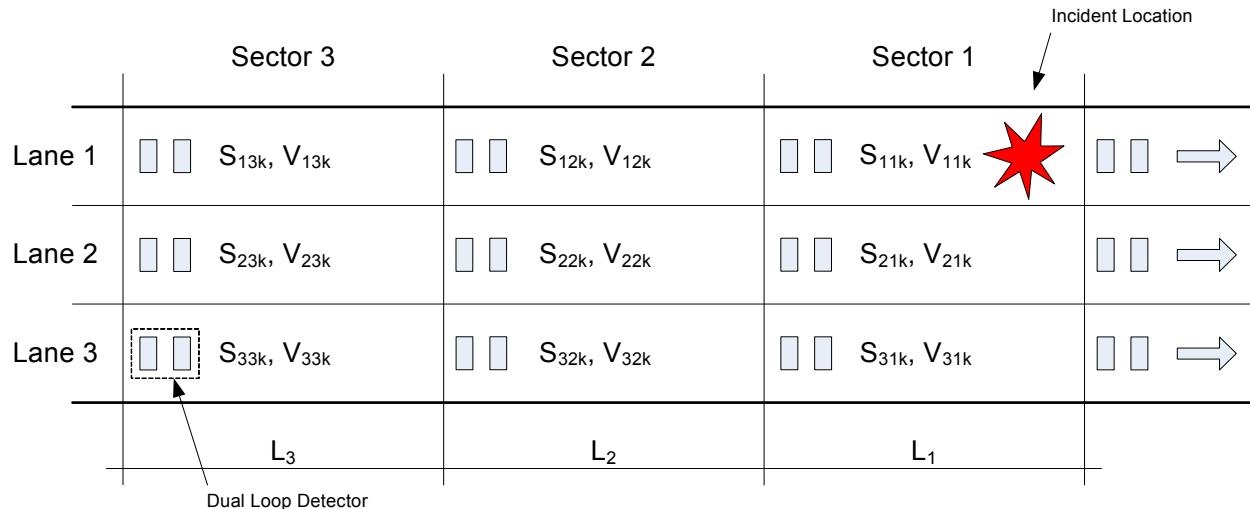


Figure 37. Sample Incident Location on Freeway.

In general,

- $L_j$  = length of sector  $j$ , assumed to be the same for all lanes within the sector;
- $V_{ijk}$  = volume per lane  $i$ , sector  $j$ , and time interval  $k$ , which is the total number of vehicles passing the sensor between time stamp  $t_{k-1}$  and  $t_k$ ;

- $S_{ijk}$  = speed per lane  $i$ , sector  $j$ , and time interval  $k$ , which is the average speed of all vehicles passing the sensor between time stamp  $t_{k-1}$  and  $t_k$ ;  
 $i$  = lane index;  
 $j$  = sector index;  
 $k$  = time interval index;  
 $n$  = number of lanes;  
 $m$  = number of sectors affected by the incident; and  
 $p$  = number of time intervals throughout the incident duration.

Under these conditions, [Equation \(1\)](#) becomes

$$d_{ijk} = L_j \cdot V_{ijk} \cdot \left( \frac{1}{S_{ijk}} - \frac{1}{R_{ijk}} \right) \quad (3)$$

- where  $d_{ijk}$  = delay per lane  $i$ , sector  $j$ , and time interval  $k$  and  
 $R_{ijk}$  = incident-free historical average speed, or reference speed per lane  $i$ , sector  $j$ , and time interval  $k$ .

[Equation \(3\)](#) applies as long as  $S_{ijk}$  is not zero.

The corresponding sector delay per time interval is the result of adding individual lane delays across all lanes:

$$d_{jk} = \sum_{i=1}^n d_{ijk} = L_j \cdot \sum_{i=1}^n V_{ijk} \left( \frac{1}{S_{ijk}} - \frac{1}{R_{ijk}} \right) \quad (4)$$

where  $d_{jk}$  = delay per sector  $j$  and time interval  $k$ .

The total sector delay during the duration of the incident is the result of adding the sector delays per time interval over all time intervals:

$$d_j = \sum_{k=1}^p d_{jk} = \sum_{k=1}^p \sum_{i=1}^n d_{ijk} = L_j \cdot \sum_{k=1}^p \sum_{i=1}^n V_{ijk} \left( \frac{1}{S_{ijk}} - \frac{1}{R_{ijk}} \right) \quad (5)$$

where  $d_j$  = delay per sector  $j$ .

In some cases, incidents—particularly major incidents—affect not just the sector where the incident took place but also other upstream sectors. Thus, the total incident delay is the sum of delays on all affected sectors:

$$D = \sum_{j=1}^m d_j = \sum_{j=1}^m \sum_{k=1}^p d_{jk} = \sum_{j=1}^m \sum_{k=1}^p \sum_{i=1}^n d_{ijk} = \sum_{j=1}^m L_j \cdot \sum_{k=1}^p \sum_{i=1}^n V_{ijk} \left( \frac{1}{S_{ijk}} - \frac{1}{R_{ijk}} \right) \quad (6)$$

where  $D$  = total incident delay.

[Equation \(6\)](#) applies only to one direction of traffic. Incidents frequently impact the other side of the freeway, especially when drivers slow down to have a look at the incident, in what is usually referred to as the rubbernecking effect. Therefore, to capture the whole effect of the incident, it would be necessary to apply [Equation \(6\)](#) to both directions of traffic. Strictly speaking, it would also be necessary to apply [Equation \(6\)](#) to affected exit ramps, entrance ramps, and frontage roads. This is currently not feasible, however, because most vehicle detection protocols on ramps and frontage roads normally do not include speed, which is a necessary component of [Equation \(6\)](#).

Notice that [Equation \(6\)](#) does not necessarily require having lane data every 20 seconds because the formulation is generic and can be used at any time resolution level. [Equation \(6\)](#) is adequate, provided volume and speed data are available at the lane level. On the other hand, some TMCs only have data at the station (or sector) level. In this case, it would be necessary to modify [Equations \(4\), \(5\), and \(6\)](#) so they can process sector-level data. First, the delay for sector  $j$  at time interval  $k$  is

$$d_{jk} = L_j \cdot V_{jk} \left( \frac{1}{S_{jk}} - \frac{1}{R_{jk}} \right) \quad (7)$$

where  $V_{jk}$  = volume per sector  $j$  and time interval  $k$ ,

$S_{jk}$  = speed per sector  $j$  and time interval  $k$ , and

$R_{jk}$  = incident-free historical average speed per sector  $j$  and time interval  $k$ .

Similarly,

$$d_j = \sum_{k=1}^p d_{jk} = L_j \cdot \sum_{k=1}^p V_{jk} \left( \frac{1}{S_{jk}} - \frac{1}{R_{jk}} \right) \quad (8)$$

and,

$$D = \sum_{j=1}^m d_j = \sum_{j=1}^m \sum_{k=1}^p d_{jk} = \sum_{j=1}^m L_j \cdot \sum_{k=1}^p V_{jk} \left( \frac{1}{S_{jk}} - \frac{1}{R_{jk}} \right) \quad (9)$$

This chapter includes sample delay calculations using both [Equations \(6\) and \(9\)](#). Since the sample calculations rely on 20-second data at the lane level, it became necessary to develop formulations to estimate  $V_{jk}$ ,  $S_{jk}$ , and  $R_{jk}$  using disaggregate data. The formulation to estimate  $V_{jk}$  is

$$V_{jk} = \sum_{i=1}^n V_{ijk} \quad (10)$$

The formulation to estimate  $S_{jk}$  is

$$S_{jk} = \frac{L_j}{T_{jk}} = \frac{L_j}{\frac{L_j \cdot \sum_{i=1}^n V_{ijk}}{\sum_{i=1}^n S_{ijk}}} = \frac{\sum_{i=1}^n V_{ijk}}{\sum_{i=1}^n S_{ijk}} \quad (11)$$

which results from first calculating the travel time for all vehicles traveling on lane  $i$  of sector  $j$  during time interval  $k$  as:

$$T_{ijk} = L_j \cdot \frac{V_{ijk}}{S_{ijk}} \quad (12)$$

then calculating the travel time for all vehicles traveling on sector  $j$  during time interval  $k$  as:

$$T_{jk} = \sum_{i=1}^n T_{ijk} = L_j \cdot \sum_{i=1}^n \frac{V_{ijk}}{S_{ijk}} \quad (13)$$

and, finally, calculating an average sector travel time  $T_{jk_v}$  per vehicle on sector  $j$  during time interval  $k$  as:

$$T_{jk_v} = \frac{T_{jk}}{V_{jk}} = L_j \cdot \frac{\sum_{i=1}^n \frac{V_{ijk}}{S_{ijk}}}{\sum_{i=1}^n V_{ijk}} \quad (14)$$

## CALCULATION OF REFERENCE SPEED

[Figure 36](#) suggests a uniform historical average speed throughout the duration of the incident. In practice, the historical average might vary substantially, particularly if the incident takes place around the beginning or end of one of the daily peak periods. This makes it necessary to calculate different reference speeds for each time interval  $k$ . Normally, all available speed data are in 20-second intervals, but there are daily variations in the archived data time stamps, which means that for each point in time during the incident, historical data may not be available for that specific time stamp. However, there are data available for a few seconds before and/or after that time. A technique that enables the calculation of the reference speed  $R_{ijk}$  for a speed  $S_{ijk}$  at a particular time interval under these circumstances is the  $k$ -nearest neighborhood ( $k$ -NN) non-parametric regression ([39](#), [40](#), [41](#)), where  $k$  is the number of nearest neighbors used for the calculation. To avoid confusion with the time interval index  $k$  in [Equations \(3\) through \(14\)](#), the researchers replaced  $k$  with  $q$  in the regression formulation. Following Davis and Nihan ([41](#)),

$$\hat{y}(t) = \frac{1}{q} \cdot \sum_i y(s_i) \quad (15)$$

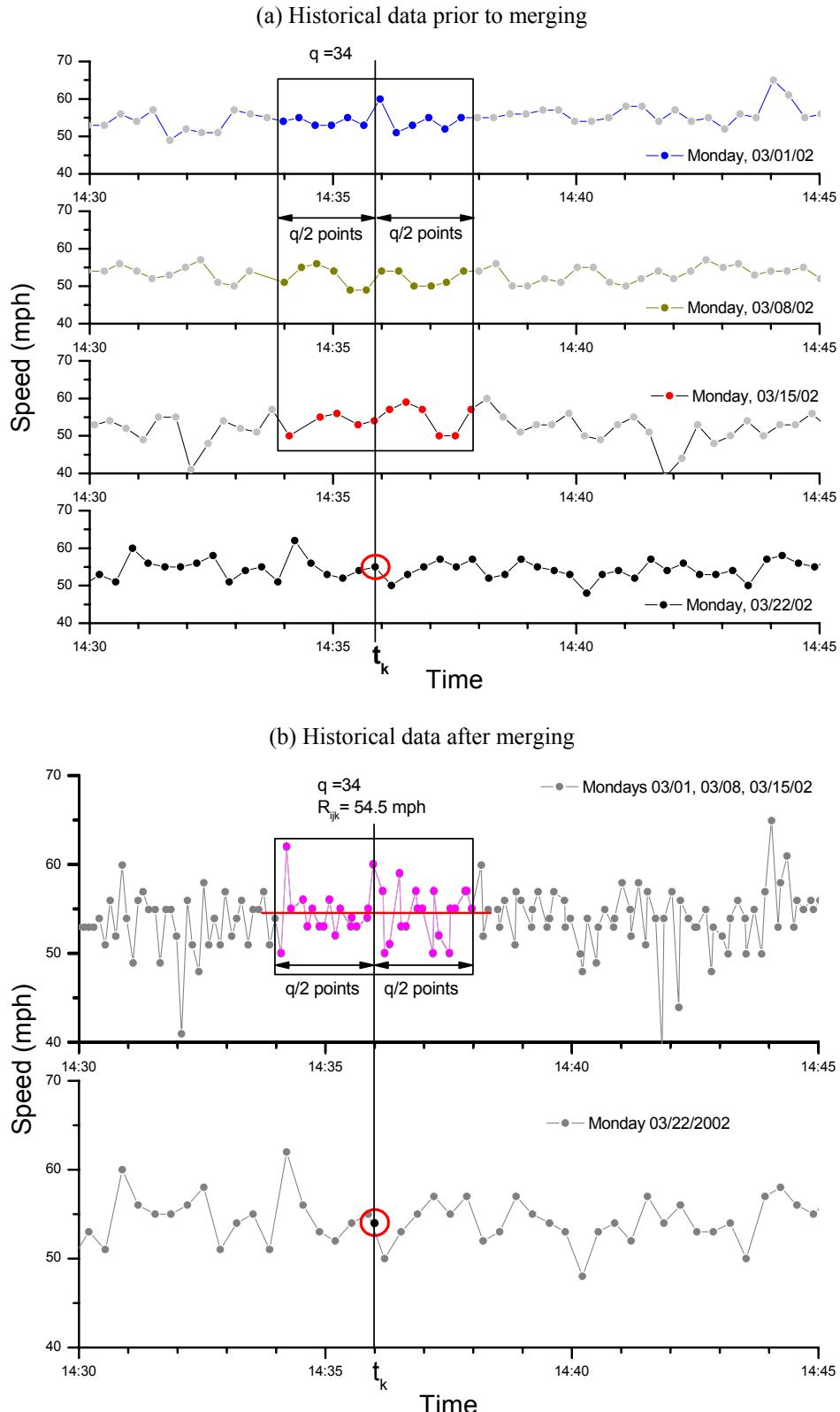
where  $y(t)$  = unknown value for an input measurement  $x(t)$ ;  
 $\hat{y}(t)$  = approximation of unknown value;  
 $x(s), y(s)$  = series of observations of input/output pairs, or learning sample; and  
 $q$  = number of nearest neighbors ( $q$ -NN)  $x(s), y(s)$  to a value  $x(t)$  used to forecast  $y(t)$ .

This research uses a variation of the nearest neighbor non-parametric regression where data from several historical time series, say, data from three non-incident Mondays, are merged into a single time series. [Figure 38](#) illustrates the concept. Merging data into a single series offers several advantages, including simplification of the reference speed calculation and flexibility in case there are gaps in one or more historical data time series. There is also evidence in the literature that merging data into a single time series does not result in increased error in the determination of central tendency estimators for the merged series [\(42\)](#).

[Figure 38a](#) shows four time series: a series for Monday, March 22, 2002, and three series corresponding to three previous Mondays. The circled record represents the point in time  $t_k$  for which it is necessary to determine reference speed  $R_{ijk}$ . [Figure 38a](#) also shows a neighborhood of points based on a  $\pm 2$ -minute time window. [Figure 38b](#) shows the merged data set from the three Mondays prior to March 22, 2002, as well as the reference speed  $R_{ijk}$  (54.5 mph) that results from an average of all speed values within the  $\pm 2$ -minute time window. Assuming three speed values per minute (i.e., speed data every 20 seconds), a  $\pm 2$ -minute time window, and three time series, the maximum possible number of speed values assuming no missing data and identical time stamps,  $q_{max}$ , is  $(2 \times 6 + 1) \times 3 = 39$ . In reality, because of gaps in the historical data, the effective number of speed values,  $q$ , was 34.

The difference between anticipated and actual number of  $q$  values to calculate  $R_{ijk}$  illustrates the importance of appropriately defining the neighborhood for  $R_{ijk}$ . There are several options to determine  $q$  depending on the width of the time window and the number of archived days included in the calculation:

- Option 1: Fix both time window and number of archived days. In this case,  $q$  depends on missing data and time step offsets. This option is the most restrictive but enables the most effective control if properly monitored. The researchers used this option.
- Option 2: Fix the time window and use as many archived days as necessary. In this case,  $q$  is fixed.
- Option 3: Leave the time window open but fix the number of archived days. In this case,  $q$  is fixed, but there is no control over the width of the time window.
- Option 4: Leave the time window and number of archived days open. In this case,  $q$  is fixed, but there is no control over either parameter.



**Figure 38. Schematic Representation of a  $q$ -Nearest Neighborhood Using  $\pm 2$  Minutes and Merged Speed Data from Three Archived Weekdays.**

Equation (15) suggests an arithmetic average to estimate the unknown value. However, the available data are speed paired with volume data. Conceptually, a speed value associated with a high volume should carry more weight than a speed value associated with a low volume. As a result, it is appropriate to estimate  $R_{ijk}$  (and  $R_{jk}$  for that matter) using a weighted harmonic average formulation similar to Equation (11), except that the summation of speed and volume is not over multiple lanes but over time in a merged data set. For each data set of merged archived data per lane, the formulation to determine  $R_{ijk}$  for a speed value  $S_{ijk}$  at  $t_k$  in a time window from  $t_{k-q/2}$  to  $t_{k+q/2}$  is

$$R_{ijk} = \frac{\sum_{a=-\frac{q}{2}}^{\frac{q}{2}} V_{ija}}{\sum_{a=-\frac{q}{2}}^{\frac{q}{2}} \frac{V_{ija}}{S_{ija}}} \quad (16)$$

where  $S_{ija}$  = speed per lane  $i$ , sector  $j$ , and index  $a$ ;  
 $V_{ija}$  = volume per lane  $i$ , sector  $j$ , and index  $a$ ;  
 $a$  = index of points in the merged series before or after  $t_k$ ; and  
 $q$  = number of speed and volume values in the neighborhood in the merged series.

Equation (16) enables the calculation of  $R_{ijk}$  provided volume and speed data are available at the lane level. If sector but not lane data are available, the formulation for calculating  $R_{jk}$  is similar to Equation (16), except it uses  $S_{ja}$  and  $V_{ja}$ :

$$R_{jk} = \frac{\sum_{a=-\frac{q}{2}}^{\frac{q}{2}} V_{ja}}{\sum_{a=-\frac{q}{2}}^{\frac{q}{2}} \frac{V_{ja}}{S_{ja}}} \quad (17)$$

where  $S_{ja}$  = speed per sector  $j$  and index  $a$ ;  
 $V_{ja}$  = volume per sector  $j$  and index  $a$ ;  
 $a$  = index of points in the merged sector-based series before or after  $t_k$ ; and  
 $q$  = number of sector speed and volume values in the neighborhood in the merged series.

An alternative formulation, which the researchers used for simplicity since they already had disaggregate data, is

$$R_{jk} = \frac{\sum_{a=-\frac{q}{2}}^{\frac{q}{2}} V_{ija}}{\sum_{a=-\frac{q}{2}}^{\frac{q}{2}} S_{ija}} \quad (18)$$

The only difference is that the number of  $q$  data pairs of speed and volume was  $n$  times as big as in [Equation \(17\)](#) to ensure the same time window. For example, for 4 days, 3 lanes per sector, data every 20 seconds, and a time window of  $\pm 2$  minutes, using [Equation \(17\)](#) one would select  $4 \times 6 \times 2 = 48$  nearest-neighbor values for the calculation of  $R_{jk}$ . By comparison, using [Equation \(18\)](#) one would select  $4 \times 6 \times 2 \times 3 = 144$  nearest-neighbor values for the calculation of  $R_{jk}$ .

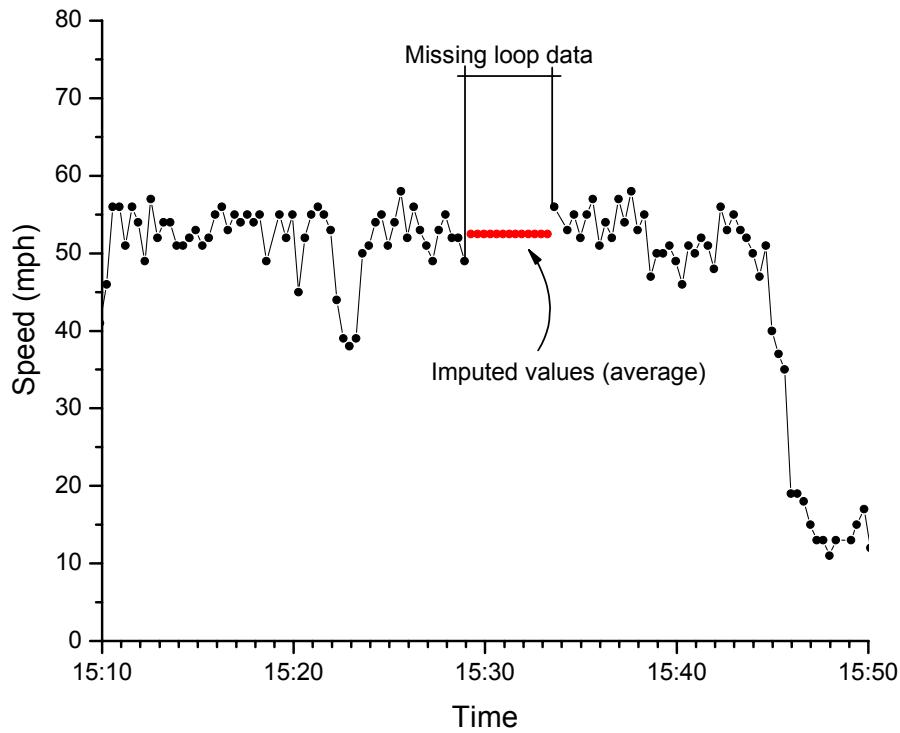
## DATA IMPUTATION

The prerequisite to calculating delay is the availability of speed and volume data for all lanes and sectors. In practice, missing or corrupted detector data are inevitable and can occur for a variety of reasons, including construction, detector failure, communication network failure, and data archival system failure ([43](#)).

Data imputation—the process of filling in missing data with estimated data—has long been the subject of research inquiry. In the case of ITS data, numerous approaches exist, ranging from heuristic imputation techniques to statistical techniques ([43](#)). Examples of heuristic techniques include time-of-day historical averages, weighted average of surrounding detectors with lane distribution, and average of surrounding time intervals. Examples of statistical techniques include iterative regression using means and covariance matrices and data augmentation. Sharma et al. ([44](#)) compared the ability of heuristic factor models, genetically designed neural networks, and time series analysis using autoregressive integrated moving averages (ARIMA) to impute annual average daily traffic and design hourly volume values. Sharma et al. found the smallest error with the genetically designed models. Nguyen and Scherer ([45](#)) proposed a modified space-time autoregressive moving average method based on a comparison between time-of-day historical averages, multiple regression on neighboring detectors, ARIMA time series analysis, space-time autoregressive moving averages, and a group model.

Many of the examples in the literature impute missing ITS data at relatively large aggregation levels (5 minutes or more). There is relatively little experience using disaggregated data, e.g., at the 20-second level. For simplicity, this research follows a simple time-space imputation approach for missing speed and volume data. The time imputation component uses data from the time series of the missing data detector before and after the data gap. As [Figure 39](#) shows, the time imputation calculates a constant average value using the first and last available data points within the gap. Provided the length of the gap is relatively small, a constant average value tends to produce very similar results as other approaches such as linear interpolation or higher-order polynomials. The space imputation component uses synchronous data averages from detectors

in close proximity to the missing data detector. The imputation technique employed in this research uses detectors from the same sector because a preliminary analysis showed that with a loop spacing of half a mile, there was less correlation between data from multiple detectors on the same lane than between data across lanes.



**Figure 39. Speed Time Series Imputation.**

The combined time-space imputation process is as follows:

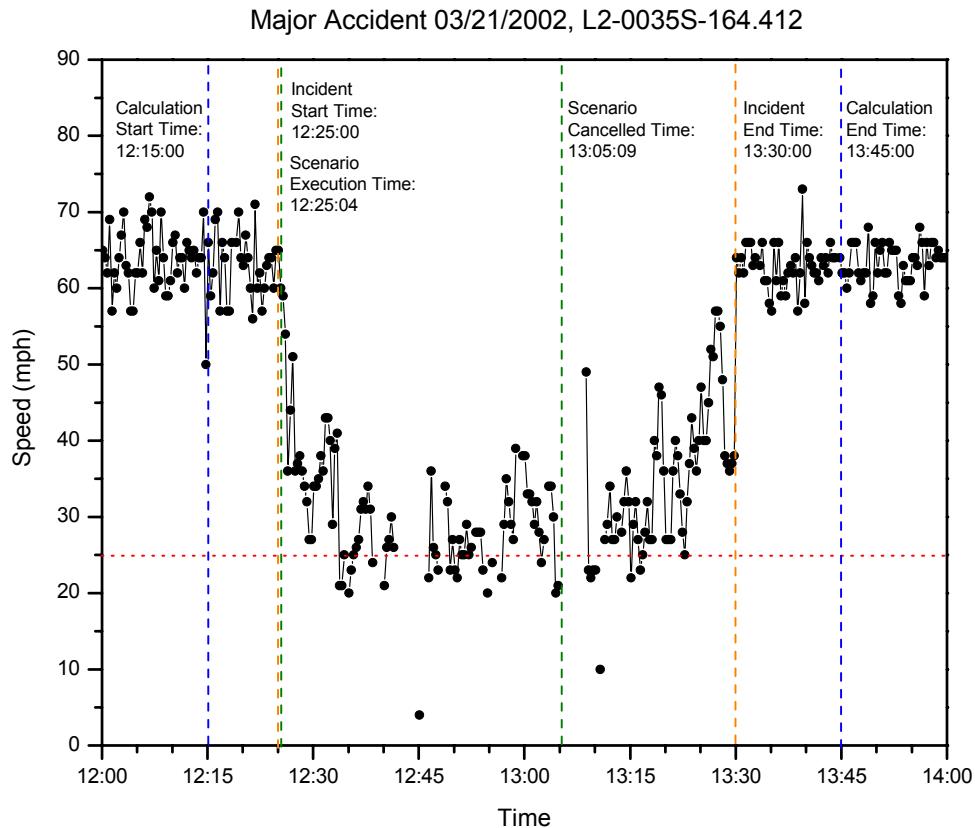
- For each detector time series, identify all gaps and apply a time imputation to each gap using a simple average value approach. The limit for time imputation was set at 10 minutes, or 30 data points, assuming 1 data point every 20 seconds.
- For gaps greater than 10 minutes, apply an arithmetic-average space imputation to each missing data point using synchronous (original) data from adjacent detectors in the same sector.
- Apply a time imputation to each remaining gap using original and/or imputed data from the previous two steps.

## INCIDENT DURATION

Strictly speaking, the equations discussed previously only apply within the period of time an incident takes place. The researchers attempted to develop a simple automated procedure to determine the start and end of incidents using archived speed data series. Efforts included comparing speed data against pre-established thresholds, speed data series smoothing, and speed

data first derivative smoothing. In part because these efforts were largely unsuccessful and because the second phase of the research will focus on the incident detection algorithm at TransGuide, the researchers decided to inspect incident speed profiles manually and visually confirm the start and end of incidents. The researchers also attempted to use the time stamps included in the incident archive (both event tables and scenario tables). However, these time stamps reflect the system reaction/response to the incident, not necessarily when the incident actually started or ended. Furthermore, these tables frequently lack critical time stamp values. For example, the scenario database frequently lacks the scenario cancellation time.

[Figure 40](#) shows the various time stamps used for the analysis. Incident start time (IST) is the time an incident started (actually the time the detector “feels” the impact of the incident), normally marked by a sharp reduction in speed. Incident end time (IET) is the time when speed becomes normal again. Scenario execution time (SET) is the time the operator displays DMS and/or LCS messages in response to the incident. Scenario cancelled time (SCT) is the time the operator cancels the scenario. [Figure 40](#) also includes a calculation start time (CST) and a calculation end time (CET), which are time stamps that mark the beginning and end of the calculations. However, it may be worth noting that incident delay values only apply between IST and IET. Also worth noting in [Figure 40](#) is the absence of additional time stamps that TMCs frequently collect and sometimes archive, such as when an incident was confirmed, moved to the shoulder, or cleared. Adding those time stamps to the analysis would be straightforward.



**Figure 40. Incident Time Stamps.**

## CASE STUDIES

The researchers applied the incident delay methodology outlined in the previous section to two sample case studies.

### Sample Incident No. 1

A major accident occurred on eastbound IH-10 south of downtown San Antonio on March 8, 2002, around 3:45 PM ([Figure 41](#)). According to the scenario database, there was a major accident on eastbound IH-10 past Probandt Street (sector SECT-0010E-573.654) on the left shoulder of the highway. The operator executed a “Major Accident” scenario from 3:49:19 PM to 3:50:22 PM. The operator also executed a second scenario of the type “Congestion” for the same sector from 4:07:38 PM to 4:10:07 PM. From a visual inspection of the speed profiles ([Figure 42](#)), the researchers concluded the congestion that occurred after the operator canceled the first scenario was still part of the same incident, and therefore decided to treat both scenarios as one.



**Figure 41. Sample Incident 1 Detector and Sector Locations.**

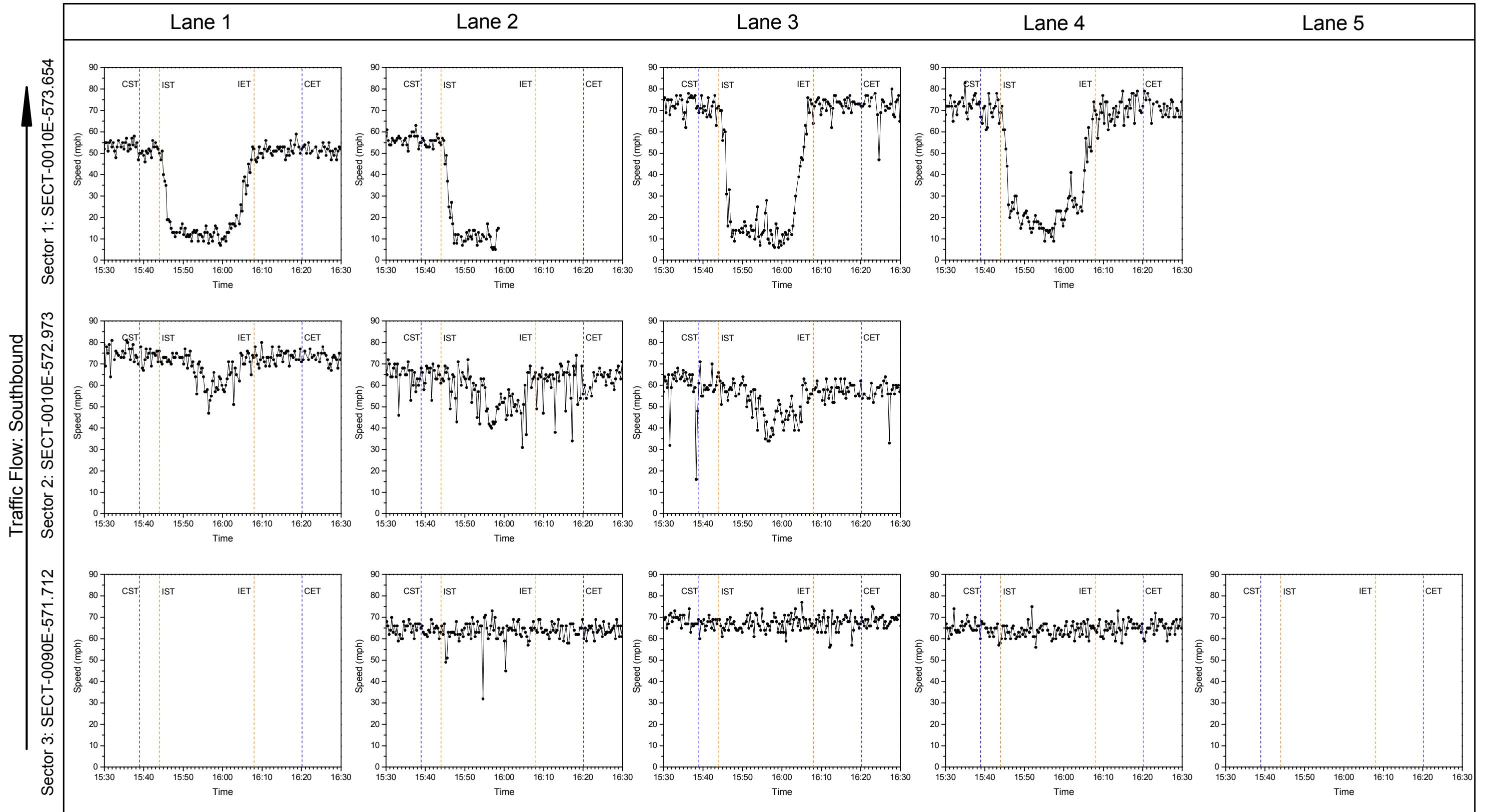
[Table 31](#) summarizes basic characteristics of the sectors and detector units involved. Notice the table includes two columns for sector length. The first column (Address Difference) results from subtracting the mile marker values included in the sector addresses. The second column (Measured) results from reading the sector length directly from the geodatabase. The researchers used this length for the delay calculations. [Figure 42](#) shows the speed profiles recorded by the detector units the day of the incident. [Figure 43](#) to [Figure 45](#) show speed profiles for the same locations using data from three archived weekdays.

**Table 31. Length and Number of Lanes per Sector for Sample Incident 1 Calculations.**

Sector		Sector Length		Detector Units
Number	Address	Address Difference (miles)	Measured (miles)	
Downstream Sector	SECT-0010E-574.117			L1-0010E-574.117 L2-0010E-574.117 L3-0010E-574.117 L4-0010E-574.117
Sector 1	SECT-0010E-573.654	0.463	0.396	L1-0010E-574.623 L2-0010E-574.623 L3-0010E-574.623 L4-0010E-574.623
Sector 2	SECT-0010E-572.973	0.681	0.643	L1-0010E-572.973 L2-0010E-572.973 L3-0010E-572.973
Sector 3	SECT-0090E-571.712	1.261	0.822	L1-0090E-571.712 L2-0090E-571.712 L3-0090E-571.712 L4-0090E-571.712 L5-0090E-571.712
<b>Total</b>		<b>2.405</b>	<b>1.861</b>	

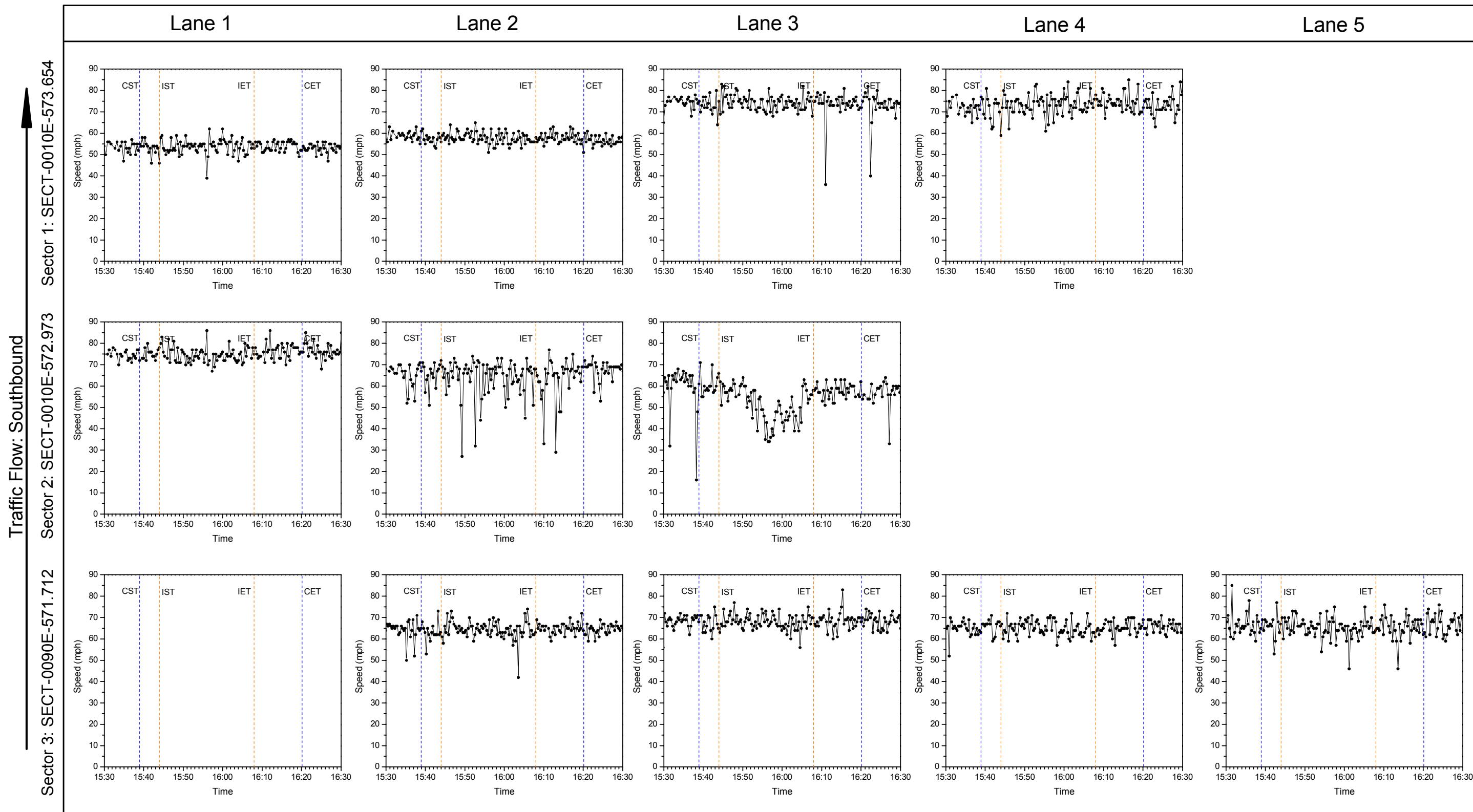
The calculations used the following time stamps: 3:39:00 PM (CST), 3:44:00 PM (IST), 4:08:00 PM (IET), and 4:20:00 PM (CET). The total incident duration, from IST to IET, was 24 minutes. [Table 32](#) shows the result of the delay calculation using disaggregate lane-by-lane data—i.e., using [Equation \(6\)](#)—without data imputation. For comparison, [Table 33](#) shows the result of the delay calculation using disaggregate lane-by-lane data with data imputation. [Table 34](#) shows the result of the delay calculation using aggregate sector data—i.e., using [Equation \(9\)](#)—without data imputation. [Table 35](#) shows the total delay in vehicle-hours calculated using sector data with data imputation.

In these tables, total delay is the delay experienced by all vehicles on all sectors for the duration of the incident according to [Equation \(6\)](#) (when using disaggregate lane-by-lane data) or [Equation \(9\)](#) (when using sector data). “Negative delay” is a quality control indicator to keep track of situations when individual incident speed values are higher than the corresponding reference speed value. Total delay does not include “negative delay,” i.e., total delay only applies whenever incident speeds are lower than the corresponding reference speed. Number of vehicles is the total number of vehicles traversing a lane or a sector during the incident. Vehicle delay is the lane or sector delay in seconds divided by the number of vehicles that traverse that lane or sector. Imputed data are the percentage of imputed speed and volume data for each lane or sector with respect to the total number of values in a complete data set.



**Figure 42. Speed Time Series by Sector and Lane for March 8, 2002 (Day of Incident).**





**Figure 43. Speed Time Series by Sector and Lane for March 1, 2002.**



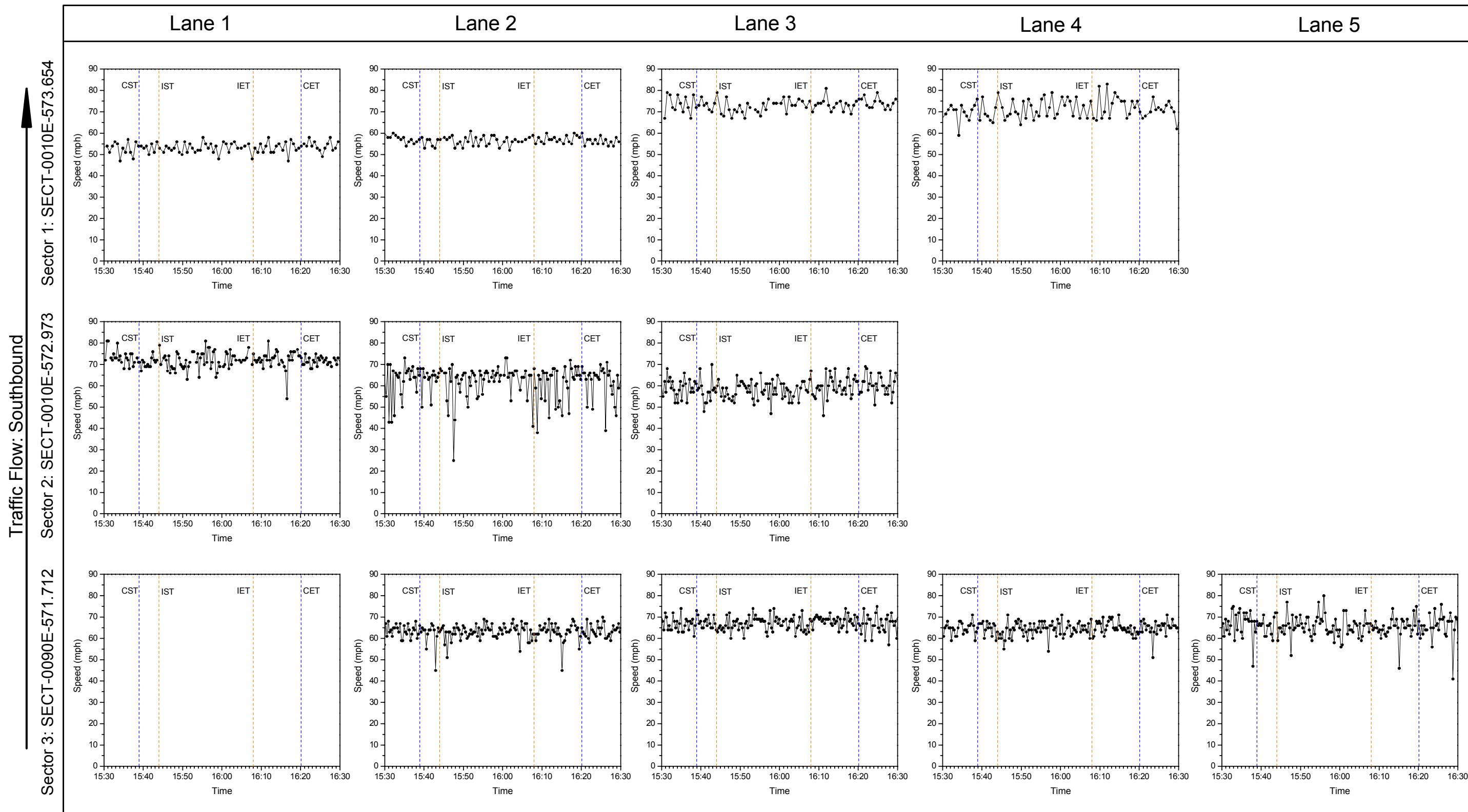
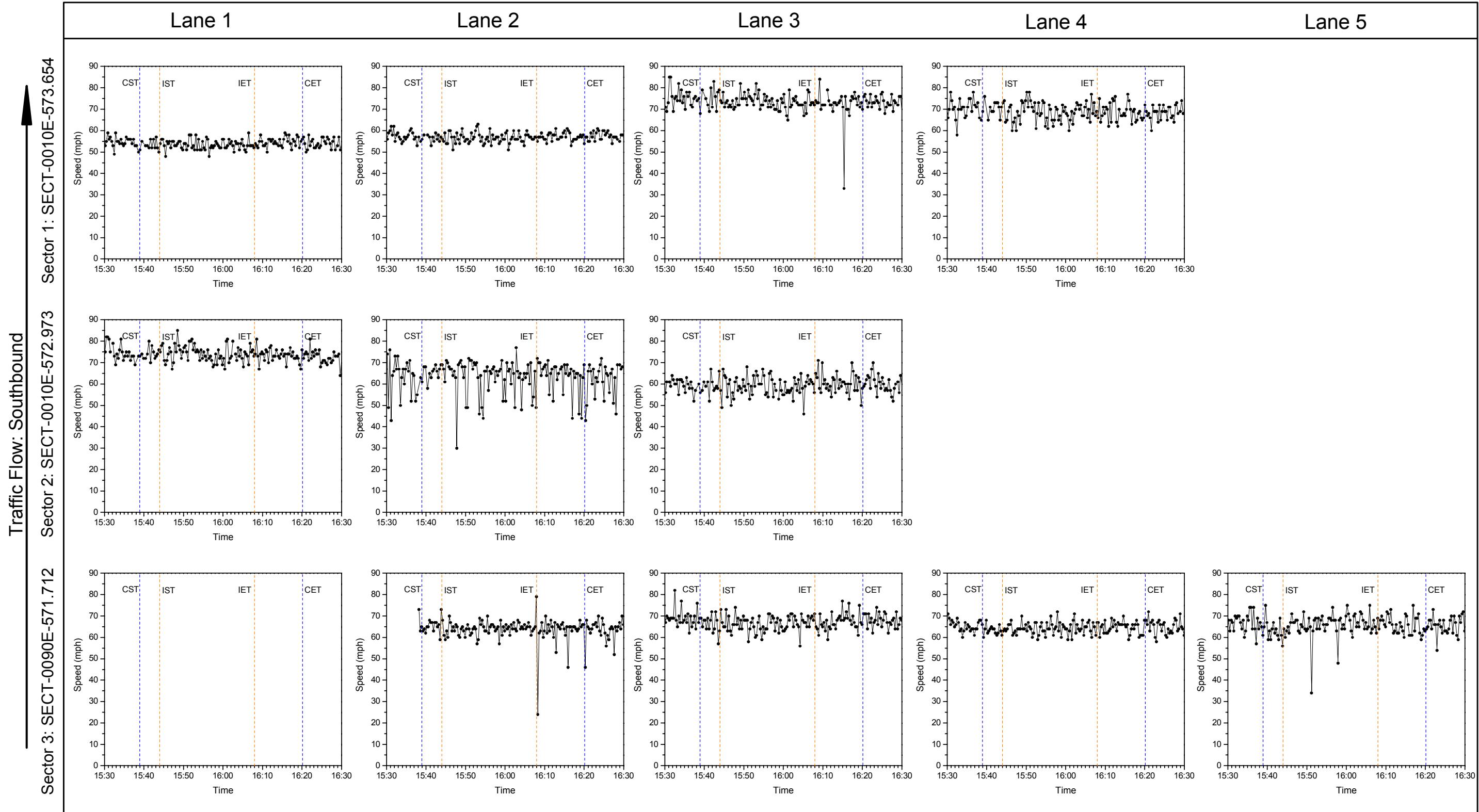


Figure 44. Speed Time Series by Sector and Lane for March 15, 2002.





**Figure 45. Speed Time Series by Sector and Lane for March 22, 2002.**



**Table 32. Incident Delay Using Disaggregate Lane-by-Lane Data without Data Imputation.**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)
Sector 1	Lane 1	9.48	29%	0.00	518	66 *
	Lane 2	5.50	17%	0.00	227	87
	Lane 3	7.14	22%	0.00	339	76
	Lane 4	6.72	21%	0.00	535	45
	<b>Subtotal</b>	<b>28.83</b>	<b>91%</b>	<b>0.00</b>	<b>1,619</b>	<b>64</b>
Sector 2	Lane 1	0.40	1%	0.01	342	4
	Lane 2	0.97	3%	0.18	568	6
	Lane 3	0.76	2%	0.04	377	7
	<b>Subtotal</b>	<b>2.12</b>	<b>7%</b>	<b>0.23</b>	<b>1,287</b>	<b>6</b>
Sector 3	Lane 1	0.00	0%	0.00	0	-
	Lane 2	0.24	1%	0.13	421	2
	Lane 3	0.11	0%	0.10	466	1
	Lane 4	0.20	1%	0.11	605	1
	Lane 5	0.00	0%	0.00	0	-
	<b>Subtotal</b>	<b>0.56</b>	<b>2%</b>	<b>0.33</b>	<b>1,492</b>	<b>1</b>
<b>Total</b>		<b>31.51</b>	<b>100%</b>	<b>0.57</b>		

\* Obtained by dividing delay per sector in seconds by number of vehicles per sector.

**Table 33. Incident Delay Using Disaggregate Lane-by-Lane Data with Data Imputation.**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)	Imputed Data (%)
Sector 1	Lane 1	10.08	27%	0.00	544	67	2.8% *
	Lane 2	8.52	23%	0.10	448	68	41.5%
	Lane 3	7.72	21%	0.00	424	66	4.2%
	Lane 4	7.06	19%	0.00	557	46	2.8%
	<b>Subtotal</b>	<b>33.39</b>	<b>92%</b>	<b>0.01</b>	<b>1,973</b>	<b>61</b>	<b>12.9%</b>
Sector 2	Lane 1	0.40	1%	0.01	353	4	2.8%
	Lane 2	0.97	3%	0.22	594	6	2.8%
	Lane 3	0.76	2%	0.04	393	7	2.8%
	<b>Subtotal</b>	<b>2.13</b>	<b>6%</b>	<b>0.27</b>	<b>1,340</b>	<b>6</b>	<b>2.8%</b>
Sector 3	Lane 1	0.14	0%	0.08	497	1	100.0%
	Lane 2	0.24	1%	0.13	421	2	0.0%
	Lane 3	0.11	0%	0.10	466	1	0.0%
	Lane 4	0.20	1%	0.11	605	1	0.0%
	Lane 5	0.15	0%	0.07	497	1	100.0%
	<b>Subtotal</b>	<b>0.85</b>	<b>2%</b>	<b>0.48</b>	<b>2,486</b>	<b>1</b>	<b>40.0%</b>
<b>Total</b>		<b>36.37</b>	<b>100%</b>	<b>0.77</b>			

\* Obtained by dividing number of imputed values per sector by sum of imputed plus recorded values per sector.

**Table 34. Incident Delay Using Sector Data *without* Data Imputation.**

Sector	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)
Sector 1	28.53	92%	0.00	1,679	61
Sector 2	2.00	6%	0.16	1,287	6
Sector 3	0.47	2%	0.24	1,492	1
<b>Total</b>	<b>30.99</b>	<b>100%</b>	<b>0.40</b>		

**Table 35. Incident Delay Using Sector Data *with* Data Imputation.**

Sector	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)	Imputed Data (%)
Sector 1	33.11	92%	0.01	1,973	60	10.3%
Sector 2	2.00	6%	0.20	1,340	5	2.8%
Sector 3	0.78	2%	0.41	2,487	1	40.0%
<b>Total</b>	<b>35.88</b>	<b>100%</b>	<b>0.61</b>			

An analysis of the results yields the following observations:

- The total delay using disaggregate lane-by-lane data without data imputation was about 32 vehicle-hours. With data imputation, this total increased to 36 vehicle-hours. A significant portion of the data was missing in lane 2 of sector 1 (42 percent). Imputation of the data from this lane had a major effect on the overall increase in incident delay.
- The total delay using sector data without data imputation was about 31 vehicle-hours, which is very similar to the 32 vehicle-hours experienced using disaggregate lane-by-lane data without imputation. Similarly, the total delay using sector data with data imputation was 36 vehicle-hours, which is practically the same as the delay experienced using disaggregate lane-by-lane data with data imputation. Overall, these results are not surprising since the sector data used for the analysis came from aggregating lane-by-lane data. More significant is that, regardless of whether the analysis used lane-by-lane data or sector data, imputation had a major effect on the calculation of delay.
- There was variation in the amount of delay experienced by each lane. In sector 1, lane 1 experienced 29 percent of the sector delay as compared to lane 4, which experienced only 21 percent. These results are consistent with the scenario database description of a major accident on the left shoulder. The low percentage for lane 2, 17 percent, is the result of missing data. Notice this value increased to 23 percent after data imputation.
- Some 29 vehicle-hours (or 92 percent) of the delay happened on sector 1, where the incident occurred, 6 percent happened on sector 2, and 2 percent happened on sector 3. The low delay value on sector 3 is a clear indication that the upstream end of the incident-related congestion happened just upstream of sector 3.
- Imputation increased the amount of data in sector 3 by 40 percent, which in turn increased the sector delay for that sector by 66 percent. However, this had a minor effect on the total delay because the delay in sector 3 was very small (0.47 vehicle-hours before data imputation).
- On average, there was a delay of about 60 seconds/vehicle on sector 1, 5 seconds/vehicle on sector 2, and 1 second/vehicle on sector 3.

- A preliminary estimate suggests the economic cost associated with this accident-related vehicle delay was about \$780. This value results from assuming a unit economic cost of \$21.36 per hour per vehicle (which results from assuming \$14.72 per hour per person per passenger car, 1.25 passengers per car, \$77.74 per hour per commercial vehicle, and 5 percent commercial vehicles, adjusted using the September 2004 Consumer Price Index) (35, 46, 47).

As mentioned previously, the calculations assumed the incident started at 3:44:00 PM and ended at 4:08:00 PM, for a total incident duration of 24 minutes. The results in [Table 32](#) to [Table 35](#) are consistent with this assumption. It follows that if the analysis uses different incident start and end times, there should be an impact in the amount of calculated delay. In the absence of a full-fledged sensitivity analysis, this section includes one additional calculation to illustrate the concept. For simplicity, this additional calculation assumes CST = IST = 3:39:00 PM and IET = CET = 4:20:00 PM. [Table 36](#) shows the result of the delay calculation using disaggregate lane-by-lane data without data imputation. [Table 37](#) shows the result of the delay calculation using disaggregate lane-by-lane data with data imputation. [Table 38](#) shows the result of the delay calculation using aggregate sector data without data imputation. [Table 39](#) shows the total delay in vehicle-hours calculated using sector data with data imputation.

A comparison between these results and those obtained previously yields the following observations:

- The total delay using disaggregate lane-by-lane data without data imputation was about 33 vehicle-hours. With data imputation, this total increased to 37 vehicle-hours. The corresponding delay values using sector data were 32 and 37 vehicle-hours, respectively. These values are very similar to the values obtained when using an incident duration of 24 minutes, clearly indicating that increasing IST and IET beyond the points where the incident actually started or ended has a relatively minor impact on the amount of total incident delay.
- Assuming data imputation, there was an average delay of about 36 seconds/vehicle on sector 1, 4 seconds/vehicle on sector 2, and 1 second/vehicle on sector 3. In the case of sector 1, the delay of 36 seconds/vehicle was 60 percent lower than the corresponding delay when using an incident duration of 24 minutes, clearly indicating that increasing IST and IET beyond the points where the incident actually started or ended had a significant impact on the calculation of delay per vehicle. This is reasonable since extending the IST and IET limits would include vehicles in the calculation that did not really feel the impact of the incident, therefore lowering the average delay per vehicle rate.

**Table 36. Incident Delay Using Disaggregate Lane-by-Lane Data *without* Data Imputation  
(Assuming Incident Duration = 41 minutes).**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)
Sector 1	Lane 1	9.64	30%	0.01	936	37
	Lane 2	5.58	17%	0.00	350	57
	Lane 3	7.17	22%	0.03	670	39
	Lane 4	6.81	21%	0.05	885	28
	<b>Subtotal</b>	<b>29.20</b>	<b>90%</b>	<b>0.09</b>	<b>2,841</b>	<b>37</b>
Sector 2	Lane 1	0.44	1%	0.03	554	3
	Lane 2	1.25	4%	0.39	956	5
	Lane 3	0.84	3%	0.09	618	5
	<b>Subtotal</b>	<b>2.53</b>	<b>8%</b>	<b>0.52</b>	<b>2,128</b>	<b>4</b>
Sector 3	Lane 1	0.00	0%	0.00	0	-
	Lane 2	0.30	1%	0.06	744	1
	Lane 3	0.20	1%	0.05	758	1
	Lane 4	0.33	1%	0.14	1,022	1
	Lane 5	0.00	0%	0.00	0	-
	<b>Subtotal</b>	<b>0.83</b>	<b>3%</b>	<b>0.58</b>	<b>2,524</b>	<b>1</b>
<b>Total</b>		<b>32.56</b>	<b>100%</b>	<b>1.19</b>		

**Table 37. Incident Delay Using Disaggregate Lane-by-Lane Data *with* Data Imputation  
(Assuming Incident Duration = 41 minutes).**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)	Imputed Data (%)
Sector 1	Lane 1	10.24	27%	0.01	962	38	1.7%
	Lane 2	8.55	23%	0.16	814	38	52.9%
	Lane 3	7.75	21%	0.03	695	40	2.5%
	Lane 4	7.15	19%	0.05	907	28	1.7%
	<b>Subtotal</b>	<b>33.70</b>	<b>90%</b>	<b>0.24</b>	<b>3,378</b>	<b>36</b>	<b>14.7%</b>
Sector 2	Lane 1	0.44	1%	0.03	565	3	1.7%
	Lane 2	1.24	3%	0.44	982	5	1.7%
	Lane 3	0.84	2%	0.09	639	5	2.5%
	<b>Subtotal</b>	<b>2.53</b>	<b>7%</b>	<b>0.56</b>	<b>2,186</b>	<b>4</b>	<b>1.9%</b>
Sector 3	Lane 1	0.20	1%	0.12	841	1	100.0%
	Lane 2	0.30	1%	0.24	744	1	0.0%
	Lane 3	0.20	1%	0.16	758	1	0.0%
	Lane 4	0.33	1%	0.19	1,022	1	0.0%
	Lane 5	0.20	1%	0.13	841	1	100.0%
	<b>Subtotal</b>	<b>1.23</b>	<b>3%</b>	<b>0.84</b>	<b>4,206</b>	<b>1</b>	<b>40.0%</b>
<b>Total</b>		<b>37.46</b>	<b>100%</b>	<b>1.64</b>			

**Table 38. Incident Delay Using Sector Data *without* Data Imputation (Assuming Incident Duration = 41 minutes).**

Sector	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)
Sector 1	28.73	91%	0.12	2,841	36
Sector 2	2.35	7%	0.44	2,128	4
Sector 3	0.66	2%	0.40	2,524	1
<b>Total</b>	<b>31.73</b>	<b>100%</b>	<b>0.95</b>		

**Table 39. Incident Delay Using Sector Data *with* Data Imputation (Assuming Incident Duration = 41 minutes).**

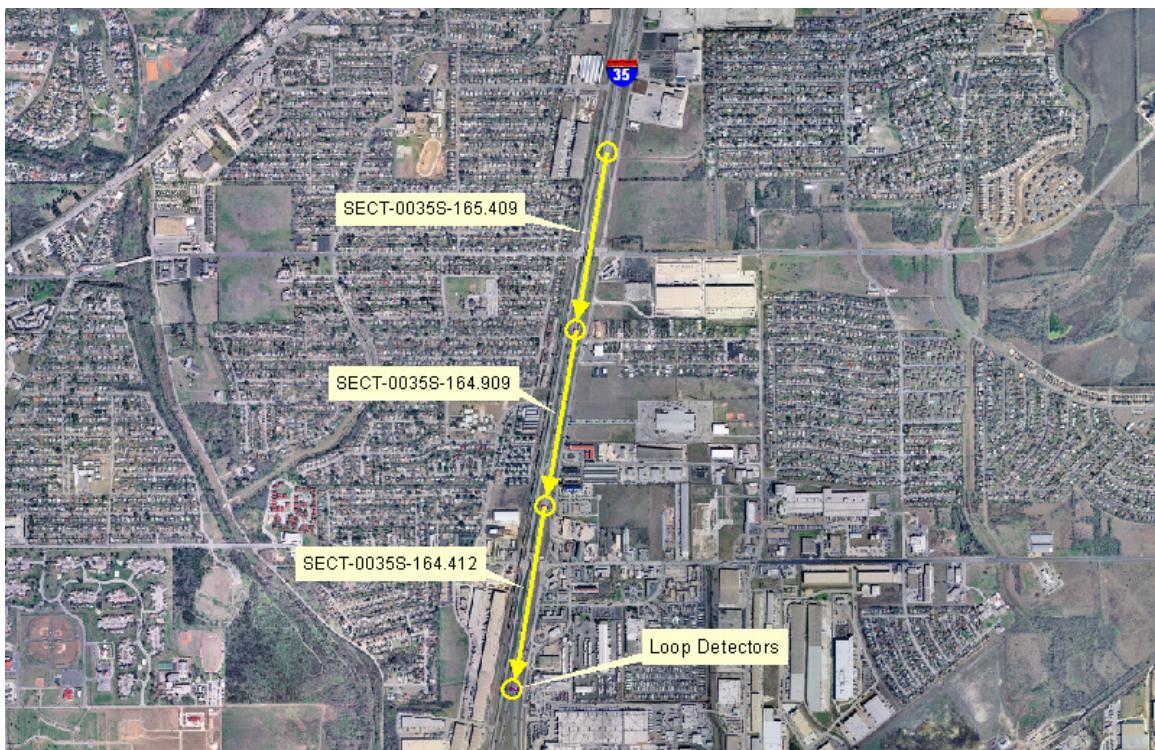
Sector	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)	Imputed Data (%)
Sector 1	33.31	91%	0.18	3,378	36	10.3%
Sector 2	2.35	6%	0.48	2,186	4	0.3%
Sector 3	1.08	3%	0.68	4,207	1	40.0%
<b>Total</b>	<b>36.75</b>	<b>100%</b>	<b>1.33</b>			

## Sample Incident No. 2

A major accident occurred on southbound IH-35 on the northeast part of town on March 21, 2002, around 12:25 PM ([Figure 46](#)). According to the scenario database, there was a major accident on the right shoulder of southbound IH-35 (sector SECT-0035S-164.412). The operator executed a “Major Accident” scenario from 12:25:01 PM to 1:05:09 PM, which included messages on changeable message signs CMS3-0035S-164.189, CMS3-0035S-164.994, and CMS3-0035S-165.938, warning motorists about the accident on the freeway.

[Table 40](#) summarizes basic characteristics of the sectors and detector units involved. As in the previous incident analyzed, Table 40 includes two columns for sector length. The researchers used the second column (Measured), which resulted from reading the sector length directly on the geodatabase. [Figure 47](#) shows the speed profiles recorded by the detector units the day of the incident. [Figure 48](#) to [Figure 50](#) show speed profiles for the same locations using data from three archived weekdays.

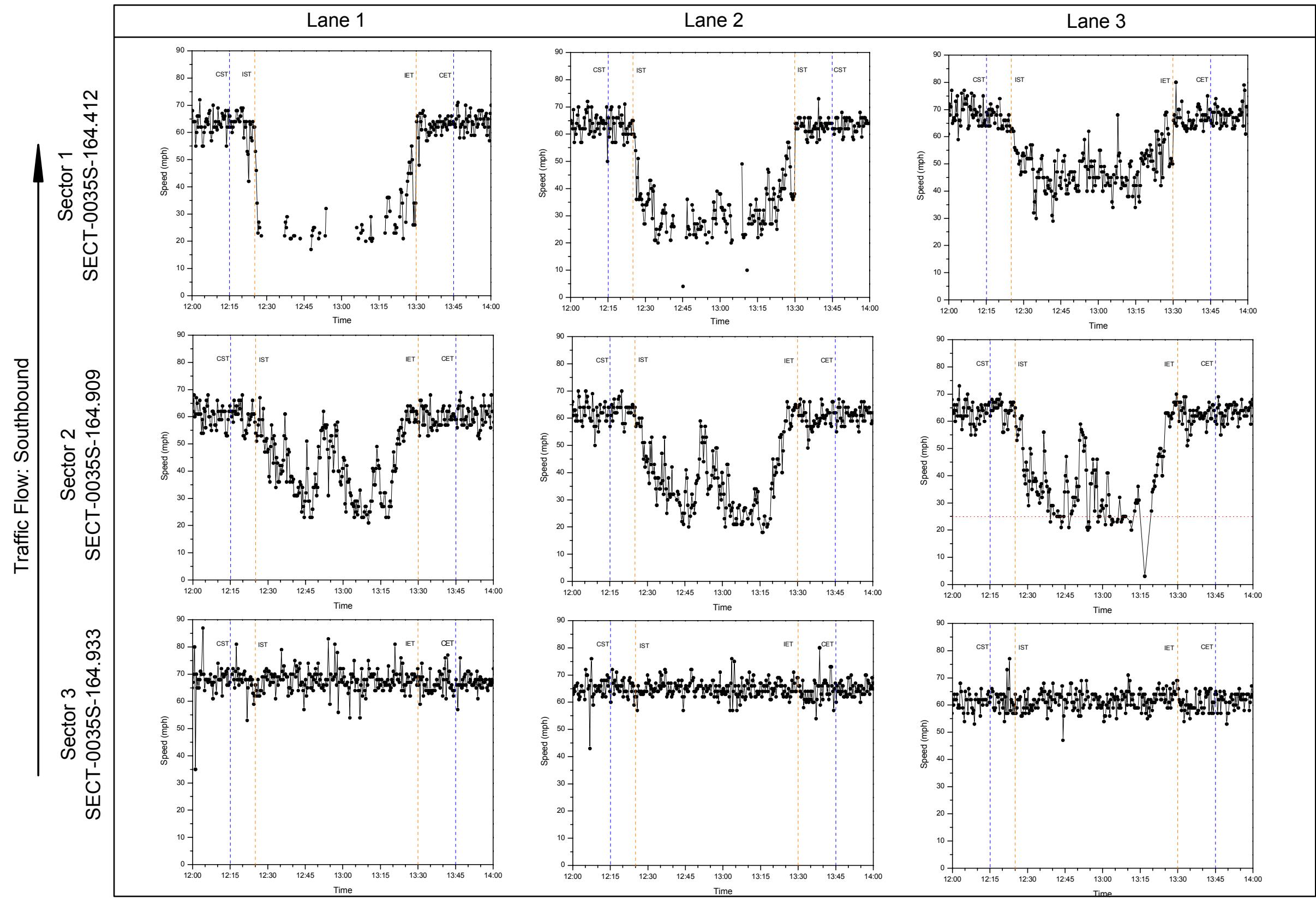
The calculations used the following time stamps: 12:15:00 PM (CST), 12:25:00 PM (IST), 1:30:00 PM (IET), and 1:45:00 PM (CET). The total incident duration, from IST to IET, was 65 minutes. [Table 41](#) shows the result of the delay calculation using disaggregate lane-by-lane data—i.e., using [Equation \(6\)](#)—without data imputation. For comparison, [Table 42](#) shows the result of the delay calculation using disaggregate lane-by-lane data with data imputation. [Table 43](#) shows the result of the delay calculation using aggregate sector data—i.e., using [Equation \(9\)](#)—without data imputation. [Table 44](#) shows the total delay in vehicle-hours calculated using sector data with data imputation.



**Figure 46. Sample Incident 2 Detector and Sector Locations.**

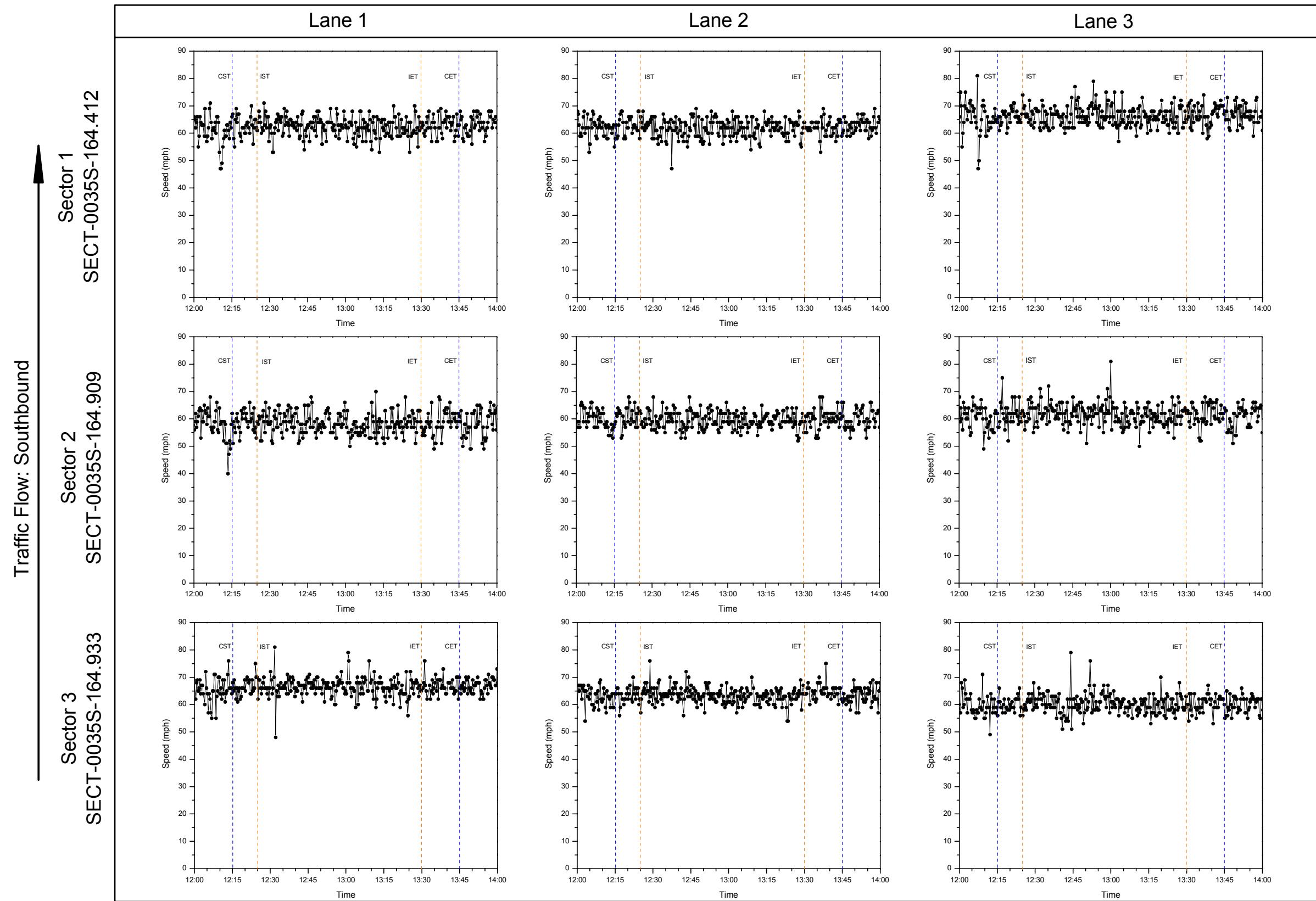
**Table 40. Length and Number of Lanes per Sector for Sample Incident 2.**

Sector		Sector Length		Detector Units
Number	Address	Address Difference (miles)	Measured (miles)	
Downstream Sector	SECT-0035S-163.893			L1-0035S-163.893 L2-0035S-163.893 L3-0035S-163.893
Sector 1	SECT-0035S-164.412	0.519	0.511	L1-0035S-164.412 L2-0035S-164.412 L3-0035S-164.412
Sector 2	SECT-0035S-164.909	0.497	0.502	L1-0035S-164.909 L2-0035S-164.909 L3-0035S-164.909
Sector 3	SECT-0035S-165.409	0.500	0.523	L1-0035S-165.409 L2-0035S-165.409 L3-0035S-165.409
<b>Total</b>		<b>1.516</b>	<b>1.536</b>	



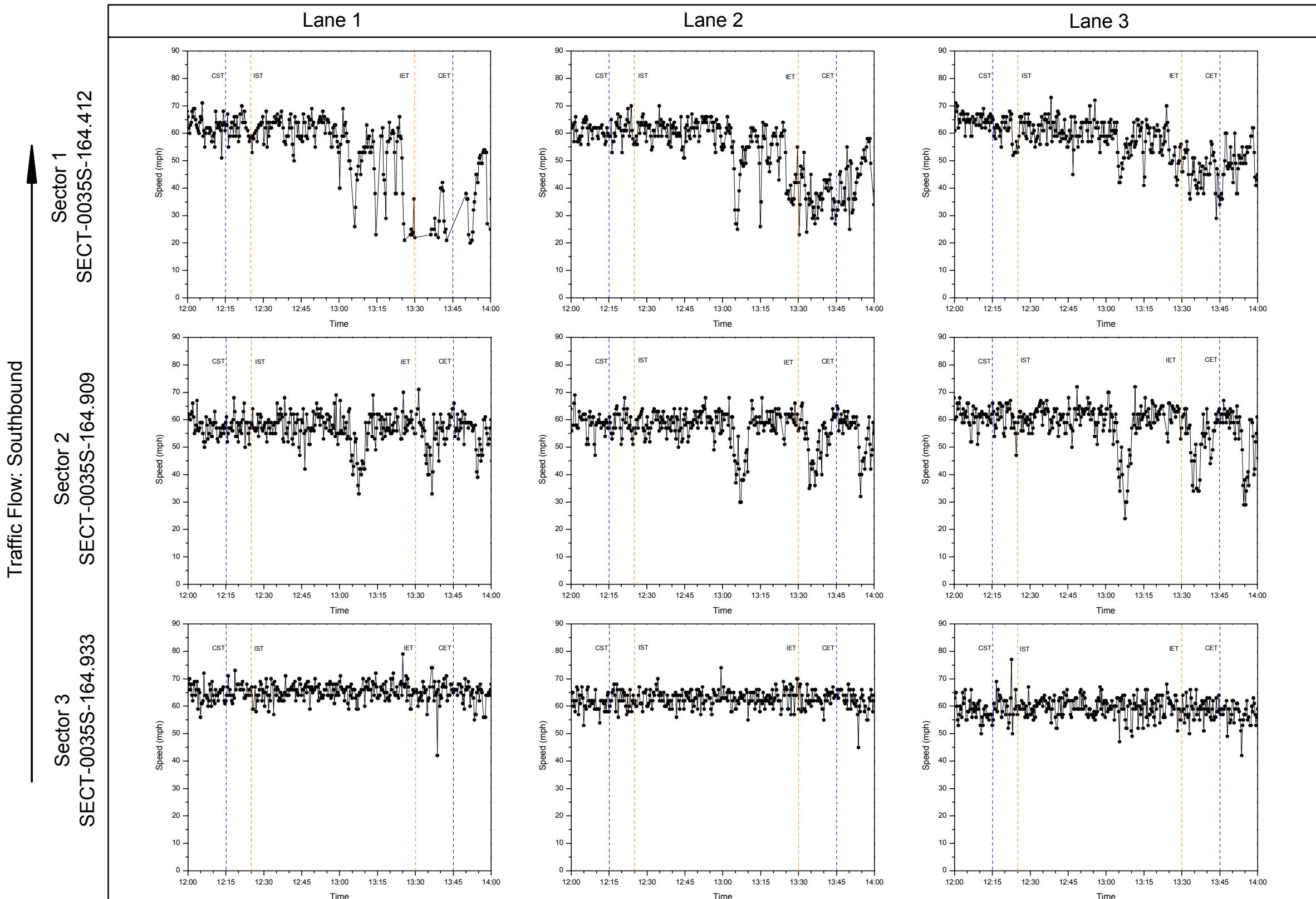
**Figure 47. Speed Time Series by Sector and Lane for March 21, 2002 (Day of Incident).**





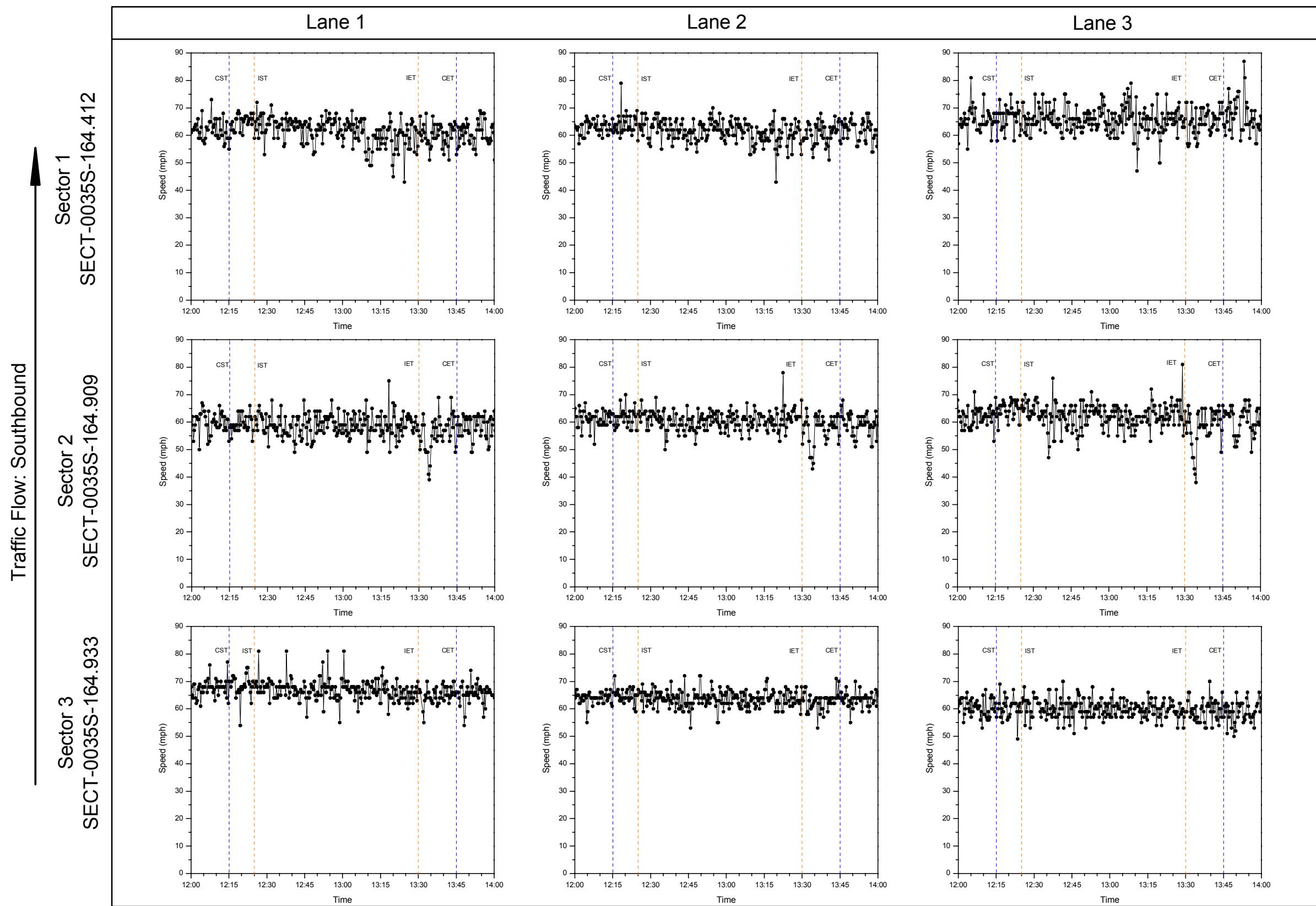
**Figure 48. Speed Time Series by Sector and Lane for March 7, 2002.**





**Figure 49. Speed Time Series by Sector and Lane for March 14, 2002.**





**Figure 50. Speed Time Series by Sector and Lane for March 28, 2002.**



**Table 41. Incident Delay Using Disaggregate Lane-by-Lane Data *without* Data Imputation.**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)
Sector 1	Lane 1	5.88	14%	0.00	554	38
	Lane 2	11.27	26%	0.00	1,140	36
	Lane 3	4.34	10%	0.01	1,400	11
	<b>Subtotal</b>	<b>21.49</b>	<b>50%</b>	<b>0.01</b>	<b>3,094</b>	<b>25</b>
Sector 2	Lane 1	4.08	10%	0.05	1,061	14
	Lane 2	7.95	19%	0.04	1,266	23
	Lane 3	8.92	21%	0.03	1,135	28
	<b>Subtotal</b>	<b>20.95</b>	<b>49%</b>	<b>0.11</b>	<b>3,462</b>	<b>22</b>
Sector 3	Lane 1	0.16	0%	0.43	1,530	0
	Lane 2	0.07	0%	0.35	1,256	0
	Lane 3	0.13	0%	0.46	1,258	0
	<b>Subtotal</b>	<b>0.36</b>	<b>1%</b>	<b>1.24</b>	<b>4,044</b>	<b>0</b>
<b>Total</b>		<b>42.79</b>	<b>100%</b>	<b>2.71</b>		

**Table 42. Incident Delay Using Disaggregate Lane-by-Lane Data *with* Data Imputation.**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)	Imputed Data (%)
Sector 1	Lane 1	19.28	27%	0.00	1,569	44	66.7%
	Lane 2	17.05	24%	0.00	1,502	41	22.1%
	Lane 3	4.49	6%	0.01	1,445	11	3.1%
	<b>Subtotal</b>	<b>40.82</b>	<b>57%</b>	<b>0.01</b>	<b>4,516</b>	<b>33</b>	<b>30.6%</b>
Sector 2	Lane 1	6.89	10%	0.05	1,423	17	14.4%
	Lane 2	9.83	14%	0.04	1,422	25	10.3%
	Lane 3	13.78	19%	0.03	1,425	35	19.0%
	<b>Subtotal</b>	<b>30.50</b>	<b>43%</b>	<b>0.11</b>	<b>4,270</b>	<b>26</b>	<b>14.5%</b>
Sector 3	Lane 1	0.16	0%	0.45	1,766	0	3.6%
	Lane 2	0.07	0%	0.36	1,292	0	3.1%
	Lane 3	0.13	0%	0.46	1,295	0	3.1%
	<b>Subtotal</b>	<b>0.36</b>	<b>0%</b>	<b>1.26</b>	<b>4,353</b>	<b>0</b>	<b>3.2%</b>
<b>Total</b>		<b>71.67</b>	<b>100%</b>	<b>2.07</b>			

**Table 43. Incident Delay Using Sector Data *without* Data Imputation.**

Sector	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)
Sector 1	21.27	50%	0.00	3,094	25
Sector 2	21.23	50%	0.08	3,462	22
Sector 3	0.22	1%	1.09	4,044	0
<b>Total</b>	<b>42.72</b>	<b>100%</b>	<b>1.17</b>		

**Table 44. Incident Delay Using Sector Data with Data Imputation.**

Sector	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)	Imputed Data
Sector 1	40.80	57%	0.00	4,515	33	30.6%
Sector 2	30.93	43%	0.08	4,148	27	14.5%
Sector 3	0.22	0%	1.14	4,170	0	3.2%
<b>Total</b>	<b>71.95</b>	<b>100%</b>	<b>1.22</b>			

An analysis of the results yields the following observations:

- The total delay using disaggregate lane-by-lane data without data imputation was about 43 vehicle-hours. With data imputation, this total increased to 72 vehicle-hours. A significant portion of the data was missing in lanes 1 and lane 2 of sector 1 (67 and 22 percent, respectively). Imputation of the data from these lanes had a major effect on the overall increase in incident delay.
- The total delay using sector data without data imputation was about 43 vehicle-hours, which is the same as the 43 vehicle-hours experienced using disaggregate lane-by-lane data without imputation. Similarly, the total delay using sector data with data imputation was 72 vehicle-hours, which is the same as the 72 vehicle-hours experienced using disaggregate lane-by-lane data with data imputation.
- There was variation in the amount of delay experienced by each lane. For example, in sector 1, lane 1 experienced 27 percent of the sector delay as compared to lane 3, which experienced only 6 percent. The difference in delay was a result of the high speed differential between lanes: for the duration of the incident, the harmonic mean speeds in lane 1 and 2 were 25 and 27 mph, respectively, as compared to 47 mph in lane 3. These results were surprising, considering the major accident was on the right shoulder. It is possible that some traffic moved over to the middle or left lanes well before the accident location because of an LCS displaying a red “x” or “lane closed” symbol, which could explain the relatively low amount of delay in lane 3. However, the number of vehicles that traversed lane 3 during the 65 minutes of the incident (1,455) was still substantial.
- Using imputed data, some 41 vehicle-hours (or 57 percent) of the delay happened on sector 1, where the incident occurred, 43 percent happened on sector 2, and <1 percent happened on sector 3. The low delay value on sector 3 is an indication that the upstream end of the incident-related congestion happened on sector 3.
- Using imputed data, there was a delay of about 33 seconds/vehicle on sector 1, 27 seconds/vehicle on sector 2, and less than 1 second/vehicle on sector 3.
- A preliminary estimate suggests the economic cost associated with the accident-related vehicle delay was about \$1,540. This value results from assuming a unit economic cost of \$21.36 per hour per vehicle, as described previously. Assuming for simplicity an economic cost of \$1,160, which is the average of the economic cost for sample incidents 1 and 2, and about 6,000 major and minor accidents that occur on TransGuide’s instrumented freeways on an annual basis, the economic impact of the vehicle delay resulting from accidents would be about \$7M per year.

As mentioned previously, the calculations assumed the incident started at 12:25:00 PM and ended at 1:30:00 PM, for a total duration of 65 minutes. The results in [Table 41](#) to [Table 44](#) are

consistent with this assumption. For completeness, the researchers completed an additional calculation assuming CST = IST = 12:15:00 PM and IET = CET = 1:45:00 PM to measure the impact of extending the IST and IET limits. [Table 45](#) shows the result of the delay calculation using disaggregate lane-by-lane data without data imputation. [Table 46](#) shows the result of the delay calculation using disaggregate lane-by-lane data with data imputation. [Table 47](#) shows the result of the delay calculation using aggregate sector data without data imputation. [Table 48](#) shows the total delay in vehicle-hours calculated using sector data with data imputation.

**Table 45. Incident Delay Using Disaggregate Lane-by-Lane Data *without* Data Imputation  
(Assuming Incident Duration = 90 minutes).**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)
Sector 1	Lane 1	6.02	14%	0.17	1,221	18
	Lane 2	11.34	26%	0.14	1,701	24
	Lane 3	4.40	22%	0.12	1,948	8
	<b>Subtotal</b>	<b>21.77</b>	<b>50%</b>	<b>0.43</b>	<b>4,870</b>	<b>16</b>
Sector 2	Lane 1	4.17	10%	0.27	1,615	9
	Lane 2	8.01	19%	0.21	1,806	16
	Lane 3	8.99	21%	0.21	1,674	19
	<b>Subtotal</b>	<b>21.17</b>	<b>49%</b>	<b>0.69</b>	<b>5,095</b>	<b>15</b>
Sector 3	Lane 1	0.24	1%	0.60	2,166	0
	Lane 2	0.12	0%	0.47	1,726	0
	Lane 3	0.19	0%	0.60	1,728	0
	<b>Subtotal</b>	<b>0.55</b>	<b>1%</b>	<b>1.67</b>	<b>5,620</b>	<b>0</b>
<b>Total</b>		<b>43.49</b>	<b>100%</b>	<b>2.79</b>		

**Table 46. Incident Delay Using Disaggregate Lane-by-Lane Data *with* Data Imputation  
(Assuming Incident Duration = 90 minutes).**

Sector	Lane	Delay (veh-h)	% of Total	Negative Delay (veh-h)	Number of Vehicles (veh)	Vehicle Delay (sec/veh)	Imputed Data (%)
Sector 1	Lane 1	19.43	27%	0.18	2,267	31	49.3%
	Lane 2	17.12	23%	0.15	2,088	30	17.0%
	Lane 3	4.55	6%	0.13	2,028	8	3.7%
	<b>Subtotal</b>	<b>41.10</b>	<b>56%</b>	<b>0.46</b>	<b>6,383</b>	<b>23</b>	<b>23.3%</b>
Sector 2	Lane 1	6.98	10%	0.27	1,985	13	10.7%
	Lane 2	9.89	14%	0.21	1,970	18	7.8%
	Lane 3	13.85	19%	0.21	1,972	25	14.1%
	<b>Subtotal</b>	<b>30.72</b>	<b>43%</b>	<b>0.70</b>	<b>5,927</b>	<b>19</b>	<b>10.9%</b>
Sector 3	Lane 1	0.24	0%	0.61	2,236	0	3.7%
	Lane 2	0.12	0%	0.48	1,770	0	2.6%
	Lane 3	0.19	0%	0.62	1,772	0	2.6%
	<b>Subtotal</b>	<b>0.55</b>	<b>1%</b>	<b>1.72</b>	<b>5,778</b>	<b>0</b>	<b>3.0%</b>
<b>Total</b>		<b>72.37</b>		<b>5.29</b>			

**Table 47. Incident Delay Using Sector Data *without* Data Imputation (Assuming Incident Duration = 90 minutes).**

	<b>Delay (veh-h)</b>	<b>% of Total</b>	<b>Negative Delay (veh-h)</b>	<b>Number of Vehicles (veh)</b>	<b>Vehicle Delay (sec/veh)</b>
Sector 1	21.47	50%	0.32	4,870	16
Sector 2	21.38	50%	0.63	5,095	15
Sector 3	0.32	1%	1.45	5,620	0
<b>Total</b>	<b>43.17</b>	<b>100%</b>	<b>2.40</b>		

**Table 48. Incident Delay Using Sector Data *with* Data Imputation (Assuming Incident Duration = 90 minutes).**

	<b>Delay (veh-h)</b>	<b>% of Total</b>	<b>Negative Delay (veh-h)</b>	<b>Number of Vehicles (veh)</b>	<b>Vehicle Delay (sec/veh)</b>	<b>Imputed Data (%)</b>
Sector 1	41.00	57%	0.36	6,383	23	23.3%
Sector 2	31.08	43%	0.64	5,926	19	10.9%
Sector 3	0.32	0%	1.50	5,777	0	3.0%
<b>Total</b>	<b>72.40</b>	<b>100%</b>	<b>2.49</b>			

A comparison between these results and those obtained previously yields the following observations:

- The total delay using disaggregate lane-by-lane data without data imputation was about 34 vehicle-hours. With data imputation, this total increased to 56 vehicle-hours. The corresponding delay using sector data was 43 and 72 vehicle-hours, respectively. These values are very similar to those assuming an incident duration of 65 minutes, clearly indicating that increasing IST and IET beyond the points where the incident actually started or ended had a relatively minor impact on the amount of total incident delay.
- Assuming data imputation, there was an average delay of about 23 seconds/vehicle on sector 1, 19 seconds/vehicle on sector 2, and <1 second/vehicle on sector 3. In the case of sector 1, the delay of 23 seconds/vehicle was 30 percent lower than the corresponding delay when using an incident duration of 60 minutes, clearly indicating that increasing IST and IET beyond the points where the incident actually started or ended had a significant impact on the calculation of delay per vehicle. This is reasonable since extending the IST and IET limits would include vehicles in the calculation that did not really feel the impact of the incident, therefore lowering the average delay/vehicle rate.

## DETECTOR DATA QUALITY CONTROL

Implicit in the application of the methodology described in previous sections is the assumption of good detector data quality control. Previous research has reported extensively on the need to implement quality control programs for ITS data (26, 27) to address critical issues such as suspicious or erroneous data, nature and extent of missing data, and accuracy and comparability of ITS data to similar data sources.

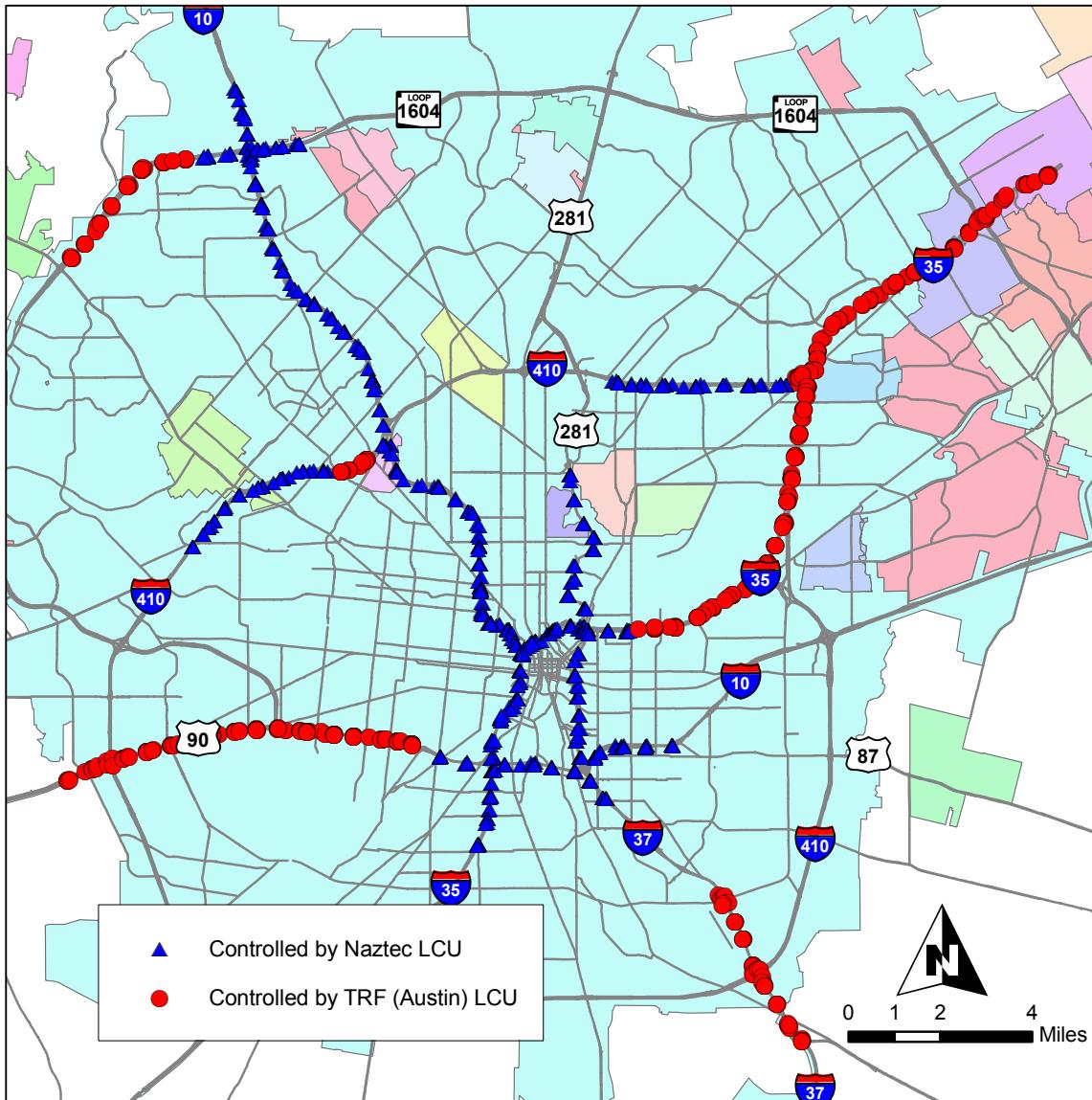
This report has touched on a number of issues related to erroneous data (e.g., incorrect scenario type characterization), missing data (in relation to the need to do data imputation), and comparability of ITS data to similar data sources (in relation to the normalization of the number of incidents using traffic volume data). Part of the effort also includes assembling quality control tests for detector data, which, for the most part, follow previous research efforts (26, 27). [Table 49](#) shows a preliminary set of quality control tests being developed. It includes first-level quality control tests, which apply to raw data files, second-level quality control tests, which could apply either to raw data file records or database table records, and third-level quality control tests, which for the most part require a previous calculation of time interval between consecutive records and are therefore more adequate for data that are already in a structured database format.

[Table 49](#) shows two types of quality control tests: “valid” record quality control tests and “abnormal” record quality control tests. “Valid” records are records with valid volume and occupancy values but invalid “by design” speed values, e.g., -1 in the case of non-speed trap detectors located on entrance and exit ramps, or zero in the case of main lane detectors when no vehicle has passed the detection zone during the detection time period. This is the case of quality control tests 2.2, 2.3, and 2.6. “Abnormal” records are records with “abnormal” combinations of speed, volume, and percent occupancy values (e.g., zero speed, zero volume, but larger than zero occupancy) that might result from causes such as faulty detectors or faulty LCU software logic. Two types of LCU and associated software are currently operational at TransGuide: Naztec LCUs and TxDOT Traffic Operations Division (TRF) LCUs (also called Austin LCUs). It is therefore of interest to determine if different types of LCU produce different quality control test results. As a reference, [Figure 51](#) shows the location of detectors controlled by Naztec LCUs and the location of detectors controlled by TRF LCUs.

Quality control test 3.1 takes into consideration basic functional relationships between flow rate, speed, and percent occupancy on the premise that such functional relationships could be used to identify potential outlier data that may be the result of equipment failure (48). While theoretically sound, however, it was not possible to calibrate the parameters of the statistical model because the model also depended on vehicle length, which currently is not part of the data collection protocol at TransGuide. Nonetheless, [Table 49](#) includes a quality control test resulting from this statistical model because other TMCs, e.g., DalTrans, do collect vehicle length data and could potentially benefit from the application of that test.

**Table 49. Draft Speed, Volume, and Occupancy Quality Control Tests.**

Quality Control Name and Description		Test	Action
<b>First-Level Tests</b>			
1.1	<b>Record format error</b> Record is in incorrect format	Record is in incorrect format	Move record to dump file
1.2	<b>Duplicate records</b>	Detector and date/time stamp are identical	Move duplicate record to dump file
<b>Second-Level Tests</b>			
2.1	<b>Extreme values</b> Unknown cause	Speed < -1 or Speed > 100 Volume < 0 or Volume > 3000 Occupancy < 0 or Occupancy > 100	Flag record
2.2	<b>Entrance or exit ramp: Valid record</b>	Speed = -1 Volume > 0 Occupancy > 0	Flag record Set Speed = <null>
2.3	<b>Entrance or exit ramp: No vehicle present</b> No vehicle passed the detection zone during the detection time period	Speed = -1 Volume = 0 Occupancy = 0	Flag record Set Speed = <null>
2.4	<b>Entrance or exit ramp: Volume is zero when occupancy is not zero</b>	Speed = -1 Volume = 0 Occupancy > 0	Flag record Set Speed = <null>
2.5	<b>Entrance or exit ramp: Occupancy is zero when volume is not zero</b>	Speed = -1 Volume > 0 Occupancy = 0	Flag record Set Speed = <null>
2.6	<b>Main lane: No vehicle present</b> No vehicle passed the detection zone during the detection time period	Speed = 0 Volume = 0 Occupancy = 0	Flag record
2.7	<b>Main lane: Speed and volume are zero when occupancy is not zero</b>	Speed = 0 Volume = 0 Occupancy > 0	Flag record
2.8	<b>Main lane: Speed and occupancy are zero when volume is not zero</b>	Speed = 0 Volume > 0 Occupancy = 0	Flag record
2.9	<b>Main lane: Speed trap not functioning properly</b>	Speed = 0 Volume > 0 Occupancy > 0	Flag record
2.10	<b>Main lane: Volume and occupancy are zero when speed is not zero</b>	Speed > 0 Volume = 0 Occupancy = 0	Flag record
2.11	<b>Main lane: Volume is zero when speed and occupancy are not zero</b>	Speed > 0 Volume = 0 Occupancy > 0	Flag record
2.12	<b>Main lane: Occupancy is zero when speed and volume are not zero</b>	Speed > 0 Volume > 0 Occupancy = 0	Flag record
<b>Third-Level Tests</b>			
3.1	<b>Maximum occupancy</b> Occupancy value exceeds a threshold, based on traffic flow theory concepts	Speed > 0 Volume > 0 Occupancy > [3,600 × Volume/(Time Interval × Speed) + 15]*[Vehicle Length + Detection Length]/52.8	Flag record
3.2	<b>Maximum flow rate</b> Calculated flow rate is larger than 3,000 vehicles per hour per lane	3,600 × Volume/Time interval > 3,000	Flag record
3.3	<b>Consecutive identical volume values</b> Consecutive identical data values are suspect	Eight or more records with identical volume values	Flag records



**Figure 51. Detectors Controlled by Naztec LCUs and TRF LCUs.**

As an illustration, [Table 50](#) shows the result of applying second-level quality control tests to 20-second speed, volume, and occupancy data from March 1 through September 30, 2002, at TransGuide. The second phase of the project will provide a more comprehensive analysis including third-level quality control tests and a determination of potential spatial and temporal effects. An analysis of the results shown in [Table 50](#) yields the following observations:

- Some 357 million speed, volume, and occupancy records had a quality control flag, of which 330 million (or 93 percent) were “valid” records and the remaining 27 million (or 7 percent) were “abnormal” records. The vast majority of “abnormal” records (22 million) had flag No. 2.10 (speed > 0, volume = 0, and occupancy = 0). Considering there were 739 million records in the database from March 1 through September 30,

2002, 27 million “abnormal” records translate to an overall “abnormal” record rate of about 4 percent.

- On average, the database contained data for 1,260 lane detectors. Assuming continuous coverage every 20 seconds from March 1 through September 30, 2002, the total potential number of records was roughly 995 million. This translates to an overall coverage rate of 74 percent.
- There were significant differences between TRF LCU records and Naztec LCU records. Even though 32 percent of LCUs were TRF LCUs, the percent of “abnormal” records associated with detectors controlled by TRF LCUs was 82 percent. The vast majority of these records had flag No. 2.10 (speed > 0, volume = 0, and occupancy = 0), with practically no records under the other flag categories. In contrast, Naztec LCU records, even though they were the minority, had representation in almost every single flag category. Some 55 percent of Naztec LCU records had flag No. 2.9 (speed = 0, volume > 0, occupancy > 0).

**Table 50. Summary of 20-Second Records Flagged from March 1 to September 30, 2002.**

Quality Control Flag	Number of Records Flagged	TRF LCU			Naztec LCU		
		“Valid” Records	“Abnormal” Records	“Valid” Records	“Abnormal” Records		
2.1	12			0	0%		12 <1%
2.2	141,733,112	32,519,628	47%			109,213,484	42%
2.3	103,817,884	36,843,211	53%			66,974,673	26%
2.4	350,556						350,556 7%
2.5	496,145						496,145 10%
2.6	84,793,744				84,793,744	32%	
2.7	352,259						352,259 7%
2.8	461,679						461,679 10%
2.9	2,654,115						2,654,115 55%
2.10	21,838,415			21,788,458	100%		49,957 1%
2.11	5,510			33	<1%		5,477 0%
2.12	483,524						483,524 10%
Total	356,986,955	69,362,839	100%	21,788,491	100%	260,981,901	100% 4,853,724 100%

## CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Previous chapters described current incident detection and data archival practices in Texas, a data model and corresponding geodatabase of ITS equipment and archived ITS data using a variety of data sources, patterns in the spatial and temporal distribution of freeway incidents in San Antonio, and a methodology for calculating incident delay using archived ITS data. This chapter summarizes the research findings and outlines recommendations for implementation and further work.

### SUMMARY OF FINDINGS

#### Traffic and Incident Data Archival Practices

[Chapter 2](#) discussed incident detection and ITS data archival practices at the following TMCs in Texas: CTECC, DalTrans, TransVISION, TranStar, and TransGuide. To the extent possible, the researchers examined system database design documents, sample traffic ITS data, incident logs, and other related information. The researchers also interviewed system analysts and operators to understand the incident detection and incident management processes that lead to the production and archiving of the data.

TMCs in Texas follow very different approaches for generating and archiving ITS traffic and incident data. Their data archives range from limited, e.g., TransVISION, to comprehensive, e.g., TranStar, or comprehensive but without a formal data model, e.g., TransGuide. Temporal archived data resolution ranges from quite aggregate, e.g., TranStar's 15-minute travel time and speed data, to disaggregate, e.g., TransGuide's 20-second detector data. Archived data types range from basic incident data descriptions at most TMCs to actual displayed message data, e.g., at DalTrans and TransGuide.

ITS hardware and software systems are also quite different across TMCs, making the process to develop standardized procedures challenging. Nonetheless, there are common elements to most TMCs, e.g., they all follow procedures to associate incident data with roadway locations or segments. TMCs are increasingly using GIS in their ATMS implementations to map ITS infrastructure and incidents, which highlights the importance of developing database and associated procedures in a geo-referenced environment.

#### Geodatabase Development

[Chapter 3](#) described the process to develop geographically referenced traffic and incident data sets in preparation for the incident evaluation phase. Although this work was specific to TransGuide, many of the procedures and findings also apply to other TMCs in Texas because they often use similar data sources. Several data sources were available to develop the geodatabase of ITS features. Examples include the TxDOT urban map file, the StratMap transportation file, and a street map from the City of San Antonio to build a road base map; flight data files and aerial photography to provide context to the vector road base map data; and schematics in Microstation format and scanned images documenting the location of ITS equipment in the field.

Because the data sources were in different formats, projections, and coordinate systems, the researchers had to apply a series of transformations to ensure the data sources overlaid correctly in a geo-referenced environment. Using aerial photography, in particular ½-foot resolution aerial photography, was critical to identify the correct location of ITS devices since it enabled the identification of a wide range of features such as pavement markings, lane configurations, traffic support structures, and even in some cases loop detectors. While using Microstation schematic files facilitated the generation of features in the GIS, using high-resolution aerial photography made a significant difference in the ability to correctly identify the location of those features. It also made it possible to identify cases where the Microstation schematics did not correctly reflect as-built locations in the field, which was critical in the case of loop detectors because TransGuide uses a mile marker identifier—derived from the Microstation schematics—as part of the feature name.

After geo-referencing the data sources, the researchers developed a GIS-based database of GIS features. Following the TransGuide ITS architecture, the researchers modeled roadway detectors, LCUs, LCSs, DMSs, CCTV cameras, and highway sectors. The researchers developed the geodatabase in ArcGIS 8.3, which is part of TxDOT's core GIS architecture. This geodatabase made it possible to generate a wide range of maps displaying ITS feature locations and archived ITS data for visualization and analysis. It also made it possible to add other layers of geographic data to the map, e.g., city limits or agency jurisdictional boundaries, which are critical pieces of information for coordinating emergency response activities.

To drive the development of the geodatabase, the researchers developed two data models that include both GIS features and archived ITS traffic and incident data: one data model (called data model "A") that represents current data archival practices at TransGuide and a second data model (called data model "B") that addresses several structural limitations of the current data archive, including data redundancy, lack of connectivity between archived incident data and archived scenario data, and lack of quality control information. Data model "A" is the model the researchers used for characterizing incident data characteristics and for calculating incident delay. Data model "B" is a modified version of data model "A," which could serve as a foundation for future archived ITS data activities at TransGuide. Both models are in Sybase PowerDesigner format, although exporting the models to other database environments such as Oracle, SQL Server, and Access to facilitate implementation at other TMCs would be straightforward.

## **Incident Characteristics**

[Chapter 4](#) included an analysis of temporal and spatial distribution of incidents on TransGuide's instrumented freeways. To perform the analysis, the researchers compiled a data set of more than 23,000 scenario records from March 2002 to May 2004 covering major accidents, minor accidents, stalled vehicles, and debris. The researchers evaluated incidents according to different categories including (a) temporal distribution of incidents by: month and season (academic year versus summer), day of week and weekday versus weekend day, and time of day (AM peak, midday, PM peak, and evening and early-morning hours); (b) distribution of incidents by severity, including main lane and shoulder blockages and duration; (c) distribution of incidents by sectors and corridors; and (d) weather, or more specifically, rain impacts on incident

frequencies. Prior to using the data set, it was necessary to update a few fields to characterize incidents more accurately. The updating process affected the scenario type field (11 percent of records were misclassified), scenario cancellation time (27 percent did not have this time), sector address for incidents on entrance and exit ramps (affecting some 40 percent of incidents), and finally the number of main lanes and shoulders blocked by each incident.

More than 850 incidents occur every month throughout TransGuide's coverage area, of which 34 percent are major accidents, 24 percent are minor accidents, 37 percent are stalled vehicles, and 5 percent are debris. There are monthly variations in incident frequency, but these variations are small, suggesting that seasonal effects have little impact on incident frequency.

On the other hand, incident frequency varies considerably from corridor to corridor and from sector to sector regardless of incident type, except in the case of debris, which exhibits a fairly uniform spatial distribution. Overall, incidents tend to be concentrated along certain corridors: IH-35, IH-10 south of Loop 410, and US 281, just north of downtown. Spatial variations are significant even after taking traffic volume levels into consideration. The sector with the highest frequency of incidents was sector SECT-0035S-164.412, which is located on southbound IH-35 around Rittiman Road. Other sectors with unusually high incident rates include sector SECT-0010E-562.581 (eastbound IH-10 around Callaghan Road), sector SECT-0035S-163.893 (southbound IH-35 south of Rittiman Road), and sector SECT-0010W-565.683 (westbound IH-10 around Vance Jackson Road). The two sectors on IH-35, SECT-0035S-164.412 and SECT-0035S-163.893, are noteworthy because they are consecutive sectors that carry a large percentage of truck traffic and exhibit considerable weaving as vehicles move to the left lane over a very short distance to continue on southbound IH-410.

There are daily variations in the number of incidents. The day of the week with the largest number of incidents is Friday, followed by Tuesday and Thursday. Regardless of incident type, daily variations in the number of incidents are statistically significant, with more incidents happening per weekday than per weekend day. Interestingly, although only 14 percent of weekly incidents occur on weekends, 48 percent of those incidents are major accidents, as opposed to 32 percent on an average weekday. In other words, if an incident happens on a weekend, it is more likely to be a serious one. The spatial distribution of incidents tends to be much more uniform for weekend days than for weekdays, regardless of incident type. Not surprisingly, the spatial distribution of incidents for weekdays, regardless of incident type, is similar to the spatial distribution of incidents for all days combined.

There are differences in the distribution of incidents by time of day. In the case of major and minor accidents, the number of incidents per hour is highest during the AM and PM peak periods (together, these two periods account for 39 percent of all incidents over a 24-hour period). In the case of stalled vehicles, the number of incidents per hour is highest during the PM peak, followed by midday, AM peak, and night. In the case of debris, the number of incidents per hour is highest during midday, followed by PM peak, AM peak, and night. The spatial distribution of incidents tends to be much more uniform at night than for other time periods during the day. Not surprisingly, the spatial distribution of incidents during daytime hours, particularly during the AM and PM periods, regardless of incident type, is similar to the corresponding spatial distribution of total number of incidents. In the case of major accidents, even though the spatial

distribution of incidents at night is more uniform than during daytime hours, there are two sectors (SECT-0281N-143.421 and SECT-0281S-143.421 on US 281 just north of downtown) with unusually high nighttime major accident rates.

Although scenario durations are typically shorter than actual incident durations, an analysis of scenario durations offered some interesting insights. On average, scenarios last 21 minutes. Major accidents have the longest average scenario duration, followed by minor accidents, stalled vehicles, and debris. These are arithmetic mean values. Using the median produces very different results. The overall median is 9 minutes. Minor accidents have the longest scenario duration, followed by major accidents, stalled vehicles, and debris. Because of the presence of records with unusually short and long durations in the scenario database, the median represents a better central tendency indicator than the arithmetic mean.

The distribution of major accident scenario durations is practically identical to the distribution of minor accident scenario durations, providing an indication that the current distinction between major accidents and minor accidents—perceived incident duration longer or shorter than 15 minutes when loading scenarios—is probably not meaningful.

Overall, 45 percent of incidents did not have main lane blockages when operators confirmed the incidents and executed scenarios. Further, 50 percent of incidents had one main lane blocked, and only about 5 percent of incidents had two or more main lanes blocked. Likewise, 57 percent of incidents had no shoulders blocked, 43 percent of incidents had one shoulder blocked, and less than 1 percent of incidents had both shoulders blocked. The number of main lanes and shoulders blocked varied by incident type. The researchers also evaluated scenario duration as a function of the number of main lanes and shoulders blocked with the expectation that scenario durations would increase as the number of main lanes and shoulders blocked increased. However, the data did not support this hypothesis. Readers should be aware that these trends represent the number of main lanes and shoulders blocked at the time the operators confirmed incidents and executed scenarios, not necessarily the number of lanes blocked when the incidents happened or as incident response personnel arrived at the scene and managed the incidents.

On average, there are about 34 incidents per day during rainy days, as opposed to 27 incidents per day when it does not rain. Major accidents account for most of the difference between rainy days and days without rain, with 14 major accidents per day during rainy days, as opposed to 8.3 major accidents per day when it does not rain. The number of minor accidents is also higher (about two more accidents) during rainy days than during days without rain. These differences are statistically significant, suggesting that rain has an impact on the frequency of major and minor accidents. On the other hand, differences in the number of stalled vehicles and debris during rainy days versus days without rain are very small and are not statistically significant.

## **Incident Delay**

[Chapter 5](#) outlined a non-parametric methodology to estimate incident delay using archived speed and volume data. Following similar approaches in the literature, the methodology to estimate incident delay uses a difference-in-travel-time approach that requires identification of travel times under normal and incident conditions, calculation of the corresponding travel time delay, and quantification of the amount of traffic affected by incidents. To ensure generalization

of the results, the formulation is disaggregated to enable the use of 20-second speed and volume data at the lane level. This formulation can also be used with data at other levels of temporal resolution. Because not all TMCs archive data at the lane level, the methodology also includes formulations that accept data at the sector, or link, level. The formulations do not handle cases where the speed reported by the detectors was zero or, in general, cases where there are “stored” vehicles in the system that the detectors did not account for at the end of each time interval. For these cases, it would be necessary to use a different formulation to handle storage delay.

The methodology uses a  $k$ -nearest neighborhood ( $k$ -NN) non-parametric regression to estimate reference speeds for the calculation of incident delay. It relies on the identification of  $k$  data points from a sample of historical speed and volume time data series in the immediate temporal vicinity of individual incident speed data records. The methodology is generic, simple, and straightforward to execute. For completeness, the researchers developed formulations for reference speed calculations using speed and volume data, both at the lane and sector levels.

The methodology uses a simple time-space imputation technique to address the issue of missing speed and volume data. The time imputation component relies on data from the time series of the missing data detector before and after the data gap. It calculates a constant average value using the first and last available data points within the gap. Provided the length of the gap is relatively small, a constant average value produces similar results as other approaches such as linear interpolation or higher-order polynomials. The space imputation component uses synchronous data averages from detectors on the same sector because a preliminary analysis showed that with a detector spacing of half a mile, there was less correlation between data from multiple detectors on the same lane than between data across lanes.

The researchers attempted to develop an automated procedure to determine the start and end of incidents using archived speed data series. Efforts included comparing speed data against pre-established thresholds, data series smoothing, and first derivative data smoothing. In part because these efforts were largely unsuccessful and because the second phase of the research will focus on the incident detection algorithm at TransGuide, the researchers decided to inspect incident speed profiles manually and visually confirm the start and end of incidents.

The researchers applied the methodology to two sample incidents in San Antonio. One of the incidents was on eastbound IH-10 south of downtown San Antonio. The other incident was on southbound IH-35 on the northeast part of town. Both incidents were classified as major accidents in the scenario database. In addition to speed and volume data from affected detectors in the vicinity of the incidents, the researchers gathered three days of incident-free archived speed and volume data from the same sensors. The day of the week associated with the incident-free data was the same as the day of the week when the incidents happened.

The analysis included a comparison of incident delay values between lane-by-lane data versus sector data, as well as imputed data versus non-imputed data. The analysis also included an evaluation of the effect of incident duration on the estimation of delay. In general, there were no significant differences between the estimates of delay using lane-by-lane data versus sector data, which was not surprising since the origin of the sector data was the more disaggregate lane-by-lane data.

On the other hand, there were significant differences between the estimates of delay using imputed data versus non-imputed data. In the case of the incident on eastbound IH-10, the percentage of data imputed ranged from 10 percent close to where the incident happened to 40 percent two sectors upstream. After data imputation, the total estimate of incident delay increased from 32 to 36 vehicle-hours, i.e., a relative increase of 12 percent. In the case of the incident on southbound IH-35, the percentage of data imputed ranged from 31 percent close to where the incident happened to 3 percent two sectors upstream. After data imputation, the total estimate of incident delay increased from 43 to 72 vehicle-hours, i.e., a relative increase of 67 percent. Not surprisingly, the greatest part of the total incident delay occurred in the first sector where the incident occurred. Data imputation was most critical in that sector. With increasing distance from the incident location, sectors contributed less to the total incident delay and imputation became less important for those sectors.

To determine the effect of incident duration on the estimation of delay, the researchers modified the time stamps associated with the start and end of the calculations. In both incidents, the additional calculations used time stamps that extended the actual duration of the incidents. Results varied according to the delay measure used. When the delay was expressed in vehicle-hours, increasing the incident start and end times beyond the points where the incident actually started or ended had a relatively minor impact on the amount of total incident delay. However, when the delay was expressed in seconds per vehicle, increasing the incident start and end times had a significant impact on the amount of delay per vehicle. This is reasonable since extending the incident start and end limits would include vehicles in the calculation that did not really experience the impact of the incident, therefore lowering the average delay/vehicle rate.

## **STEPS/RECOMMENDATIONS FOR IMPLEMENTATION**

This report described procedures to evaluate the completeness, accuracy, and usefulness of archived incident data as well procedures to derive characteristics and performance measures from the archived data. Steps required to implement the procedures include the following:

- Apply the geodatabase and associated archived ITS data model at TransGuide. As mentioned previously, the researchers developed a data model (called data model “B”) that addresses structural limitations of the current data archive, such as data redundancy, lack of connectivity between incident data and scenario data, and lack of quality control information. Implementation of the geodatabase would likely be in two phases:
  - Offline phase: In this phase, operators and managers use a GIS application such as ArcView—which is part of TxDOT’s core GIS architecture—to generate ITS feature maps and reports offline.
  - Online phase: In this phase, in addition to the offline mapping capabilities, an interactive geo-referenced map becomes part of the operators’ consoles. This phase requires migration from the current non-geo-referenced mapping environment to a standardized, interactive GIS environment that supports industry standard functionality (such as database querying, multiple layer display, and reporting).

- Use high-resolution, e.g.,  $\frac{1}{2}$ -foot, aerial photography as background on operator console maps. As this research demonstrated, using high-resolution aerial photography enables the effective identification of a wide range of features such as pavement markings, lane configurations, traffic support structures, and even in some cases loop detectors. In combination with CCTV cameras and interactive maps displaying ITS features, aerial photography could be an invaluable asset to TMC operators, particularly in situations where road base maps do not adequately represent roadway features on the ground. The downside of high-resolution aerial photography is file size. To minimize this impact, it would be advisable to use files that cover relatively small areas, limiting lateral coverage to the freeway right-of-way or some other minimum distance that TxDOT considers acceptable. It may be worth noting that many local jurisdictions already have programs in place to acquire high-resolution aerial photography on a regular basis, e.g., once a year. If TMCs can access this data source as part of an inter-agency agreement, the actual cost to TxDOT would be minimal.
- Develop quality control mechanisms to reliably collect critical time stamps associated with incidents, such as incident time, detection time, verification time, scenario execution time, response time (for simplicity, time when the first responder arrived at the scene), moved-to-shoulder time, clearance time, scenario cancellation time, and back-to-normal-conditions time. Such time stamps provide important information about the way incidents evolve over time and can translate into useful quantitative performance measures and reports (49). Current implementations already collect some of these time stamps, but additional protocols are needed to ensure consistency in the time stamp data collection process, e.g., the scenario cancellation time. Other time stamps, e.g., incident time and back-to-normal-conditions time, are not part of current data collection protocols. However, if operators could access real-time speed profiles from affected detectors on their consoles, they might be able to pinpoint when incidents start and when traffic conditions go back to normal. Developing this capability would enable operators to more effectively determine when to cancel incident-related scenarios and, if necessary, display messages on the DMSSs advising motorists about traffic congestion that still remains from already cleared incidents.
- Implement database queries to document spatial and temporal patterns in the distribution of incidents. This research focused on the development and evaluation of the procedures, rather than the coding needed to automate the production of maps and tabular reports, which depends on the actual hardware and software implementation at each TMC. The database queries are simple and straightforward. However, to maximize the usefulness of the reporting procedures, they should be as automated as possible. Readers should be aware that this research only focused on a handful of categories (month, season, day of week, and so on) and that additional categories may be necessary to address the needs of individual TMCs. In particular, this research found two measures to be quite useful to evaluate incident distributions: number of incidents per day per mile (expressed for convenience as number of incidents per 100 or 1,000 weekdays per mile, depending on the aggregation level) and number of incidents per VMT (expressed for convenience as number of incidents per 100 million VMT). The second measure is a stronger indicator of risk because it includes the effect of traffic volume. However, the fact that the two measures produced similar incident rate rankings suggests that it might be possible to use a simpler measure that does not depend on traffic volume.

- Develop and implement strategies to manage and/or reduce high incident rates at critical locations. This report outlined procedures to detect spatial and temporal patterns in the distribution of incidents. As such, the procedures can serve both for documenting existing conditions and as a preliminary forecasting tool. Readers should notice that the length of the incident record analyzed was about 27 months, which was probably not long enough to detect long-term patterns or account for localized regression-to-the-mean effects (which result in subsequent observations tending to the mean). However, the locations with the highest incident rates, regardless of categorization procedure, also had physical or traffic characteristics that set them apart from other locations. In other words, such locations would likely exhibit higher incident rates than other locations on the network, even after considering localized regression-to-the-mean effects. For those locations, it would be advisable to consider management strategies such as (a) optimizing inter-agency incident management procedures, (b) optimizing LCS and/or DMS locations, (c) optimizing freeway signage, or (d) examining geometric design constraints.
- Update the C2C data model ([10](#)) to incorporate findings from this research. Revising the C2C data model was not the purpose of the research. However, in the process of reviewing this model to outline potential data elements that could become part of the archived incident data model, the researchers found a few areas where the C2C data model could benefit from the findings in this research. Introducing these changes would provide additional context to the data served using C2C protocols. Some of the recommended changes to the C2C data model are:
  - include additional time stamp data items in the incident data message, as discussed previously in this chapter;
  - add an incident identifier data item to the DMS data message to provide a linkage to the corresponding incident data records;
  - add an incident identifier data item to the LCS data message to provide a linkage to the corresponding incident data records;
  - add an incident identifier data item to the CCTV camera data message to provide a linkage to the corresponding incident data records;
  - add a quality control flag data item to the traffic conditions data message; and
  - add an incident identifier data item to the emergency management data message to provide a linkage to the corresponding incident data records (under the assumption the system generates such records in the event of catastrophic events).
- In the long run, change the equipment naming convention at TransGuide. TransGuide uses a mile marker identifier as part of the feature name, which is derived from Microstation schematics. However, these schematics do not necessarily reflect the actual location of ITS features on the ground. A relational database structure that assigns a location-independent unique identifier (e.g., a unique number) to a feature, along with separate fields that document the roadway name, direction, and mile marker, could easily solve this problem. If necessary, there could be more than one mile marker field (e.g., one field that includes the Microstation schematic mile marker, a second field that documents the control section station, and a third field that documents actual measurements on the ground). Using GIS-based linear referencing tools, some of these linear distance measures could be automatically generated.
- In the long run, develop an updated sector data model at TransGuide that explicitly considers roadway discontinuity points (e.g., points where ramps and direct connectors

connect with freeways and points where lower and upper sectors split and merge). The current sector model—which also applies to lane segments—defines a sector as a linear feature connecting two consecutive detector groups. The sector address, therefore its name, usually coincides with the name of the connecting upstream detector group. This modeling approach is appropriate as long as there are no discontinuities on the road (such as ramps, connectors, horizontal/vertical splits, or horizontal/vertical merges). However, if there are discontinuities between consecutive detector groups, it becomes difficult to manage incident situations, beginning with determining the sector that should be associated with the incident. An updated model that takes into consideration such discontinuities would effectively solve this problem.

- Consider the use of standard web-based mapping tools such as ArcIMS—which is part of TxDOT's GIS architecture—to enable the production of interactive maps and reports that remote users could access using platform-independent browsers. Several TMCs are already beginning to use GIS-based online mapping tools, which only emphasizes the advantages of using a geodatabase approach for managing ITS locations and data.

## RECOMMENDATIONS FOR FURTHER RESEARCH WORK

This report has outlined a number of areas that need further work. A summary of research needs follows:

- Develop automated procedures to incorporate weather data, in particular rainfall data, into TMC data collection protocols to help anticipate weather related incidents. The research showed a positive correlation between rainy days and incident frequency. However, TMC operators typically do not record weather information (e.g., dry, rainy, foggy) or roadway surface condition information (e.g., dry, wet, covered by ice), even though the interface to enter these data elements is already in place at several TMCs. The National Weather Service makes rain gage and radar data continuously available to the public. The National Weather Service also produces geo-referenced data sets containing rainfall data on a 4 kilometer (2.5-mile) grid centered over each radar site. Using GIS techniques, it should be possible to overlay this grid on the ITS feature and sector map to (a) determine whether it was likely that it rained where and when an incident happened, (b) estimate the approximate rainfall amount, and (c) automatically add this information to the incident record without operator's input.
- Further test the methodology to calculate incident delay. There are several areas that need additional testing, in particular the non-parametric regression, the imputation algorithm, and the effect of the assumed start and end time stamps. Other researchers have used non-parametric regression approaches in the context of ITS data. However, additional testing is necessary to optimize the number of data points used for the regression, particularly if there are gaps in the historical data series that might lead to errors in the calculation. The imputation algorithm is a simple algorithm that combines a time-space-time interpolation sequence. The algorithm is promising, but it would be necessary to conduct additional tests to determine its feasibility more conclusively, both in terms of imputed data results and algorithm performance.

- Develop and test procedures to calculate storage delay. As mentioned previously, the methodology described in this research does not handle cases where the speed reported by the detectors is zero or, in general, cases where there are “stored” vehicles in the system that the detectors do not account for at the end of each time interval. A formulation that handles storage delay would address this problem.
- Continue the testing of the 20-second speed, volume, and occupancy data quality control tests. This report included results for the second-level quality control tests, but additional testing is necessary to assess the validity of the third-level quality control tests.
- Update the C2C model to accept network definitions other than just node and link. TMCs such as TransGuide and CTECC gather speed, volume, and occupancy at the lane level. However, the current C2C implementation only supports aggregate directional node and link data. While it is possible to consider each freeway lane as an independent link for the purpose of supporting the current C2C implementation, a more robust, elegant solution would be to consider a link to be composed of lanes which might or might not have data depending on the local TMC implementation. This architecture would eliminate unnecessary conversions, would explicitly consider the relationship between adjacent lanes, would facilitate quality control, and would make the process of exchanging data among centers more transparent. The research would also need to update the C2C model to more effectively account for nodes that describe physical freeway discontinuity points (e.g., lane drops, points where ramps and direct connectors connect with freeways and points where lower and upper sectors split and merge).

## REFERENCES

1. Skabardonis, A., Petty, K., Bertini, R., Varaiya, P., Noeimi, H., and Rydzewski, D. I-880 Field Experiment. Analysis of Incident Data. *Transportation Research Record 1603*, TRB, National Research Council, Washington, D.C., 1997, pp. 72-79.
2. Skabardonis, A., Petty, K., and Varaiya, P. Los Angeles I-10 Field Experiment. Incident Patterns. *Transportation Research Record 1683*, TRB, National Research Council, Washington, D.C., 1999, pp. 22-30.
3. Bertini, R., Rose, M., and El-Geneidy, A. *Using Archived Data to Measure Operational Benefits of ITS Investments, Volume 2: Region 1 Incident Response Program*. Report No. TNW2004-01.2. Portland State University, Department of Civil and Environmental Engineering, Portland, Oregon, June 2004.
4. Smith, K., and Smith, B. *Forecasting the Clearance Time of Freeway Accidents*. Report No. STL-2001-01. National ITS Implementation Research Center, 2001.  
<http://www.gmupolicy.net/its/papers.htm>. Accessed August 30, 2004.
5. *Report on RDMT Implementation. Systems Testing and Training*. Report AU03308B. Office of the City Auditor, Austin, Texas, August 21, 2003.  
<http://www.ci.austin.tx.us/auditor/downloads/au03308b.pdf>. Accessed March 10, 2004.
6. *Risk Analysis of 911-RDMT Project. Summary*. Report No. S99561. Office of the City Auditor, Austin, Texas, April, 2000. [http://www.ci.austin.tx.us/auditor/pub\\_911.htm](http://www.ci.austin.tx.us/auditor/pub_911.htm). Accessed February 10, 2004.
7. *Advanced Traffic Management System. Operator's Manual*. Traffic Operations Division, Texas Department of Transportation, Austin, Texas, January 2003.
8. *ATMS 2.5A Data Dictionary*. Texas Department of Transportation, Austin, Texas, December 2002.
9. *Operational Concept Document*. Report DalTrans-OCD-1.15. Southwest Research Institute, Texas Department of Transportation, Mesquite, Texas, January 7, 2002.
10. *Center-to-Center Communications. Status Interface Control Document*. Report C2C-SICD-3.1.0. Texas Department of Transportation, Austin, Texas, June 25, 2003.
11. Dallas-Fort Worth Intelligent Transportation Systems. Texas Department of Transportation, 2004. <http://dfwtraffic.dot.state.tx.us/>. Accessed August 30, 2004.
12. Universal Detector Data Archive. Texas Transportation Institute, Texas Department of Transportation, 2004. <http://ttidallas.tamu.edu/DetectorDataArchive/>. Accessed August 30, 2004.
13. *Tarrant County Traffic Management Center. TransVISION Software. Database Dictionary Version 2.0*. Lockheed Martin Transportation Systems, Texas Department of Transportation, Houston, Texas, January 2002.
14. *Houston TranStar. Greater Houston Transportation and Emergency Management Center*. Texas Department of Transportation, Metropolitan Transit Authority of Harris County, City of Houston, Harris County, Texas. <http://www.houstontranstar.org/>. Accessed August 30, 2004.
15. *TransGuide Intelligent Transportation System. Software Design Document. Version 2.0*. Report TGITS-SDD-2.0. Southwest Research Institute, Texas Department of Transportation, San Antonio, Texas, May 2003.

16. *TransGuide Intelligent Transportation System. Software Users Manual. Version 2.0.* Report TGITS-SUM-2.0. Southwest Research Institute, Texas Department of Transportation, San Antonio, Texas, May 2003.
17. Traffic Statistics. Texas Department of Transportation, San Antonio, Texas. <http://www.transguide.dot.state.tx.us/docs/statistics.html>. Accessed August 30, 2004.
18. Texas Department of Transportation (TxDOT) Urban Files. Texas Natural Resources Information System (TNRIS). <http://www.tnris.state.tx.us/DigitalData/TxDOT/txdot.htm>. Accessed August 27, 2004.
19. StratMap. Texas Natural Resources Information System (TNRIS). <http://www.tnris.state.tx.us/stratmap/index.htm>, 2004. Accessed August 27, 2004.
20. ArcGIS Data Interoperability. Environmental Systems Research Institute. <http://www.esri.com/software/arcgis/extensions/datainteroperability/about/features1.html>. Accessed August 30, 2004.
21. Shackelford, S. *Cartographic Concepts*. Texas Department of Transportation, Austin, Texas, August 2000.
22. *Survey Guide*. Texas Department of Transportation, Austin, Texas, February 1999.
23. *CAD Transformation Toolbar*. Environmental Systems Research Institute, July 2001. <http://arcobjectsonline.esri.com/ArcObjectsOnline/default.asp?URL=/arcobjectsonline/samples/arcpy/cad/transformbar/transcadbarprj.htm>. Accessed August 30, 2004.
24. Middleton, D., Clayton, A., Quiroga, C., and Jasek, D. *Truck Accommodation Design Guidance: Final Report*. Research Report 4364-1. Texas Department of Transportation, Austin, Texas, 2003.
25. Schrank, D., and Lomax, T. *The 2004 Urban Mobility Report. Appendix B, Methodology for 2004 Annual Report*. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, 2004. <http://mobility.tamu.edu/ums/report/methodology.stm>. Accessed September 27, 2004.
26. Turner, S. *Guidelines for Developing ITS Data Archiving Systems*. Report 2127-3. Texas Department of Transportation, Austin, Texas, September 2001.
27. Turner, S., Eisele, W., Gajewski, B., Albert, L., and Benz, R. *ITS Data Archiving: Case Study Analyses of San Antonio TransGuide Data*. Report No. FHWA-PL-99-024. Federal Highway Administration, Washington, D.C., August 1999.
28. National Climatic Data Center. National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration. <http://www.ncdc.noaa.gov/oa/ncdc.html>. Accessed August 30, 2004.
29. The CODIAC System. Joint Office for Science Support. National Oceanic and Atmospheric Administration, University Corporation for Atmospheric Research. <http://www.joss.ucar.edu/codiac/>. Accessed August 30, 2004.
30. May, A. *Traffic Flow Fundamentals*. Prentice-Hall, Englewood Cliffs, New Jersey, 1990.
31. Fu, L. A Fuzzy Queuing Model for Real-Time, Adaptive Prediction of Incident Delay for ATMS/ATIS. *Transportation Planning and Technology*, Vol. 27, No. 1, 2004, pp. 1-23.
32. Qi, Y. *Incident Delay Analysis and Estimation*. Polytechnic University, Brooklyn, New York, 2002.
33. Skabardonis, A., Petty, K., Noeimi, H., Rydzewski, D., and Varaiya, P. I-880 Field Experiment: Data-Base Development and Incident Delay Estimation Procedures.

- Transportation Research Record 1554*, TRB, National Research Council, Washington, D.C., 1996, pp. 204-212.
34. Quiroga, C. Performance Measures and Data Requirements for Congestion Management Systems. *Transportation Research Part C*, No. 8, 2000, pp. 287-306.
  35. Schrank, D., and Lomax, T. *The 2004 Urban Mobility Report*. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, 2004.  
<http://mobility.tamu.edu/ums/report>. Accessed September 27, 2004.
  36. Petty, K. *Incidents on the Freeway: Detection and Management*. Ph.D. Dissertation, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, California, 1997.
  37. Lindley, J. *Quantification of Urban Freeway Congestion and Analysis of Remedial Measures*. Report No. FHWA-RD-87-052. Federal Highway Administration, Washington, D.C., October 1986.
  38. Skabardonis, A., Varaiya, P., and Petty, K. Measuring Recurrent and Nonrecurrent Traffic Congestion. *Transportation Research Record 1856*, TRB, National Research Council, Washington, D.C., 2003, pp. 118-124.
  39. Smith, B. *Forecasting Freeway Traffic Flow for Intelligent Transportation System Applications*. Ph.D. Dissertation, Department of Civil Engineering, University of Virginia, Charlottesville, Virginia, 1995.
  40. Altman, N. An Introduction to Kernel and Nearest-Neighbor Nonparametric Regression. *The American Statistician*, Vol. 46, No. 3, 1992, pp. 175-185.
  41. Davis, G., and Nihan, N. Nonparametric Regression and Short-term Freeway Traffic Forecasting. *Journal of Transportation Engineering*, ASCE, Vol. 117, No. 2, 1991, pp. 178-188.
  42. Kitagawa, G., and Gersch, W. *Smoothness Priors Analysis of Time Series*. Springer-Verlag, New York, 1996.
  43. Smith, B., Scherer, W., and Conklin, J. Exploring Imputation Techniques for Missing Data in Transportation Management Systems. *Transportation Research Record 1986*, TRB, National Research Council, Washington, D.C., 2003, pp. 132-142.
  44. Sharma, S., Lingras, P., and Zhong, M. Effect of Missing Value Estimations on Traffic Parameters. *Transportation Planning and Technology*, Vol. 27, No. 2, April 2004, pp. 119-144.
  45. Nguyen, L., and Scherer, W. Imputation Techniques to Account for Missing Data in Support of Intelligent Transportation Systems Applications. Report No. UVACTS-13-0-78. United States Department of Transportation, Washington, D.C., May 2003.
  46. Bohuslav, T. *Value of Time and Road User Costs*. Memorandum to District Engineers, Texas Department of Transportation, Austin, Texas, March 20, 2003.
  47. Consumer Price Index. U.S. Department of Labor, Bureau of Labor Statistics.  
<http://www.bls.gov/cpi/home.htm>. Accessed September 30, 2004.
  48. Park, E., Turner, S., and Spiegelman, C. Empirical Approaches to Outlier Detection in Intelligent Transportation Systems Data. *Transportation Research Record 1840*, TRB, National Research Council, Washington, D.C., 2003, pp. 21-30.
  49. Balke, K., Cooner, S., Durkop, B., Fenno, D., and Arredondo, R. *Measuring and Improving Incident Response*. Report No. 4907-S. Texas Department of Transportation, Austin, Texas, January 2001.



## **APPENDIX A. SPATIAL DISTRIBUTION OF INCIDENTS BY SEASON**





**Figure 52. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months).**

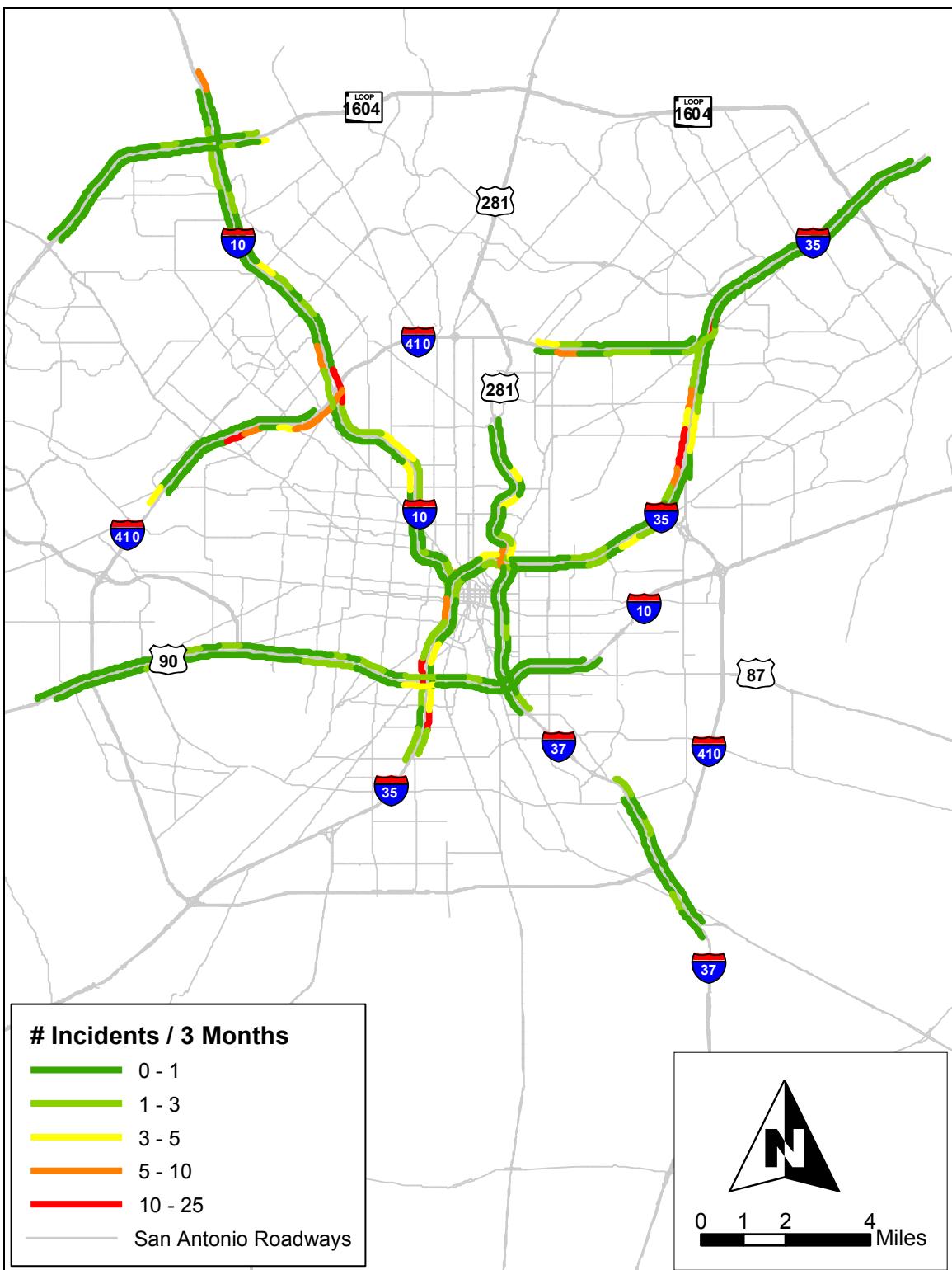
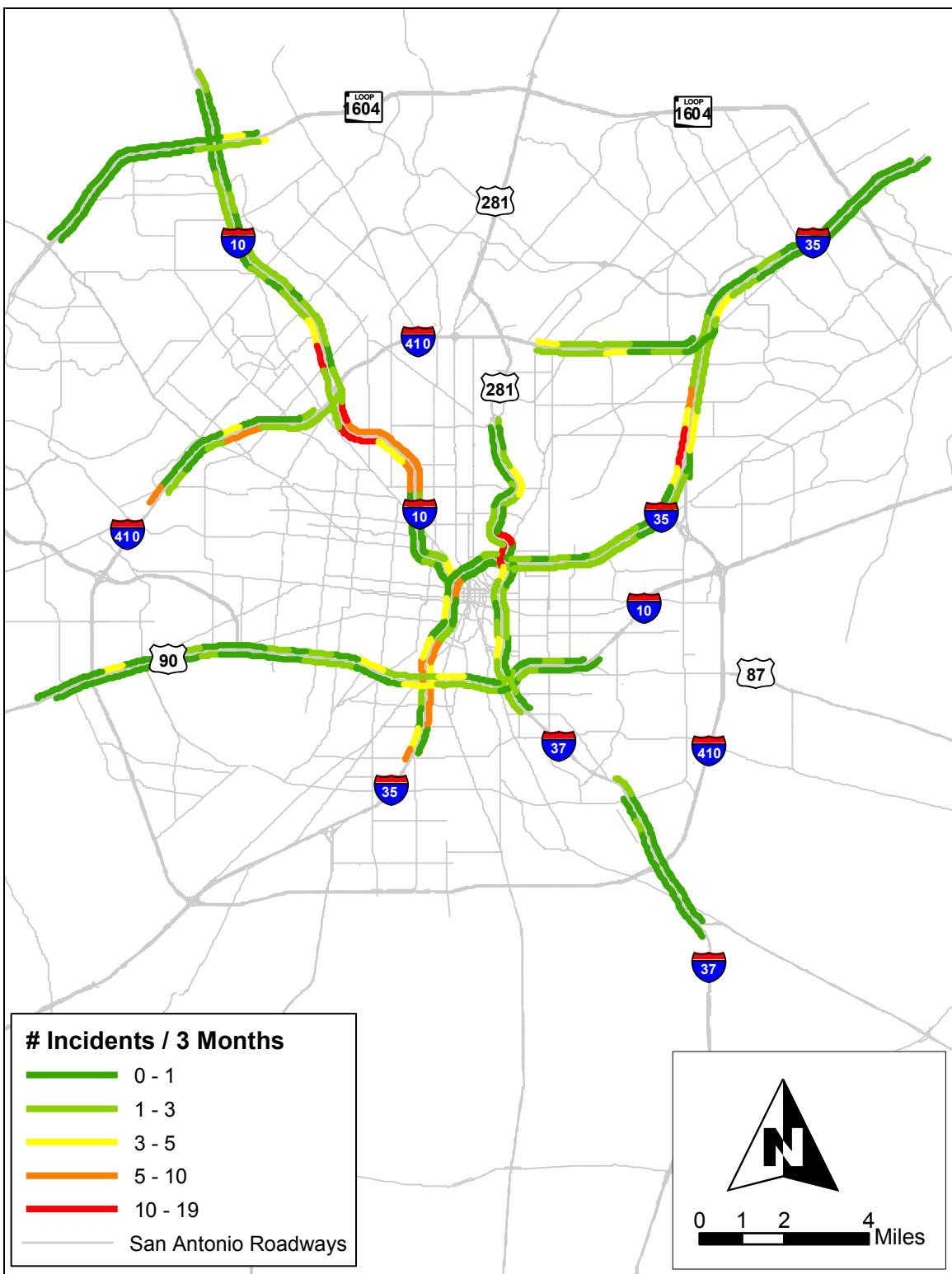


Figure 53. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002.



**Figure 54. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.**

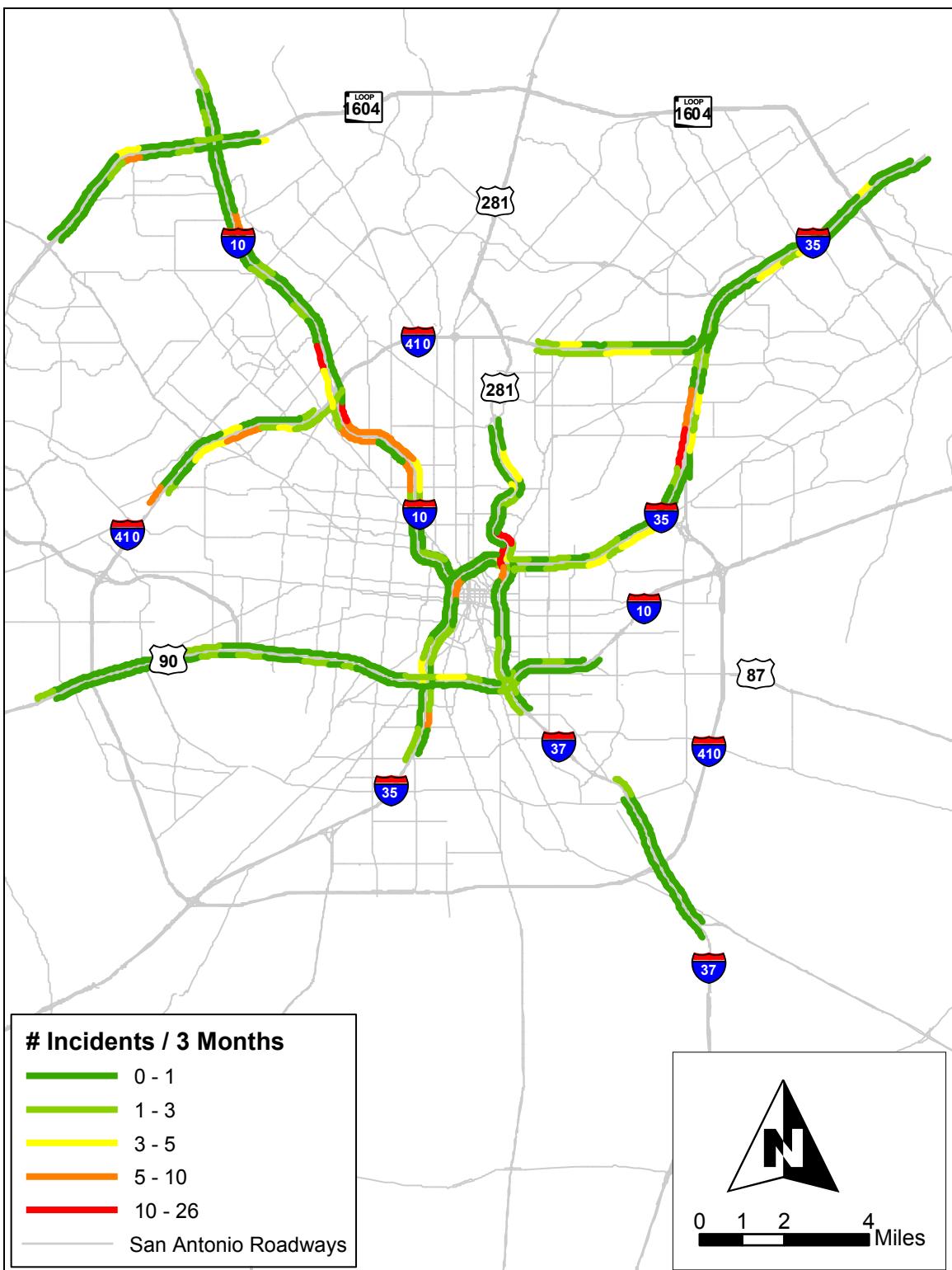
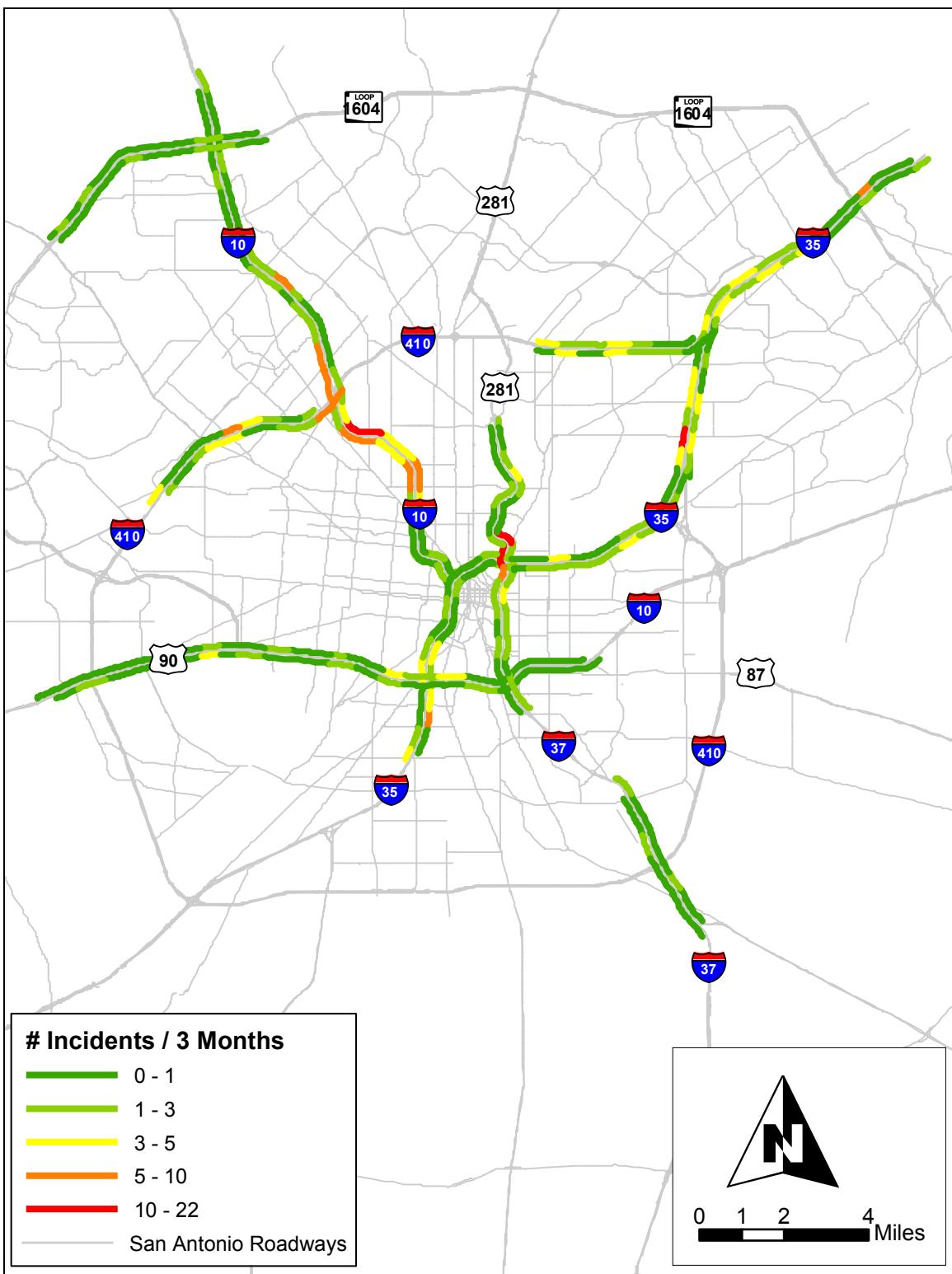


Figure 55. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003.



**Figure 56. Average Number of Major Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.**



**Figure 57. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months).**

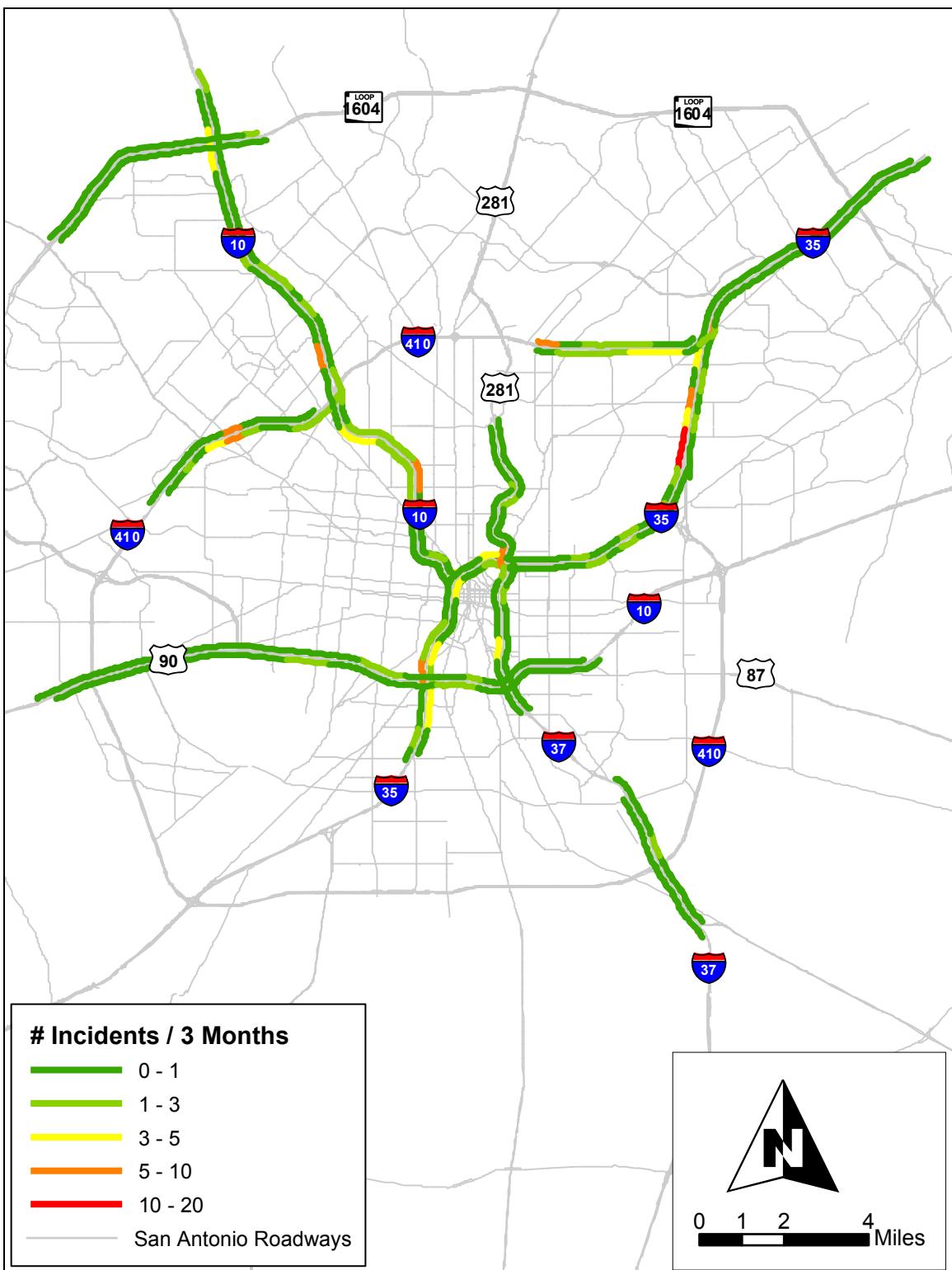


Figure 58. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002.

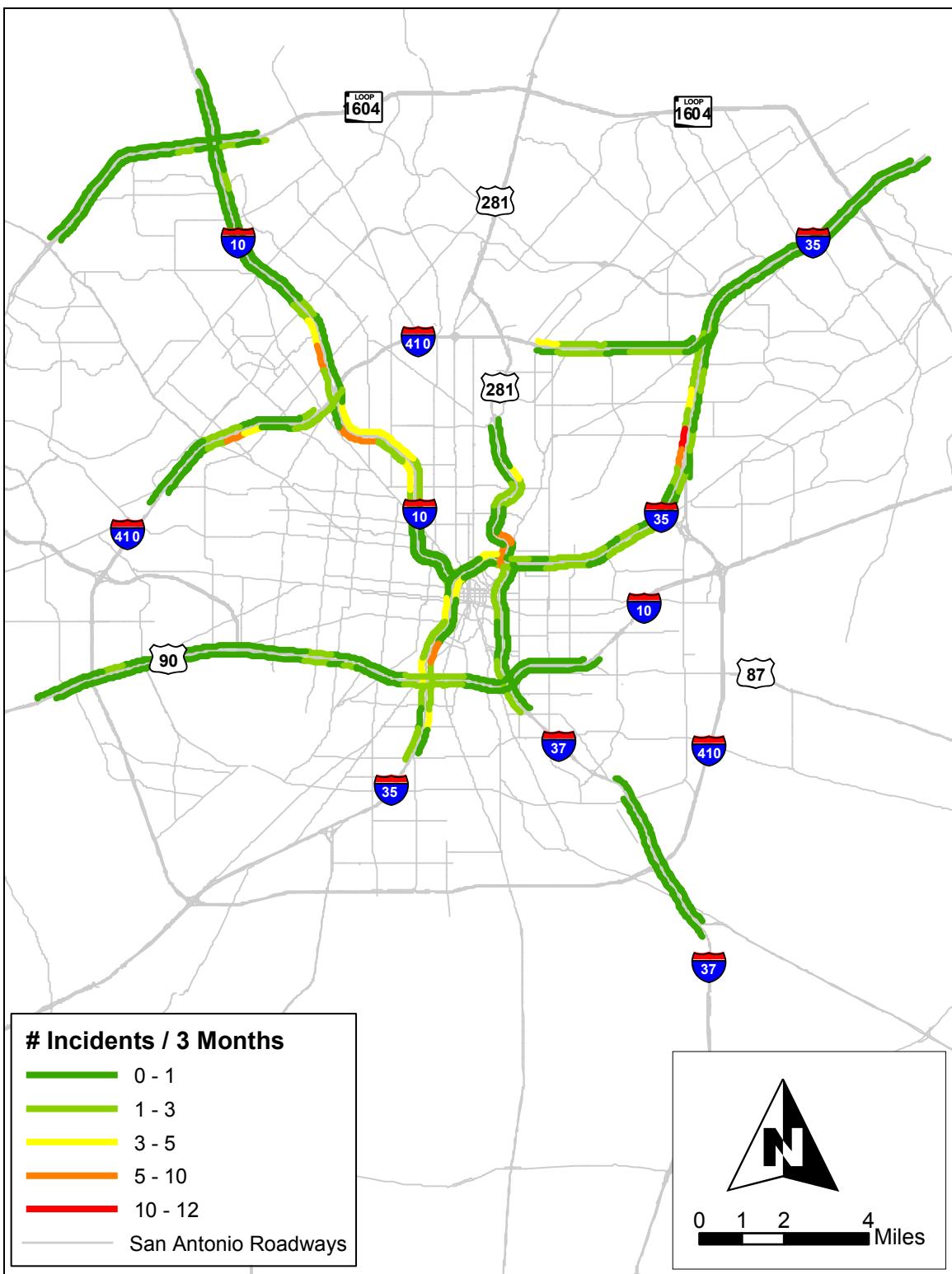
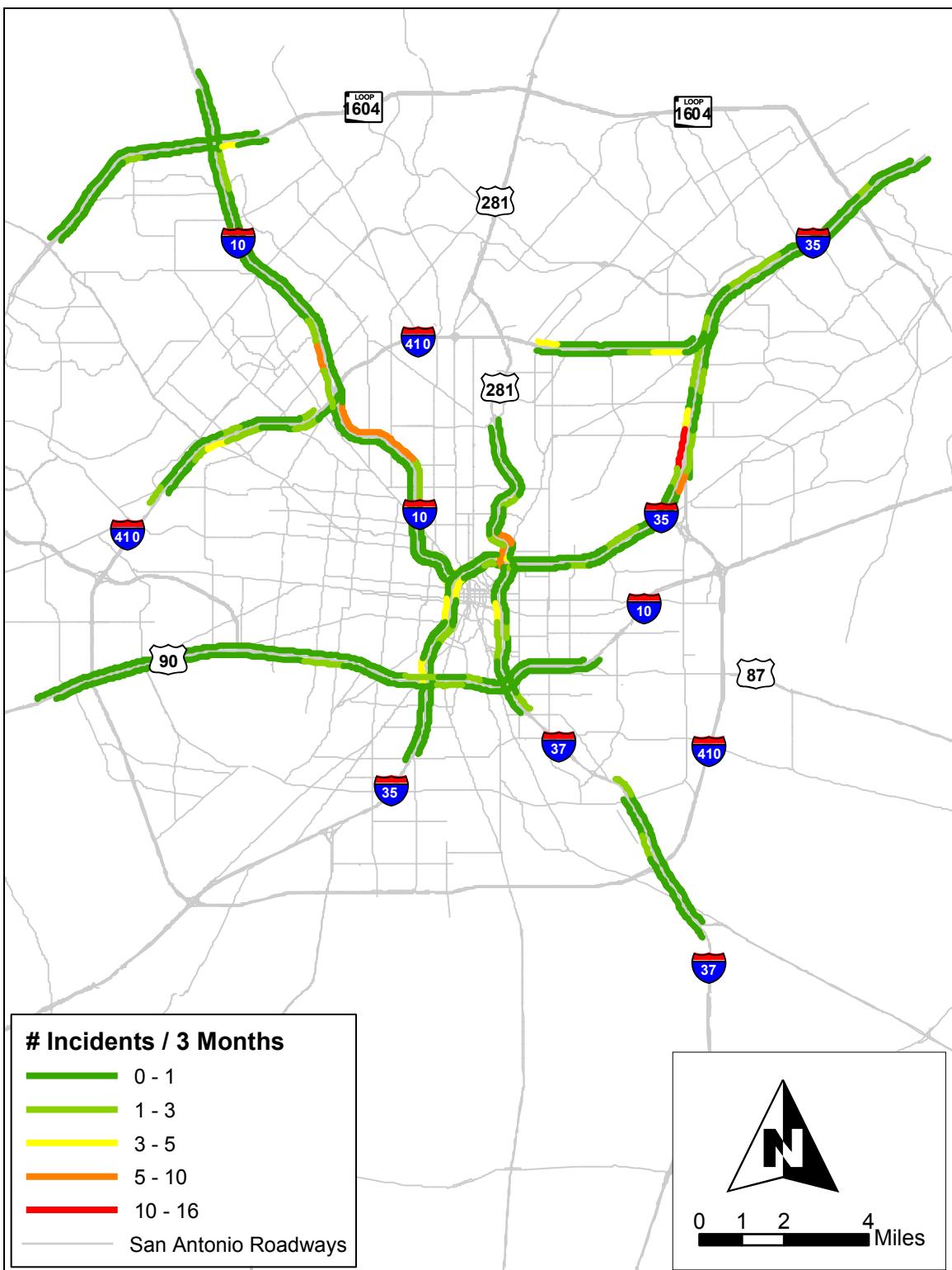
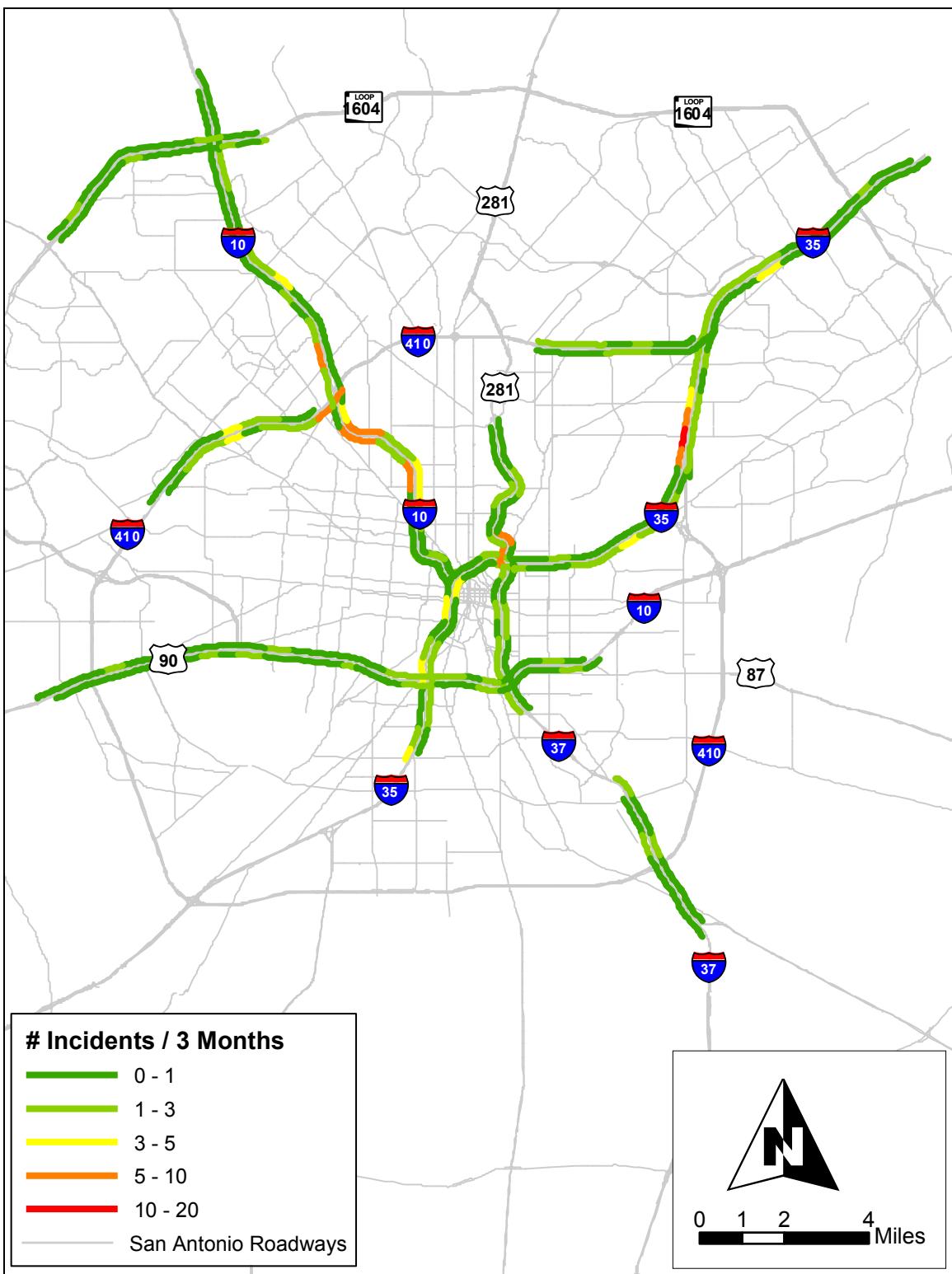


Figure 59. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.



**Figure 60. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003.**



**Figure 61. Average Number of Minor Accidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.**

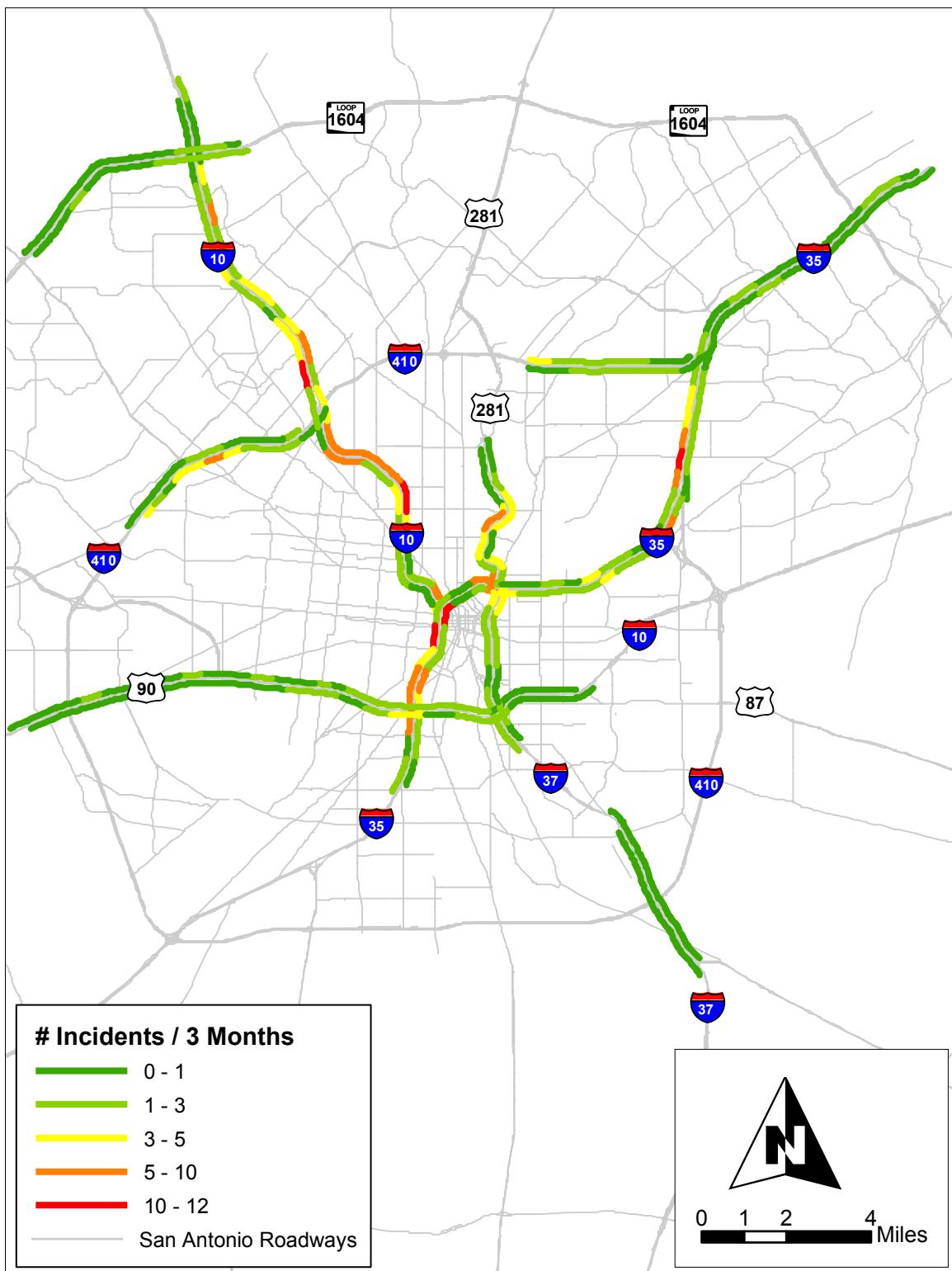


Figure 62. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months).

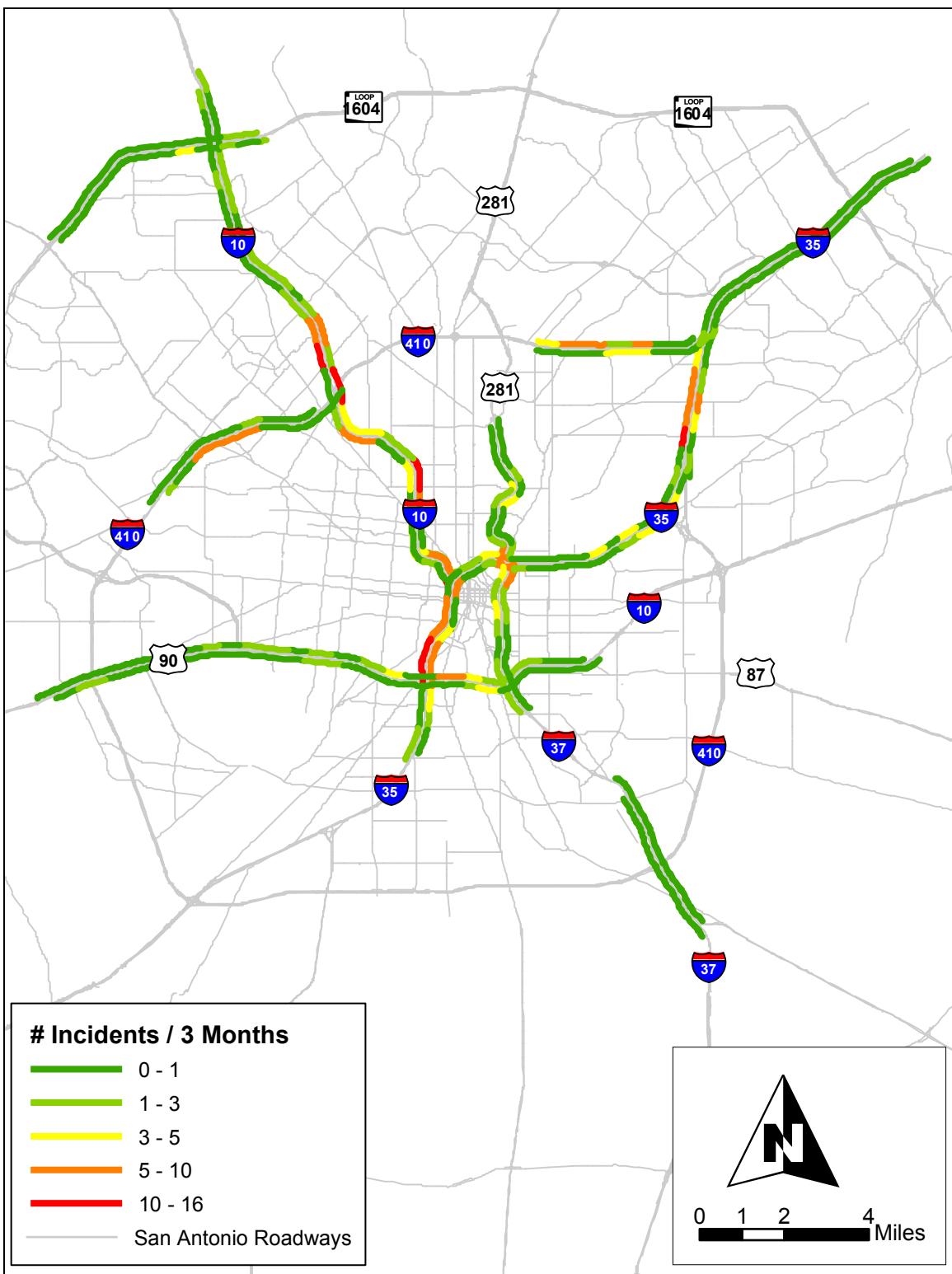
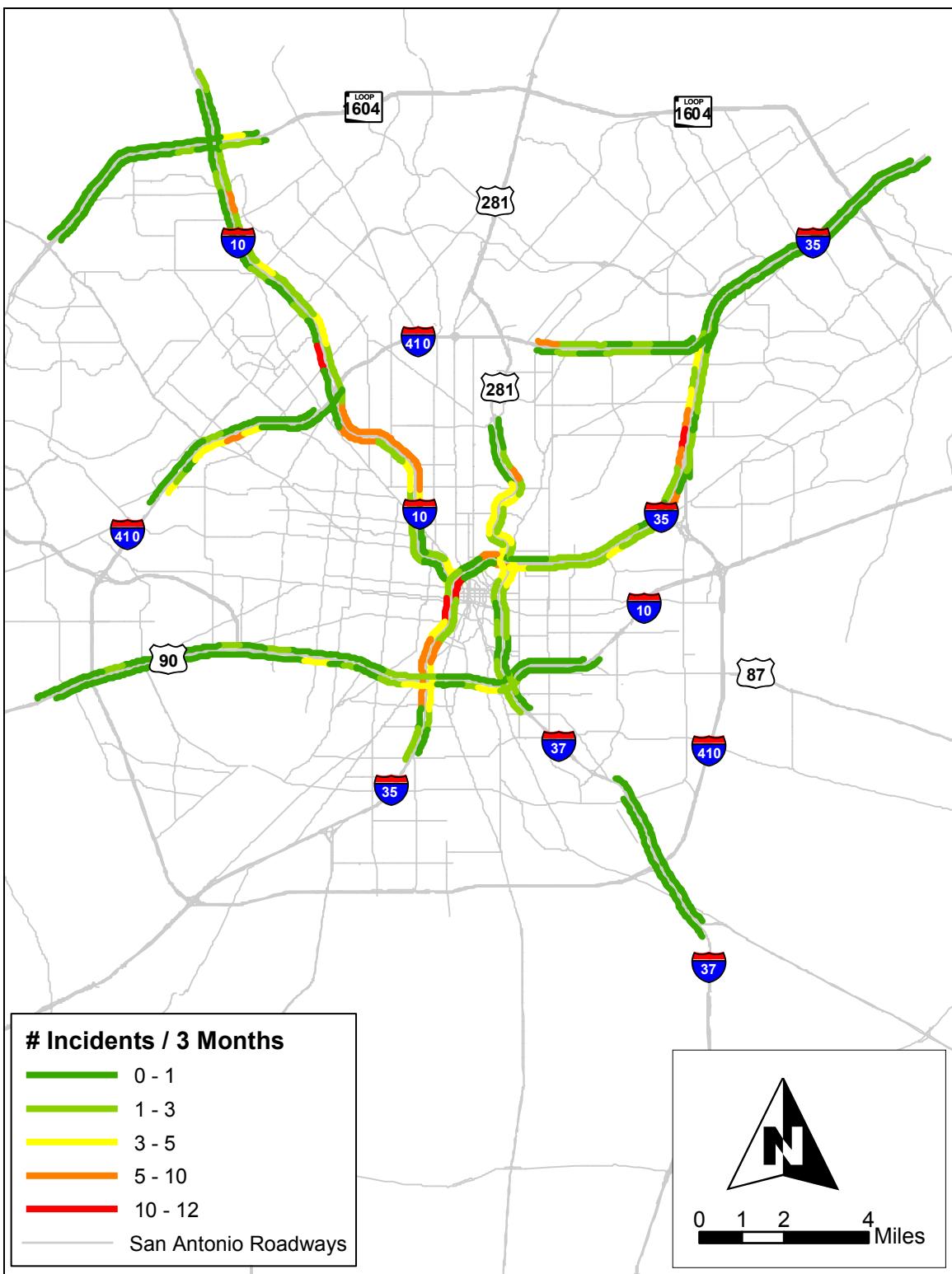


Figure 63. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002.



**Figure 64. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.**

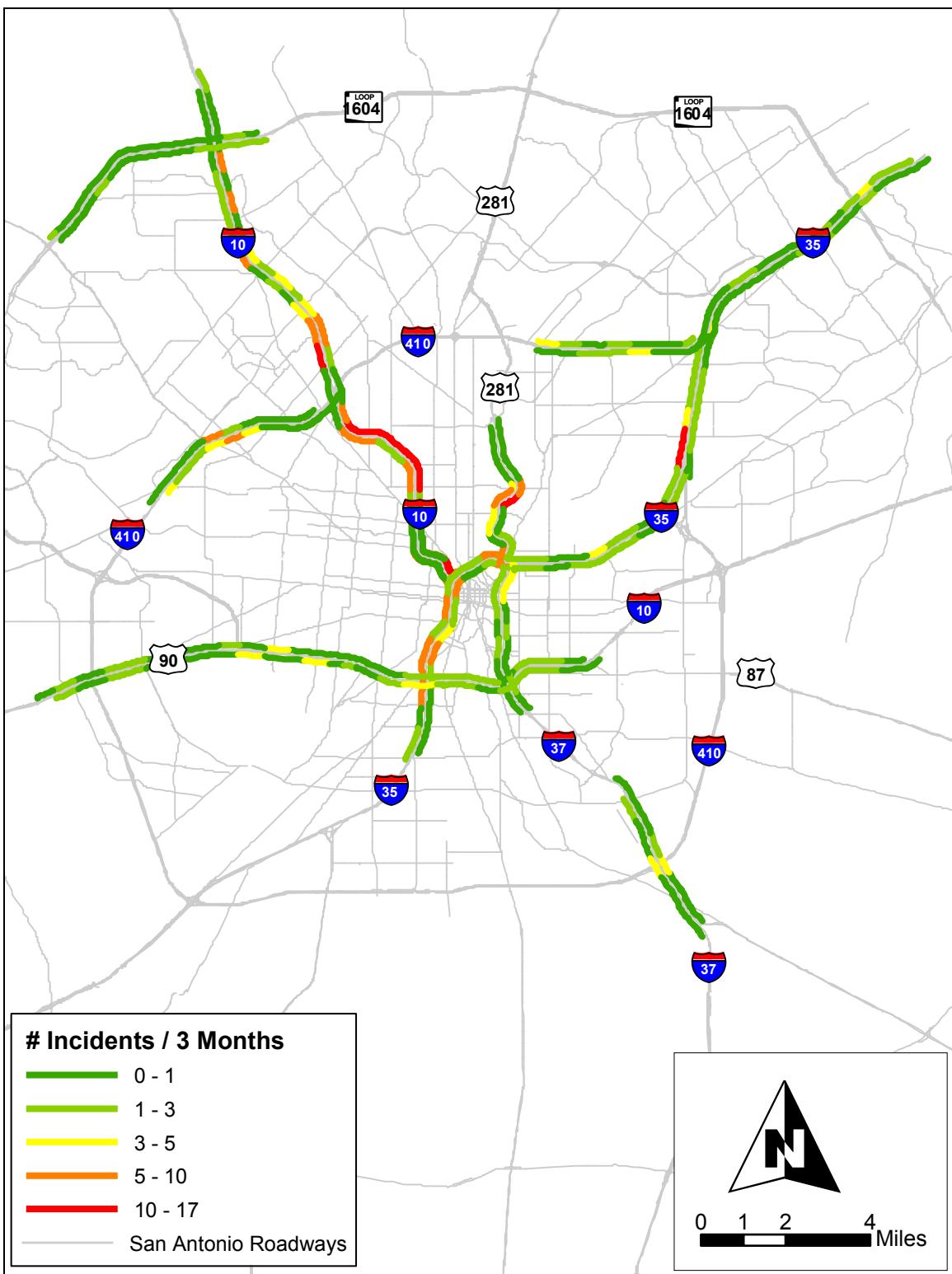


Figure 65. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003.

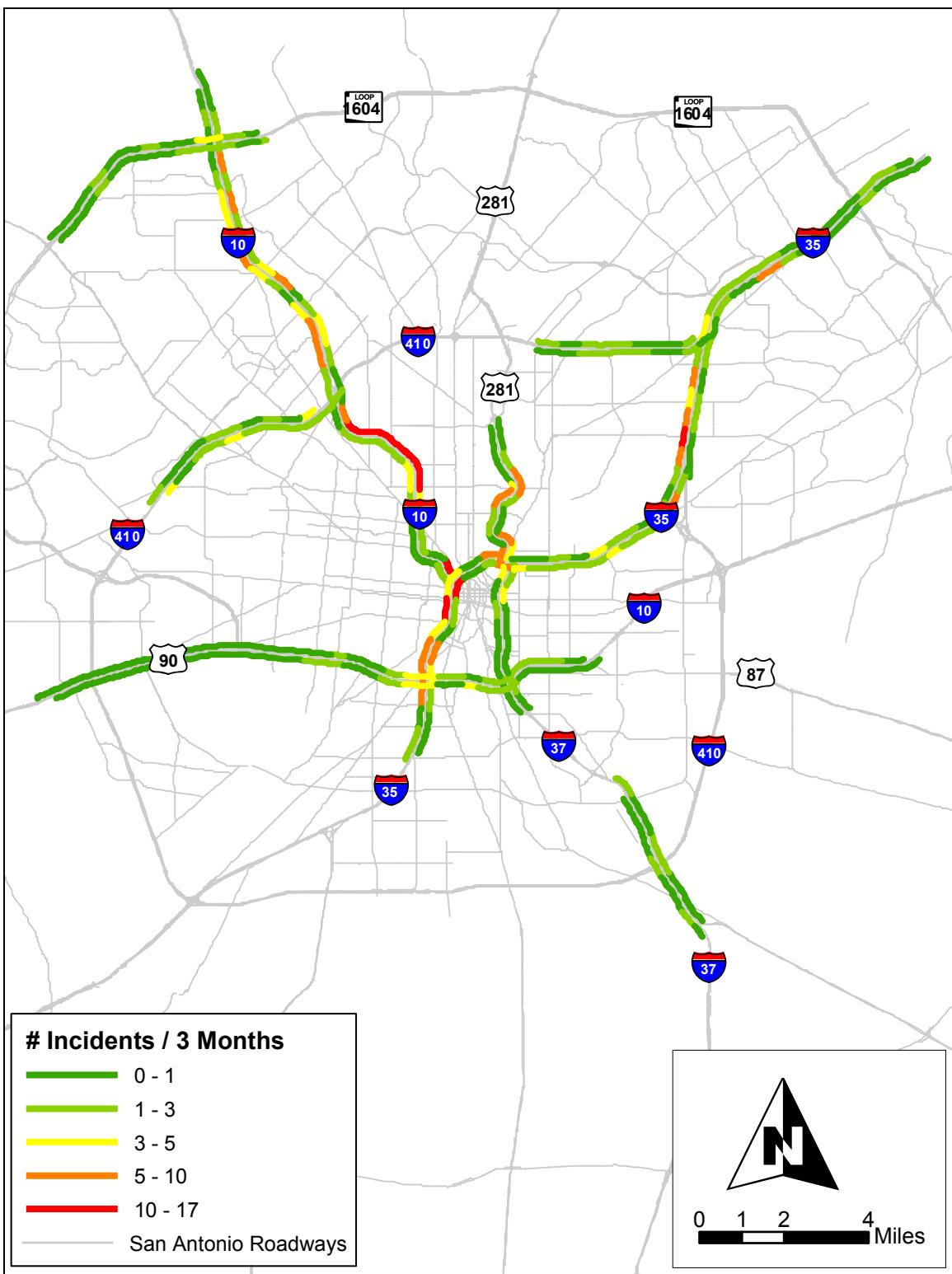
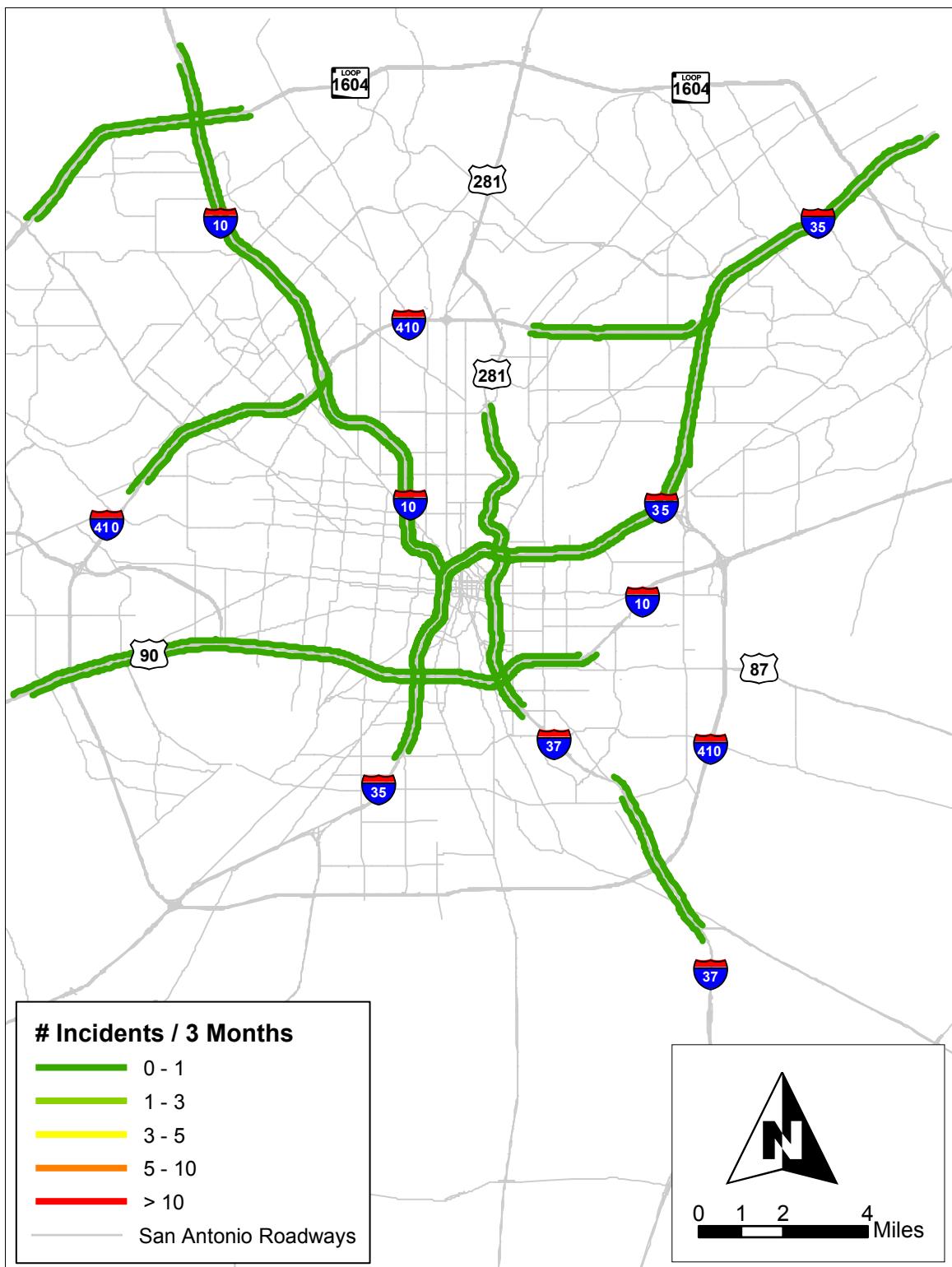


Figure 66. Average Number of Stalled Vehicle Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.



**Figure 67. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months).**

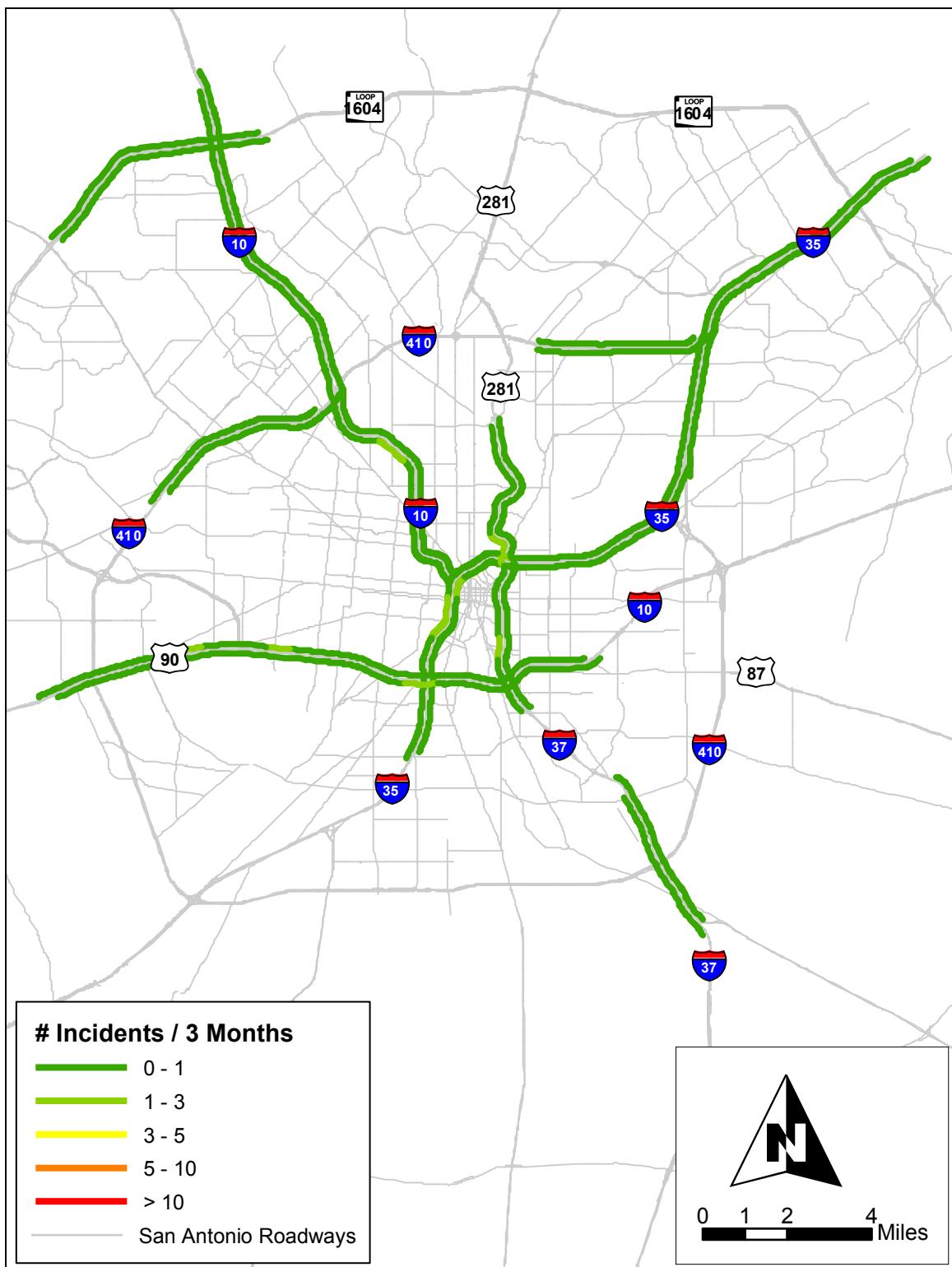
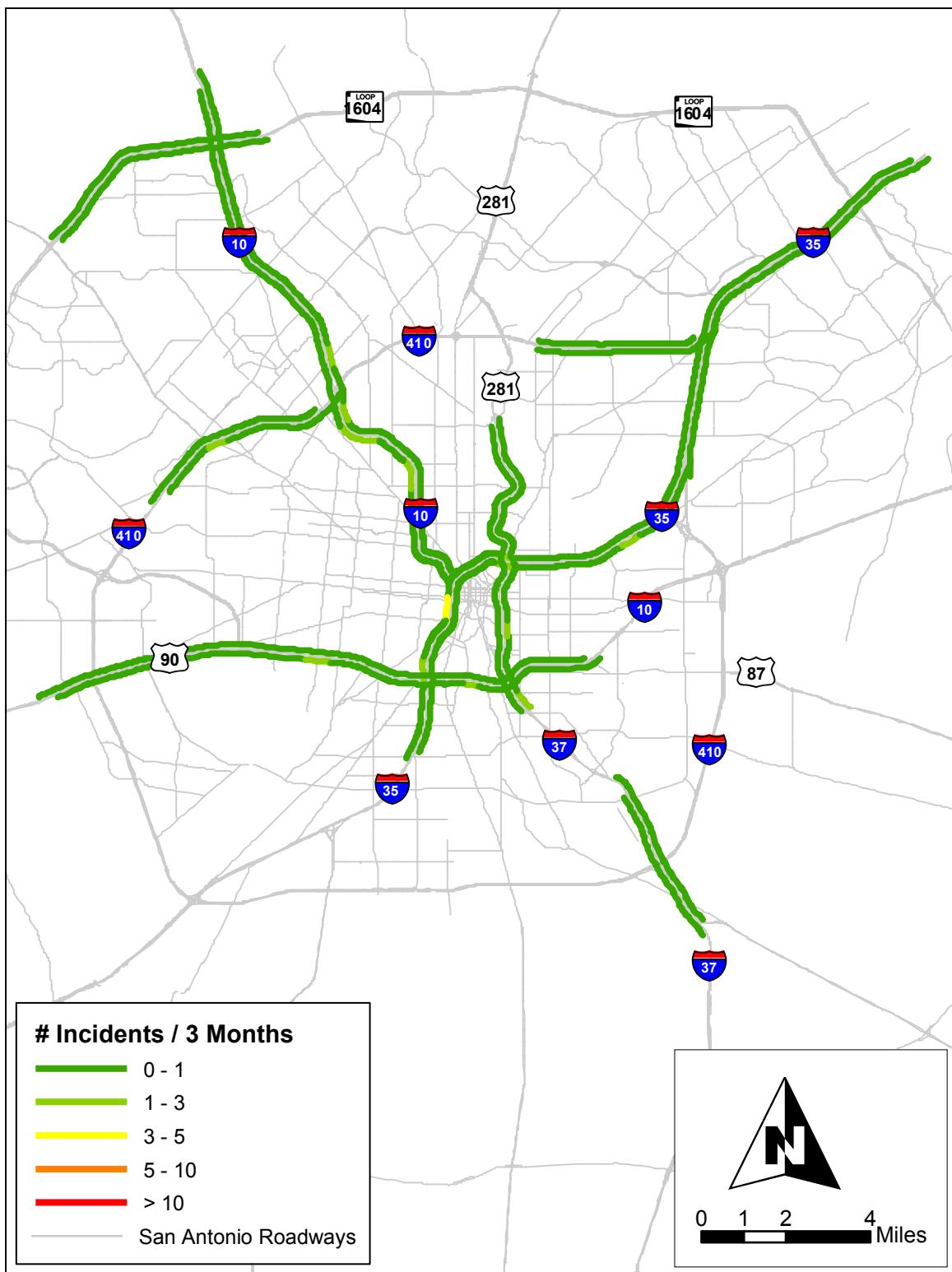
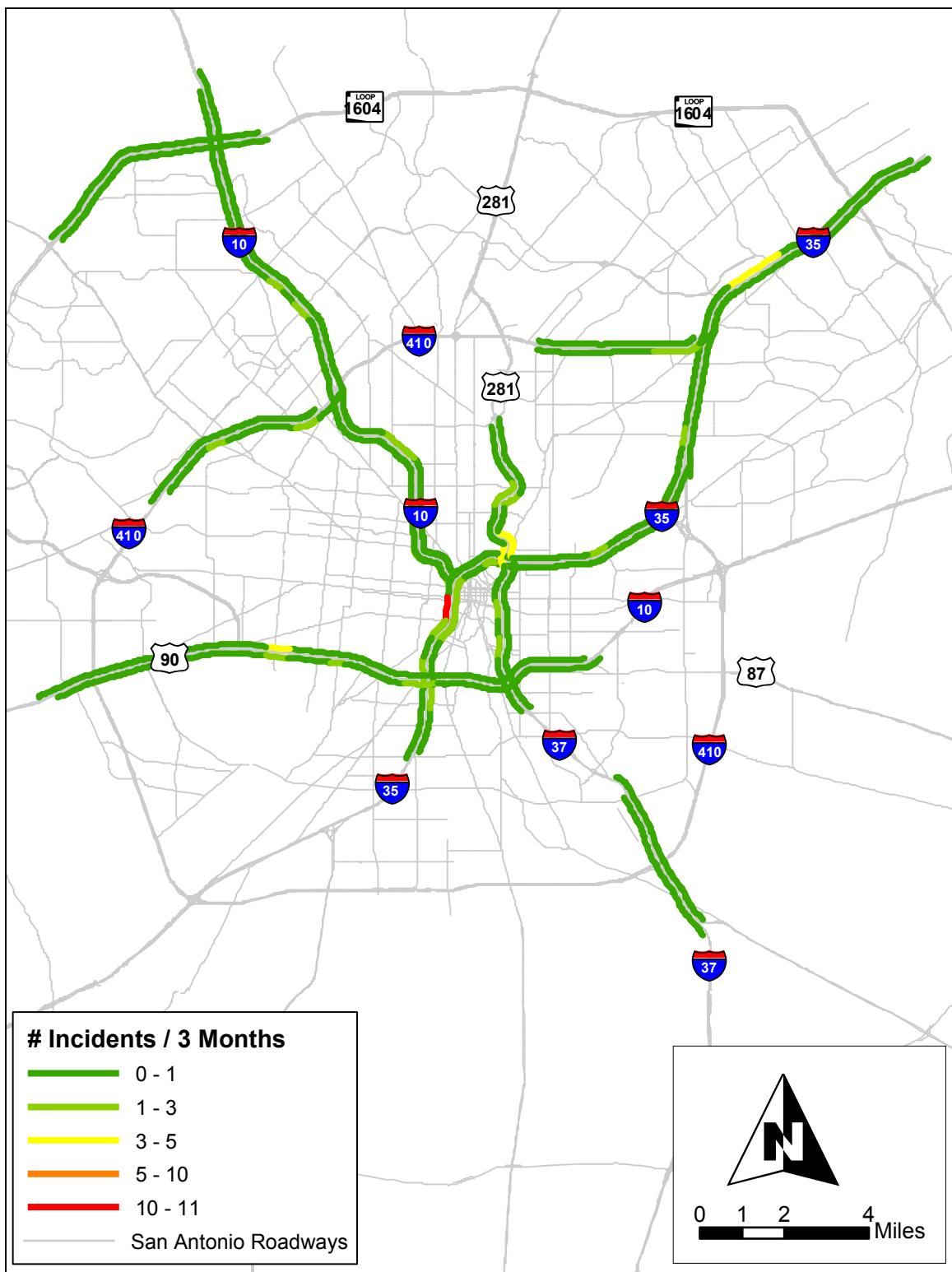


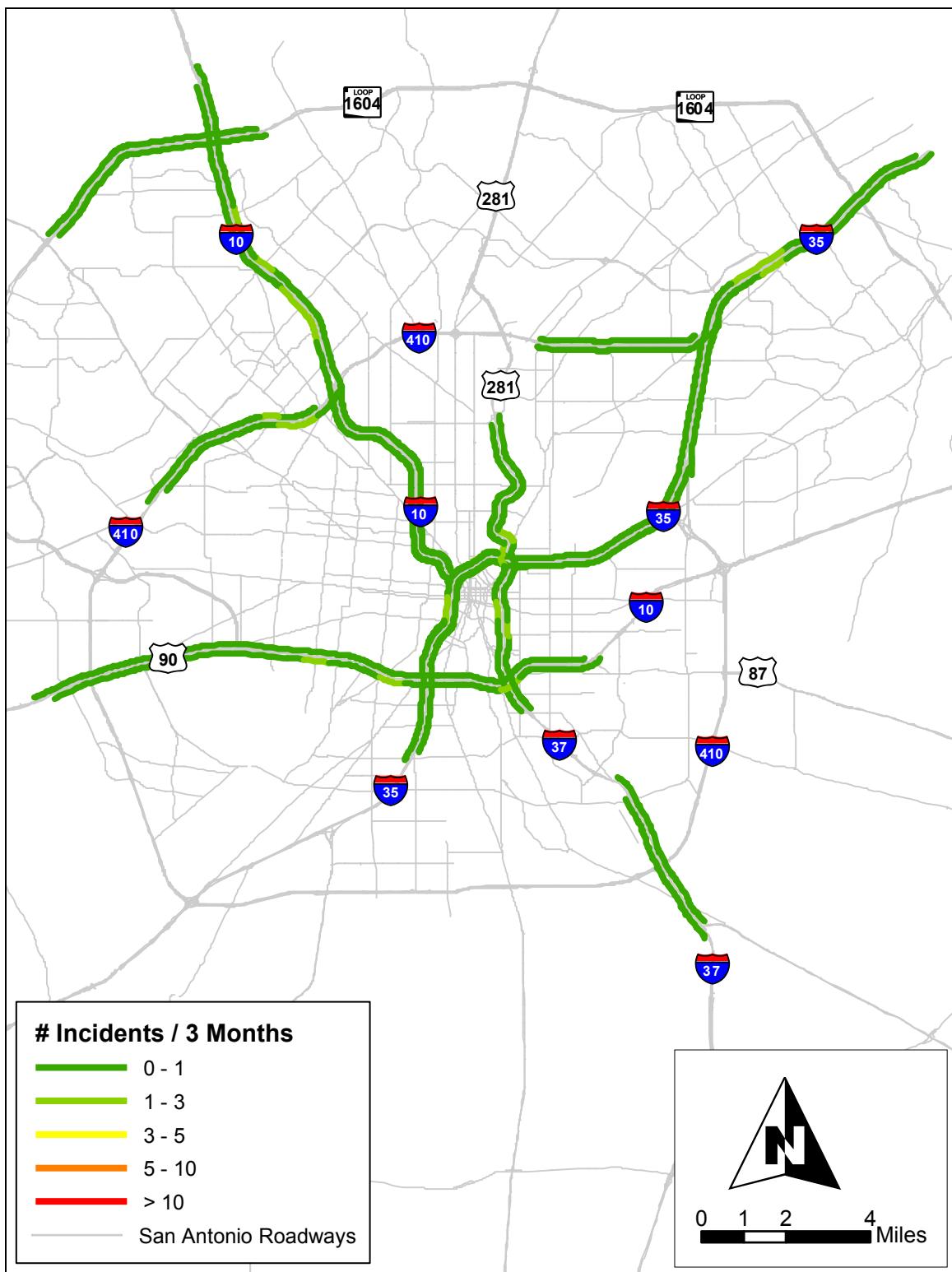
Figure 68. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2002.



**Figure 69. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2002-03.**



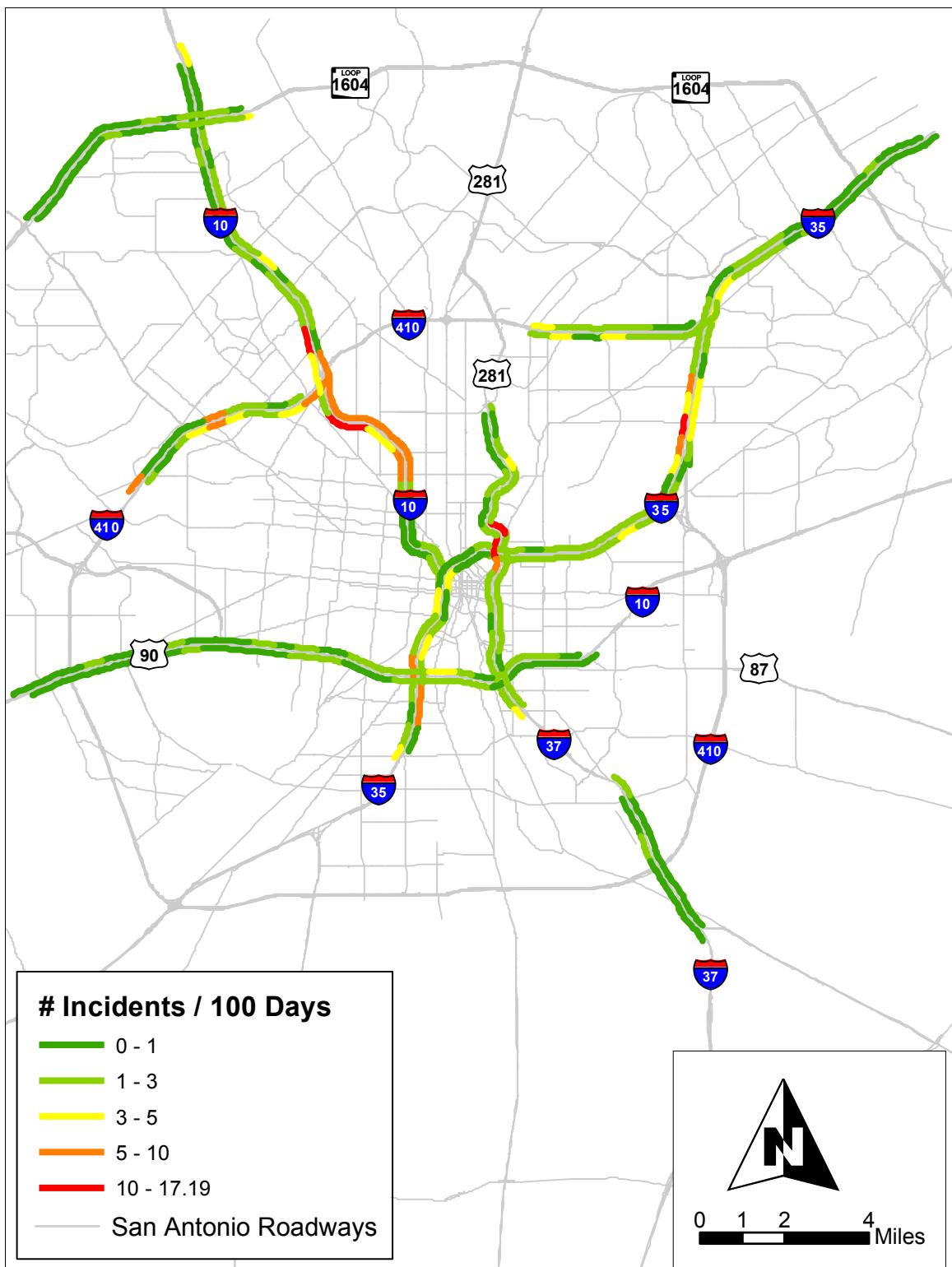
**Figure 70. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Summer 2003.**



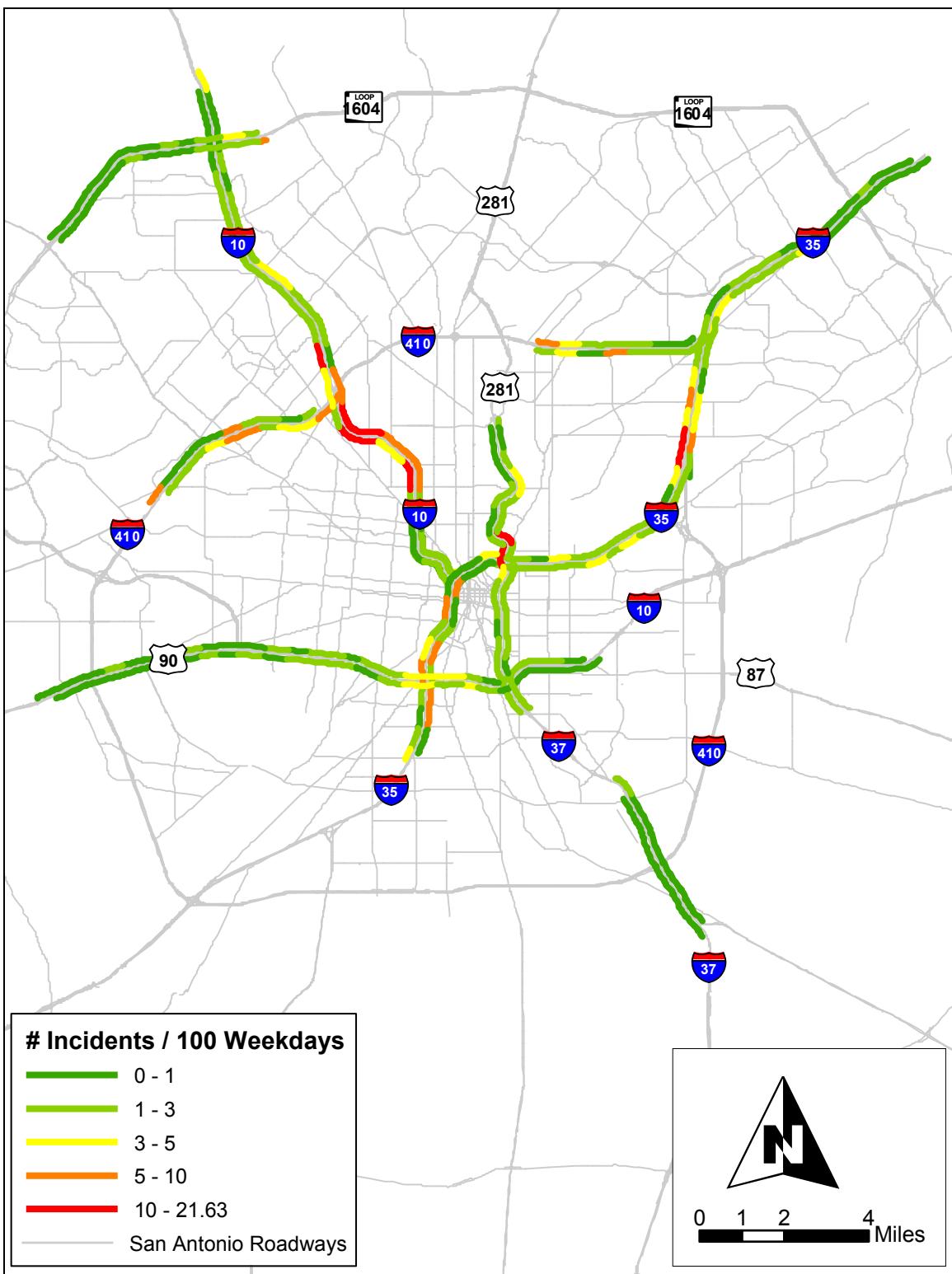
**Figure 71. Average Number of Debris Incidents per Month (Expressed as Number of Incidents per 3 Months)—Academic Year 2003-04.**

**APPENDIX B. SPATIAL DISTRIBUTION OF INCIDENTS BY DAY OF  
WEEK**





**Figure 72. Average Number of Major Accidents per Day (Expressed as Number of Incidents per 100 Days).**



**Figure 73. Average Number of Major Accidents per Weekday (Expressed as Number of Incidents per 100 Days).**

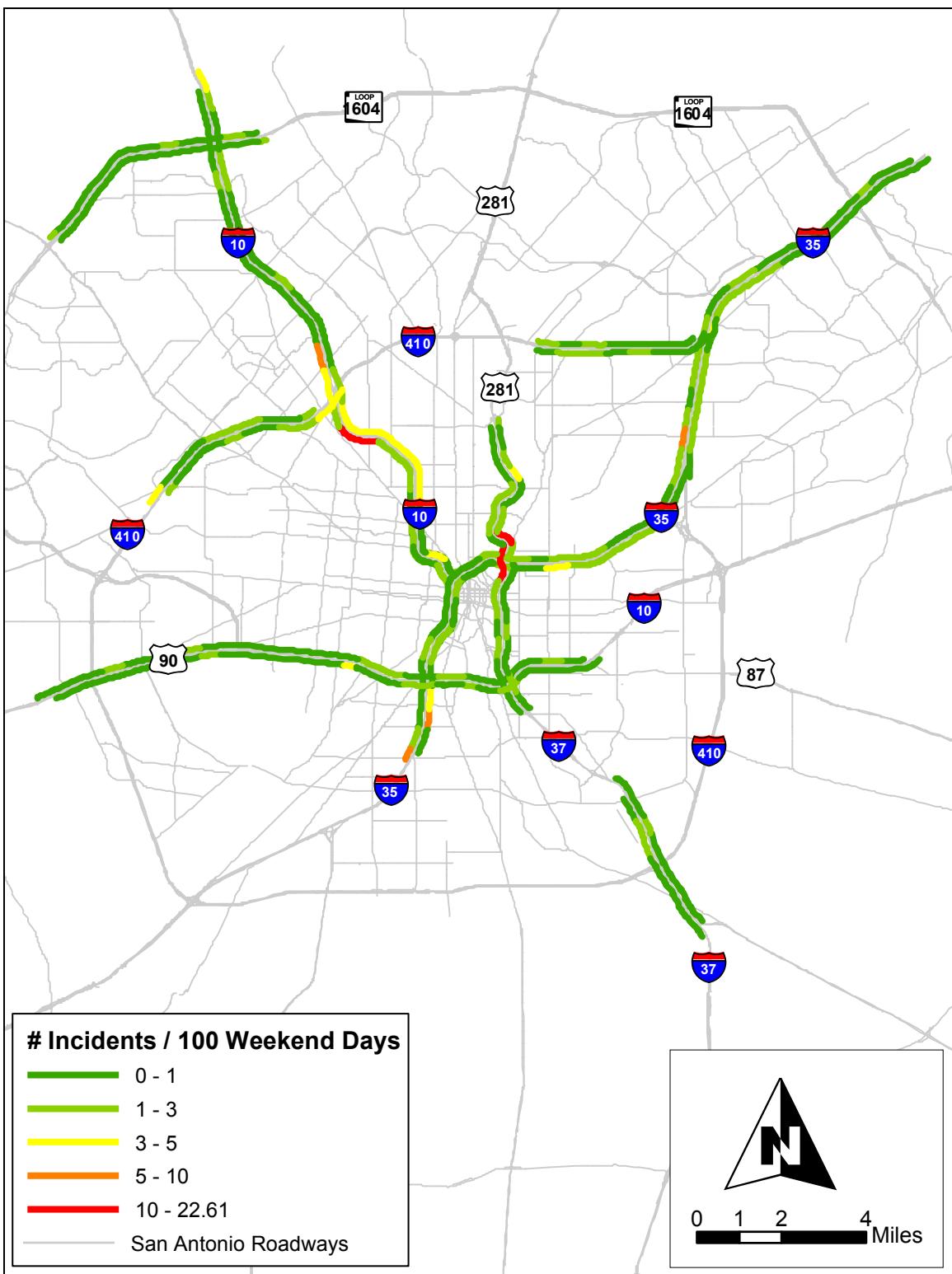
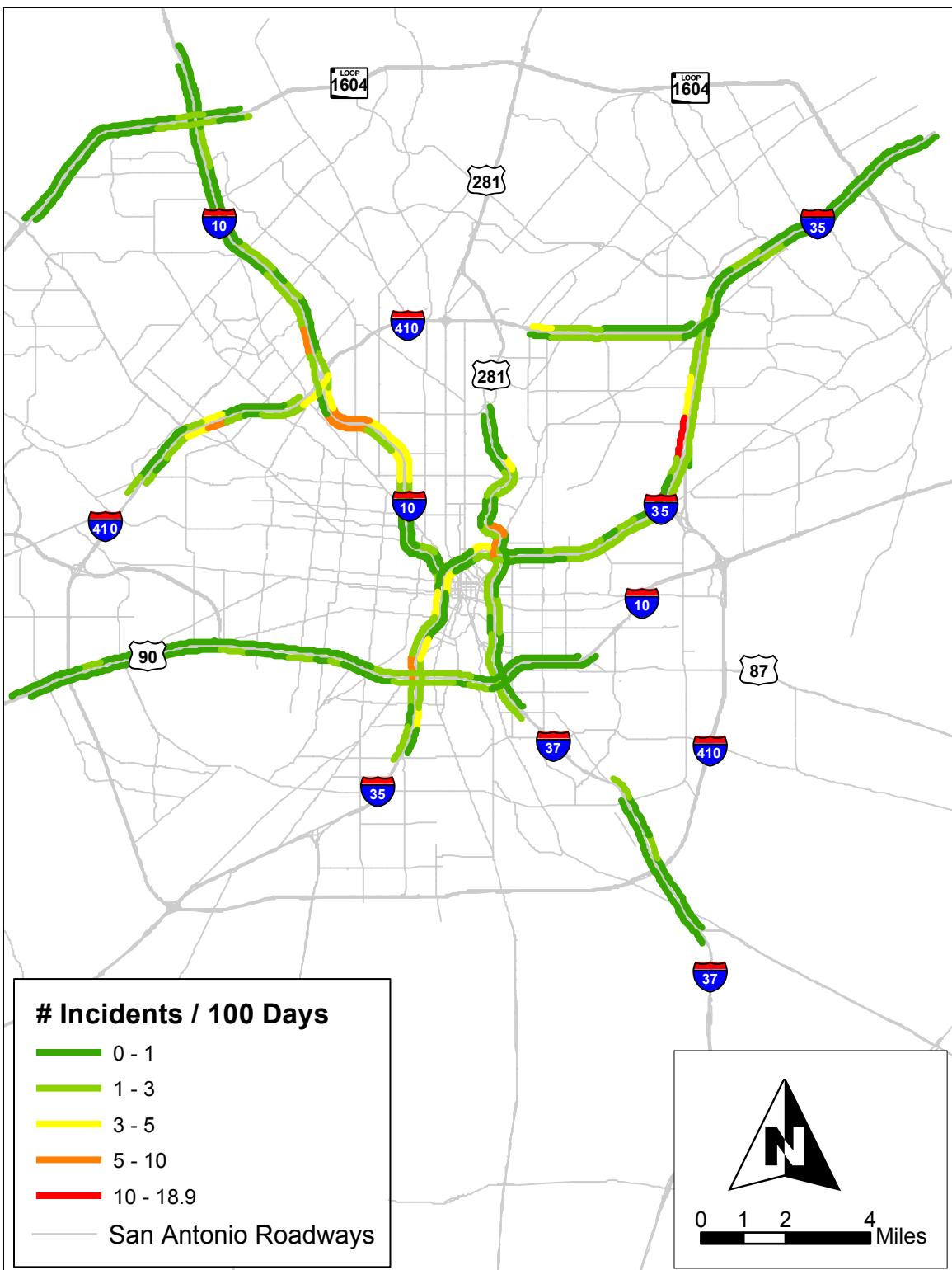
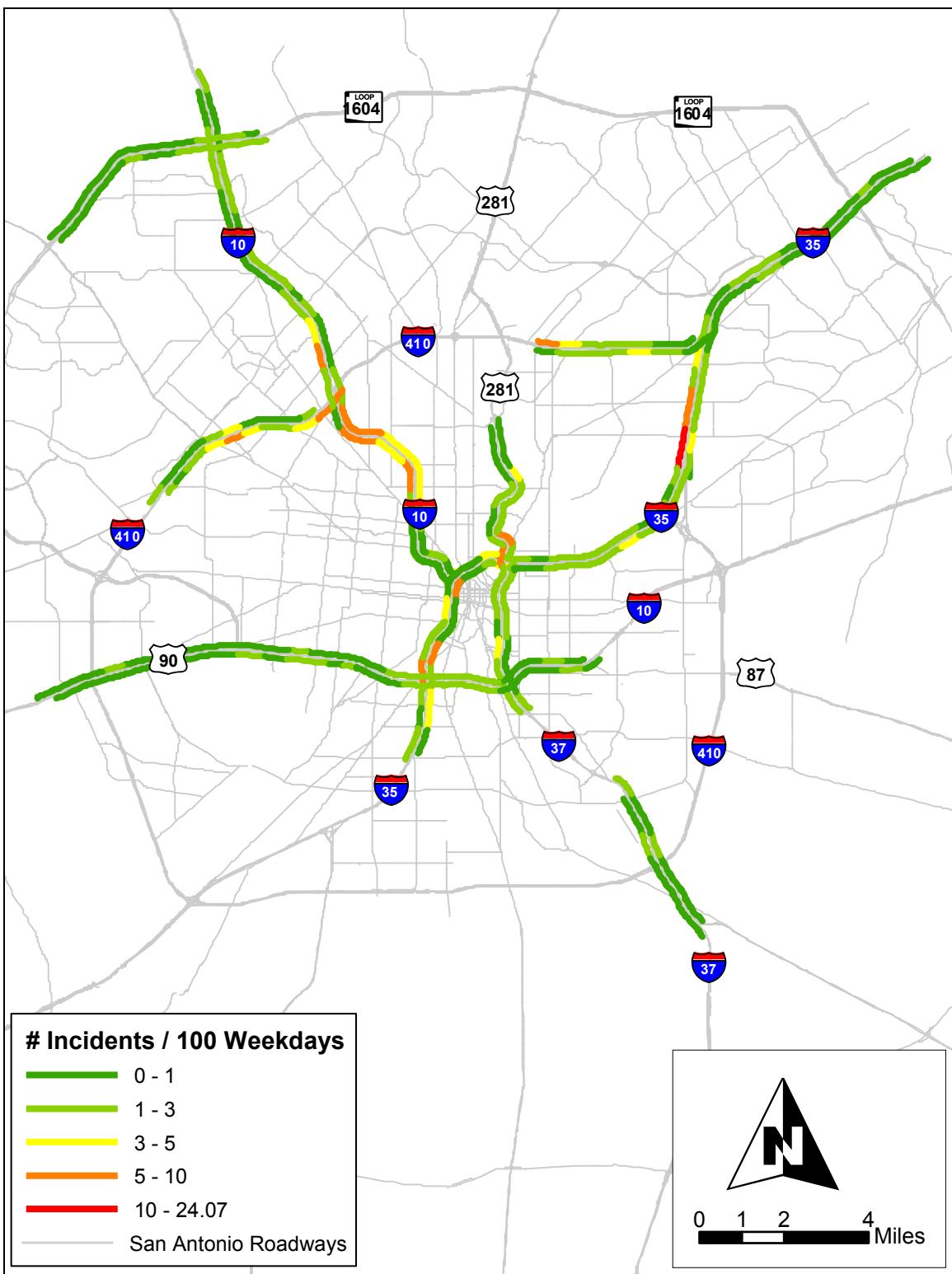


Figure 74. Average Number of Major Accidents per Weekend Day (Expressed as Number of Incidents per 100 Days).



**Figure 75. Average Number of Minor Accidents per Day (Expressed as Number of Incidents per 100 Days).**



**Figure 76. Average Number of Minor Accidents per Weekday (Expressed as Number of Incidents per 100 Days).**

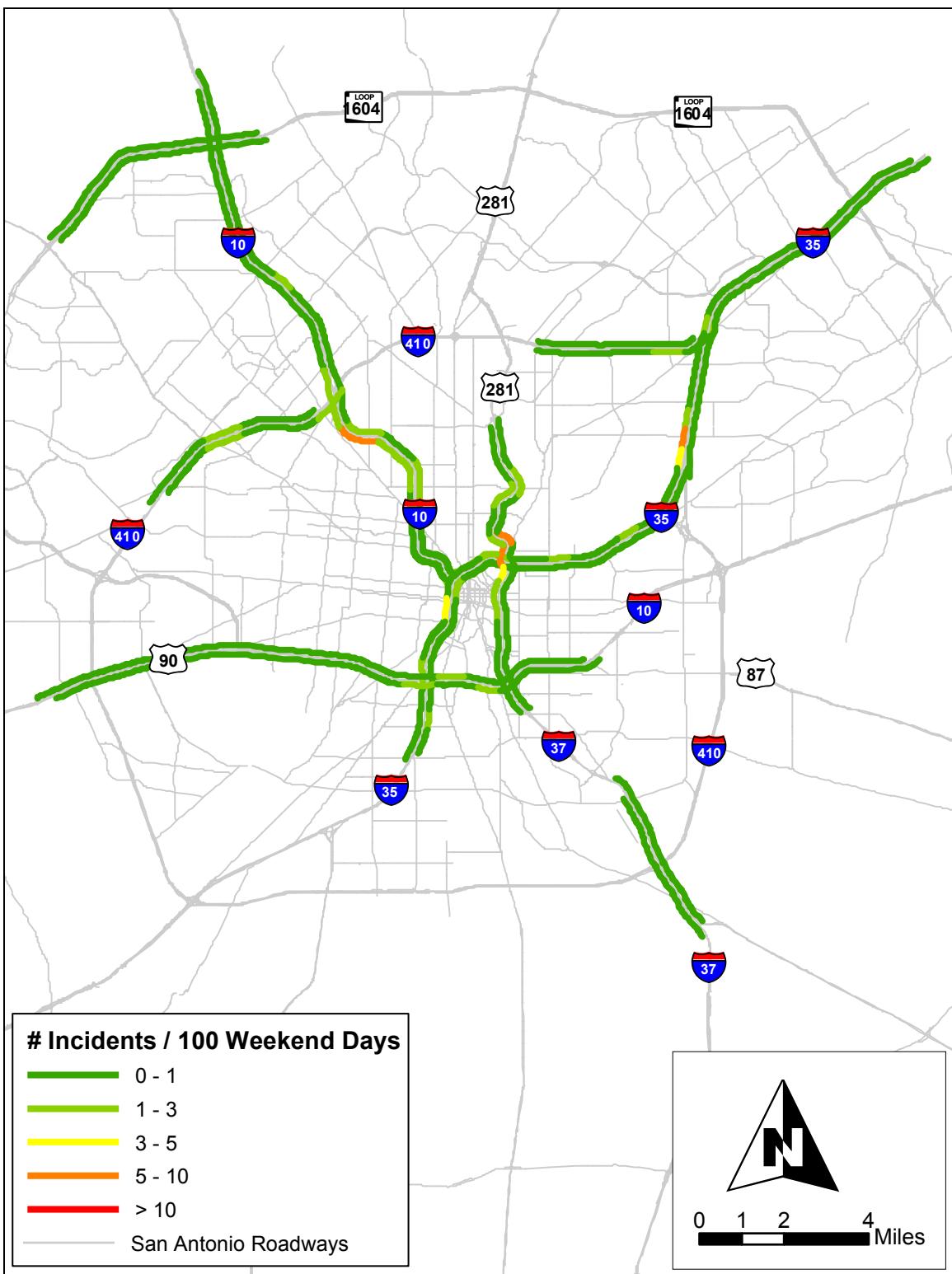
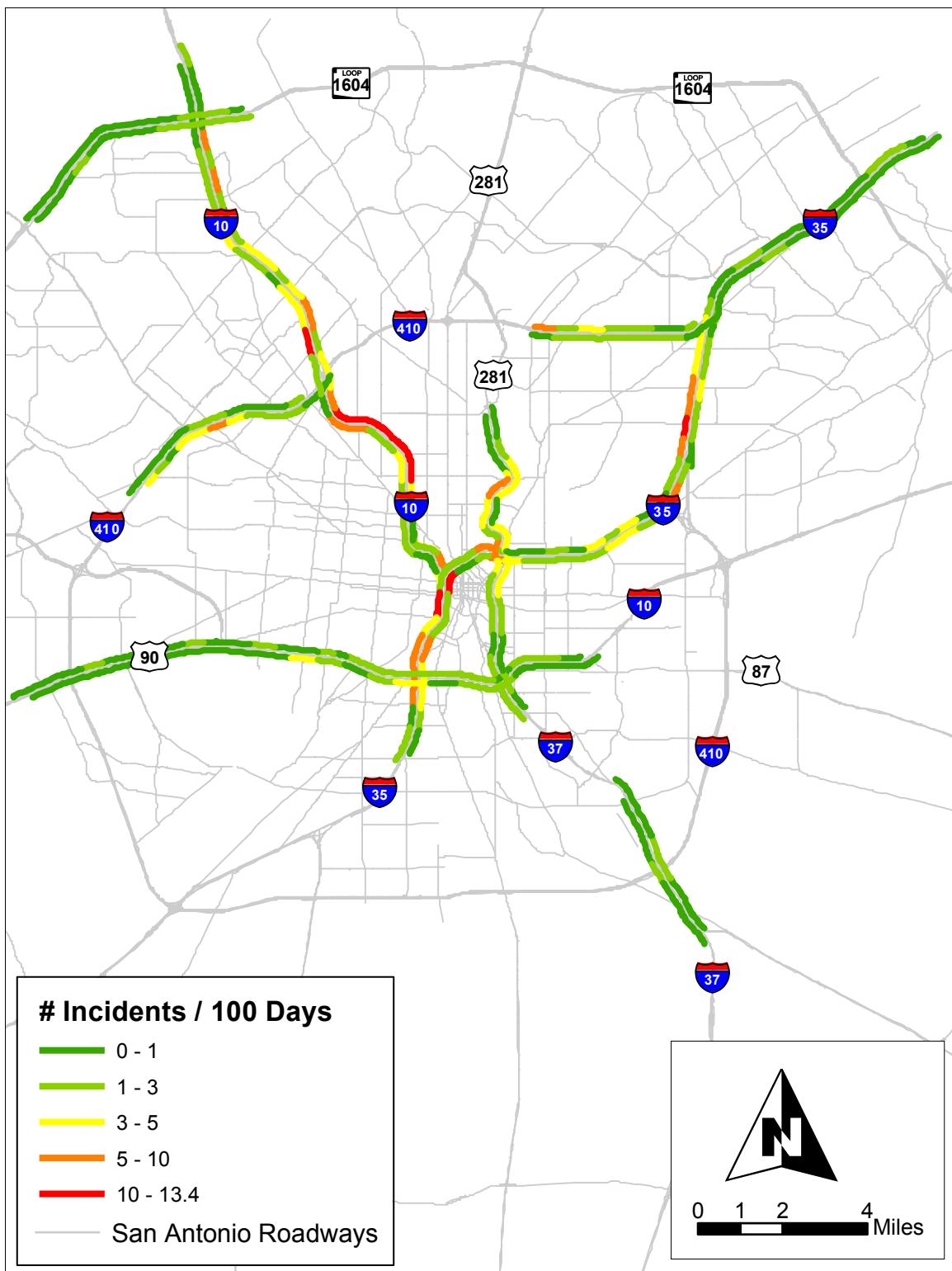
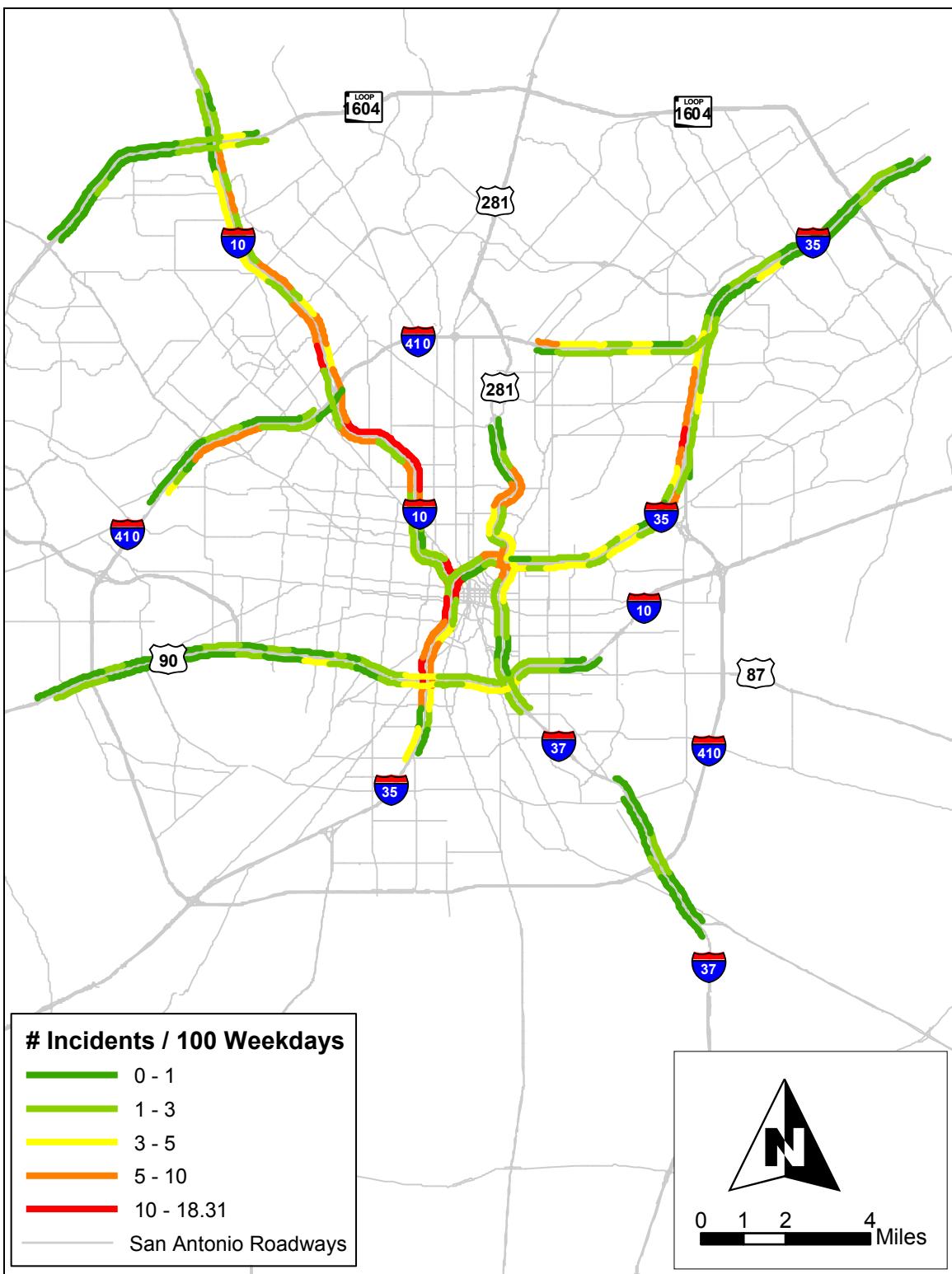


Figure 77. Average Number of Minor Accidents per Weekend Day (Expressed as Number of Incidents per 100 Days).



**Figure 78. Average Number of Stalled Vehicle Incidents per Day (Expressed as Number of Incidents per 100 Days).**



**Figure 79. Average Number of Stalled Vehicle Incidents per Weekday (Expressed as Number of Incidents per 100 Days).**

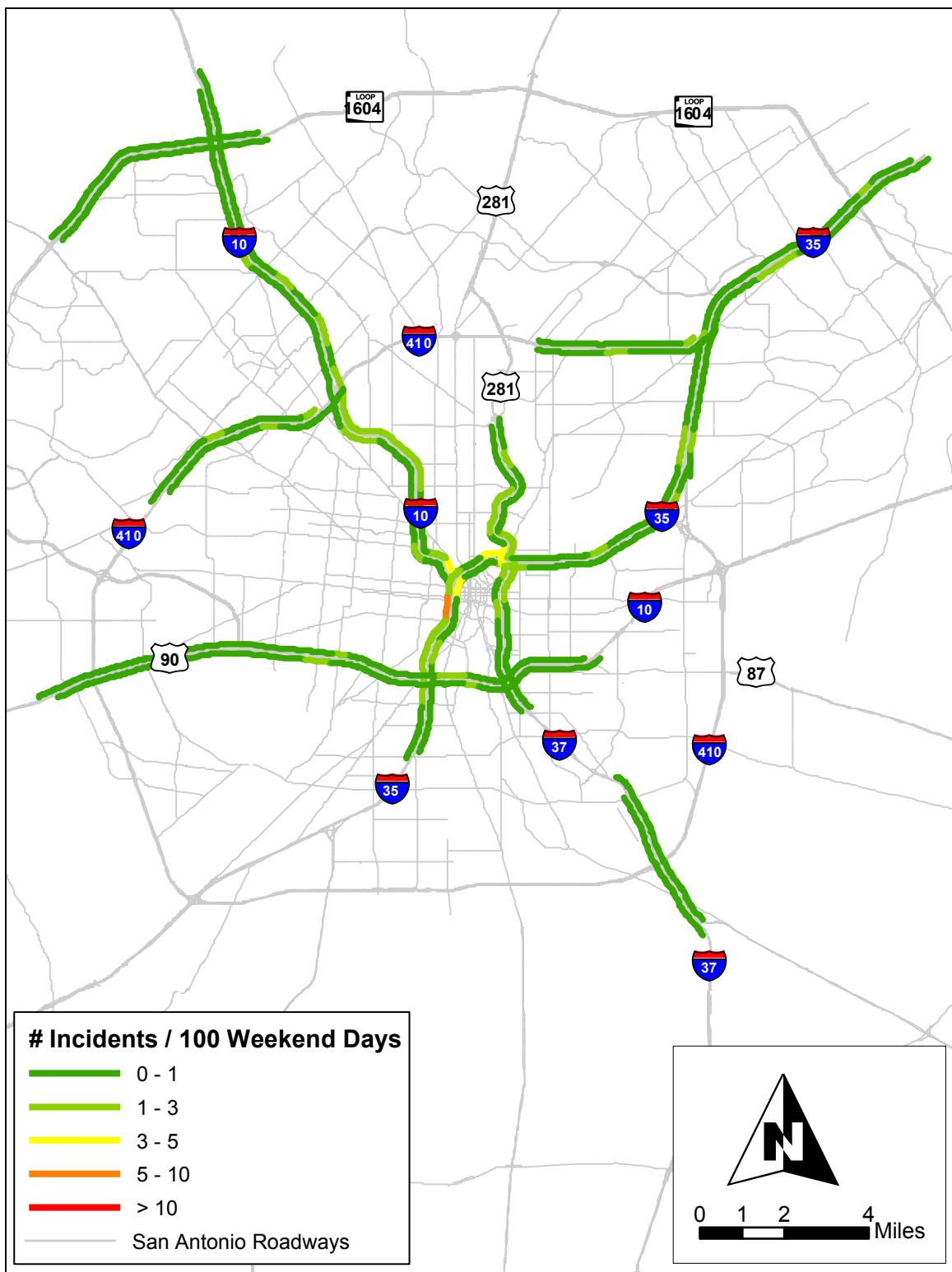


Figure 80. Average Number of Stalled Vehicle Incidents per Weekend Day (Expressed as Number of Incidents per 100 Days).

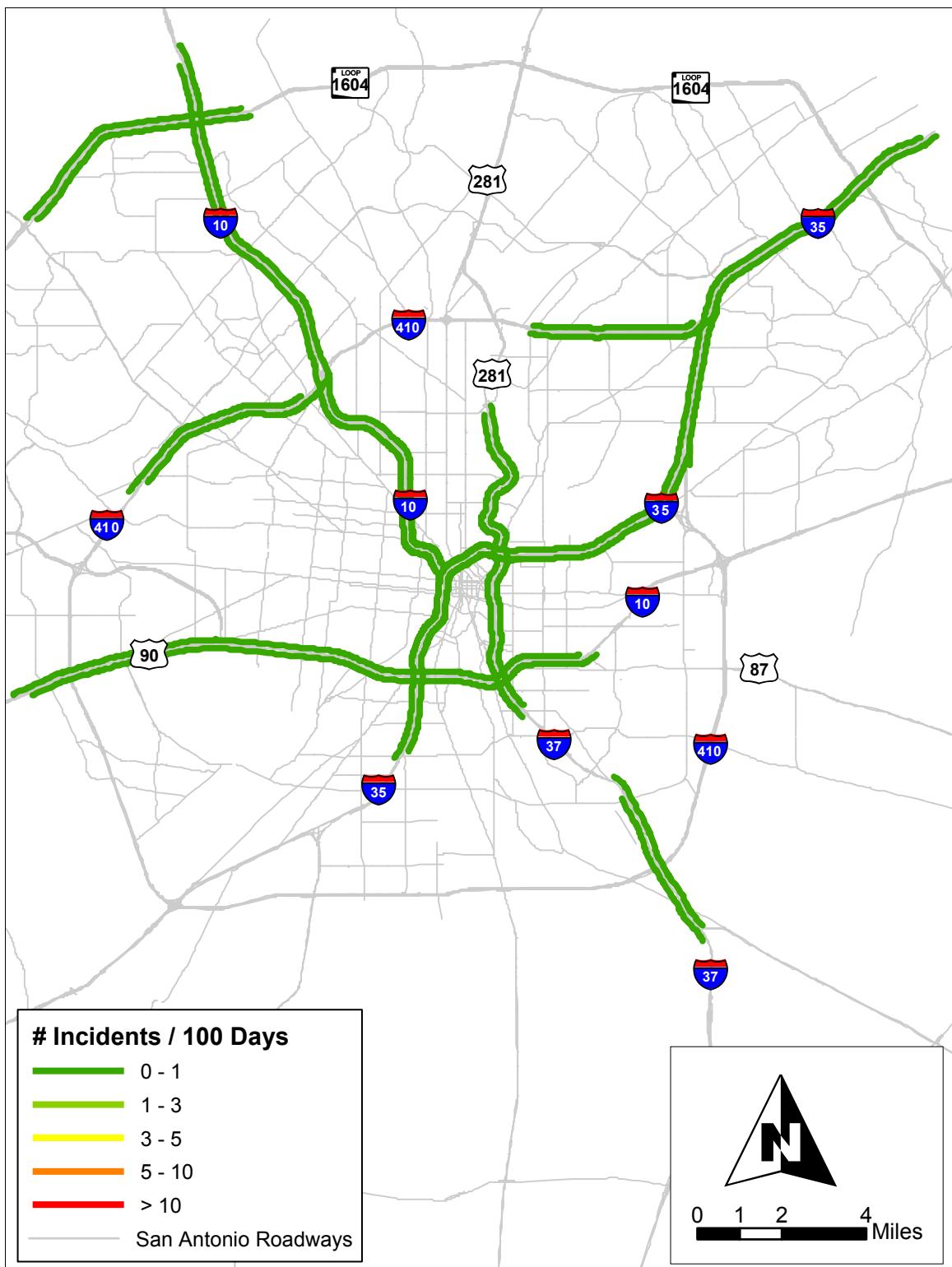


Figure 81. Average Number of Debris Incidents per Day (Expressed as Number of Incidents per 100 Days).

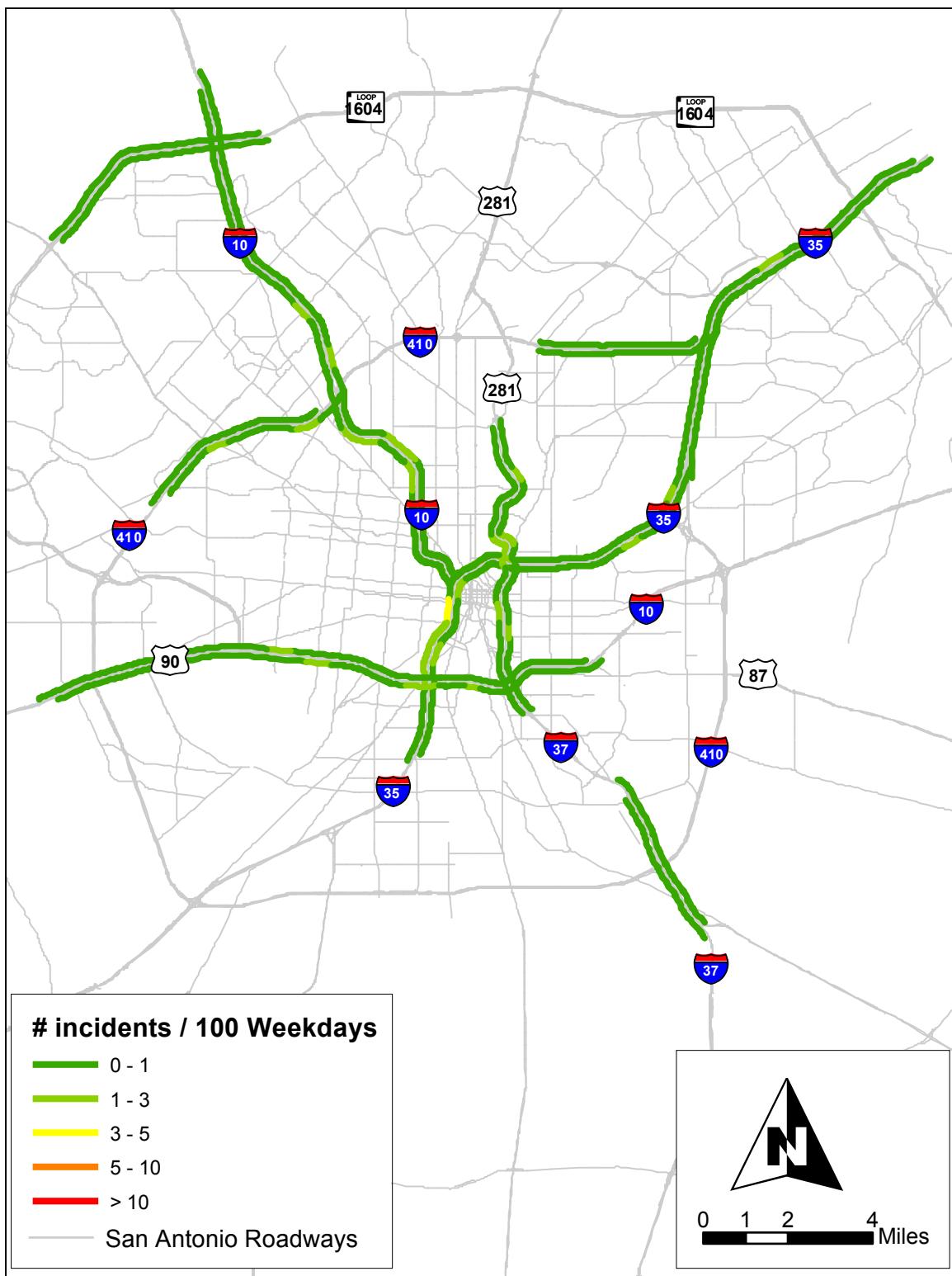


Figure 82. Average Number of Debris Incidents per Weekday (Expressed as Number of Incidents per 100 Days).

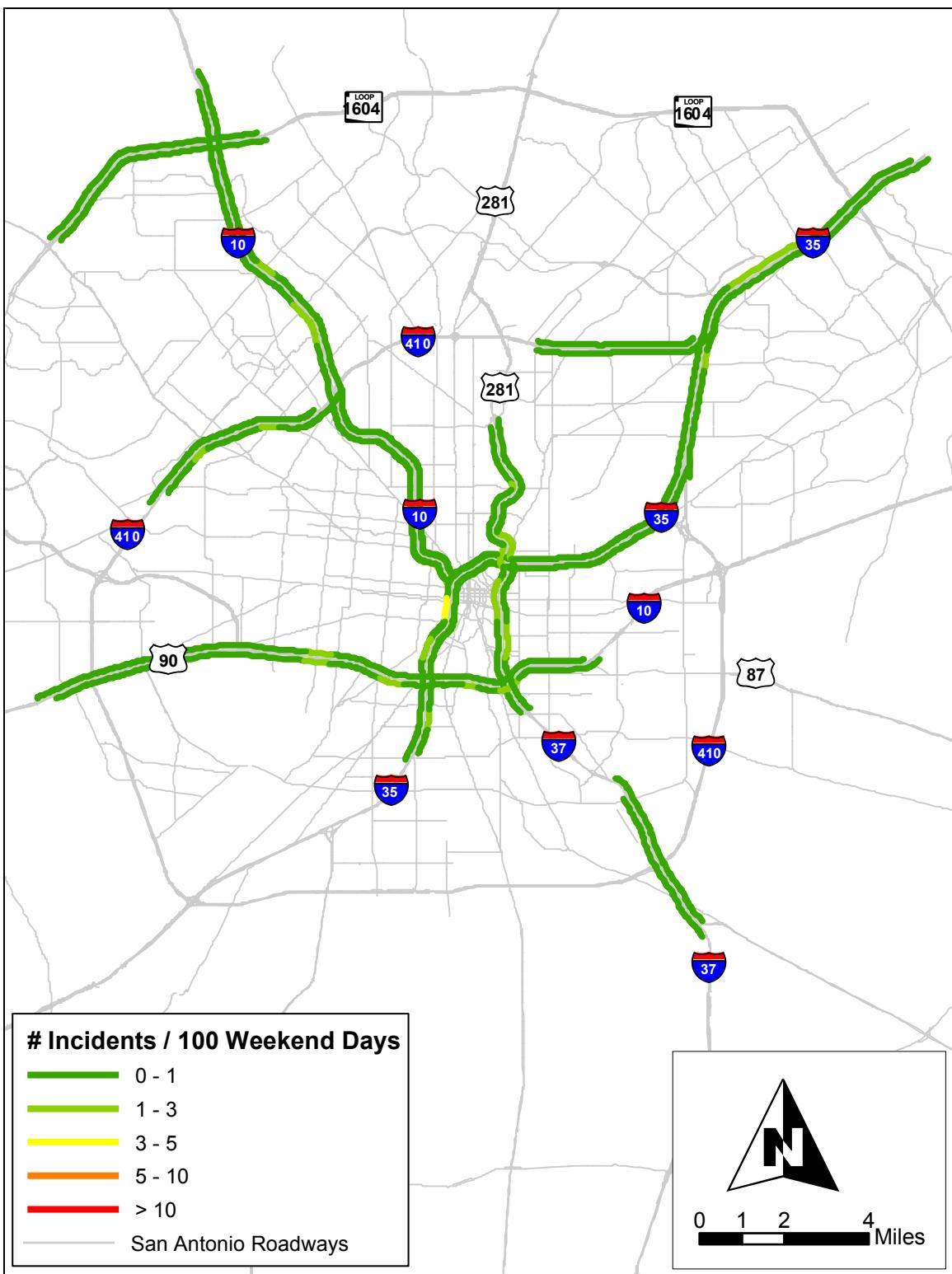


Figure 83. Average Number of Debris Incidents per Weekend Day (Expressed as Number of Incidents per 100 Days).

## **APPENDIX C. SPATIAL DISTRIBUTION OF INCIDENTS BY TIME OF DAY**



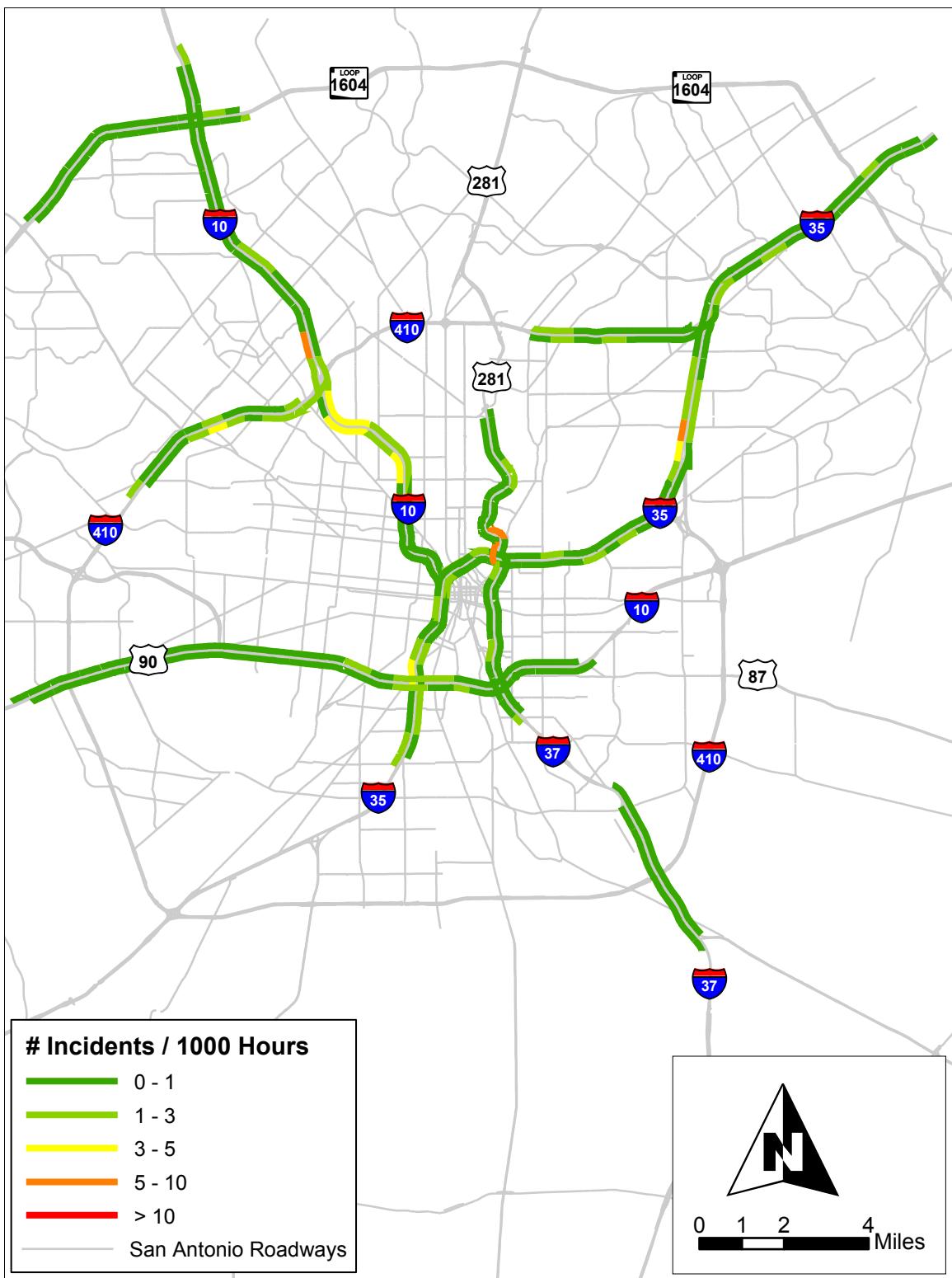
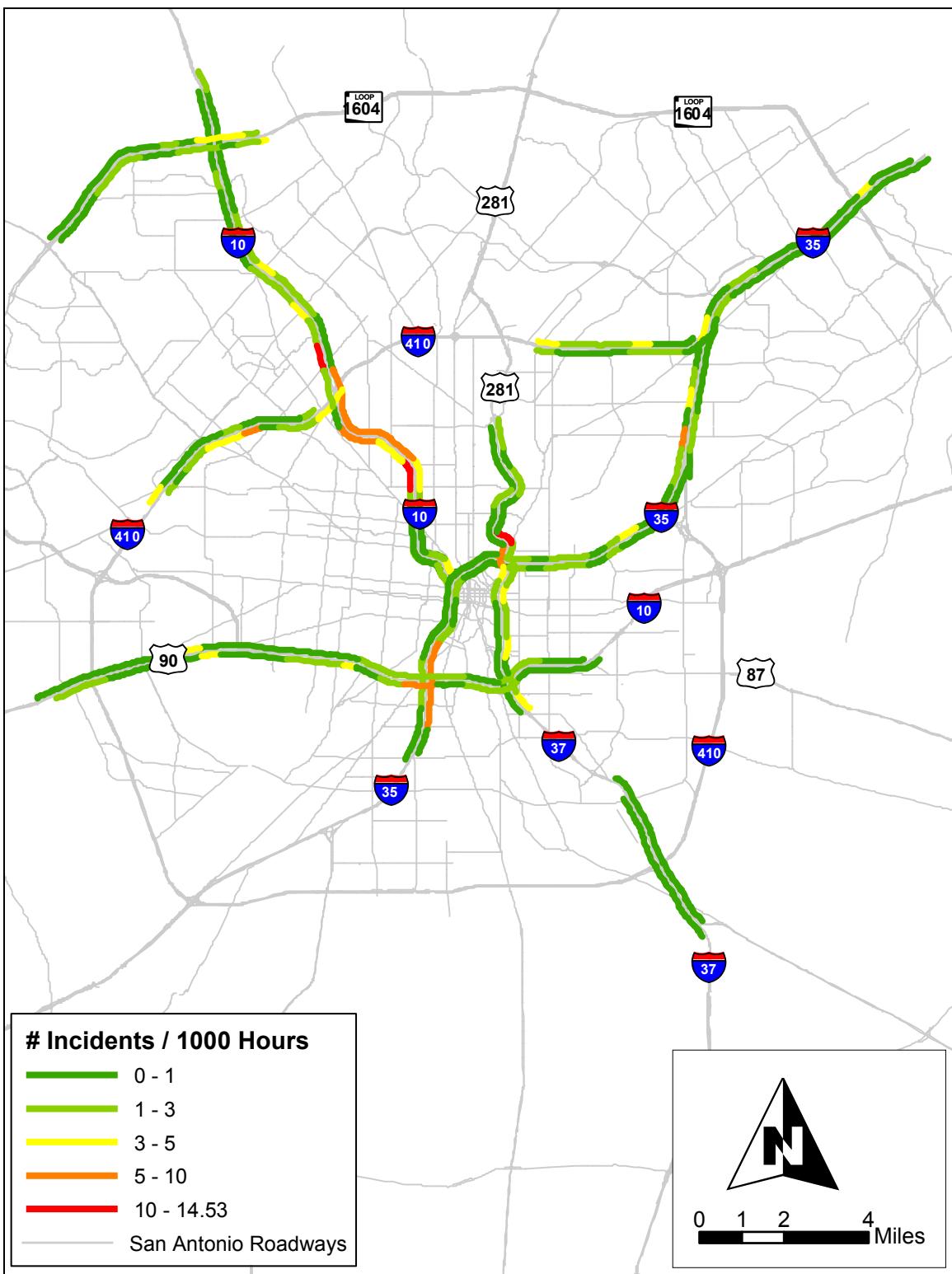


Figure 84. Average Number of Major Accident Incidents per 1000 Hours.



**Figure 85. Average Number of Major Accident Incidents per 1000 Hours during AM Peak Hours (7-9 AM).**

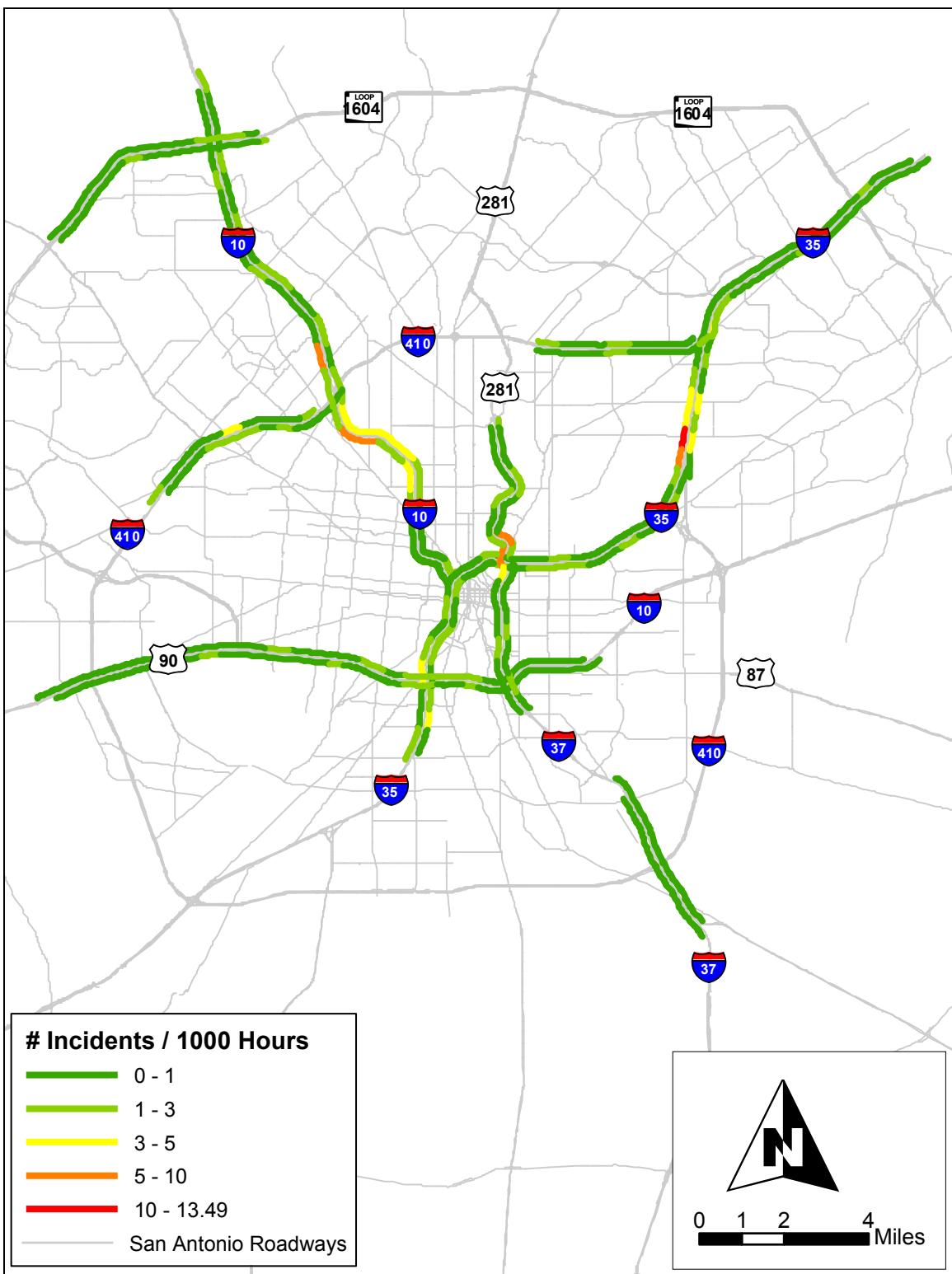
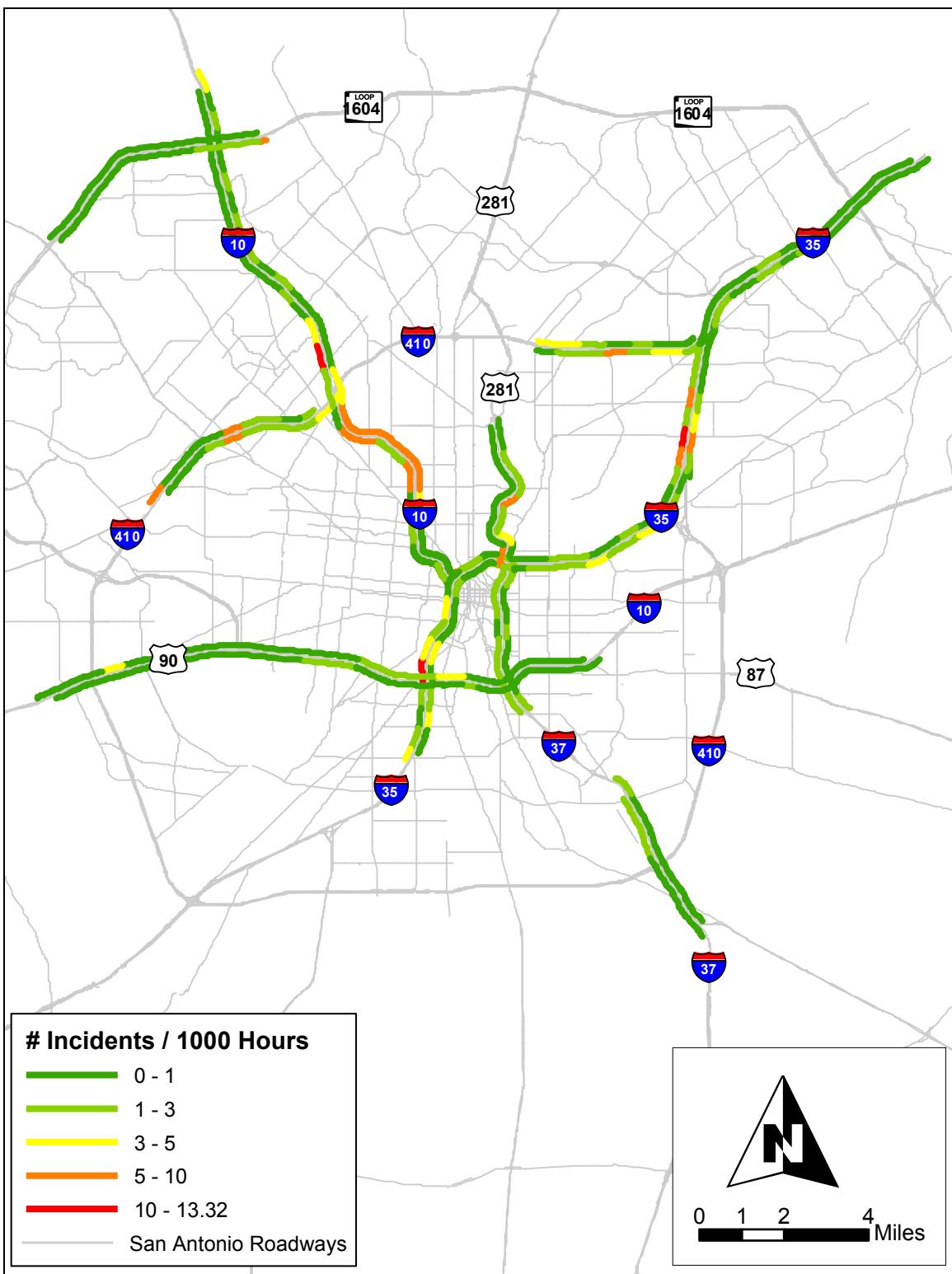


Figure 86. Average Number of Major Accident Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).



**Figure 87. Average Number of Major Accident Incidents per 1000 Hours during PM Peak Hours (4-7 PM).**

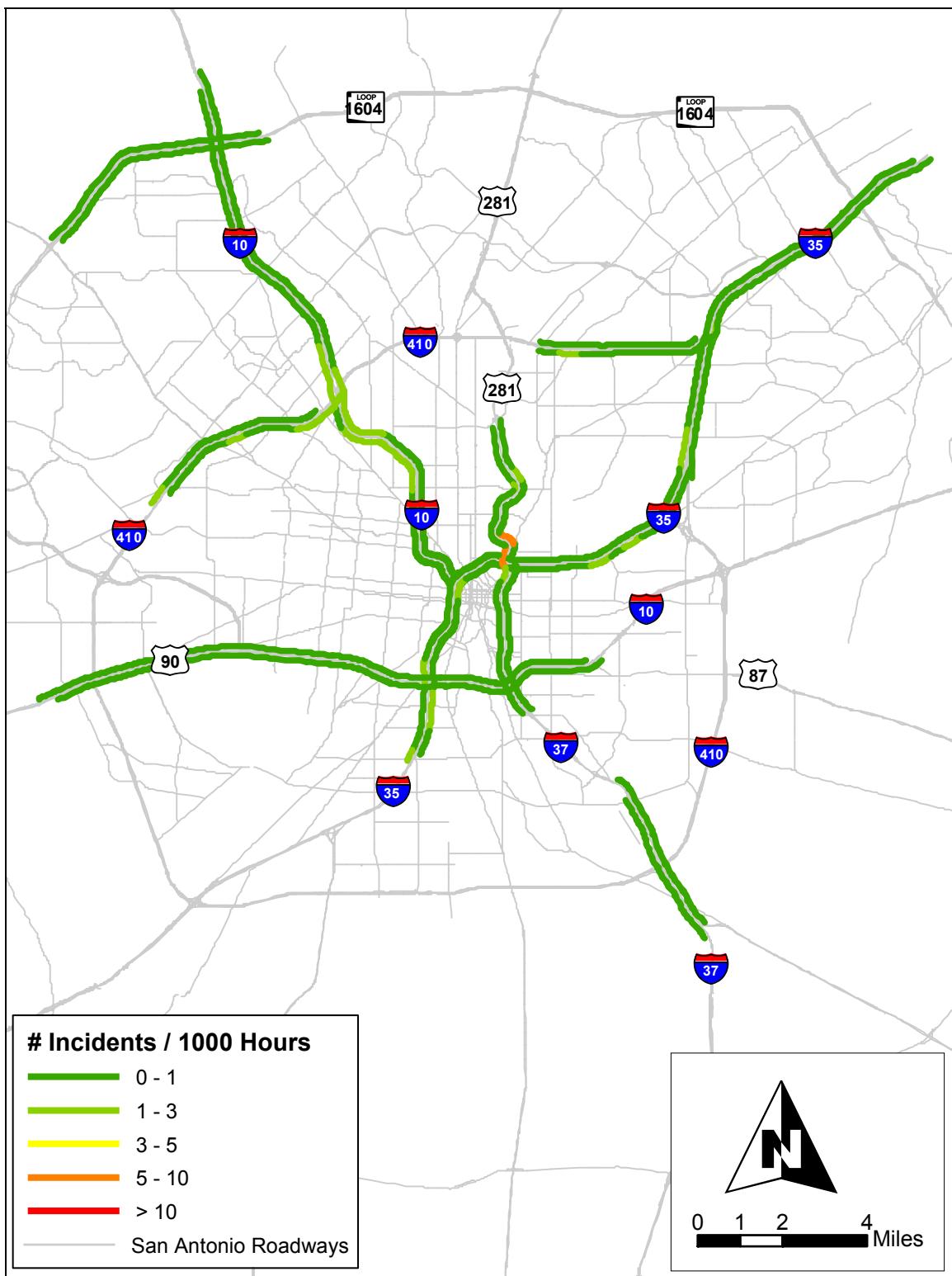


Figure 88. Average Number of Major Accident Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).

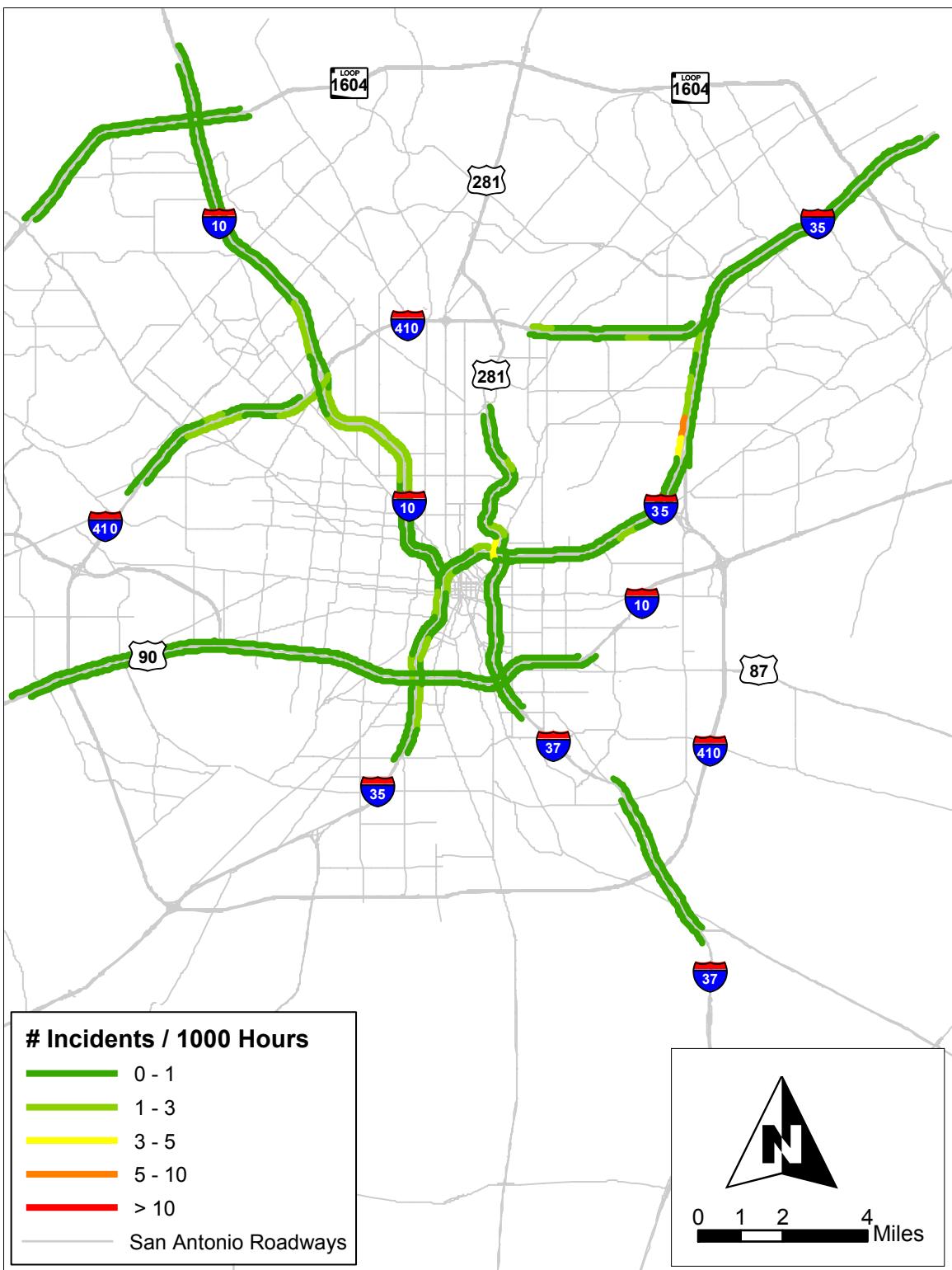
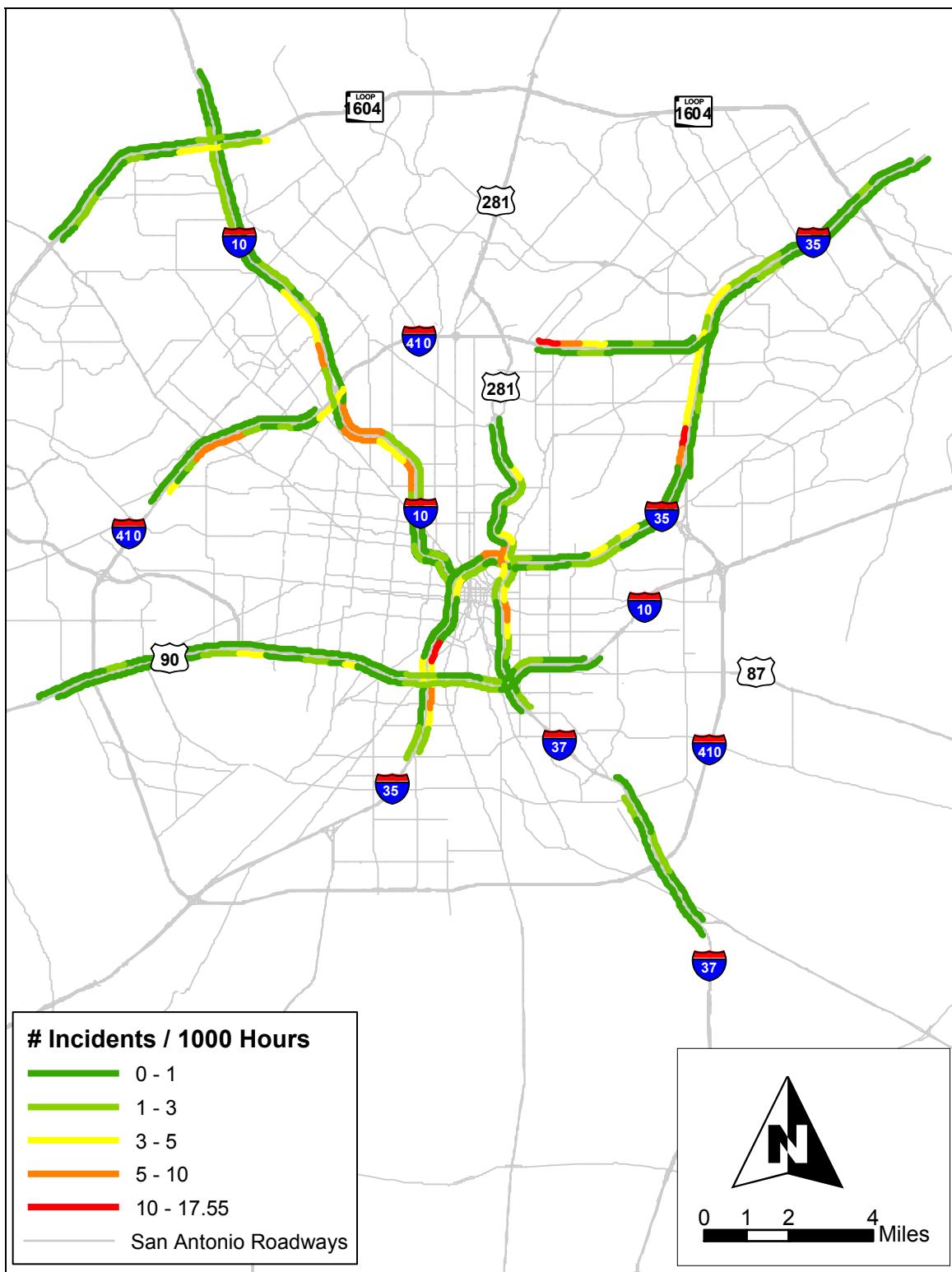
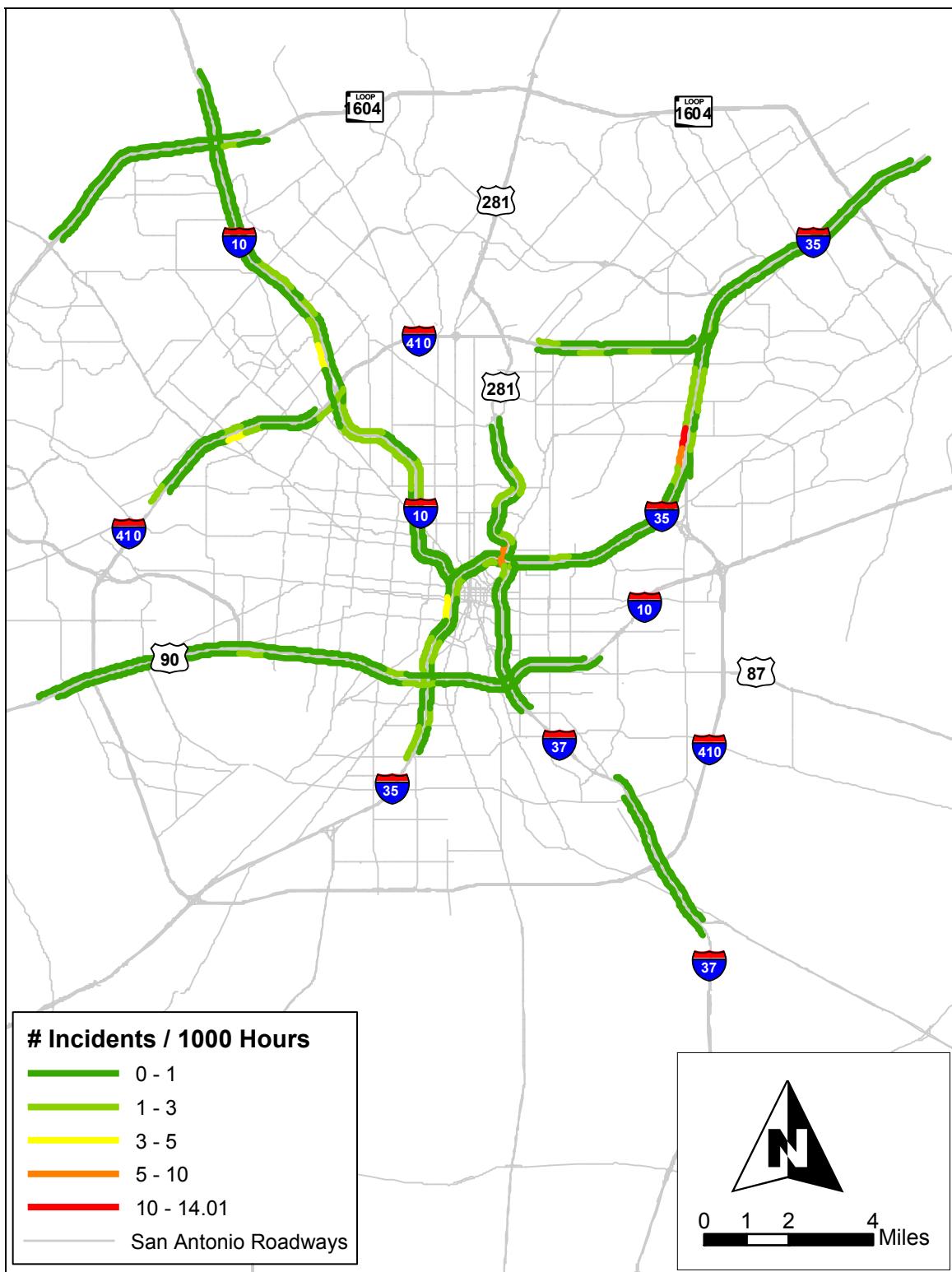


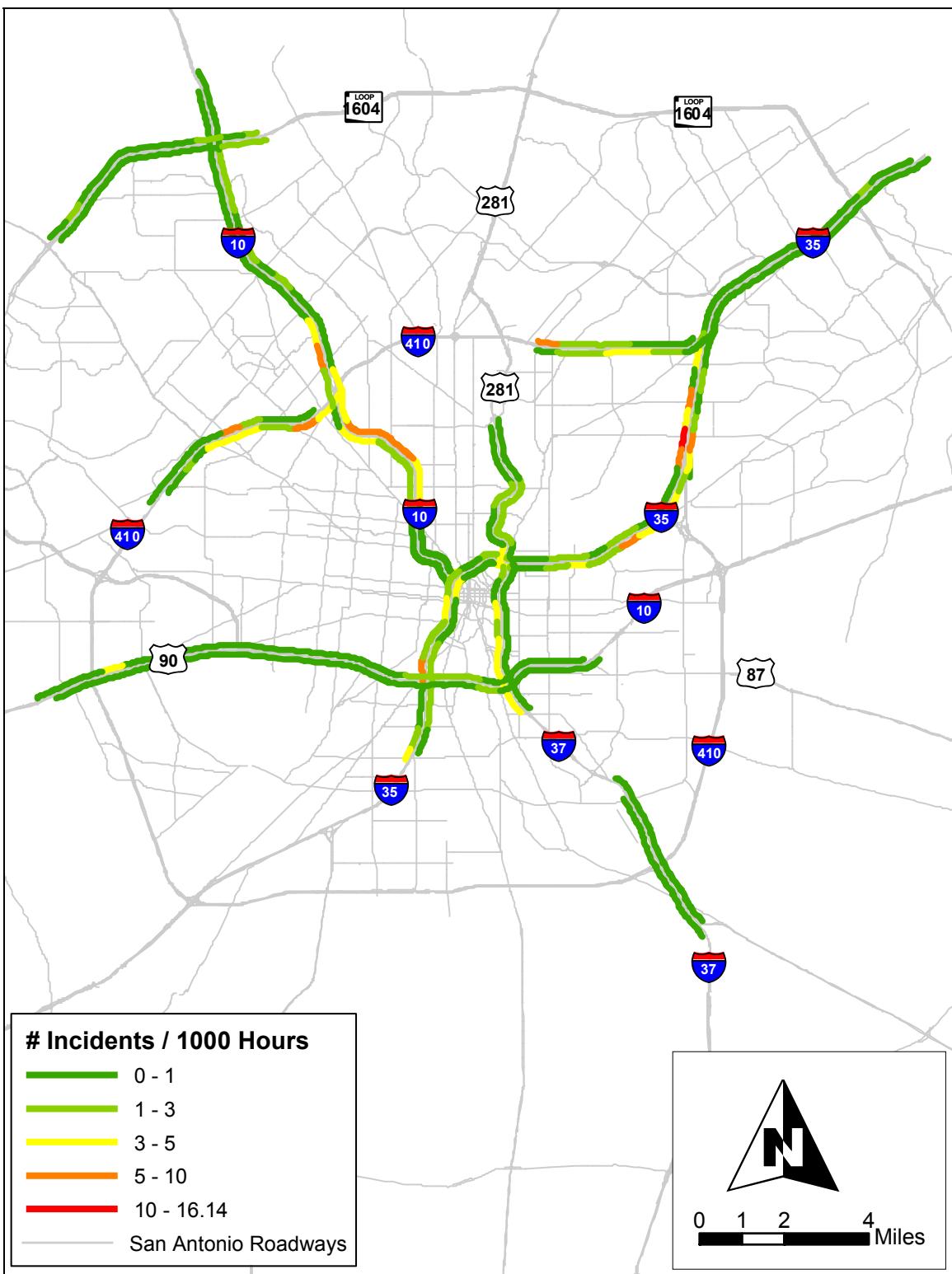
Figure 89. Average Number of Minor Accident Incidents per 1000 Hours.



**Figure 90. Average Number of Minor Accident Incidents per 1000 Hours during AM Peak Hours (7-9 AM).**



**Figure 91. Average Number of Minor Accident Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).**



**Figure 92. Average Number of Minor Accident Incidents per 1000 Hours during PM Peak Hours (4-7 PM).**

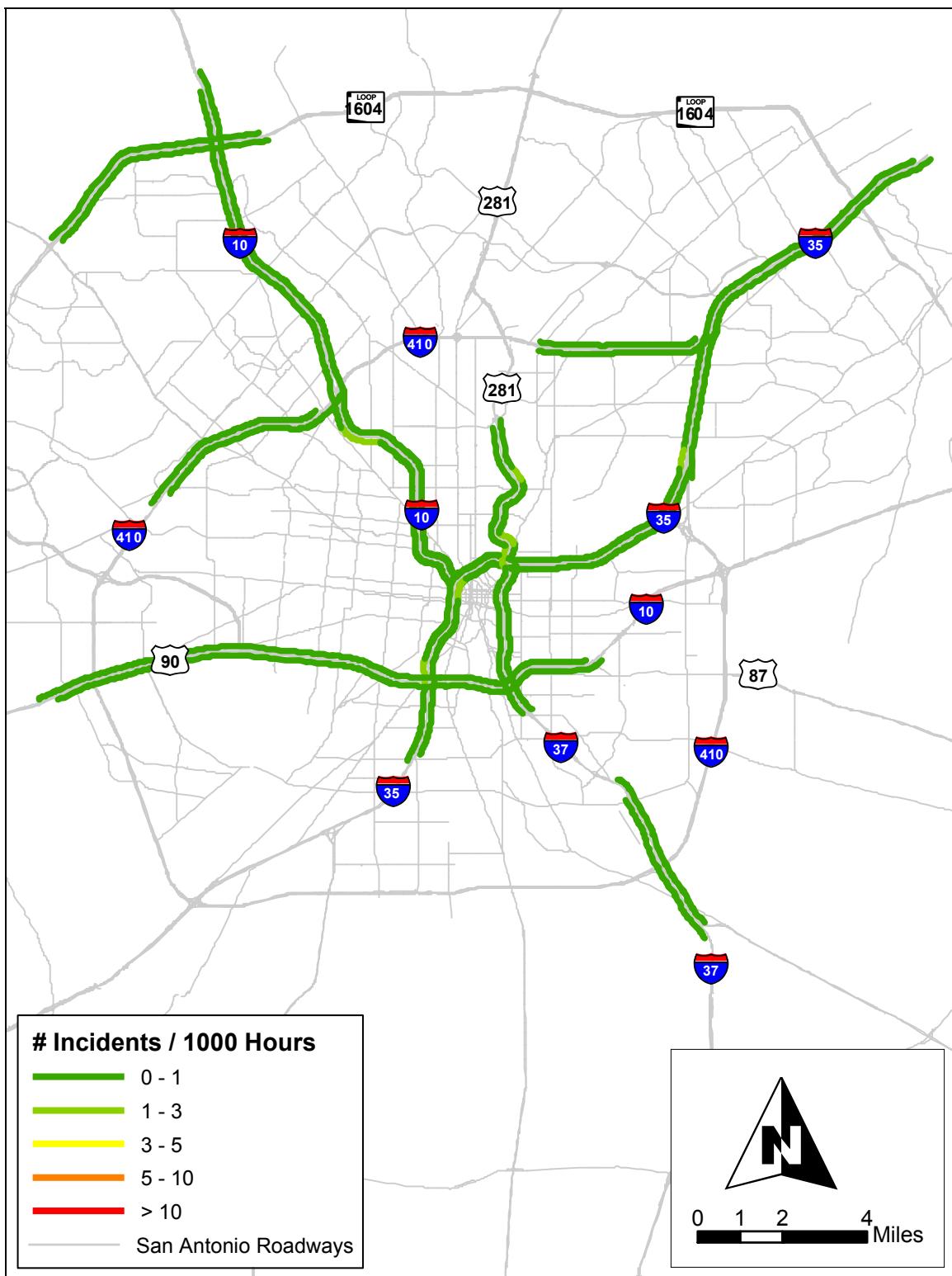


Figure 93. Average Number of Minor Accident Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).

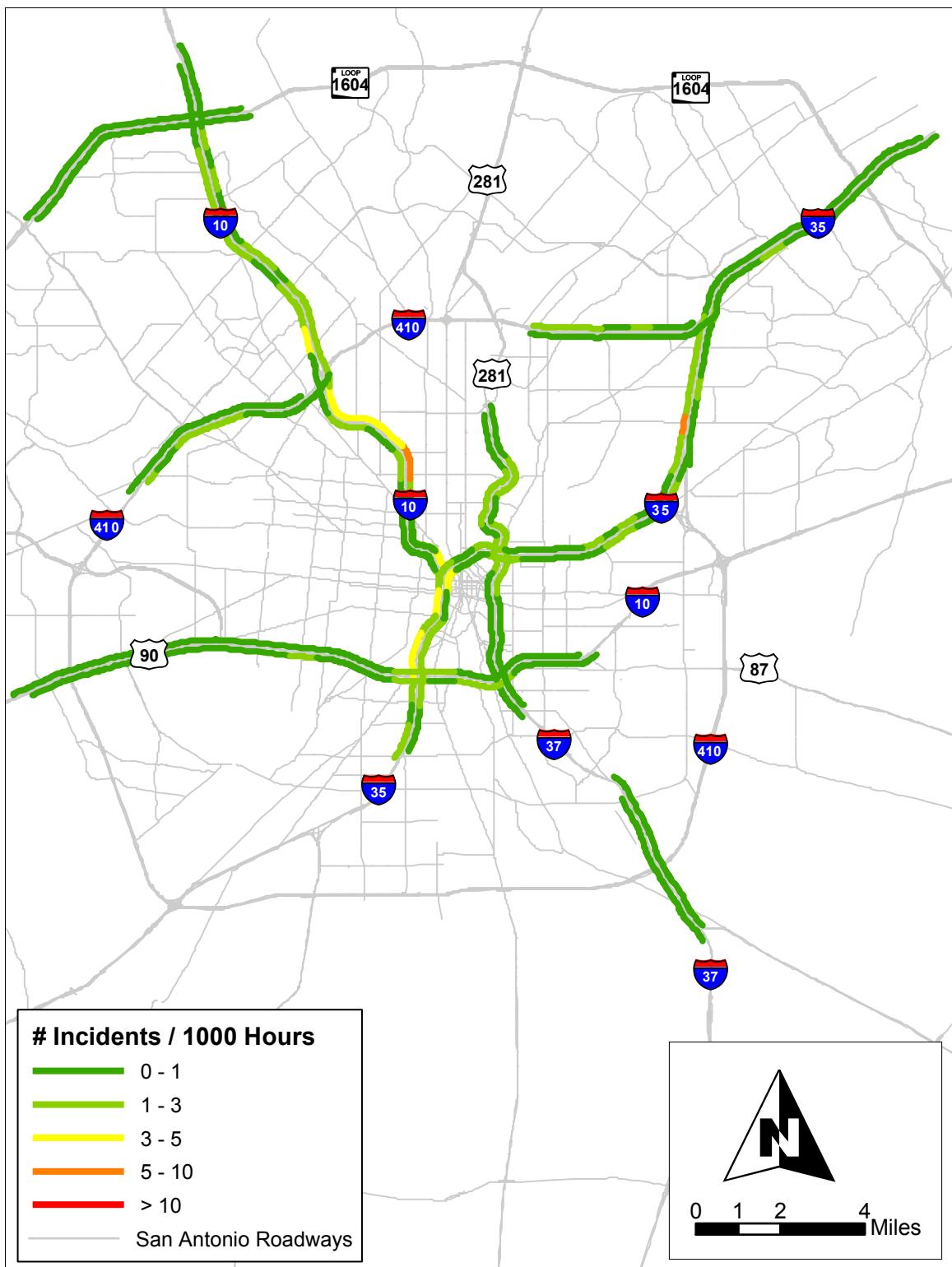
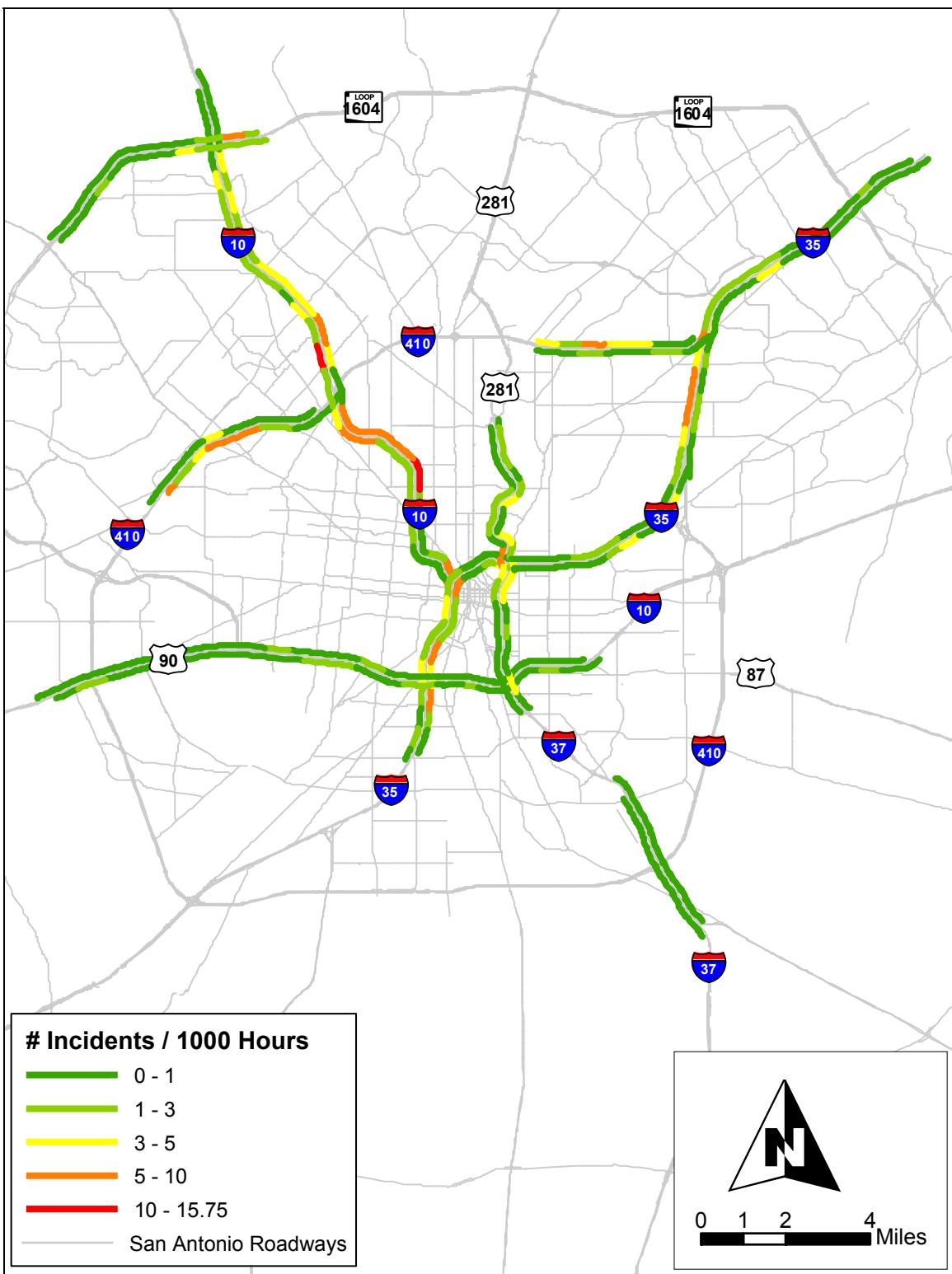


Figure 94. Average Number of Stalled Vehicle Incidents per 1000 Hours.



**Figure 95. Average Number of Stalled Vehicle Incidents per 1000 Hours during AM Peak Hours (7-9 AM).**

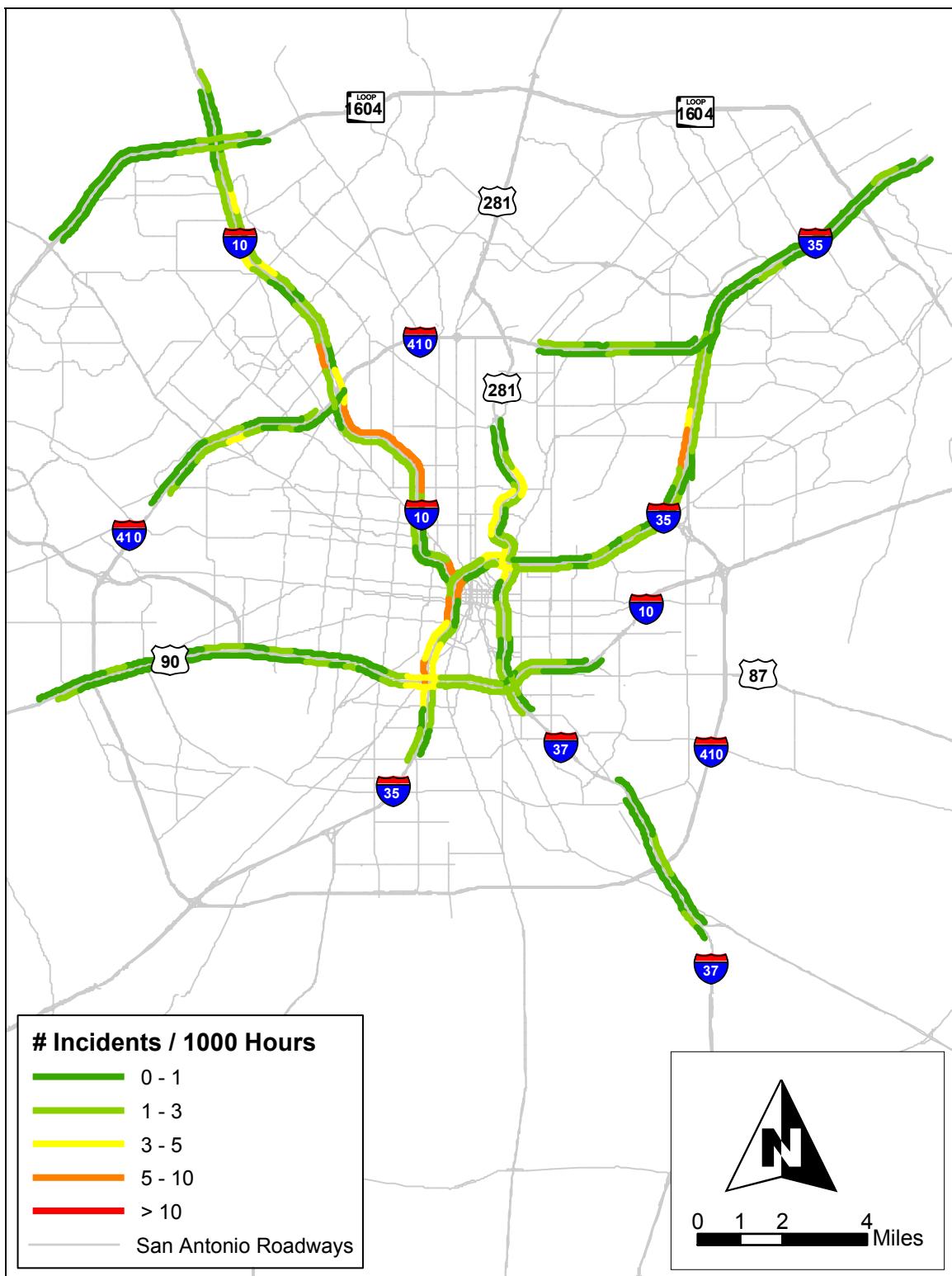


Figure 96. Average Number of Stalled Vehicle Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).

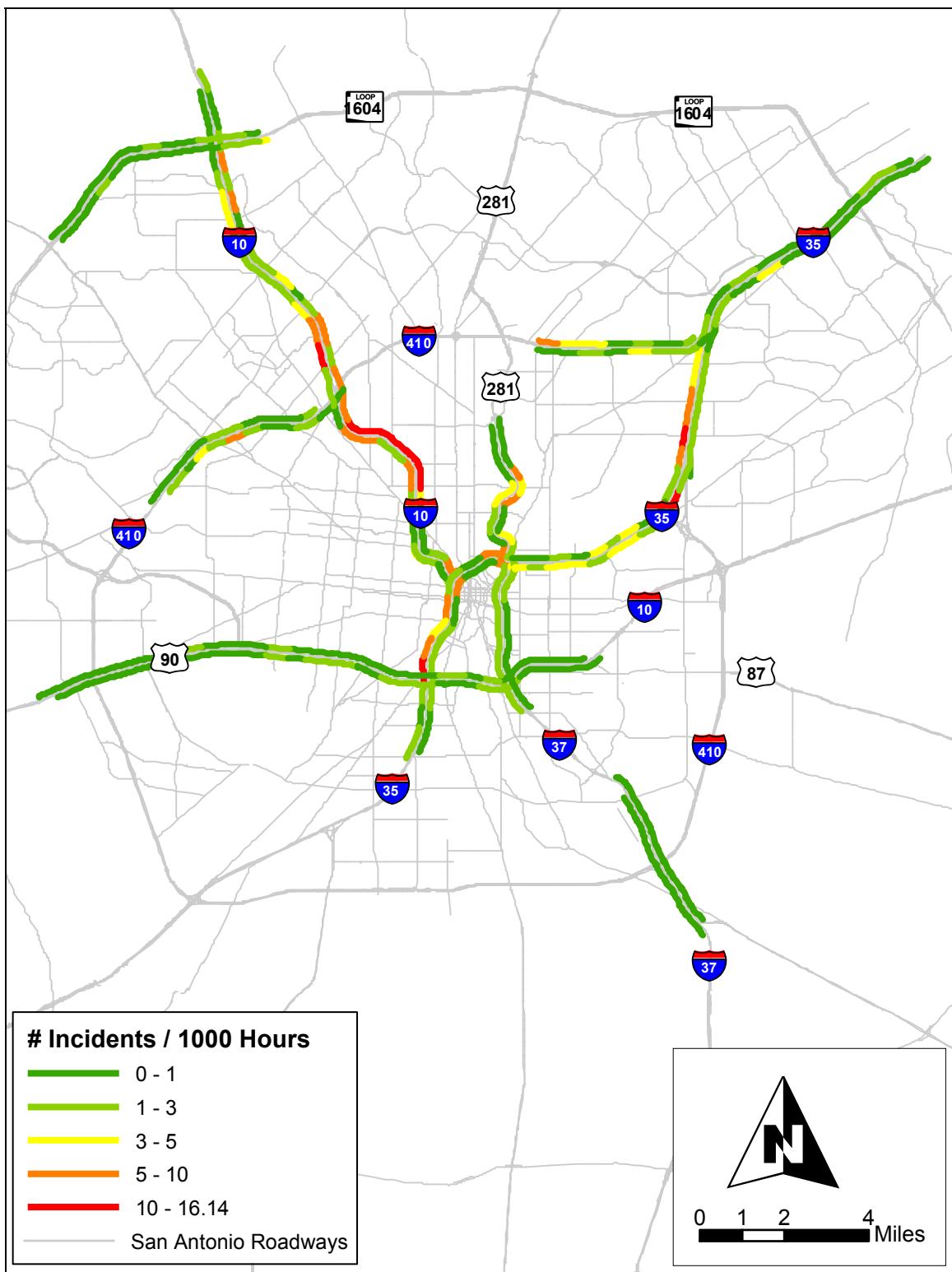
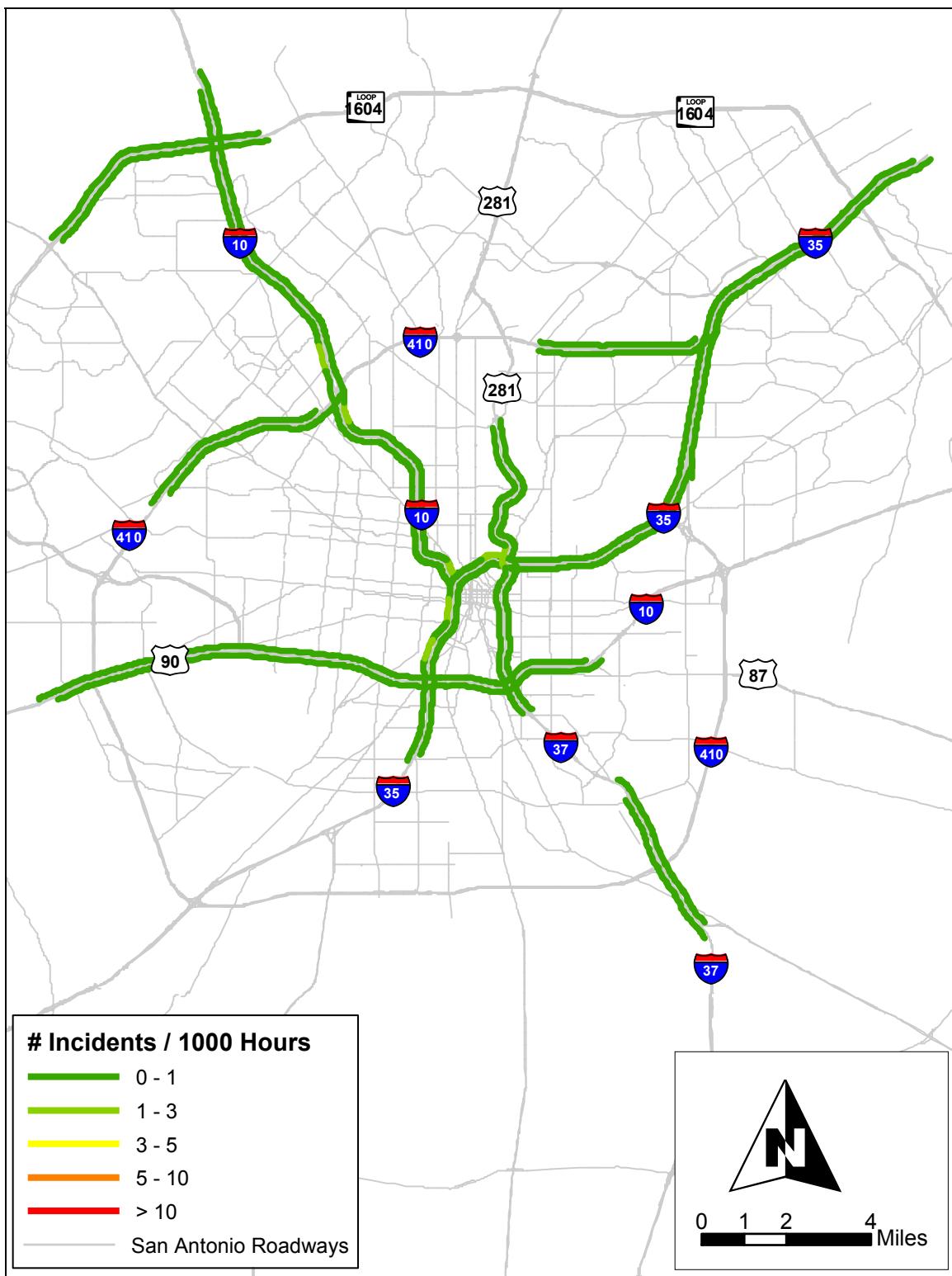


Figure 97. Average Number of Stalled Vehicle Incidents per 1000 Hours during PM Peak Hours (4-7 PM).



**Figure 98. Average Number of Stalled Vehicle Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).**

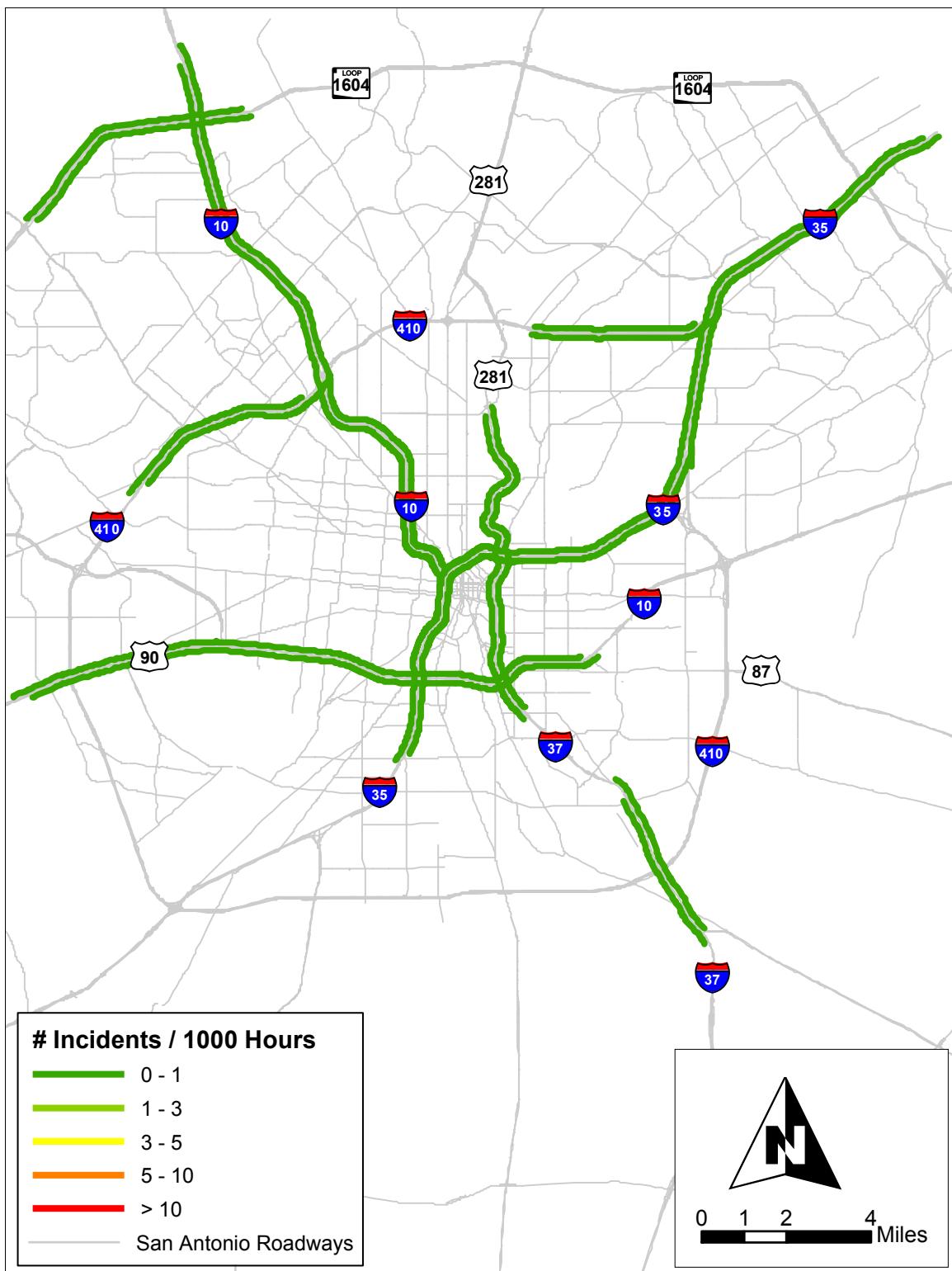


Figure 99. Average Number of Debris Incidents per 1000 Hours.

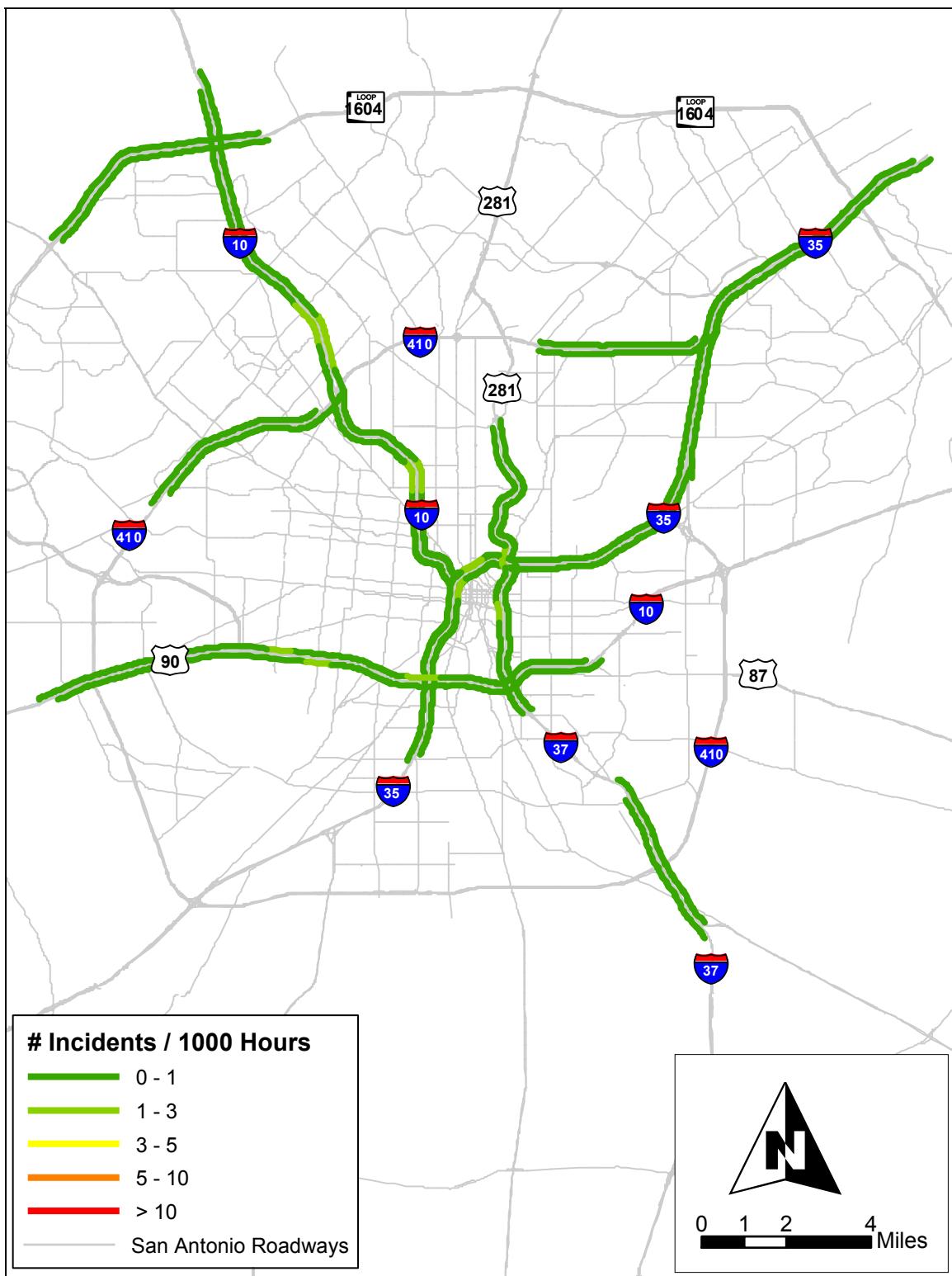
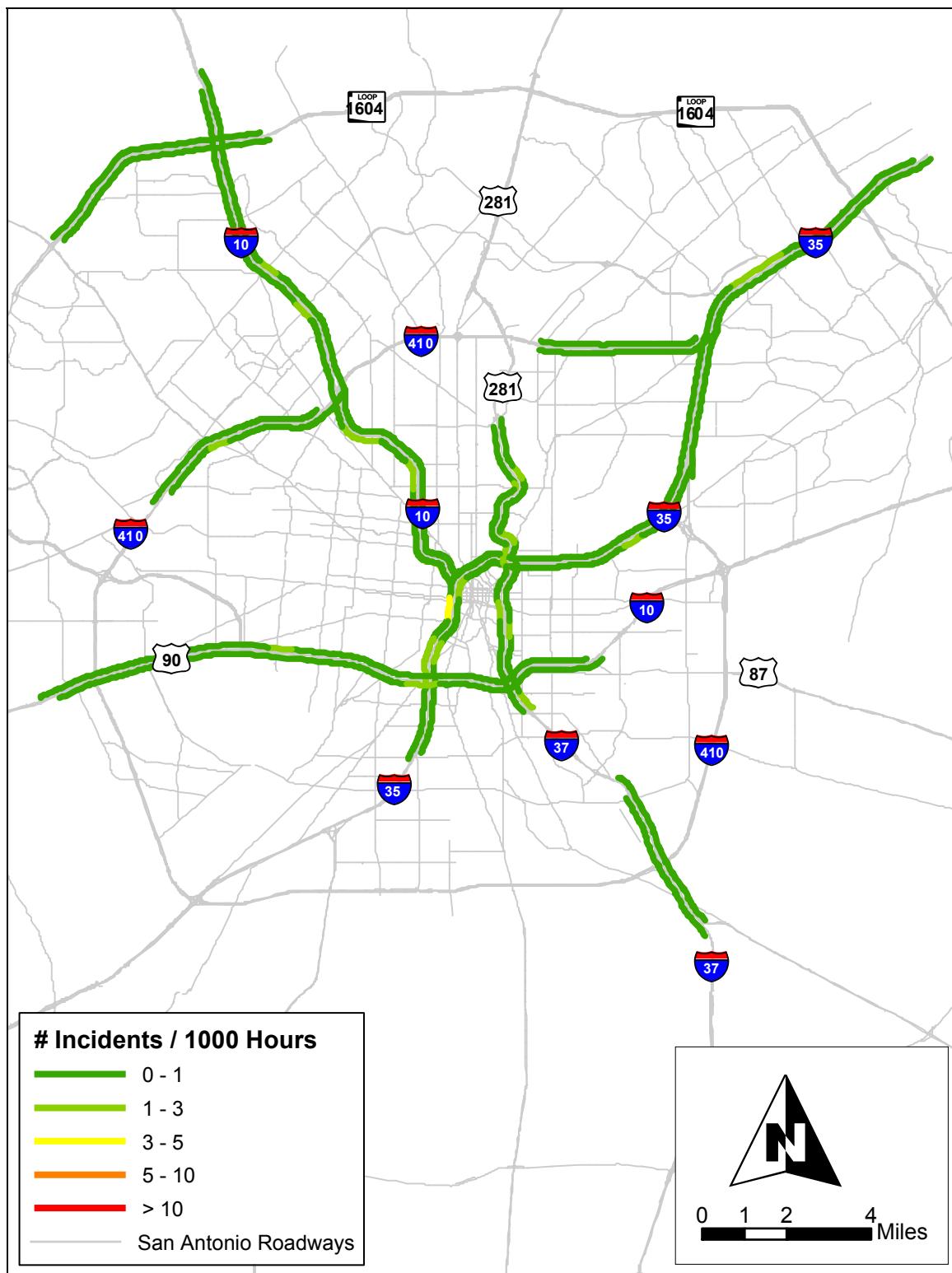


Figure 100. Average Number of Debris Incidents per 1000 Hours during AM Peak Hours (7-9 AM).



**Figure 101. Average Number of Debris Incidents per 1000 Hours during Midday Hours (9 AM-4 PM).**

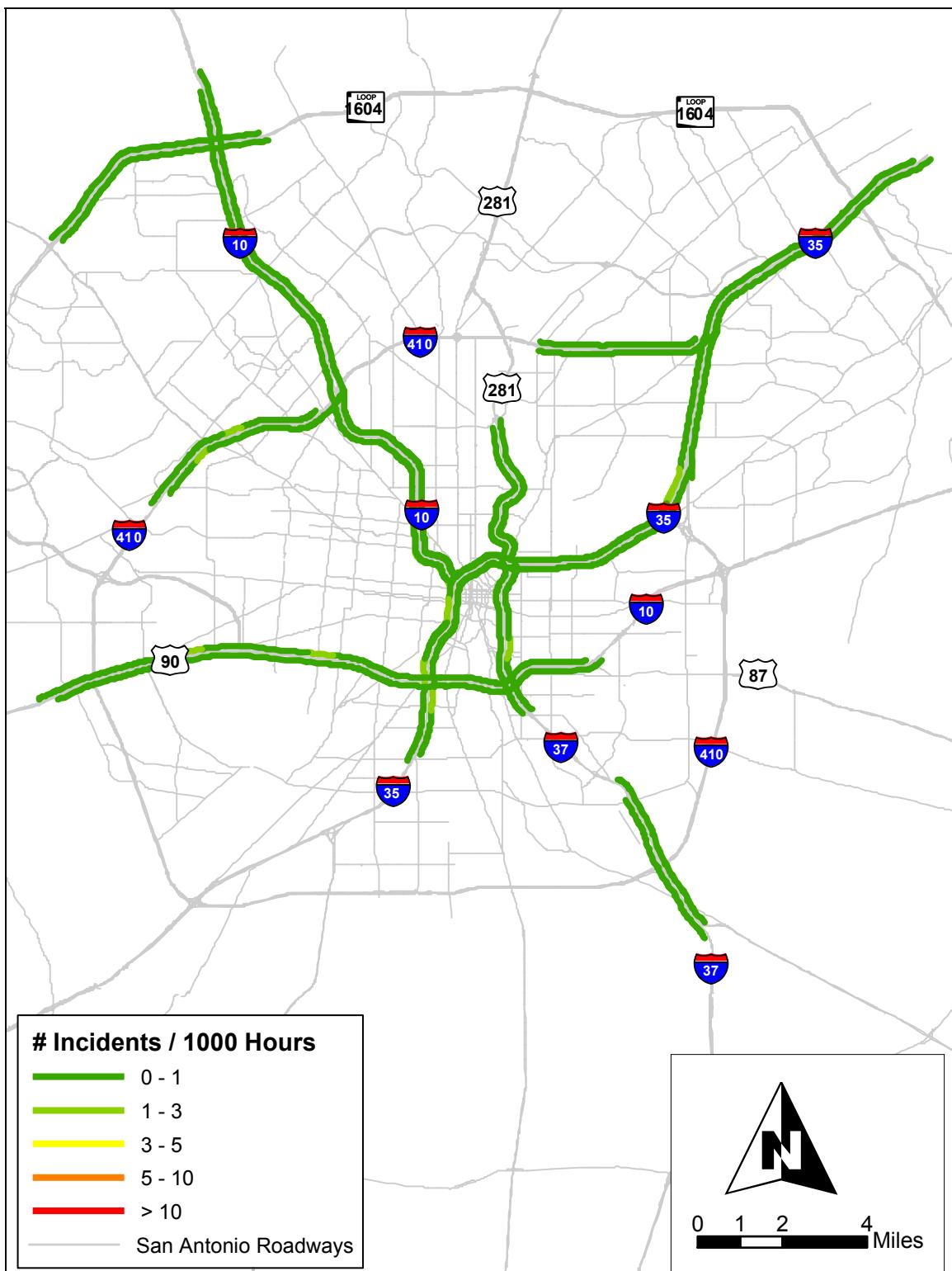
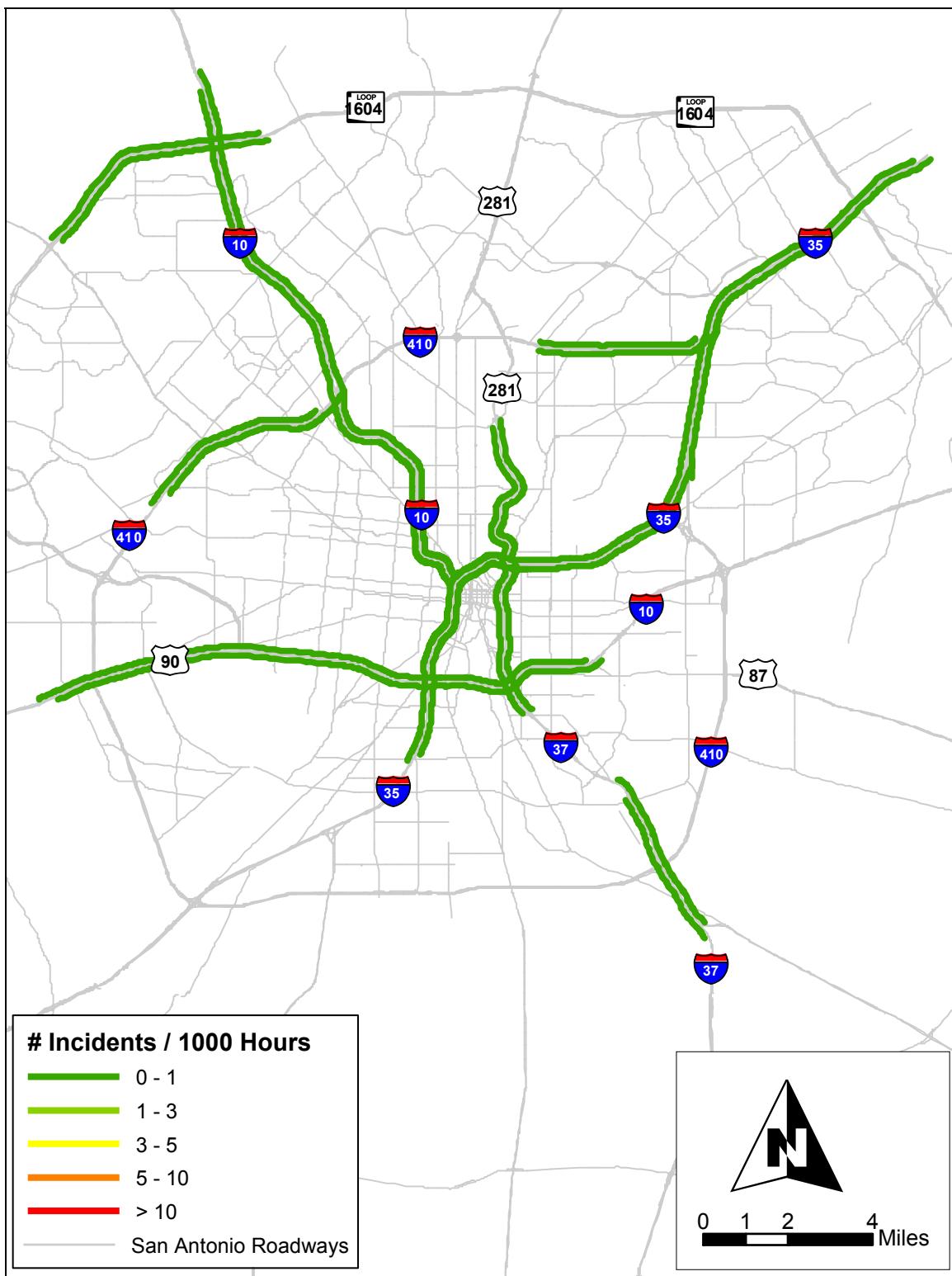


Figure 102. Average Number of Debris Incidents per 1000 Hours during PM Peak Hours (4-7 PM).



**Figure 103. Average Number of Debris Incidents per 1000 Hours during Nighttime Hours (7 PM-7 AM).**