CHAPTER 5
SAFETY MODEL DESCRIPTION AND SENSITIVITY ANALYSIS

5.1 Introduction

This chapter presents the safety model that was developed to capture the benefits of traffic signal coordination. Three main sections are hereby presented below. The first section presents the safety model with its input and output components and the calculation procedures needed to estimate the accident risk. The second and third sections present the sensitivity analysis performed in order to utilize the safety model and investigate if traffic signal coordination improves safety conditions on a network. Field data evaluation using a Global Positioning System (GPS) floating car in Scottsdale/Rural road in Phoenix will be presented in order to demonstrate the differences occurred in before and after signal coordination conditions. Finally, the safety model will be also tested in a micro-simulation environment using the INTEGRATION traffic simulation model.

In chapter 4, the GES extraction procedures were presented, with a description of the variables used from the three main files of the database. It was also shown that a total of 80 pre-crash states from the accident type variable were used in order to produce the accident rates for the safety model.

5.2 Safety model description and input

Before explaining the procedures followed for the input to the model, a brief description of the model needs to be presented. The safety model that is developed for the purposes of this thesis is a regression model that will be incorporated in INTEGRATION but also used for field data evaluation. The following sections will describe how the regression coefficients were obtained. The model requires the facility free-speed as an input in order to calculate the accident risk.

Two main sources of input besides the facility free-speed are needed for the safety model. These are the property damage crash rates developed in chapter 4 as well as the injury severity crash rates. However, these rates indicated a different trend and therefore it will be furthermore explained below together with the crash rates per accident type that were used as the initial input for the development of some basic equations.

5.2.1 Model input - damage severity crashes

Before describing the main programs that compute the accident risk, the regression coefficients and trend-lines for damage severity crashes were produced. Regression analysis was performed using the raw accident rate data. This was done in order to develop the equations for the trends the crash rates follow. The data used for this procedure are the data described in section 4.3.4 in chapter 4. The 14 crash types described in Table 4-2 were also used in order to investigate the accident damage by crash type. Two basic calculations are followed in this analysis. First, the damage probability per crash is calculated using the frequencies directly as they were extracted from the database. This was done by dividing the crash frequency for a given damage level by the total number in order to calculate the probability of such a crash to occur.

Figure 5-1 below illustrates the damage probability per crash type for the fourteen crash types.

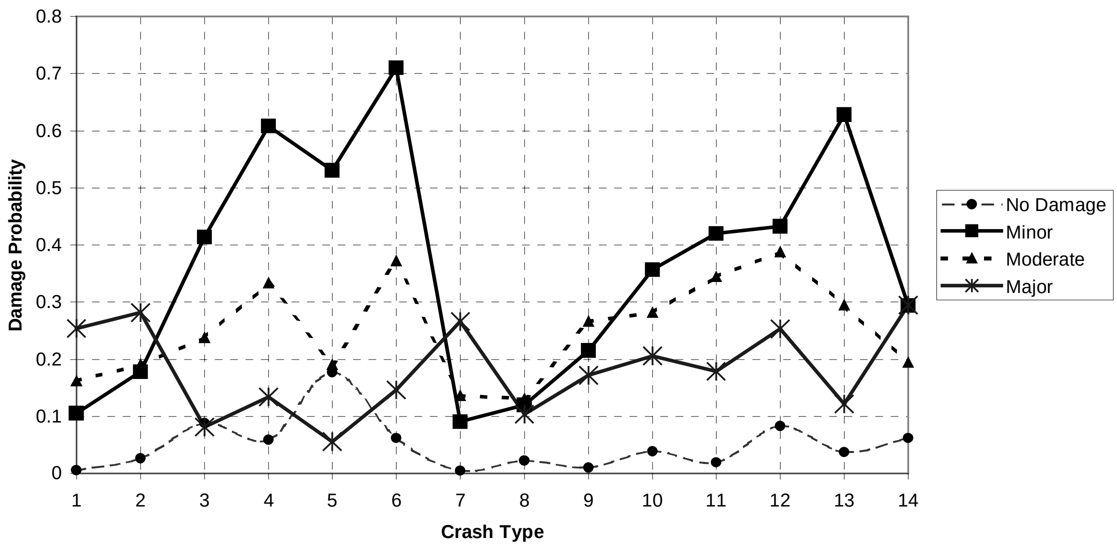

Figure 5-1 Damage probability per crash type

The above figure clearly illustrates that minor damage crashes are more likely to occur with rear-end crashes (crash type 4) to have higher probabilities in the range of 0.6 (for a minor damage rear-end crash to occur). Severe damage (major) crashes are more likely to occur for opposite direction or intersecting paths crash configurations such as crash types 7 and 12.

After examining the probability of a damage severity crash to occur, the probability of damage level per crash was calculated and presented in Figure 5-2 below. The probability as a function of speed limit is illustrated below, together with the trend-lines produced (2nd degree polynomial). This was done in order to use the regression coefficients to calculate the accident risk as it will be shown in the next section. Speed limits range from 20 to 70 mph.

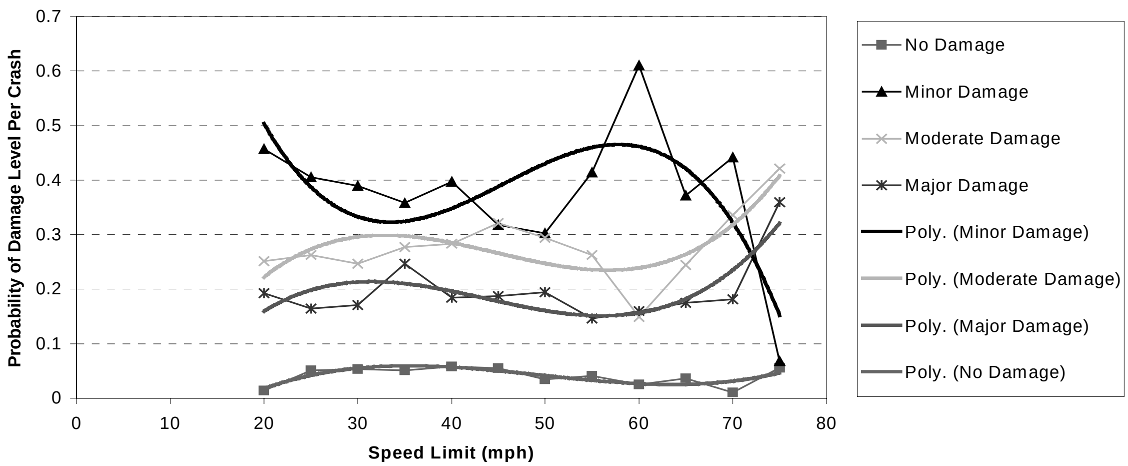

Figure 5-2 Probability of Damage Level per Crash by Speed Limit

It is obvious from the figure above that the no-damage, moderate damage and major damage levels follow the same trend. However, as expected, minor damage crashes have lower probabilities for higher speed limits (facility free-speed).

5.2.2 Model input -injury severity crashes

A similar approach to the one used for the damage severity crashes was followed for the injury severity crashes. Figure 5-3 below presents the probability level per crash for a specific speed limit (range of 20-70 mph). Trend-lines in the form of a polynomial fit are presented in this figure with no injury cases having higher probabilities. No-injury crashes comprise nearly the 60 percent of police reported accidents, hence the trend produced using the GES extracted data follows the same logic. However, the probability for a fatal crash to occur is much lower as expected.

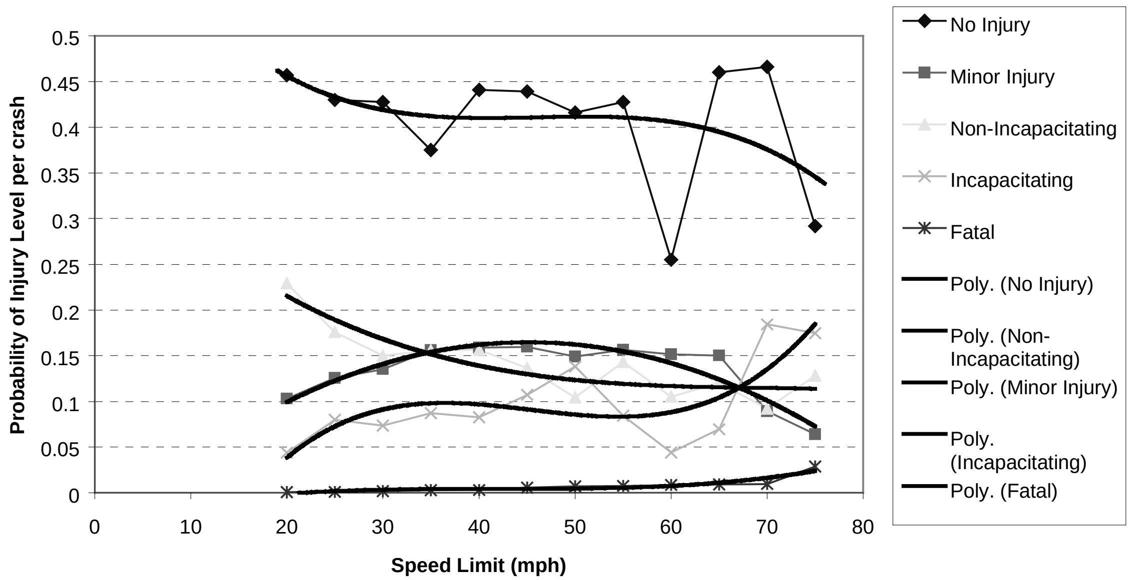

Figure 5-3 Probability of Injury Level per crash by speed limit

5.2.3 Model input – raw crash rates

The raw accident data by accident type and speed limit comprise the initial input. Fourteen accident types and a fifteenth providing total figures are shown in Figure 5-4 below. The rates were produced and presented in chapter 4. An exponential trend-line was created for the total crash rate shown as type 15 in the chart. The rates for all types are characterized by a negative exponential distribution thus yielding higher accidents by type per million VMT for lower speed limits and lower rates for higher speed limits. Data were for speed limits from 0-75 mph. From all fifteen accident types, the one with the highest rates was the rear-end type.

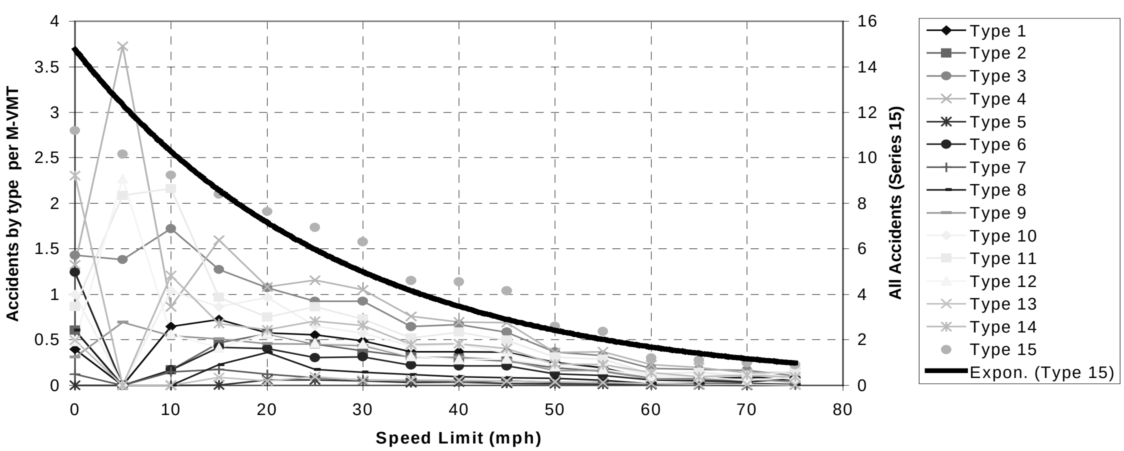

Figure 5-4 Raw accident rate data by accident type and speed limit

Due to the fact that the accident risk for facilities with free-speeds less than 20 miles per hour is identical to that of 20 mph, the rates considered as an input to the model start from 20 mph. Similarly, facilities with free-speeds in excess of 70 mph have the same accident risk as a facility with a free-speed of 70 mph therefore, the range used was 20-70 mph. Figure 5-5 below illustrates the raw accident rate data only for the range of 20-70 mph. The natural logarithm of the rates from 20-70 mph was then computed using equation 1 below.

$$A = \left[Ln(acc\_rate) + (Spd\_Lim / 3600\right] \qquad [1]$$

where:

A = natural log of accident rate

acc_rate = raw accident rate in crashes per million vehicle miles traveled

Spd_Lim = speed limit in miles per hour (converted into seconds)

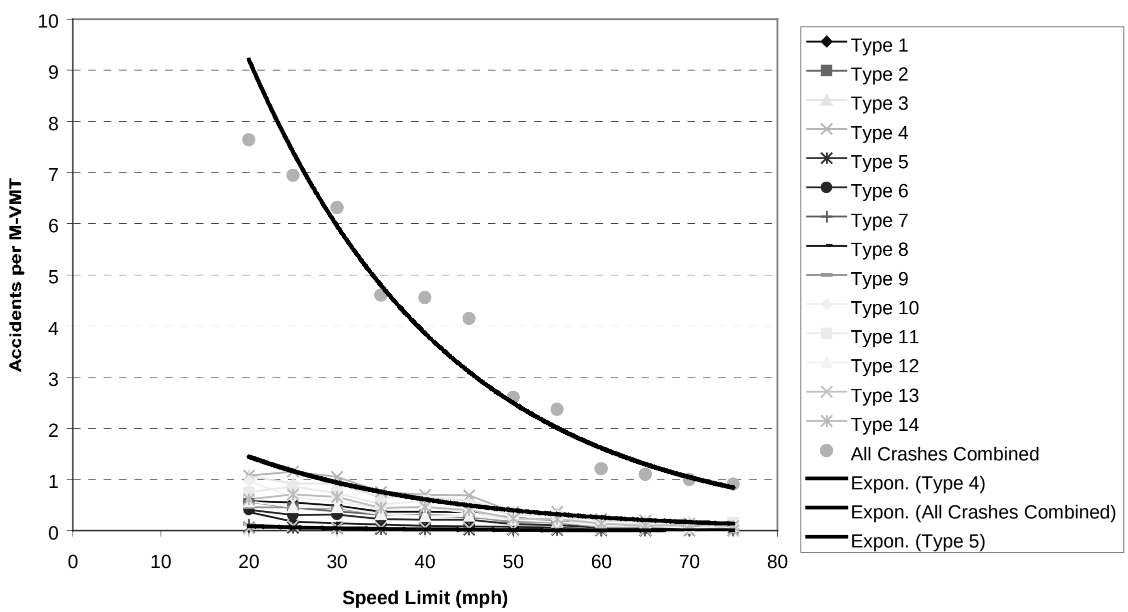

Figure 5-5 Accidents per million VMT for speed limits 20-70 mph

After computing the natural log of the rates, the average of all the values computed using equation 1 was then calculated. The deviation of that average was also computed as a next step in order to obtain the coefficients for the equations that will be used as an input to the safety model. In Figure 5.5 above, it is shown that for all the crashes combined the distribution is exponential. The crash rate is lower for higher speed limits. This is typical when exposure is vehicle miles traveled. By computing the crashes per million vehicle seconds, the exponential distribution will be more "flattened" mainly because for lower speed limits the changes in the crash rates are not significant.

The regression coefficients were then calculated using the regression analysis tool in Excel. The values for these coefficients were computed for all fourteen accident types together with the total accident rate. Figure 5-6 below illustrates the distribution of R^2 versus the crash types (for the regression analysis described earlier). This distribution can be described as satisfactory for the calculated data as on average figures, R^2 is higher than 0.62.

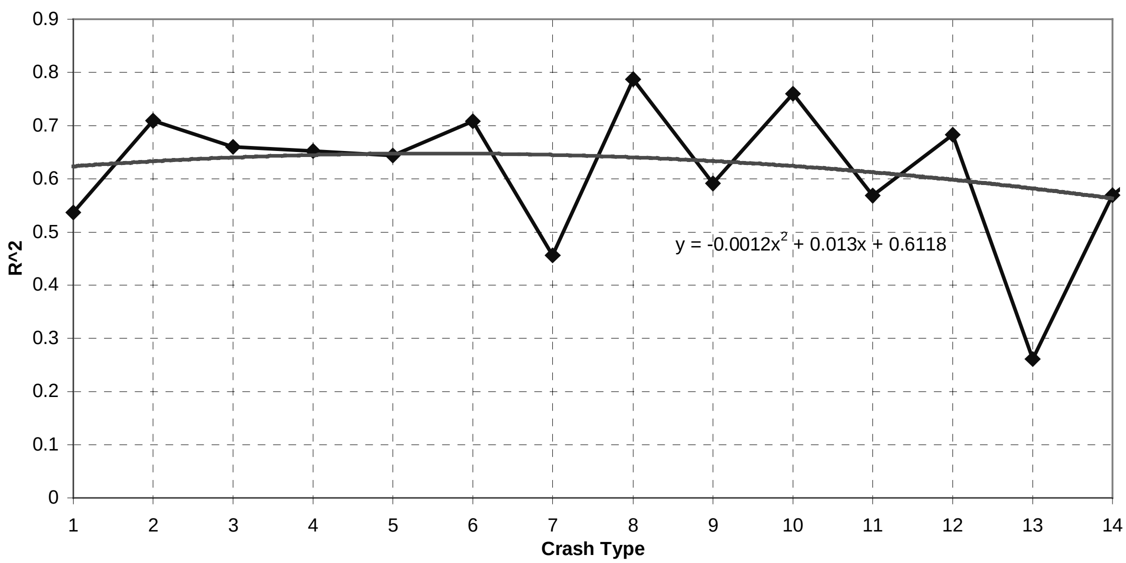

Figure 5-6 R^2 versus crash type

The figures described in this section along with the equations formed using the regression analysis were used as an input form for the safety model within the simulation model called INTEGRATION. The following section will present the main program and subroutines used to calculate the accident risk within INTEGRATION.

5.3 Safety Model Implementation

The safety model was primarily developed based on GES accident data in order to demonstrate how it can be used to evaluate the impacts of alternative transportation system implementations and in this case, traffic signal coordination. The FORTRAN code used to calculate the accident risk is included in Appendix C. The code includes a *main* program and three subroutines, which interact with the main program as shown in Figure 5-7 below.

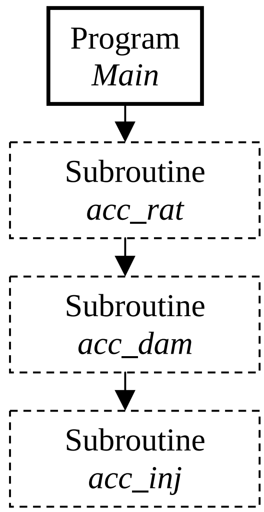

Figure 5-7 Flowchart of FORTRAN code

The model computes two accident rates, as follows:

1. The number of crashes per million vehicle seconds and
2. The number of crashes per million vehicle kilometers.

The above accident rates are also computed for 14 crash types and the total crashes as explained in chapter 4, as a function of facility free-speed. Further classifications include accident rates by level of damage and injury severity.

5.3.1 Subroutine Acc_Rat

Subroutine acc_rat is the first subroutine that is called by the program main. This subroutine computes the accident risk for a specific facility that is defined by its free-speed. The free-speed in kilometers per hour (variable xspd) is used as input, together with two regression coefficients (c_1 and c_2) they were described in the previous sections in this chapter. The accident risk is then calculated using equation 2 below.

$$p_1 = exp\ (c_1 * spd + c_2) \qquad [2]$$

where:

p_1 = accident risk in crashes per million vehicle seconds

spd = free-speed in miles per hour (20-70 mph)

c_1 and c_2 = regression coefficients

Coefficients c_1 and c_2 refer to the 14 accident types as well as type 15 which is the total. Due to the fact that INTEGRATION uses kilometers per hour as a unit for speed, the speed is converted into mph by dividing the free-speed (variable xspd) by 1.6. Also, the model is only valid for free speeds of 20 to 70 mph, therefore for speeds less than 20 mph, the model assigns a speed of 20mph and for greater than 70 mph, a speed of 70 mph. Finally, the subroutine also computes the accident risk in crashes per million kilometers by dividing by the free-speed. Subroutine acc_rat is included in Appendix C.

5.3.2 Subroutine Acc_Dam

This subroutine calculates the damage subjected on the vehicle for all crashes categorized by the speed limit (facility free-speed). There are four major damage levels (minor, moderate, major and no damage) and the range in speeds is the same as in the previous subroutine, i.e. 20-70 mph. For each damage severity level a different equation is used, utilizing three regression coefficients and variable spd. Equations 3-6 below display the method these rates are calculated.

$$Dam(1) = c_1 + c_2 * S + c_3 * S^2 + c_4 * S^3 \quad [3]$$

$$Dam(2) = c_5 + c_6 * S + c_7 * S^2 + c_8 * S^3 \quad [4]$$

$$Dam(3) = c_9 + c_{10} * S + c_{11} * S^2 + c_{12} * S^3 \quad [5]$$

$$Dam(4) = c_{13} + c_{14} * S + c_{15} * S^2 + c_{16} * S^3 \quad [6]$$

where:

Dam(1) = no damage crashes

Dam(2) = minor damage crashes

Dam(3) = moderate damage crashes

Dam(4) = major crashes

S = speed in miles per hour

A normalization check is performed in order to normalize the accident risk to sum up to 1.0.

5.3.3 Subroutine Acc_Inj

This subroutine estimates the maximum severity injury incurred on the passengers of a vehicle for all crashes on a specific facility as defined by its free-speed. Five different levels of injury severity are considered in this subroutine as follows:

- No Injury
- Possible Injury
- Non Incapacitating Injury
- Incapacitating Injury
- Fatal Injury

As in subroutine acc_dam, equations estimate the maximum injury severity as shown in equations 7-11 below. The subroutine is only valid for speeds in the range of 25-70 mph. Any facilities with free-speed less than 25 mph are estimated to have the same injury probability as a facility with free-speed of 25 mph. The same rule applies for facilities with free-speeds greater than 70 mph.

$$Inj\ (1) = c_1 + c_2 * S + c_3 * S^2 + c_4 * S^3 \qquad [7]$$

$$Inj\ (2) = c_5 + c_6 * S + c_7 * S^2 + c_8 * S^3 \qquad [8]$$

$$Inj\ (3) = c_9 + c_{10} * S + c_{11} * S^2 + c_{12} * S^3 \qquad [9]$$

$$Inj\ (4) = c_{13} + c_{14} * S + c_{15} * S^2 + c_{16} * S^3 \qquad [10]$$

$$Inj\ (5) = c_{17} + c_{18} * S + c_{19} * S^2 + c_{20} * S^3 \qquad [11]$$

where:

Inj (1) = no injury crashes

Inj (2) = possible injury crashes

Inj (3) = non incapacitating injury crashes

Inj (4) = incapacitating injury crashes

Inj (5) = fatal injury crashes

S = speed in miles per hour

A normalization check is performed in order to normalize the accident risk to sum up to 1.0.

5.4 Sensitivity Analysis

In the previous sections, the safety model was presented. The model was then tested to capture the safety impact of signal coordination using field data from Phoenix. It was shown that the scenario where traffic signal coordination was imposed, improved the safety conditions on the network by means of experiencing a decrease of the accident risk and an increase in average speed. In this chapter, the Phoenix network will be described in more detail and some information regarding the simulation performed. A sensitivity analysis on a small sample network and the Phoenix network will also be presented. Finally, emphasis will be given on a particular accident type (rear-end) where some results will be presented in terms of accident rates produced. The objective is to reduce crashes on major arterial corridors using signal coordination.

5.4.1 Micro-Simulation Evaluation

In order to test the safety model in a micro-simulation environment, two networks were used for this task. First, the model was tested on a small sample network as illustrated in Figure 5-8 below. The network was coded in INTEGRATION and consists of 5 links and 10 nodes. Each link has a length of 1 km and a different vehicle type was assigned for each link. This was done so as to compare the accident risk produced by a single vehicle driving along a 1km link. Different free-speeds were assigned starting from 120 km/h and ending at 40 km/h. The output file called *summary.out* is included in Appendix C, section C.4. Five columns produced by INTEGRATION, yielded results for all five vehicle types used.

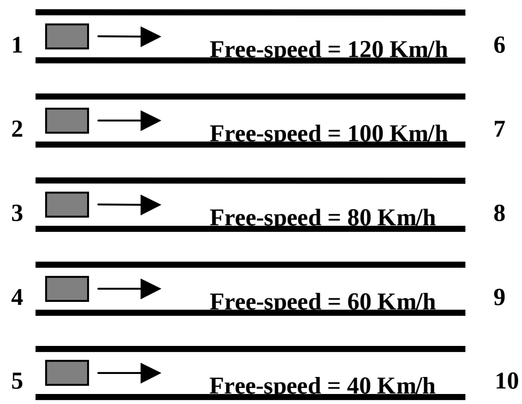

Figure 5-8 Sample network

The results of the simulation are shown in Figure 5-9 below. The accident risk results followed the trend of the input data that was initially used for the model within INTEGRATION. The accident risk on facilities with higher free-speed is lower whereas for lower free-speeds, the risk for an accident is much higher. The average accident risk for all 5 links was estimated to be $1.28*10^{-6}$ (crash risk). The fact that this small and simple network produced correct results and the output statistics followed the trend given to the model indicated some consistency. Next step was to simulate a much larger network such as the Scottsdale/Rural Road in Phoenix where the demand and scale of the network were much larger. Also, despite the fact that the model was tested for a single vehicle as it was shown in the previous chapter, the presence of a large amount of vehicles as well as the traffic signals complicated the situation. The next section will deal with these issues so as to demonstrate the efficiency of the safety model within a micro-simulation environment.

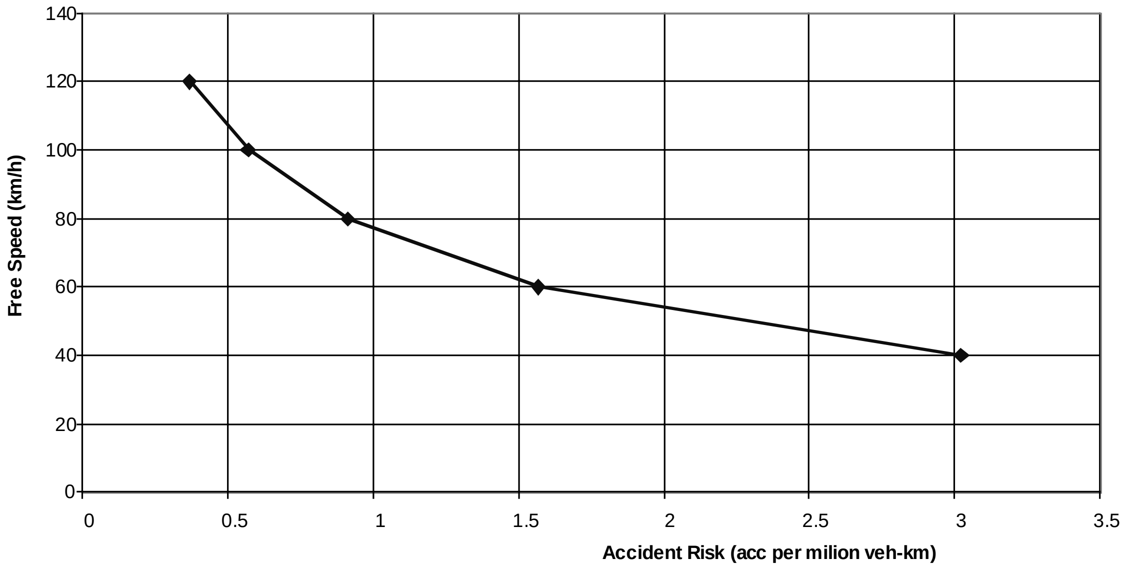

Figure 5-9 Sample network output results

5.4.2 Metropolitan Model Deployment Initiative (MMDI)

Before proceeding in using the safety model in a micro-simulation environment for a larger network, some background information for the Model Deployment Initiative need to be presented. The Scottsdale/Rural road corridor in Phoenix is part of the Model Deployment Initiative.

The evaluation of the safety benefits of Intelligent Transportation Systems for the Metropolitan Model Deployment Initiative (MMDI) required the development of a safety model to capture these benefits. The MMDI project involves installing Intelligent Transportation Infrastructure (ITI) in four cities in the US. These cities include New York, San Antonio, Phoenix, and Seattle. The objective of the MMDI evaluation project is to evaluate the throughput, safety, environmental and integration benefits of Intelligent Transportation Systems (ITS). For the development of this thesis, part of the road network of the City of Phoenix, AZ was used. The corridor used will be described below regarding its characteristics. As mentioned before, the ITS component that needed to be tested for its safety impact was traffic signal coordination. The safety model developed for the purposes of this thesis is part of a larger study that includes models evaluating fuel and emissions, as well as throughput and efficiency.

5.4.3 Phoenix Signal Coordination

Traffic signal coordination implements traffic signal timing patterns that respond to traffic conditions and transit or emergency vehicles. One of the possible benefits of signal coordination is the impact it will have on safety on a certain facility. Better signal coordination can improve traffic flow on a road and subsequently, the accident risk will be less. Eight major arterials are included in the Phoenix MMDI project and this thesis deals with one of them: the Scottsdale / Rural Road corridor in Phoenix. This corridor falls in the jurisdiction of the cities of Tempe and Scottsdale. The type of signal control under consideration is coordinated signal control. In such cases, the signals are coordinated to operate at the same cycle length or multiples of this cycle length.

5.4.4 Scottsdale/ Rural Road

Scottsdale/Rural Road is one of the most congested corridors in Phoenix carrying heavy traffic along the north-south corridor. The fact that this corridor serves two major trip generators such as the downtown of the city of Scottsdale and the Arizona State University in the city of Tempe causes more traffic congestion (especially during special events). The capacity of this corridor is increased using signal coordination. Delay along the corridor is decreased by traffic signal coordination. Also the fact that the arterial falls between two different jurisdictions causes more problems in signal coordination. Further study on this topic was conducted by Sin (1999).

The Phoenix inter-jurisdictional signal coordination was therefore examined using macroscopic traffic modeling, to test the regional impacts on network flows and demands. The characteristics of this arterial are shown in table 5-1 below.

Table 5-1 Scottsdale/Rural Road Characteristics

Length of corridor	**10 Km (6.25 miles)**
Number of Traffic Signals	**21**
Number of nodes	**576**
Number of links	**1,016**
Total Demand	**130,870 vehicles**

5.4.5 Simulation of the Scottsdale/Rural road

In order to examine the possible benefits of traffic signal coordination on safety, the safety model developed was used within INTEGRATION. The model input and FORTRAN code as explained before are embedded in the simulation software. After simulating the sample network with the 5-liks, a larger scale network is now considered. Figure 5-10 below illustrates the Scottsdale/Rural road network as it was coded within INTEGRATION.

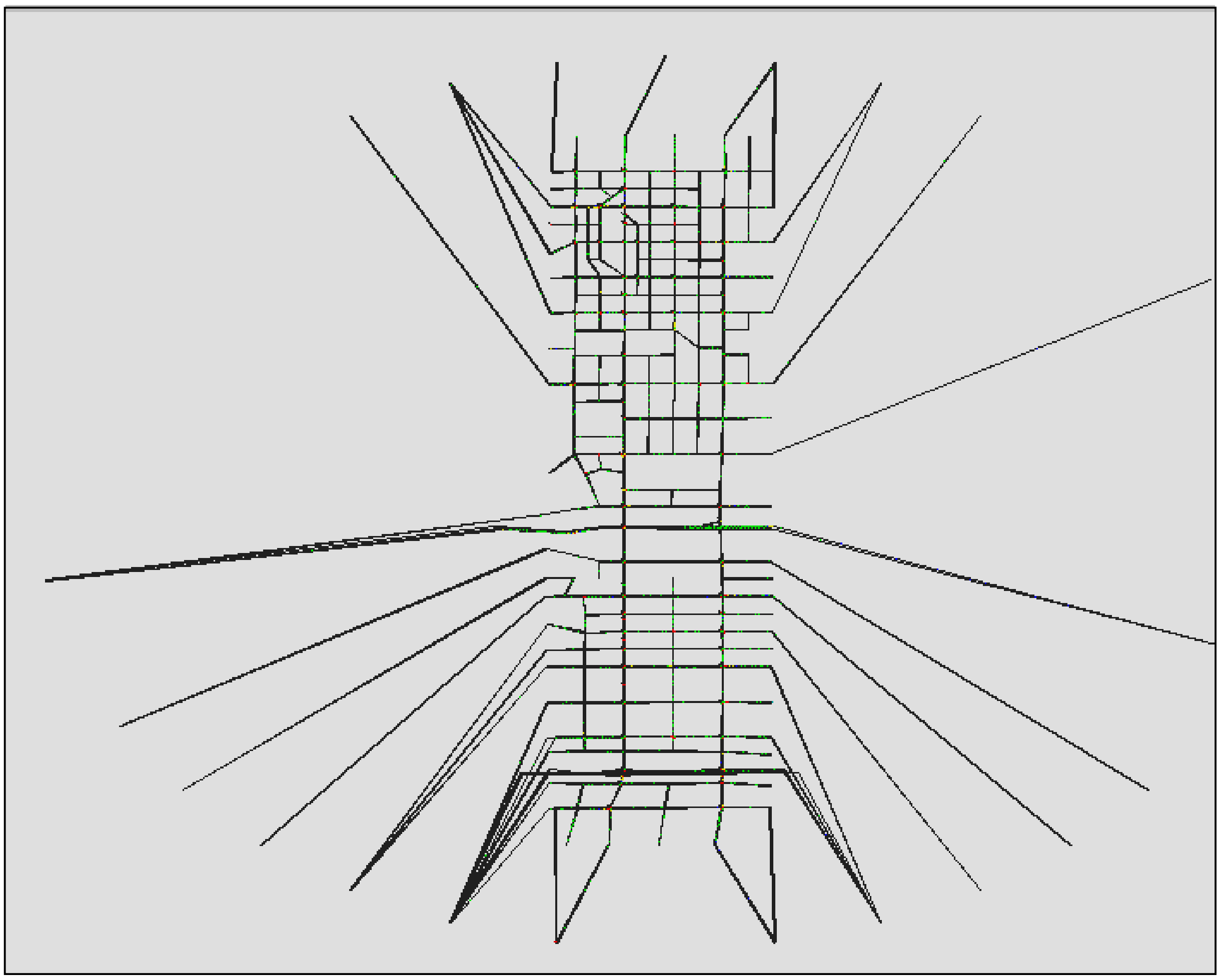

Figure 5-10 Screen Capture of INTEGRATION (Scottsdale/Rural Road)

The simulation of the Scottsdale/Rural road corridor was completed using INTEGRATION 2.20 for Windows. Input files from the above network were obtained from the simulation study executed by the Center for Transportation Research (CTR) at Virginia Tech as part of the MMDI project. Before and after signal coordination files with a demand of nearly 130,000 vehicles were used in order to compute the accident risk for this facility. As mentioned before, the Scottsdale/Rural road has a speed limit of 45 mph and was considered to be a principal arterial.

The simulation output from INTEGRATION is included in Appendix C, section C.8. The summary files produced by the simulation model are included in sections C.8.1 and C.8.2.
Summary1.out refers to the before signal coordination conditions. For this scenario, 123,961 vehicles cleared the network completing 493,410 vehicle kilometers. The INTEGRATION summary file for this scenario estimated a number of 10,334,000 crashes for this network. This translates to a crash rate of 20.94 crashes per vehicle kilometer traveled for this network.

Summary2.out refers to the after scenario where the signals are coordinated. The demand remained the same. The vehicles cleared the network completing 493,079 veh-Km. The fact that the signals were coordinated, produced a lower accident risk than the before scenario. For this case, the crashes were reduced to 9,834,000. This translates to a crash rate of 19.9 crashes per vehicle kilometers traveled. Even though this network was much larger than the sample network and signals were coordinated, the change in the after situation was evident. The decrease was in the accident risk was approximately 4.9%, a figure in the same range as the field data analysis.

5.5 Field Data Evaluation

The safety model yielded successful results in a micro-simulation environment. Traffic signal coordination had a significant impact on safety and decreased the risk for having an accident. However, field data from the Scottsdale/Rural road were available through the use of GPS floating cars as presented in the following section.

5.5.1 GPS Floating Cars

The Global Positioning System (GPS) floating car was used for this study. GPS in general is a satellite positional system managed by the U.S. military. GPS technologies are currently utilized in many areas such as the military, commercial or personal use. More specifically, GPS technology is becoming popular within the transportation field. GPS is used for travel-speed studies, origin-destination investigations and highway inventory management. The use of GPS technology can provide temporal and spatial information of a floating vehicle.

For the purposes of this thesis, data collected in Phoenix, using GPS floating cars are analyzed. The accuracy of the equipment associated with the floating car ranges from millimeter accuracy to 100 meters. However, even 100 meters of accuracy are adequate to obtain the speed, a key parameter in these studies. Vehicles were equipped with GPS unites that collected information such as date, time, latitude and longitude. Speeds were also collected at 1 or 2 second intervals. Also, a laptop computer and the GPS signal receiver were installed in each test vehicle in order for the receiver to acquire satellite signals and to save them in the form of a text file.

The field data were collected during before and after signal coordination periods. Three time periods were identified for collection of data as shown in Table 5-2 below. In addition to the above-mentioned information, continuous volume counts (48-hour period) and 15-minute turning movement counts during AM and PM peaks were also obtained. Four GPS floating cars were used for data collection at the Scottsdale/Rural road in Phoenix. A total of 301 trips were completed having 141 trips in the before and 160 trips in the after periods as presented in the table below.

Table 5-2 Number of trips of GPS floating cars on Scottsdale/Rural road

		Period			
Data Set	**Direction**	**A.M Peak**	**Midday**	**P.M Peak**	**Total**
Before (Jan. 99)	**Northbound**	26	26	17	69
	Southbound	27	27	18	72
After (Feb. 99)	**Northbound**	29	27	26	82
	Southbound	27	26	25	78
	Total	109	106	86	301

Post processing of the data sets is required, and the software package ArcView is used. Figure 5-11 below illustrates the Scottsdale/Rural road corridor where the data were collected. The total length of the road section under study is approximately 7 miles. More information on the Scottsdale/Rural road network was also presented in the micro-simulation sensitivity analysis section.

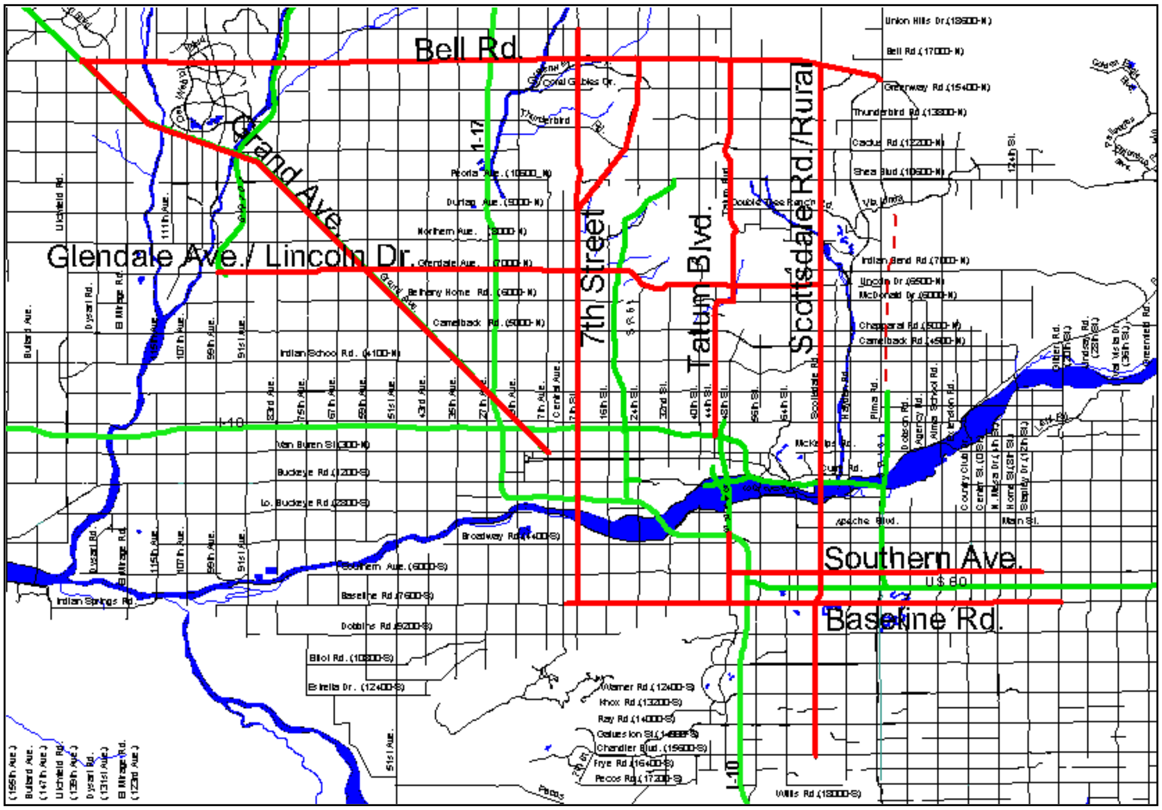

Figure 5-11 Phoenix Traffic Corridors- Scottsdale/Rural road

The SAS program that processed the data obtained from the GPS floating cars as well as the process of the safety model is included in Appendix C, Section C.7.1 The ANOVA results from the SAS Univariate Procedure are also included in Appendix C, Section C.7. Some very interesting results were obtained from the use of the data and the complete analysis of the 301 trips. Tables 5-3 to 5-8 below illustrate the output in terms of an accident risk (probability of having an accident).

Five different crash risks were computed for before and after scenarios as follows:

- Average Crash Risk
- Injury Crash Risk
- Fatal Crash Risk
- Minor Damage Crash Risk
- Moderate Damage Crash Risk
- Major Damage Crash Risk

Table 5-3 below presents the results obtained for the three different periods of the day in two directions: northbound and southbound. Except from midday hours on the southbound direction, all the rest periods experienced a lower accident risk with the southbound PM peak to have the higher impact, thus having almost 20% less chances for a crash to occur. For the northbound approach, the average difference was 5.1%, considerable decrease. The numbers in the table represent an absolute crash risk, for example the crash risk for a crash to occur during the PM peak was found to be 0.000037 for the before situation, and 0.000029 for the after.

Table 5-3 GPS Floating Car: Crash Risk for all crashes (numbers in crash risk *10^{-6})

	Northbound				Southbound			
Period	**AM**	**Midday**	**PM**	**Average**	**AM**	**Midday**	**PM**	**Average**
Before	24.780	25.650	28.960	26.463	23.670	24.040	37.350	28.353
After	23.540	24.450	27.350	25.113	23.300	24.800	29.910	26.003
Difference	5.00%	4.68%	5.56%	5.10%	1.56%	-3.16%	19.92%	8.29%

Table 5.4 presents the injury crash risk in a similar fashion like the previous table. The probability for having an injury crash on the facility is much lower than the average crash risk and this can be justified by the fact that as explained in chapter 3, almost 30% of the police reported accidents include injuries to a person (s). The impact of signal coordination is also evident for the injury crash risk, especially for the afternoon peak on the southbound direction.

Table 5-4 GPS Floating Car: Injury Crash Risk (numbers in crash risk *10^{-6})

	Northbound				Southbound			
Period	**AM**	**Midday**	**PM**	**Average**	**AM**	**Midday**	**PM**	**Average**
Before	11.900	12.310	13.850	12.687	11.370	11.550	17.760	13.560
After	11.300	11.740	13.080	12.040	11.180	11.900	14.280	12.453
Difference	5.04%	4.63%	5.56%	5.10%	1.67%	-3.03%	19.59%	8.16%

The minimal exposure for fatal crashes in general produced much a lower risk for these cases. The fatal crash risk is certainly very low, in the range of 0.0000001, which is a very low risk. Percentage difference is also lower than the previous cases with an average of 2.5% lower risk for the northbound direction but a higher, almost 5% for the southbound direction. It must be emphasized that despite the small amount of data, the southbound afternoon peak still experiences a 125 lower risk. The data presented in the tables of this section were drawn using the SAS Univariate procedure (see sections C.7 and C.8 in Appendix C) and were statistically significant as the 95% confidence interval was satisfied and the results were satisfactory.

Table 5-5 GPS Floating Car: Fatal Crash Risk (numbers in crash risk *10^{-6})

	Northbound				Southbound			
Period	**AM**	**Midday**	**PM**	**Average**	**AM**	**Midday**	**PM**	**Average**
Before	0.103	0.105	0.112	0.107	0.100	0.102	0.126	0.109
After	0.101	0.103	0.108	0.104	0.100	0.102	0.111	0.104
Difference	**1.94%**	**1.90%**	**3.57%**	**2.50%**	**0.00%**	**0.00%**	**11.90%**	**4.57%**

The following three tables refer to property damage crash risk only, separated by the damage level. Even though the major damage risk is of greater importance, the moderate damage crash risk is higher from the rest. Results from the GES database justify this fact. The probability of having a minor damage crash is in the range of 1.1*10^{-6} to 1.4*10^{-6}. The impact of traffic signal coordination is also evident and was nearly the same for both directions, in the range of 4-4.5% lower crash risk for the after scenario.

Having a moderate or major damage crash is also more common but taking into account the fact that these data were drawn from a 45 mph facility. In table 5-6, the impact of traffic signal coordination yielded a lower accident risk for minor damage crashes. Improvement was experienced in all directions and all periods of the day. Moderate damage crash risk was found to be higher than the minor and the major cases. Still, the after signal coordination scenario was better than the before with the average difference in the range of 5% higher to 17% lower.

Table 5-6 GPS Floating Car: Minor Damage Crash Risk (numbers in crash risk *10^{-6})

	Northbound				Southbound			
Period	**AM**	**Midday**	**PM**	**Average**	**AM**	**Midday**	**PM**	**Average**
Before	1.230	1.250	1.310	1.263	1.190	1.220	1.410	1.273
After	1.180	1.210	1.250	1.213	1.150	1.200	1.300	1.217
Difference	**4.07%**	**3.20%**	**4.58%**	**3.96%**	**3.36%**	**1.64%**	**7.80%**	**4.45%**

Table 5-7 GPS Floating Car: Moderate Damage Crash Risk (numbers in crash risk *10^{-6})

	Northbound				Southbound			
Period	**AM**	**Midday**	**PM**	**Average**	**AM**	**Midday**	**PM**	**Average**
Before	10.930	11.340	13.260	11.843	10.450	10.520	18.120	13.030
After	10.350	10.800	12.470	11.207	10.390	11.100	13.840	11.777
Difference	**5.31%**	**4.76%**	**5.96%**	**5.38%**	**0.57%**	**-5.51%**	**23.62%**	**9.62%**

Table 5-8 GPS Floating Car: Major Damage Crash Risk (numbers in crash risk $*10^{-6}$)

	Northbound				Southbound			
Period	**AM**	**Midday**	**PM**	**Average**	**AM**	**Midday**	**PM**	**Average**
Before	7.41	7.66	8.44	7.837	7.08	7.23	10.42	8.243
After	7.06	7.31	7.99	7.453	6.92	7.35	8.65	7.640
Difference	**4.72%**	**4.57%**	**5.33%**	**4.89%**	**2.26%**	**-1.66%**	**16.99%**	**7.32%**

5.5.2 Speed Changes-Floating Cars

As mentioned before, the GPS field data included speed measurements in miles per hour. Before and after signal coordination situations yielded different speeds for each period of the day.
Table 5-9 below presents the speeds during the before and after signal coordination cases. The average speed on the northbound approach was 42.5 mph in the before case and improved to almost 45 mph in the after. Almost the same impact of signal coordination was observed for the southbound approach where the before was 41.6 mph and the after 44 mph, a 5.6% increase in speed. A significant increase in speed occurred on the afternoon peak period for the southbound traffic. It is important to emphasize the impact the speed has on the average crash risk on this facility. The improvements in speed can smoothen the traffic flow and hence reduce the crash risk.

Table 5-9 GPS Floating Car: Speeds for before and after conditions (in mph)

	Northbound				Southbound			
Period	**AM**	**Midday**	**PM**	**Average**	**AM**	**Midday**	**PM**	**Average**
Before	45.39	43.55	38.53	42.49	47.45	46.91	30.47	41.61
After	47.87	45.95	41.01	44.94	48.22	45.41	38.21	43.95
Difference	**-5.46%**	**-5.51%**	**-6.44%**	**-5.77%**	**-1.62%**	**3.20%**	**-25.40%**	**-5.62%**

5.6 Analysis of the Safety Impacts of Signal Coordination in Phoenix

In the previous sections the GPS floating car study was presented and the final results indicated that the crash risk is reduced after the signals were coordinated in Phoenix. However, a study was performed by Carter et al of SAIC (Science Applications International Corporation) using local accident data for the same network in Phoenix. The study performed focused primarily on intersections and rear-end crashes but some general conclusions were drawn. The purpose for presenting a summary of their findings is to compare the GPS floating car analysis with the analysis where crash data were used directly from the area.

5.6.1 Description of the study

Since Safety is a primary component of MMDI, the Arizona Department of Transportation Database (ADOT) for crash data was used to investigate the impact of signal coordination on safety. Traffic signal coordination has been deployed nationally on over 18% of arterial miles in 78 largest metropolitan areas that have arterial traffic management (Carter et al.).

The analysis in Phoenix considered coordination, crash type, year, roadway and direction of travel. The ultimate objective was to determine the number of crashes occurred with and without signal coordination. Thirteen roads with coordinated/uncoordinated signals were selected for the study. Also, 158 intersections of which 121 were coordinated and 37 uncoordinated.

In order to determine the number of crashes, the ALLIS database was used. This is an accident database with data collected by the Arizona Department of Transportation (ADOT) and is a comprehensive database of all police reported crashes. Information from the database included the location of the crash, manner of collision, injuries, fatalities and police reported cause.

Five years of data were extracted from 1993-1997 with a total of 345,000 crashes. Annual Average Daily Traffic (AADT) data were available for the period of 1993-98 for the cities of Mesa, Tempe and Glendale in the greater area of Phoenix. The Maricopa County Traffic Count Database for the year 1998 was also used mainly for extracting AADT information.

5.6.2 Methodology used to compute the crash rates

A certain methodology was used in order to compute the crash rates based on the information previously mentioned. First, the number of Vehicles Entering Intersection (VEI) needed to be calculated. Equation 1 below shows how this number was obtained. The data for each intersection were obtained from the databases.

$$VEI = 0.5 * [\text{Approach AADT for four legs}] \qquad [1]$$

In order to investigate whether signal coordination significantly impacted overall intersection crash rates in Phoenix the following parameters were considered:

- Mainline and Through Streets only
- Intersection Only
- All crash types
- All causes
- All weather, season, time of day
- All directions

The total intersection crashes investigated were nearly 7700. Using the crash data extracted, the Factors considered above and AADT figures, the crash rates were computed.

5.6.3 Results of the study

By using the methodology described above, the crash rates for coordinated versus uncoordinated intersections were estimated (for the year 1996) as follows:

- Uncoordinated: ***0.62*** crashes per million vehicles entering the intersection
- Coordinated: ***0.51*** crashes per million vehicles entering the intersection

In terms of all crashes considered, the main conclusion was that the average yearly crash rates were 3% to 18% lower for coordinated intersections. However, as mentioned earlier, rear-end crashes will be the dominant crash type that will be impacted by signal coordination. Therefore considered rear-end crashes only by hypothesizing that for through streets, rear-end collisions most likely to be impacted by coordination. For the Maricopa County, 36% of total crashes were rear-ends. They also accounted for 36% of total crashes. Therefore, the crash rates for 1996 were as follows:

- Uncoordinated: ***0.29*** rear-end crashes per million vehicles entering the intersection
- Coordinated: ***0.21*** rear-end crashes per million vehicles entering the intersection

On an average scale, the average yearly rear-end crash rates were 14% to 43% lower for coordinated intersections. Also, some variances were found to be significant for some years.

As a final outcome, crash rates for coordinated intersections varied between 5% -65% lower for coordinated intersections from one roadway to another. Some roadways showed benefit of signal coordination on one direction but a dis-benefit in the opposing direction.

5.6.4 Comparison of the GPS floating car results and the Arizona Database outcomes

Overall, the two studies yielded very similar results, thus indicating that by coordinating the signals, the risk for a crash to occur decreases. In the case of GPS floating cars, an average reduction of the crash risk was observed to be in the range of 1.6% - 23.6% for all crash types included. The Arizona database results yielded a similar range a bit larger though. For this study the average difference in crash rates was between 14% - 43%. However, it must be emphasized that the Arizona database study considered only intersections, whereas the GPS floating car study considered all crashes on the network and had the GES as a basis for the development of the crash rates.

5.7 Summary

In this chapter, the safety model developed was described in terms of the crash rates that were computed and the overall estimation of the crash risk in both using field data and micro-simulation.

The safety model used the crash rates that were presented in chapter 4 and though the three subroutines, calculated the accident risk. Regression analysis and some statistics for the model output was also presented in this chapter.

As mentioned in the introduction of this thesis, the main scope for this study was to quantify the safety impacts of traffic signal coordination. This was achieved by developing the safety model and testing it in two different environments. First, the model was used in a micro-simulation environment using the traffic model called INTEGRATION. After simulating the Scottsdale/Rural road network, the crash risk was found to be less when the signals were coordinated and this decrease was in the range of 5%. Then, the model was tested using field data from the same network (Scottsdale/Rural road) where GPS floating cars were used. This analysis yielded very interesting results for the crash types examined as well as the different variations in speeds for before and after signal coordination cases. The crash risk was found to be decreased for coordinated signals and this decrease was in the range of 1.6%-23.6%.

Finally, in order to validate the results from the field data using the GPS floating cars, a study performed in the same area (Phoenix) was presented. This particular study used actual crash data from the Arizona database and yielded similar results as the field data shown in this chapter. The crash rates were reduced significantly. Average yearly crashes (probability) were 14% to 43% less for coordinated intersections.