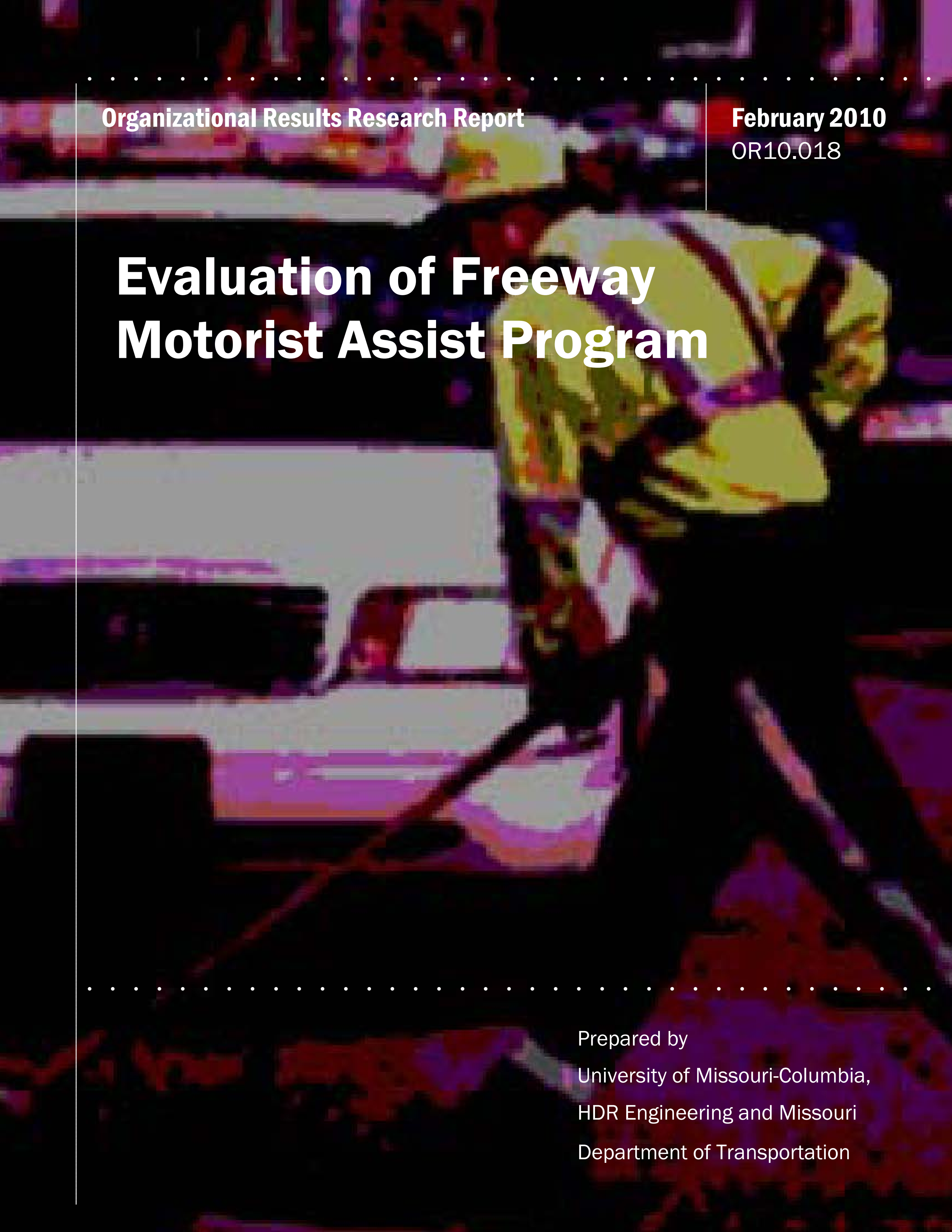

**Organizational Results Research Report**

**February 2010**
OR10.018

# Evaluation of Freeway Motorist Assist Program

Prepared by
University of Missouri-Columbia,
HDR Engineering and Missouri
Department of Transportation

**FINAL REPORT**
RD 09-004

# Evaluation of Freeway Motorist Assist Program

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16. Abstract

This evaluation of the Motorist Assist (MA) program in St. Louis estimated that MA has an annual benefit-cost ratio (B/C) of 38.25:1 using 2009 dollars. This estimate was based on nationally accepted AASHTO methodology and was based on 1082 secondary crashes reduced per year and an average crash value of $72,350/crash. This B/C is an astonishing figure that is larger than all of the B/Cs reported in literature for other similar freeway service patrol programs. One factor that contributed to this B/C was the large secondary crash reduction ratio estimated using actual data from the years prior to and after MA was first deployed in 1993. Other factors include the low cost of operations and the high cost of secondary crashes. MA is a critical component of an overall Traffic Incident Management (TIM) strategy. Responders, such as the police, validate this perspective by commenting that MA is better equipped to handle traffic control, which allows the police to take other actions such as investigating the incident. The evaluators recommend for MA to be strengthened.

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# RESEARCH RESULTS

A sustainable transportation system requires better utilization of available limited resources to deliver a **safe** and **efficient** transportation system. Sustainability is the act of balancing the environmental, community, and economic needs of the man-made and natural environments in which we live for present and future generations.

MoDOT is a national leader in developing and implementing Traffic Incident Management (TIM) elements as part of a Missouri transportation system. From the successful Motorist Assist (MA) programs in St. Louis and Kansas City to its statewide Emergency Response (ER) efforts on major interstates, MoDOT is partnering with other emergency response staff to better use resources to deliver a quicker, safer clearance of incidents along major congested roadways. Through these TIM efforts, MoDOT and its partners are providing a more sustainable transportation system addressing the three elements of sustainability: environment, community and economy through the achievement of a safer and more efficient transportation system.

This research document builds on an earlier document that evaluated the St. Louis MA program, and establishes and updates current benefits of this program. The following is a summary of findings:

**St. Louis Motorist Assist Program**

- **Benefit-cost ratio is 38.25 to 1**
- **Reduced 1,082 secondary crashes per year with annual net social benefits of $78,264,017**
- **Reduced $ 1,130,000 in annual congestion cost**
- **Supports Community Emergency Response**
    - **Safer and Quicker Incident Response and Clearance**
    - **Reduction in ER resources for TIM activities freeing them up for other Community needs**

The three elements of sustainability are present in the St. Louis Regional TIM activities. Environmental issues pertain to both natural and man-made. Improved air quality and safer transportation facilities are direct benefits for the community.

The community's transportation needs are better served when regional partners work cooperatively together to maximize limited resources. Having the right person (i.e. MA Operator) doing what they are trained for (i.e. traffic control) can save lives and time while improving the quality of life for those living in or traveling through the community.

A region's economy is strongly linked to how well its transportation system performs. The movement of people and goods impacts everyone from travel expenses to products purchased. Improving safety and reducing traffic congestion gained through TIM activities will save lives, time and money.

Everyone wins – the traveling public gains improved safety and reduced travel times at less cost. Emergency Response gains improved safety within incident sites and reduction in time spent on scene through quicker coordinated clearances. Highway agencies (e.g. MoDOT) gain improved traffic flow along their transportation facilities with results in improved satisfaction of the traveling public that financially supports regional emergency response and highway agencies.

# EXECUTIVE SUMMARY

A sustainable transportation system requires better utilization of available limited resources to deliver a **safe** and **efficient** transportation system. MoDOT is a national leader in developing and implementing Traffic Incident Management (TIM) elements as part of the sustainable transportation system in Missouri. From the successful Motorist Assist (MA) programs in St. Louis and Kansas City to its statewide Emergency Response efforts on major interstates, MoDOT is partnering with other emergency responders to better utilize resources to deliver a quicker, safer clearance of impacting incidents along major congested roadways. Through these TIM efforts, MoDOT and its partners are providing a more sustainable transportation system that helps to achieve the two foremost objectives of providing safer and efficient travel in Missouri.

This research document builds on an earlier document that evaluated the St. Louis MA program to establish and update current benefits of this program. The following is a summary of findings:

- St. Louis MA Program benefit-cost ratio was 38.25:1
- St. Louis MA Program reduced 1,082 secondary crashes per year
- St. Louis MA Program reduced $1,130,000 in annual congestion cost

The Motorist Assist (MA) program is St. Louis is a freeway service patrol program that performs critical Traffic Incident Management (TIM) functions such as incident detection, verification, traffic control and clean up, and, in addition, motorist assists. In 2003, an evaluation of MA concluded that the benefit-cost ratio (B/C) of MA was 11.2:1. That evaluation analyzed data immediately before and after the deployment of MA and produced a crash reduction factor that is used by this current study. The alternative to using a crash reduction factor would be to extrapolate the "without MA" trendline 19 years or to regress the number of secondary crashes on factors such as incident duration, lane blockage, hourly flow, and time of the day. Figure "I", reproduced from the previous study, illustrates graphically the significant differences in secondary crash trends before and after MA is implemented. This evaluation updates the previous study to reflect: 1) the temporal (longer hours) and spatial (wider coverage) expansions of MA; 2) the use of better safety and traffic data; 3) improved secondary crash methodology; 4) the use of national guidelines, the AASHTO Redbook, for analyzing highway user benefits; 5) the use of statistically significant differences between secondary and primary crash characteristics; and 6) proper discounting to update to present dollar values.

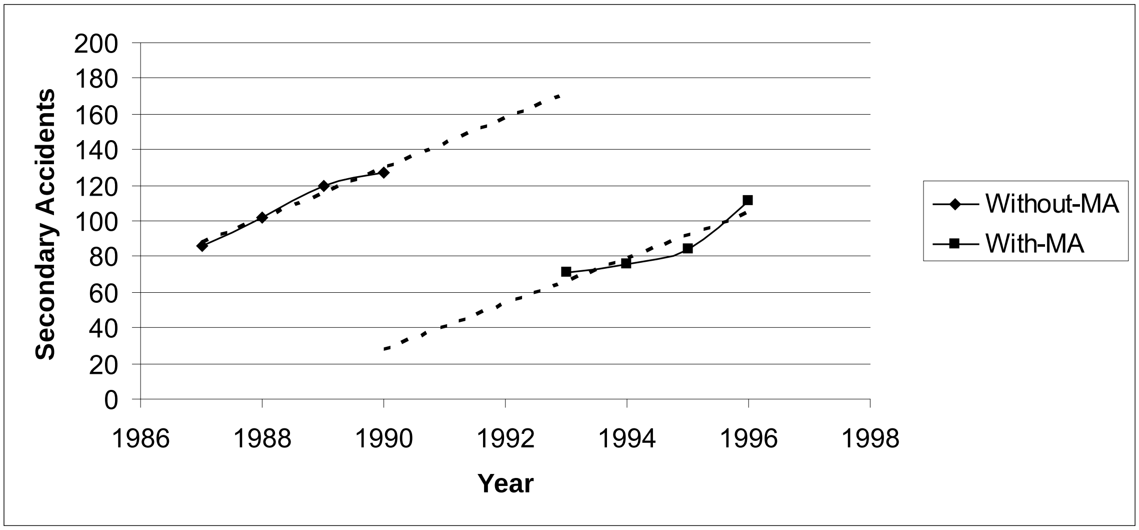

Figure I. Secondary Crashes Before and After MA on I-270 (UMC, 2003)

The report in 2003 only examined two freeways, namely I-70 and I-270, since MA's initial coverage was limited in scope. Now there is full MA coverage on all freeway segments, therefore the benefits and costs are both increased. However, the benefits increased much more than the cost. Also, the crash data shows an interesting differentiation between primary and secondary crash characteristics. Table I shows that there is a higher percentage of both fatal and PDOs for secondary crashes that is statistically significant. Specifically, average secondary fatal crashes are 0.829% per year compared with 0.337% per year for primary. The more severe crashes dominate costs, thus secondary crashes cost more and are more severe than primary crashes on the average.

This fact illustrates the importance of incident management programs in general and MA specifically. AASHTO published the "Redbook" in 2003 that recommended higher valuation for severity than some other sources and also a larger discount rate of 3%. In the previous study, a more conservative rate of 2% was used. The discovery of the difference in severity between secondary and primary crashes coupled with the larger discount rate led to an increase of valuation of average crashes from $30,000/crash (2002) to $72,350/crash (2009 dollars).

**Table I. Crash Percentage by Severity**

| Year | Secondary |  |  |  | Primary |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Fatal | Disabling Injury | Minor Injury | PDO | Fatal | Disabling Injury | Minor Injury | PDO |
| 2000 | 1.15 | 2.20 | 22.93 | 73.72 | 0.28 | 2.21 | 25.51 | 72.00 |
| 2001 | 0.62 | 1.24 | 23.26 | 74.88 | 0.32 | 2.42 | 24.61 | 72.66 |
| 2002 | 1.02 | 2.54 | 20.36 | 76.08 | 0.38 | 2.26 | 24.41 | 72.95 |
| 2003 | 0.79 | 2.03 | 22.94 | 74.24 | 0.26 | 2.25 | 24.51 | 72.99 |
| 2004 | 0.48 | 2.63 | 20.36 | 76.53 | 0.31 | 2.43 | 23.85 | 73.41 |
| 2005 | 0.82 | 2.11 | 21.87 | 75.20 | 0.31 | 1.95 | 25.57 | 72.16 |
| 2006 | 0.91 | 2.17 | 22.37 | 74.54 | 0.26 | 2.02 | 23.57 | 74.14 |
| 2007 | 0.75 | 2.25 | 22.47 | 74.53 | 0.30 | 2.15 | 23.23 | 74.32 |
| 2008 | 0.66 | 2.51 | 18.34 | 78.50 | 0.34 | 2.42 | 24.15 | 73.09 |
| Weighted Average | 0.829 | 2.026 | 21.89 | 75.25 | 0.337 | 2.18 | 24.28 | 73.20 |

Actual field data from Missouri was used in this study. Some simulation and mathematical modeling were performed for analyzing mobility benefits and estimating delays. However, no simulation and mathematical modeling were performed as part of the safety and crash analysis of MA. Average crash characteristics from St. Louis were used to develop the methodology for extracting secondary crashes.

The new B/C estimated for MA is 38.25:1 annually using 2009 dollars. This is a staggering value when compared to other highly effective safety countermeasures. Even if all the costs were not fully captured, the benefit is nonetheless an incredibly large number.

MA is a critical component of an overall Traffic Incident Management (TIM) strategy. Interviews with police agencies consistently affirm the service patrol's excellent working relationship with police, and the service patrol's value in handling traffic control in TIM which enables police to focus on other TIM duties that are more suitable for police. As a result of the benefit-cost analysis, evaluators recommend that Freeway MA should be continued and strengthened as a regional TIM component

# GLOSSARY

| | |
|---|---|
| B/C | Benefit-to-cost ratio: a popular method for assessing the societal benefits against the costs of a particular project or alternative. |
| Gateway Guide | The Intelligent Transportation Systems initiative in St. Louis, Missouri, which includes a regional Traffic Management Center. |
| FSP | Freeway Service Patrol: a service provided by departments of transportation that involve patrolling sections of roadways, managing incidents, and assisting motorists. |
| IPC | Incident Progression Curve: a curve displaying the queue resulting from incidents over time and space that is used for classifying secondary crashes. |
| MA | Motorist Assist: a freeway service patrol program in the St. Louis region that includes Emergency Response in the off hours. |
| TIM | Traffic Incident Management: the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and safety and mobility impact of incidents. |
| TMC | Traffic Management Center. |
| ER | Emergency Response: are resources, including police, fire, ambulance, wrecker services, etc., needed to assist in clearance of incidents from transportation facilities |
| VMS | Variable Message Sign. |

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# 1. INTRODUCTION

This report presents the results from a benefit-cost (B/C) analysis of the Motorist Assist (MA) program in St. Louis, Missouri.

## 1.1 Coverage and Scope of Motorist Assist

The MA Program debuted on February 1st, 1993, in the St. Louis region. Initially, only four vehicles patrolled just three routes with a total centerline mileage of 31.5 miles. The hours of operation were limited to the morning and evening peak periods only. In 1996, the program was expanded by nine operators and four trucks. The additional manpower and equipment allowed for an increase in both the number of centerline miles patrolled and expanded the hours of operation to 5:00AM to 12:00PM and 1:00PM to 7:30PM. Another expansion in 2001 added I-44 and I-64/US 40 from west of Mason Rd into St. Charles County as patrol areas. In August 2002, MA began patrolling on Saturday and Sunday for the first time. Currently, MA trucks patrol St. Louis area freeways from 5:00 a.m.-7:30 p.m., Sunday to Sunday and include the following roadways:

- Route 364-Page Avenue I-270 to Rte. 94
- I-44 Six Flags Road to Downtown St. Louis
- I-55 Highway A (Festus) to Downtown St. Louis
- I-64/Rte. 40 Rte. 94 to Downtown St. Louis
- I-70 Mid Rivers Mall Drive to Downtown St. Louis
- I-170 all
- I-270/I-255 Riverview Drive to Jefferson Barracks Bridge

The coverage map is shown in Figure 1.1.

**Figure 1.1 Motorist Assist and Gateway Guide Coverage (MoDOT, 2009)**

## 1.2 Purpose of Motorist Assist

The purpose of the MA Program is to promote freeway safety and expedite the flow of high volume traffic by assisting disabled motorists in the patrol areas, clearing roadways of stalled vehicles and debris, and assisting emergency personnel at accident locations. MA improves the flow of traffic and increases safety by detecting and responding to incidents quickly, removing incidents in a timely manner, and providing high-visibility traffic control devices at incident scenes. Figure 1.2.1 illustrates some of the services that MA performs. Specific services include:

- Push a disabled vehicle out of a traffic lane
- Provide traffic control at an incident scene
- Remove debris from the roadway
- Establish initial containment of a hazardous materials spill
- Give directions to a lost motorist
- Mark an abandoned vehicle with the date and time to expedite removal by police
- Contact police to tow an abandoned vehicle impeding traffic flow
- Make basic repairs to a disabled or stalled vehicle
- Provide a stranded motorist a ride to a safe location
- Allow a motorist the use of a cellular phone
- Change a flat tire
- Dispense fluids such as gasoline or engine coolant

**Figure 1.2.1 Example of MA Operator Assisting in Debris Clean Up**

In addition to the many primary functions, throughout its existence MA program has accepted several secondary purposes. For instance, major accidents require a prolonged presence of emergency personnel to provide a “buffer zone” between moving traffic and the incident scene and to close necessary traffic lanes or even an entire freeway. MA helps to fill this role by ensuring safety at an accident scene and by maintaining a presence at the point of a lane or freeway closure. An additional secondary function is checking for state property damage. Each roundtrip of MA on a beat serves as a basic inspection for malfunctions and damage to the freeway system. Lighting facilities not working and damaged guard rails are just a couple examples of the types of problems possibly noted by MA. Also, since the inception of Gateway Guide, the Intelligent Transportation System (ITS) for the St. Louis region, MA has become an integrated component of the system. Operators in the field provide information on traffic problems resulting from both recurrent congestion and incidents. Details of incident location and approximate clearance time are provided to dispatchers at Gateway Guide’s Transportation Management Center (TMC), which in turn transmit the information to the public via ITS outlets such as the media, dynamic message boards, and the Gateway Guide website.

## 1.3 Interactions with Other Agencies

Since incident management is an important role of FSPs such as MA, it is important to understand the context of Traffic Incident Management (TIM) and the roles of each of the factors. The factors involved with TIM usually include police, fire, 911 dispatch, towing and recovery, emergency medical services, hazardous materials (HAZMAT), transportation agencies, and the media (FHWA, 2000). The success of TIM depends not only on each partner performing capably, but also on the efficient coordination among all the partners. While there might be some overlap in some of the functions, there are certain functions that are particular to a specific partner. In the case of MA, some functions such as debris removal, traffic control, detection, and verification can be performed by others, such as the police. However, MA/TR is the most suitable partner for many of those functions because of the training, equipment, and its role as part of the overall Intelligent Transportation Systems’ (ITS) deployment in St. Louis. One could argue that some functions, such as traffic control, can also be performed by the police. However, many police agencies prefer that MA handle such functions so that the police can be freed up for other tasks such as accident investigation, and MA operators have more traffic control equipment than other responders such as arrow boards, barricades, and cones. The following police agencies were contacted to obtain their qualitative assessment of their working relationship with MA:

- Jefferson County Police
- Pevely Police Department
- Festus Police Department
- Arnold Police Department
- St. Louis City Police
- St. Louis County Police
- Eureka Police Department

Due to availability, only three interviews were conducted. The telephone interviews were with Captain David Kaltenbronn of Pevely Police Department, Lieutenant David Wilson of Eureka Police Department, and Chief Tim Lewis of Festus Police Department. The overwhelming response from the interviews was that MA was extremely valuable as responders in TIM and that they complement well the other responders such as police. Captain Kaltenbronn said that MA operators are pleasant to work with and communicate well with the police. He was extremely satisfied with MA. His agency is composed of ten road officers and fourteen officers total. He said that when an officer performs traffic control, it takes away from other functions such as doing accident investigations or handling other residential or commercial issues. Lieutenant Wilson echoed the same sentiment that MA operators communicated well with the police and that they were quick to respond. Lieutenant Wilson said that MA operators were better equipped to handle some of the traffic issues because they had more training in traffic and possessed more suitable equipment. The Eureka police department is composed of 25 officers and is responsible for a section of I-44 as well as a ten square mile region that includes the Six Flags amusement park. The police sentiments can be best summed up the words of Chief Lewis: “We need it [MA], don’t get rid of it.”

# 2. LITERATURE REVIEW

This literature review contains eighteen additional references that had not been used in the 2003 Evaluation of the Motorists Assist in St. Louis. Also, the web pages from the departments of transportation of 12 states are reviewed. This review contains basic information for the operation of the Freeway Service Patrols (FSP) of 22 cities in the 12 states, and information on the B/C from ten cities. The B/C ranged from 2:1 to 36:1 with an approximate average of 13.5:1. All of the references agreed that service patrols reduced incident times, promoted better highway service, and improved safety. One limitation of this literature review is that each city or state used the variables that it deems relevant to calculate the B/C. Since the operation schemes were so different between states and sometimes between cities in the same state, it became almost impossible to establish comparisons between them. For example, in the Evaluation of the Service Patrol Program in the Puget Sound Region, Washington, the intent was to compare the performance of the FSP between the cities of Seattle and Tacoma and determine if one was performing better that the other. The investigation concluded that both cities were performing fairly under their different schemes. The methods used in evaluations included direct analysis of crash, assist, and traffic data; simulation-based analysis; mathematical modeling and queue modeling; and surveys.

## *2.1 Review of Motorist Assist Evaluations*

Most references mentioned that there was no agreed upon definition of what a secondary incident was, so each researcher had to establish the relationship between primary and secondary incidents. Since most states filed each incident separately, researches relied on queuing and traffic flow theory to establish relationships between incidents. There had been issues about the reduced number of secondary crashes found normally on databases. Current literature stated that incidents on freeways account for approximately 60% of all congestion delay in the United States (Pal et al., 1998; Skabardonis et al., 1999; Khattak et al., 2004; Chou, 2008). Incidents that cause delays included vehicle breakdowns, debris in the roadway, spilled loads, abandoned vehicles, pedestrians on the roads, crashes, or any other incident that causes a reduction in the capacity of the road. Since the 1960's, the departments of transportation (DOTs) of several states and cities in the United States implemented various forms of Freeway Service Patrol programs (FSP) to help minimize the effects that these incidents have on the performance of the highways and to help improve safety for the drivers. FSP programs proliferated in the 1970's and 80's, mainly because of availability of federal and local funds, and because of the DOTs and general public acceptance. But in the 1990's, due to budget constraints, the need rose for evaluating the benefits of the FSP programs and comparing them to the programs costs. Program costs were readily available from financial statements since the implementation of the programs, but estimating the benefits from the programs required making a comparison between the effects of an incident that is managed through a FSP program versus the effects of the same or a similar incident managed under normal conditions (without FSP program).

Donnell et.al. (1999) presented an evaluation of the Penn-Lincoln Parkway Service Patrol. The Pennsylvania DOT contracted a local towing company that provides assistance during traffic peak hours in the Penn-Lincoln Parkway using only three tow trucks. For this study, the authors had access to an extensive State Police database of incidents that occurred prior to the implementation of the service patrol. Data from similar accidents that occurred prior and post implementation of the FSP were paired and the incident response time, incidence clearance time, vehicle-hours of delay, fuel consumption and vehicle emissions of the similar incidents were directly compared. The study showed that due to the assistance of the service patrol, the incident response times were reduced by an average of 8.7 minutes, incidents were cleared an average of 8.3 minutes faster, and the system experienced 547,000 hours less of total delay and the monetary savings was 6.5 million dollars per year. This resulted in a benefit-to-cost ratio of 30:1.

The methods used to collect data from FSP evaluations were varied. Two of the largest data collection experiments, performed by Skabardonis et al., published the results of data collected on the I-880 highway (1997) and the I-10 freeway 1999), both located in Los Angeles, California. Both databases were collected using probe vehicles to determine vehicle trajectories, loop detectors to determine volumes and lane occupancy, and incident records from the police and the FSP. Specifically for the I-10 project, the researchers deployed 7 probe vehicles at 5.7 minute headways to record the type of incident (e.g. crash, breakdown, other), the severity (as the number of lanes closed), the description of the vehicles, the location, and the type of help present (e.g. police, FSP, other). Statistical analysis was performed. The lognormal distribution was found to provide the best fit to the data. Approximately 50% of the incidents reported during the I-10 experiment were vehicle breakdowns located on the shoulders. The researchers concluded that incident durations were greatly affected by the incident type, the severity of the incident, and the type of assistance provided.

Pal, Latoski, and Sinha evaluated the Hoosier Helper program in northern Indiana (1998). The Hoosier Helper program started operations in 1991 with three pickup trucks and three vans that provided services between 6:00 am and 8:30 pm, and in 1996 expanded to a 24 hour operation. Data collected from the service logs for the daytime and 24 hour service periods revealed that approximately 70% of the incidents required the FSP to perform small services such as changing flat tires or supplying gasoline. The second most common service provided was removing abandoned vehicles from the shoulders. Crash assistance only accounted for 5 to 7 % in each period respectively. Therefore, severity was not an important factor. They also used the XXEXQ network simulation model. The model performs User Equilibrium traffic assignment using the Bureau of Public Roads link functions and generates travel times for individual vehicles and for the entire system. The importance of the XXEXQ model is that it could document the movement of vehicles from the affected road into other roads in the network. Eight scenarios were evaluated for the daytime operation and six scenarios for the 24 hour operation. The benefit-to-cost ratio was estimated at 3:1 before 1996, and an increase of 9:1 was estimated for the 24 hour operation after 1996. The authors also concluded that safety was increased by the 24 hour operation by reducing secondary incidents by 18.5%.

Simulation-based computer models were also used for evaluating the performance of FSP when data prior to the implementation was not available. In 2009, Chou (2009) estimated the benefit-to-cost ratio of the Highway Emergency Local Patrol (HELP) in New York State using the CORSIM microscopic simulation model. Six hundred and ninety three (693) incidents that were assisted by HELP were replicated in CORSIM, both with assistance and without assistance. Each incident was replicated 5 times using different random seeds or input information to ensure proper fit with real data. The only parameter modified in CORSIM was to adjust for rubbernecking. Using conservative assumptions for economic parameters (1 passenger per vehicle, average fuel consumption, etc.) the benefit-to-cost ratio was estimated as 2:1. CORSIM was also used by Heath and Turochy (2008) to evaluate the Alabama Service and Assistance patrol (ASAP). Thirty scenarios were developed and tested using the program database and CORSIM. Results in the form of benefits to cost ratios of vehicular volumes, speeds, delays and emissions were generated. The benefits to cost ratios of the variables using conservative figures were estimated and the B/C ration ranged from 1.7:1 to 23.4:1.

Other methods used include mathematical modeling, deterministic queue modeling, and evaluative surveys. Guin et. al. (2007) used the Traffic Incident Management Handbook provided by the Federal Highway Administration (FHWA, 2000) to develop a mathematical model to represent the motorist assist data generated by the Georgia NaviGAtor program. The model proved to fit the data reasonably well and took into consideration vehicular delay, fuel consumption, secondary crashes and emissions. The NaviGAtor program had a benefit-to-cost ratio of 4.4:1. One drawback from this mathematical model was that it could not be easily transferred to other systems because it was created to fit specifically one set of data. A deterministic queue model was used by Dougald and Demetsky (2008) to measure delays and to estimate the benefit-to-cost ratio of the Northern Virginia Safety Service Patrol (NOVA SSP). Queue models could be used by virtually any agency to model delays. Using conservative figures for estimating fuel consumption and vehicle emissions, the benefit-to-cost ratio for the NOVA SSP was estimated in 5.4:1. The Tennessee Freeway Service Patrol program used surveys to estimate the adequacy of its FSP program (Baird et. al., 2003). Motorists that had been assisted on the road were given a return postage paid comment card to evaluate the services received. Between the years 2001 and 2003, 11,000 cards had been returned and 99% of the evaluations were excellent. The drawback from this evaluation is its subjective nature.

## *2.2. Review of Secondary Crash Analysis Methodology*

In addition to reviewing literature on MA and TR, the literature pertaining to secondary crashes was also reviewed. The use of the term “secondary crash” instead of “secondary accident” was intentional in order to emphasize the potential for reducing such crashes due to improved incident management and traveler information on the primary incident. Even though there is consensus on the importance of incident management and reduction of secondary crashes, the methods for analyzing secondary crashes are not well defined. The development of this research is based upon previous work in the area of crash analysis and safety. In an important paper on the analysis of secondary crashes, (Raub

1997), Raub presents a methodology for the temporal and spatial analysis of incidents on urban arterials in order to identify the secondary crashes. Raub (1997) found that more than 15% of the crashes reported by police may be secondary in nature. He also found that such crashes result from external distractions instead of internal distractions or driver perception error. For his analysis, he assumed crash effect duration of 15 minutes plus the clearance time. He also assumed a distance of effect of less than 1600 meters (1 mile). In other words, if a crash occurred within these temporal and spatial boundaries, then it is considered to be secondary.

More recently, Moore et al. (2004) examined secondary crash rates on Los Angeles freeways using crash records from the California Highway Patrol's First Incident Response Service Tracking system as well as data from loop detectors on Los Angeles freeways. They defined secondary crashes as crashes occurring upstream of the initial incident in either direction within or at the boundary of the queue formed by the initial incident. A static threshold of 3.2 km (2 miles) and 2 hours was used for forming this boundary. Several levels of filters served to eliminate erroneous data. Another example of the use of static threshold is Hirunyanitiwattana and Mattingly (2006); they used a threshold of 3.2 km (2 miles) and 1 hour in the same direction.

Several recent studies have focused on determining the interdependence between road incidents and the secondary incidents that can be caused by them. Khattak et al. (2008) used the incident database provided by the Virginia Transportation Research Council and applied an Ordinary Least Squares regression model to estimate the relation between primary and secondary incidents. The researchers defined a secondary incident as one that occurs in the same direction as the primary incident and within its time duration. The only exception to this definition was that if the primary incident blocked one or more lanes, then the primary incident duration time would be increased by 15 minutes. After applying the models, the researchers concluded that secondary incidents are closely related to longer durations of primary incidents; therefore, transportation agencies should focus their roadway assistance efforts to providing expedited attention to reducing primary incidents durations in order to reduce the possibility of secondary incidents.

Zhan et al. (2008) proposed a different definition to secondary incidents. In their research, they determined that secondary incidents are those that occur within the queue formed by a primary incident. Using a cumulative arrival and departure traffic delay model, the researchers determined the maximum queues and queue dissipation times from a comprehensive database provided by the Florida Department of Transportation. After identifying all pairs of primary and secondary incidents from the database, the researchers used a logistic regression model to estimate the possibility of secondary incidents. Their conclusions where similar to the conclusions of Khattak et al.: secondary incidents are closely related to the durations of primary incidents; therefore, reducing the durations of lane blockage could significantly reduce secondary incidents.

One possible drawback from the research presented in the two previous paragraphs is that the definition used to identify secondary incidents only considered incidents that occurred in the same direction, which left out incidents that could have occurred in the opposite direction due to distractions caused by the primary incident (rubbernecking). Zhang and Khattak (2009) focused on identifying the time gap between a primary incident and its related multiple secondary incidents, with special attention to incidents in the opposite direction to the primary incident. By using built-in statistical models in MATLAB, the authors concluded that 60% of first secondary incidents and 50% of secondary incidents in the opposite direction occur within 20 minutes of the primary incident occurrence.

Some of the earlier studies exemplify the use of static (fixed) thresholds for classifying secondary crashes. Figure 2.2.1 shows a graph of the progression of an incident. The origin represents the onset of the primary incident. The horizontal axis represents time elapsed since the incident occurred. The vertical axis represents the growth of the queue from the location of the incident. The letters A through F, represent 6 crashes that occurred after the onset of the primary incident and downstream from the incident. If a crash falls within the influence of the primary incident, (i.e. the crash happened within the queue of the primary) then the crash is considered to be secondary. The static/fixed thresholds of queue length and time are superimposed on this progression. Progression refers to the growth and decline of the queue length as the incident progresses through the various stages. In general, the various stages of an incident include the onset, the arrival of response teams, the clearance to the shoulder, the completion of clearance, and the normalization of traffic. The progression is also a function of both the demand (traffic) and the supply (road capacity). With the demand changing constantly, it is clear that the assumption of static thresholds would not capture field conditions as well as dynamic thresholds. Some would argue that on the average, the total number of secondary crashes can still be estimated accurately with static thresholds if the area of the static threshold rectangle is the same as the area under the progression curve. This argument requires the assumption that crashes are independent from the location and time of the primary incident. For example, Figure 2.2.1 shows that the same number of crashes (three) is classified as secondary using a static threshold or an actual incident progression curve. However, by definition, secondary crashes differ in cause from primary crashes. Therefore even if the average number of crashes is captured accurately with static thresholds, the crashes themselves are still misclassified. Referring back to the example and looking at the static thresholds, the total number of secondary crashes is estimated correctly even though crash B is a false positive (should have been excluded) and crash E is a false negative (should have been included). The elimination of such type I and type II classification errors is one primary motivation for the development of dynamic thresholds. It is intuitive that crashes that occur near the time of the onset of the primary crash but far away from its location should be not classified as secondary since the queue growth is limited by the speed of the shockwave. However, this can occur if a static threshold is used.

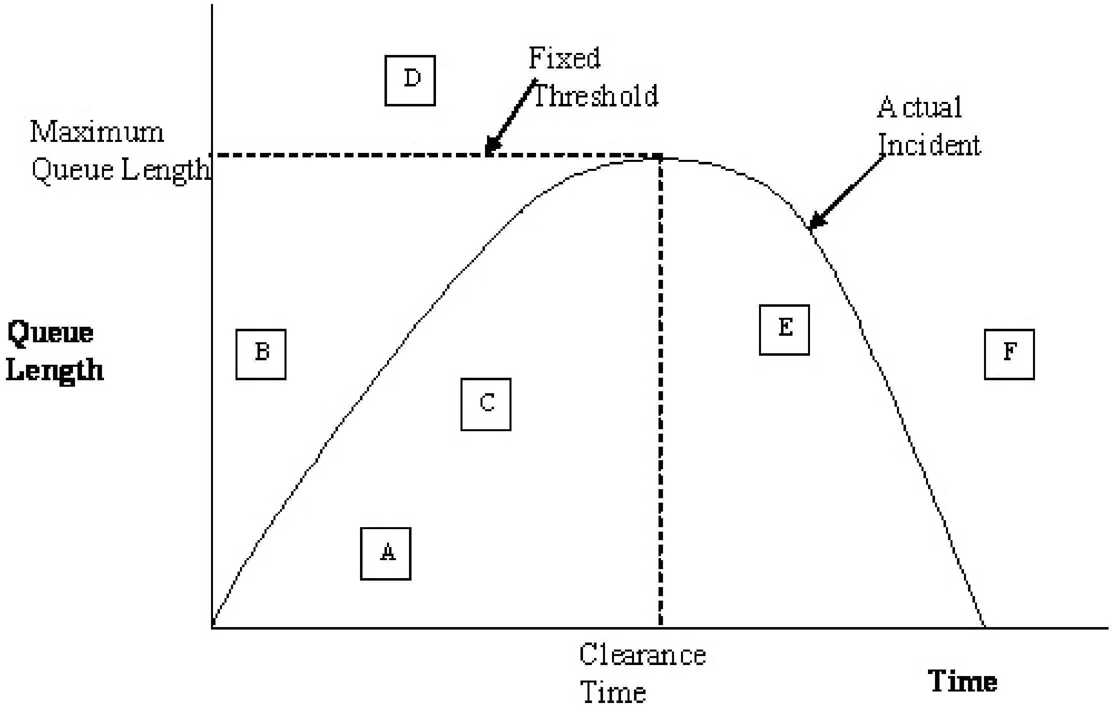


**Figure 2.2.1 Comparison between Static and Dynamic Thresholds**

There were other articles that relate to secondary crashes but did not address the secondary crash extraction process directly. Karlaftis et al. (1999) examined the primary crash characteristics that influence the likelihood of secondary crash occurrence. They suggested that clearance time, season, type of vehicle involved, and lateral location of the primary crash were the most significant factors. The economic benefit of secondary crash reduction for the Hoosier Helper freeway service patrol program was also presented. There were several articles that addressed the magnitude and impact of incident delays. These include Garib et al. (1997), Giuliano (1989), Skabardonis et al. (1996), Morales (1997), Sullivan (1997), Smith et al. (1987), Lindley (1987), and Lee et al. (2003). Many of these articles tried to estimate the impact of crashes. This project, on the other hand, used the direct derivation of the impacts (queue lengths over time) from intranet traffic reports.

# 3. MA SAFETY EVALUATION METHODOLOGY

## *3.1 Safety Data*

Safety data collected from the Missouri Uniform Accident Report (MUAR) forms is used in this project. These reports are part of the Statewide Traffic Accident Records System (STARS) that began with support from the National Highway Traffic Safety Administration (NHTSA) (STARS, 2002). The current 2002 revision of the form complies with Federal guidelines. STARS receives recommendations and support from various organizations and agencies including the Automobile Club of Missouri, police and sheriff departments throughout the State, and various Missouri departments such as Health, Revenue, and Transportation. One hundred and one (101) separate fields from approximately 65,000 MUAR reports have been processed with data files ranging in size from 40 MB to 77 MB. A large number of fields are examined in order to maximize existing crash information. Even though there is potential to use many of the fields, many fields are not being filled in by police agencies and thus are not usable. This could be partly due to the type of crash that resulted in the use of only a short form MUAR. This could also be due to the lack of information or the burden of collecting such data. For example, there are several fields pertaining to towing companies, e.g. company, address, zip code, and telephone that are usually not filled in. Such data could have been useful for estimating towing response in absence of FSP involvement.

This study includes data from the following freeways for the years 2000 to 2008.

- I-44
- I-55
- I-64
- I-70
- I-170
- I-255
- I-270

## *3.2 Identifying Secondary Crashes*

Traffic incidents are defined as an unplanned randomly occurring traffic event that adversely affects traffic safety and operations. Thus incidents could be as trivial as vehicle breakdowns, or as severe as multi-vehicle crashes. Secondary crashes are crashes which result from an existing primary incident. Most times these crashes occur at the end of queues that are developed from the primary incident. Quickly opening the highway after an incident reduces the potential for secondary crashes. It is easy then to see the value of analyzing secondary crashes when considering traffic incident management strategies such as MA. On the other hand, the effects of such systems on primary crashes would be much less, because many of these crashes are caused by driver error such as fatigue, intoxication, or aggressive driving. Therefore traditional analysis of primary crashes and crash rates will not reveal the full potential of such systems. One important step in evaluating incident management systems is the identification of secondary crashes. The police crash report contains a field that describes downstream conditions as “accident ahead” or “congestion ahead”. The difficulty with the police determining whether the crash is primary or secondary is that they are limited spatially (at one location) and temporally (responding to the current crash). Since the effect of primary crashes can persist long after it has been cleared, it is difficult to determine at the scene of a crash if it is due to recurrent or non-recurrent congestion. The use of the category “accident ahead” for finding secondary crashes would undercount the number of crashes while adding the category “congestion ahead” would severely over-count the number of crashes. Therefore, the crash reports themselves do not contain enough information for classifying secondary crashes.

In order to accomplish the identification of secondary crashes, several other objectives need to be achieved. First, the boundary of the primary incident needs to be specified in order to define the temporal and spatial region of influence of the primary incident. In other words, one needs to determine the length of the queue throughout the duration of the incident. The duration can include the incident normalization period and not just the period up to the incident clearance. In other words, even after the incident has been cleared, it might take a significant length of time before the traffic condition reverts to normal. This boundary of influence is termed the Incident Progression Curve (IPC). Second, once incident progression curves are developed for individual incident, master curves are produced by combining individual curves. The intent is to produce an aggregate measure of secondary crashes by classifying the number of secondary crashes over a significant time period such as a year or multiple years. In other words, these master curves can provide control or information for differences in the severity of crashes and in the level of congestion or more specifically the volume over capacity ratio (v/c).

Traffic management centers and traffic news agencies can provide wide spatial coverage of incidents as well as track the incidents over time. They can use information from aircrafts, elevated traffic cameras, MA, emergency management (fire, police, ambulance, and HAZMAT), and motorist calls. They can also monitor and update this information throughout the course of an incident. Such intranet traffic information can be independent from police information; therefore such information can complement the crash database from the police. Data fusion helps to incorporate all the available information sources including intranet traffic reports and the crash database. By analyzing individual traffic reports in detail, the reporting times of the incident and the dynamic locations of the back of the queue can be found. The difference between the initial and final times gives an estimate of the total duration of the incident, and the distance from the location of the incident to the back of the queue gives an estimate of the length of the roadway that is affected by the incident. A total of 480 incidents were extracted from the traffic reports for freeways I-70 and I-270 in St. Louis, Missouri. These were the incidents that contained some sort of backup or queue information. For these incidents, the extent of traffic information varied from covering the incident progression for the entire duration to reporting the incident with initial back up reports. The intranet traffic reports are used for developing IPCs. Figure 3.2.1 shows the IPC for PDO primary incidents and Figure 3.2.2 shows the IPC for injury and fatal primary incidents. In order to use the IPCs presented in Figures 3.2.1 and 3.2.2, one first identifies the severity of the primary incident and the v/c when the incident occurred. If a potential crash falls within this IPC curve then it is considered to be a secondary crash. In other words, if the crash occurred at a close proximity upstream from the primary incident and at the same time occurred recently after the onset of the primary incident then it is considered to be secondary. Because fatal crashes are rare events, there are not enough reports to generate a separate IPC for fatal incidents. Table 3.2.1 presents relevant the maximum queue length, the time of the maximum queue, and the time to normalization. For example, an injury crash during heavy traffic will have a median maximum queue length of 4.91 miles at 68 minutes and a time to normalization of 127 minutes.

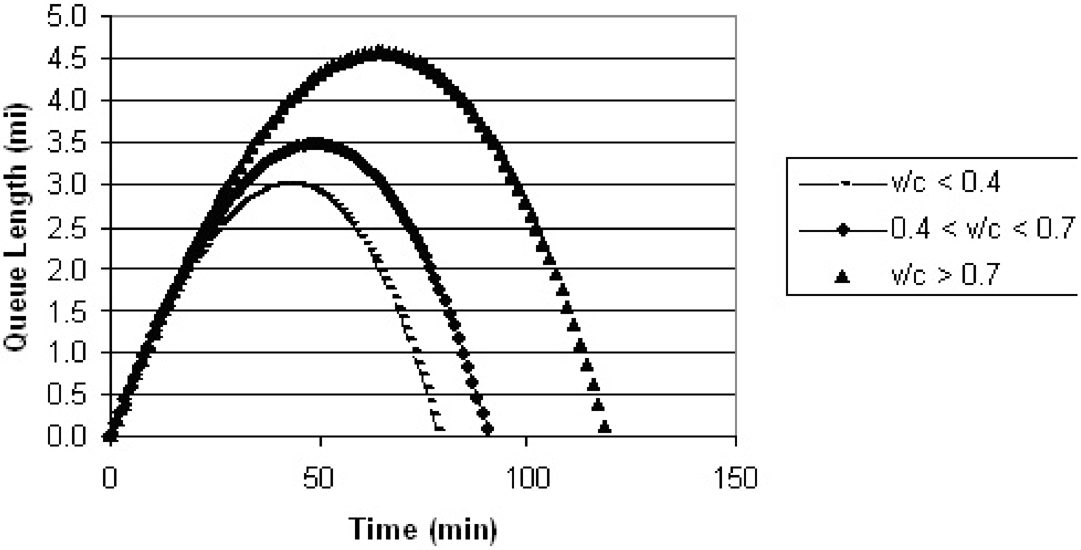


**Figure 3.2.1 IPC for PDO crashes.**

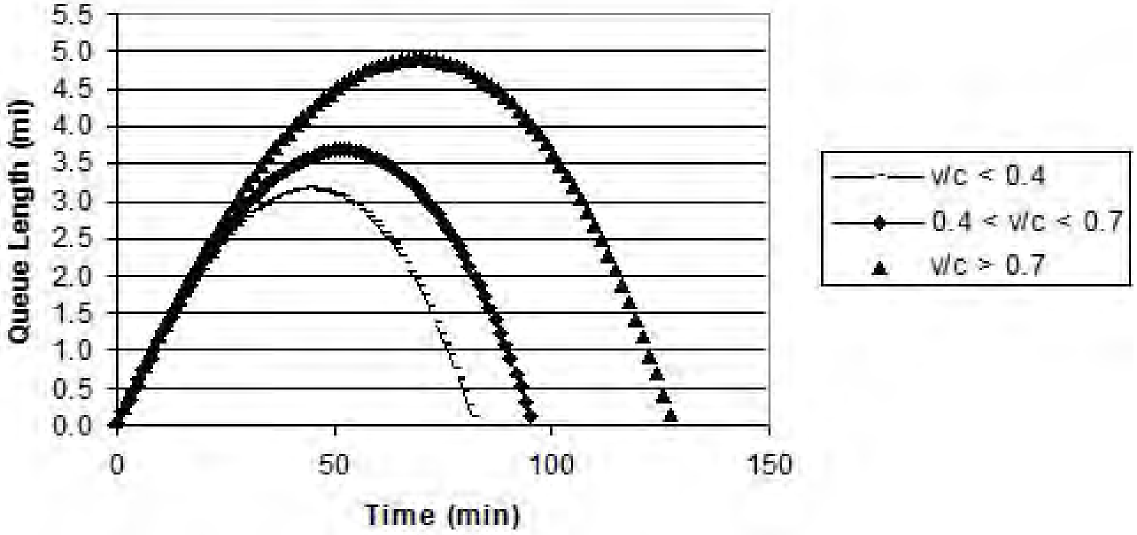


**Figure 3.2.2 IPC for Injury and Fatal crashes.**

**Table 3.2.1 IPC Parameters Based on Severity and v/c Ratio**

| Description | Criteria | Maximum Queue (km) | Time of Max. Queue (min) | Time to Normal. (min) |
|---|---|---|---|---|
| Light | PDO, v/c < 0.4 | 4.86 (3.02 mi) | 42 | 78 |
| Medium | PDO,<br>0.4 < v/c < 0.7 | 7.21 (3.48 mi) | 48 | 90 |
| Heavy | PDO, v/c > 0.7 | 7.35 (4.57 mi) | 64 | 118 |
| Light | INJ, v/c < 0.4 | 5.09 (3.16 mi) | 44 | 82 |
| Medium | INJ,<br>0.4 < v/c < 0.7 | 5.92 (3.68 mi) | 51 | 95 |
| Heavy | INJ, v/c > 0.7 | 7.90 (4.91 mi) | 68 | 127 |

In using Figures 3.3.1 and 3.3.2, the v/c ratio is required. This value, however, can require significant labor to derive directly as the crash database will need to be linked with traffic data along with freeway geometric data (lane configuration). Instead, a relationship between the "time of the day" and v/c was developed. In general, non-incident traffic levels are fairly predictable throughout course of the day. For example, Figure 3.2.5 shows volumes on I-64, and it shows v/c ratios corresponding to different time periods. The relationship between v/c and time of the day is as follows:

- v/c>0.7: 4:00-6:00 pm and 7:00-10:00 am
- 0.4<v/c<0.7: 10:00 am-4:00 pm
- v/c<0.4: all other times

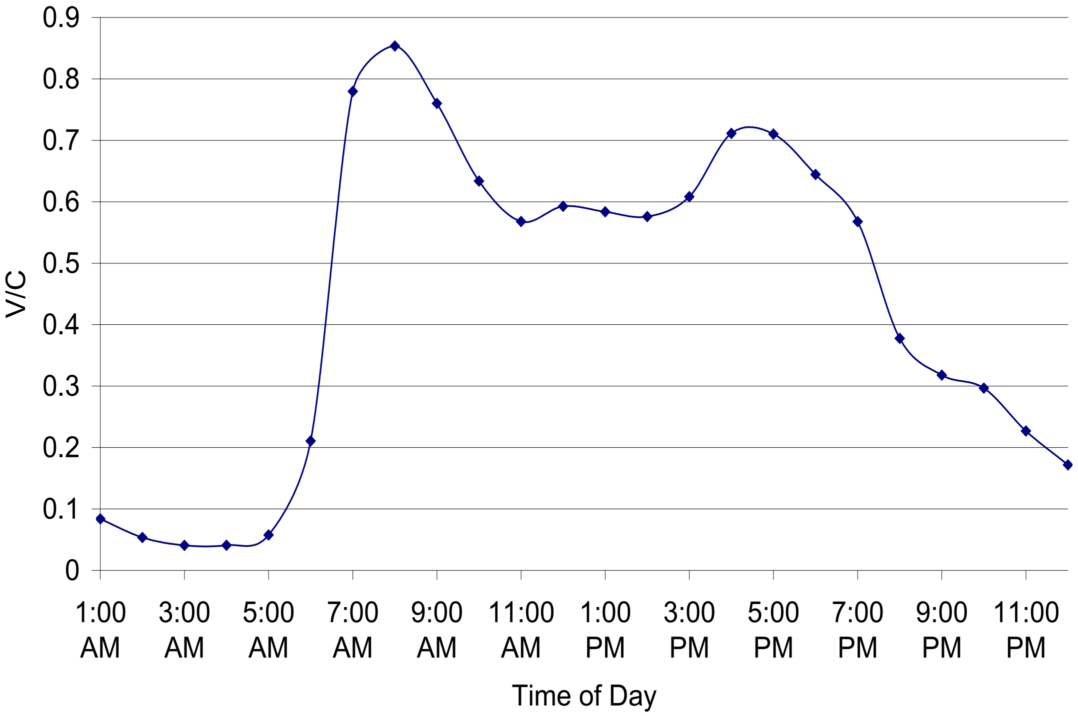


**Figure 3.2.5 Typical v/c Throughout a 24 Hour Period**

The police crash database is processed and the secondary crashes are classified using the master IPC.  In processing the database, a convention for formatting crash reports is developed so that the appropriate information from the crash database is extracted and formatted.

# 4. MA SAFETY EVALUATION RESULTS

## 4.1 Comparison between Secondary and Primary Crash Characteristics

Crash reports were examined to determine if there were statistically significant differences between secondary and primary crash severities. A previous study of several arterials and expressways in California showed that secondary crashes represented an increase in collision risk of over 600 percent (Volpe, 1995). Table 4.1.1 presents the severity characteristics of primary and secondary crashes by year in St. Louis. Table 4.1.1 shows the percentage of each crash severity. For example, Row 1 shows that of all secondary crashes in 2000, 1.15% are fatal, 2.20% are disabling injury, 22.93% are minor injury, and 73.72% are PDO, and the percentages add up to 100%. Table 4.1.1 contains data from all freeways in the St. Louis region. These include I-70, I-270, I-44, I-64, I-55, I-170, and I-255. Data from I-64 for the years 2007 and 2008 are not used because of the I-64 reconstruction. The last row contains the average of the all the years from 2000 to 2008.

In comparing the severity of primary and secondary crashes, there is an interesting diverging of the upper and lower ends of the severity. On the one hand, the percentage of fatal crashes is higher for secondary as compared to primary. The percentage of fatal crashes increases 2.46 times by 0.49% (0.337% to 0.80%). On the other hand, the percent of PDO's is higher for secondary as compared to primary. The percentage of disabling injury crashes decreases 1.07 times by 0.15 (2.18% to 2.03%) and the percentage of minor injury crashes decreases 1.11 times by 2.40% (24.29% to 21.89%) while the percentage of PDO crashes increases 1.03 times by 2.05% (73.20% to 75.25%). In other words, for secondary crashes, there are both a higher percentage of the most serious crashes and the least serious crashes. Perhaps, this phenomenon can be explained as follows. The increase in the more severe crashes can be due to the sudden and unexpected encounter of a queue especially if pre-queue speeds are high. While the increase in the least severe crashes can be due to an increase in low speed rear end crashes during more congested conditions. There are, perhaps, also other feasible explanations to the divergent phenomenon. However, in order to examine the phenomenon more closely, there is a need to examine specific crash characteristics in detail which can involve significant labor.

The statistical significance of the difference in crash severity percentage between primary and secondary crashes is examined using the Student T-Test. A one-tailed heteroscedastic T-Test is applied because the variances between the two samples are significantly different. The differences in the average percentage of crashes is significant for fatal ($p=3.95\text{x}10^{-05}$), minor injury (0.0004) and PDO (0.0071), and is not significant for disabling injury (0.3788). Typically, p values less than 5% (0.05) or 1% (0.01) are considered to be statistically significant, i.e., the null hypothesis assuming no difference can be rejected. Even though changes in minor injury and PDO are just as statistically significant as the change in fatalities, the magnitude of change in fatalities is much greater by 2.46 times.

In summary, it is important to note the differing severity characteristics between secondary and primary crashes. The most significant is perhaps the fact that fatal crash percentage is much higher for secondary crashes at around a 2.5 times increase. This difference in average crash percentage is found to be statistical significant. These results point to the importance of managing the primary incident quickly and efficiently as to reduce fatal crashes.

**Table 4.1.1 Crash Percentage by Severity**

| Year | Secondary | | | | Primary | | | |
|---|---|---|---|---|---|---|---|---|
| | Fatal | Disabling Injury | Minor Injury | PDO | Fatal | Disabling Injury | Minor Injury | PDO |
| 2000 | 1.15 | 2.20 | 22.93 | 73.72 | 0.28 | 2.21 | 25.51 | 72.00 |
| 2001 | 0.62 | 1.24 | 23.26 | 74.88 | 0.32 | 2.42 | 24.61 | 72.66 |
| 2002 | 1.02 | 2.54 | 20.36 | 76.08 | 0.38 | 2.26 | 24.41 | 72.95 |
| 2003 | 0.79 | 2.03 | 22.94 | 74.24 | 0.26 | 2.25 | 24.51 | 72.99 |
| 2004 | 0.48 | 2.63 | 20.36 | 76.53 | 0.31 | 2.43 | 23.85 | 73.41 |
| 2005 | 0.82 | 2.11 | 21.87 | 75.20 | 0.31 | 1.95 | 25.57 | 72.16 |
| 2006 | 0.91 | 2.17 | 22.37 | 74.54 | 0.26 | 2.02 | 23.57 | 74.14 |
| 2007 | 0.75 | 2.25 | 22.47 | 74.53 | 0.30 | 2.15 | 23.23 | 74.32 |
| 2008 | 0.66 | 2.51 | 18.34 | 78.50 | 0.34 | 2.42 | 24.15 | 73.09 |
| Weighted Average | 0.829 | 2.026 | 21.89 | 75.25 | 0.337 | 2.18 | 24.28 | 73.20 |

## *4.2 Temporal Variation in Number of Crashes*

Figure 4.1.1 shows the number of crashes on all St. Louis freeways for this decade (i.e. years 2000-2008). The number of secondary crashes correlates somewhat with the number of all crashes. The correlation coefficient is 0.719. This correlation is intuitive since secondary crashes can result from primary crashes, but secondary crashes can also result from non-crash incidents. The number of annual crashes stabilized around approximately 8,300 from 2000 to 2006 and then dropped to approximately 7,000 in 2007 and 2008. The investigation into the causes for the drop in total number of crashes is outside the scope of this project. However, the following are some possible reasons for explaining the trend of decreased number of crashes. One reason is the concerted efforts of people working in highway safety throughout the State. This can include umbrella organizations such as Missouri Coalition for Roadway Safety, and organizations involved in engineering, enforcement, education, and medical services. This can also include MoDOT efforts in improving engineering such as the installation of rumble strips and median cable barriers. Another reason can be the drop in transportation demand due to various reasons including the downturn in the economy and the rise in gasoline prices. Figure 4.2.2 shows that the annually unadjusted gasoline prices have increased almost two-fold from 2003 to 2008.

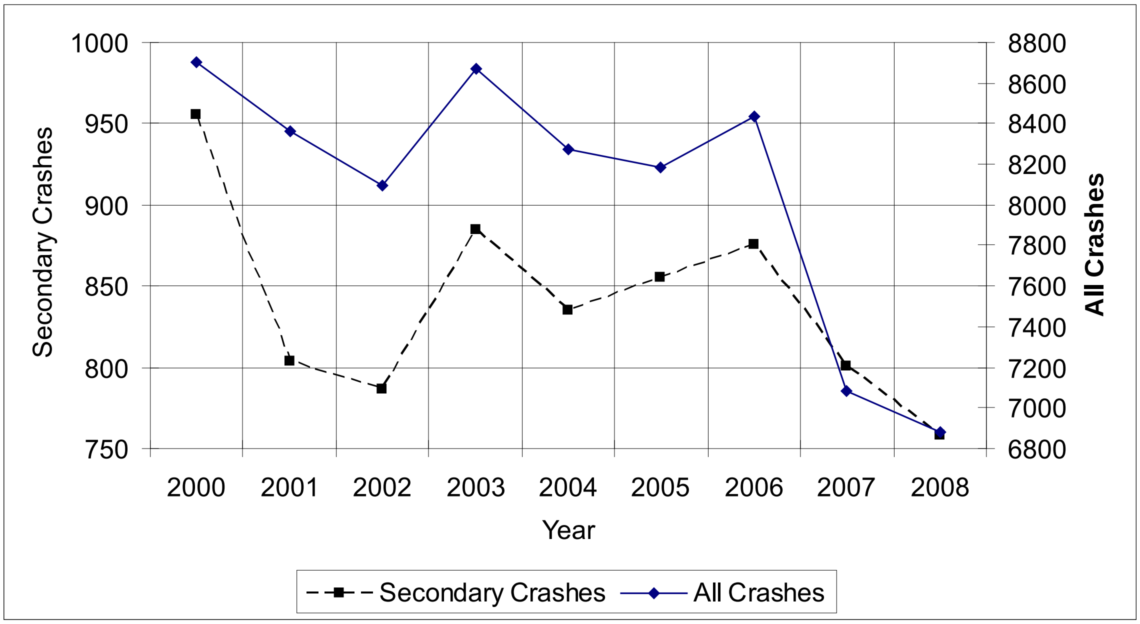


**Figure 4.2.1 Number of St. Louis Primary and Secondary Crashes by Year**

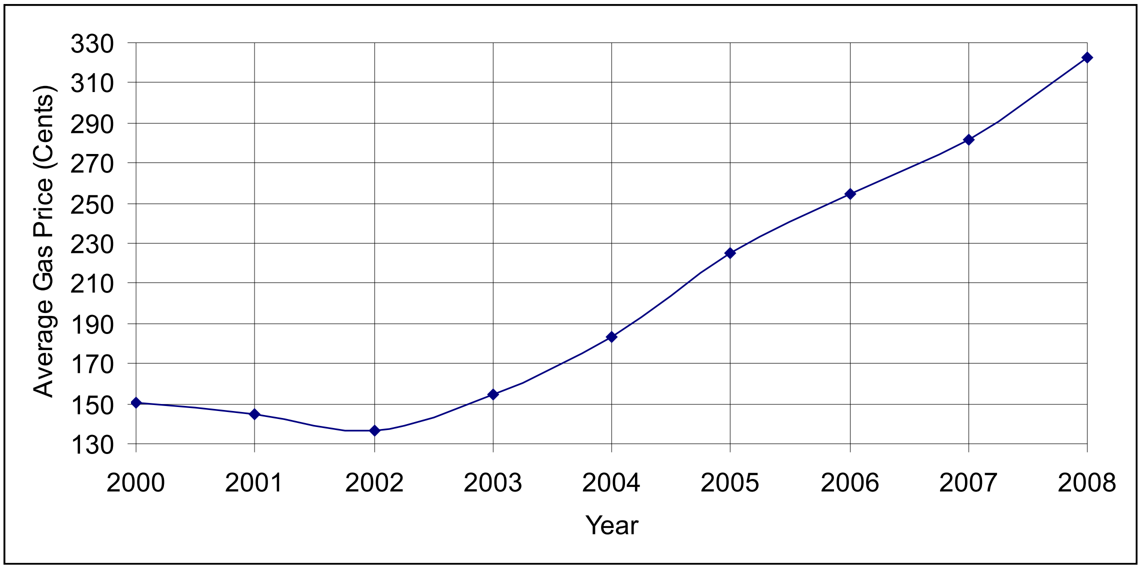


**Figure 4.2.2 Annualized Weekly Retail Gas Prices (Energy Information Administration. Official Energy Statistics from the U.S. Government)**

## *4.3 Overview of Cost Benefit Analysis (CBA)*

Cost Benefit Analysis (CBA) can be separated into three general steps. First, there is a systematic cataloguing of impacts as benefits and costs. It is typical in performing CBA to consider the costs and benefits of the society as a whole, and the net social benefit is computed by subtracting the net social costs from the net social benefits. Second, there is a valuing in dollars by monetizing impacts and discounting to the net present value (NPV). And third, there is the determining of net benefits relative to the status quo or baseline. CBA is often used to efficiently allocate society's resources. Most of the time, CBA is performed ex ante or while a project is under consideration and before it is started or implemented. Rarely, is a CBA is performed ex post or at the end of the project after all the costs are "sunk". Thus the current ex post analysis of MA is unique and offers valuable results since past data is used instead of future forecasts.

Regarding the valuation of crashes, the non-profit National Safety Council (NSC) explains that the calculable costs of motor vehicle crashes are wage and productivity losses, medical expenses, administrative expenses, motor vehicle damage, and employers' uninsured costs (NSC, 2007). The calculable costs, however, do not include the value of a person's natural desire to live longer or to protect the quality of one's life. This is instead captured in a willingness-to-pay analysis or observing actual market behavior. Miller mentions the following four examples of valuation (Miller, 1993):

- how much of a wage premium people working in risky jobs must be given to compensate them for the additional risks
- consumers' willingness to pay for safety features (safer cars)
- individual behavior with respect to decisions concerning the use of pedestrian tunnels and seat belts
- willingness to invest in specific ways to increase health and safety

There are several organizations that valuate injuries and/or crashes by severity. For example, the National Safety Council values the average comprehensive cost by injury severity as $4,100,000 for death, $208,500 for incapacitating injury, $53,200 for non-incapacitating evident injury, $25,300 for possible injury, and $2,300 for no injury (NSC, 2007). The Missouri High Crash Location (HAL) Manual values fatal crashes at $3,390,000, injury crash at $44,100, and PDO crash at $3,220 (MoDOT, 1999). The AASHTO Redbook values the net perceived user cost of fatal crashes at $3,723,700, all injury crashes at $172,800, and PDO crashes at $200 (AASHTO, 2003). The aforementioned numerical values are very similar even though economists disagree somewhat on the details of valuation methodology.

### 4.3.1 Discounting

A discount rate is used to translate 2003 dollars to present 2009 values. The discount rate accounts for the change in the value of money over time. In other words, it accounts for the society's perception of what a 2003 dollar is worth in 2009. This perception is important since there is a need to account for lost opportunity costs, i.e. the option to use the funds for something besides what it was used for. For example, financial markets give a positive interest rate on money that is set aside for the future. The Redbook suggests the use of a 3% discount rate when the benefits are in constant, inflation-removed dollar. For the MA safety evaluation, the AASHTO crash severity values are discounted to 2009 dollars as follows:

- $4,446,293 per fatal crash
- $206,332 per injury crash
- $239 per PDO crash

Each severity percentage in Table 1 for secondary crashes is multiplied with the corresponding 2009 injury crash cost results in the proportional value of secondary crashes. Adding all crash severity values will results in the cost per average secondary crash of **$72,350**. In other words, this amount accounts for the fact that 0.829% of all secondary crashes are fatal and they contribute a cost of $30,870; 23.92% are injury crashes and they contribute a cost of $41,329.50 per crash; and 75.25% are PDO crashes and they contribute a cost of $150.50 per crash.

### 4.3.2 Difference in Secondary Crashes

One major challenge in CBA is to estimate the impact of an alternative. Often times this involves forecasting into the future. The challenge is obvious since forecasting requires making assumptions about the future such as the growth of the population and future travel patterns. For ex post (after the fact) analysis, a comparable challenge presents itself in the form of recreating the past for an alternative that did not exist. The extrapolation from a particular year of analysis to earlier or later years is sometimes known as the annual travel measurement problem (Redbook, 2003, pg. 5-3). The Redbook explains, "Some project benefits are amenable to relatively simple extrapolation because the user benefits are fixed, or trend over time only in response to a particular, predictable variable." For example, when benefits are related to transactions with vehicles, then the number of transactions scales easily with traffic volumes. Even in cases where the underlying relationships are complex, extrapolation can still be performed because there is a stable mathematical relationship between traffic volumes and user benefits.

In this study, assumptions are required for the past in order to estimate the number of secondary crashes that would result if MA did not exist. In order to avoid duplicating previous work, some assumptions are made that are based on the previous MA study. In the previous study, only two principal freeways are examined: I-70 and I-270. Previously, the coverage of MA is not as extensive as it is today. Thus the first assumption is one of geographical homogeneity. Thus the percentage of secondary crashes that are reduced on I-70 and I-270 are assumed to be similar to freeways in the remainder of St. Louis. In other words, the benefits realized on I-70 and I-270 apply similarly to other freeways. This assumption is fairly reasonable since the population of drivers is the same and volume over capacity (v/c) ratios would account for the differences in volume and capacity between I-70/I-270 and the remaining freeways. In addition, the freeways are similarly designed. The second assumption is one of temporal invariance. Thus the types and level of benefits that are achieved by MA in the 1990's are assumed to be similar in the 2000's. The magnitude of the benefits will be scaled according to the actual number of secondary crashes. This again is a reasonable assumption since the fundamental characteristics of the drivers, the MA program, and the regional network have not changed significantly between the two decades. To explain what is meant by fundamental characteristics, the following few examples are presented:

- the retrofitting of the entire population of vehicles to include collision avoidance radar

- the major expansion or reduction of the scope of services of MA
- the implementation of significant geometric design changes

The normal growth in the St. Louis region and the regular economic oscillations that produce increases or decreases in freeway volumes should not theoretically alter the type or the level of benefits achieved by MA. Such changes could affect the overall number of crashes, but the proportion of secondary crashes should remain somewhat proportional to the number of total crashes. Figure 4.2.1 illustrates this empirically with data from St. Louis, as shown previously.

These assumptions are implemented using a regional factor, $F_r$ that translates the number of secondary crashes into the number of crashes that would have been prevented by the MA program. The following equations explain this process:

$$F_r = \frac{C_{NMA} - C_{MA}}{C_{MA}} \quad (4.3.2.1)$$

Where, $F_r$ is the reduction factor, $C_{NMA}$ is the number of secondary crashes without MA, i.e. non-MA, $C_{MA}$ is the number of secondary crashes with MA. $F_r$ is estimated using I-70 and I-270 data from 1993 to 1996 from the previous study. Since MA started in 1993, 1993 to 1996 represent the years closest to pre-MA conditions. For that period, $C_{NMA}$ is 1,781 and is estimated using regression, $C_{MA}$ is 789 and is based on actual data, and the resulting $F_r$ is 1.259.

$$C_{NMA1} - C_{MA1} = C_{MA1} * F_r \quad (4.3.2.2)$$

Where, $C_{NMA1}$-$C_{MA1}$ is the reduction in crashes attributable to MA in the 2000s, $C_{MA1}$ is the number of secondary crashes on all St. Louis freeways in the 2000s with MA deployed, and $F_r$ is as previously defined. Table 4.3.2.1 shows the average annual secondary and primary crashes on every freeway in St. Louis. For example, Row 5 shows that there is, on the average, 1.9 fatal, 4.2 disabling injury, 44.1 minor injury, and 127 PDO secondary crashes a year on I-70. The average annual number of secondary crashes, $C_{MA1}$, is 859.4 for 2000 to 2008 as shown in Table 4.3.2.1. Multiplying by $F_r$, the number of crashes reduced by MA is calculated as 1,082. Multiplying $C_{NMA1}$-$C_{MA1}$ by the cost per crash, the total annual net social benefit of $78,264,017 is obtained.

The reported costs for operating MA are $2,015,378 for 2008 ($2,075,839 in 2009 dollars). In performing benefit-cost analysis, the entire social cost must be computed for the entire program. The operating cost does not account for the capital investments related to several categories. These include equipment such as the vehicle and tools that are used by the operators, the equipment that is housed in the MA garage, and other miscellaneous equipment such as computers, radio (communications), and AVL housed in the MA garage. These also include infrastructure such as the building costs and overhead associated with the operation of the building. And costs associated with training the MA operators and staff would need to be accounted. An additional category that is difficult to capture is the synergistic benefit of the MA as part of the Gateway Guide program. MA operators are an integral part of Gateway Guide, and they work closely with the TMC when managing incidents. However, it is unclear how much of the cost borne by Gateway Guide should be attributed to causing MA productivity. If only operating costs is used, then MA would have an average annual safety B/C of around 37.7:1.

The B/C ratio is much higher than other highly effective crash reduction and safety countermeasures. There are two other system-wide freeway safety countermeasures that are in the top nine list of proven safety countermeasures. These are rumble strips and cable median barriers (FHWA, 2009). The following are some examples of results from studies that have estimated B/C for such countermeasures. The B/C for centerline rumble strips for high volume roads (ADT > 4500) is estimated to be 26.42 (Carlson and Miles, 2005). The B/C for median cable barriers is estimated to be between 0.8 to 5.5 depending on the median width (Hammond and Batiste, 2008). The MA B/C ratio of 37.7:1 far exceeds other highly effective safety countermeasures. From an engineering standpoint, MA should be considered one of the most cost effective safety programs in existence in the St. Louis region.

**Table 4.3.2.1 Average Annual Crashes on Freeways in St. Louis, 2000-2008**

| | Secondary | | | | | Primary | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fwy. | Fatal | Disabling Injury | Minor Injury | PDO | Total | Fatal | Disabling Injury | Minor Injury | PDO | Total |
| I-44 | 2.0 | 3.3 | 24.8 | 99.0 | 129.1 | 7.8 | 33.7 | 271.7 | 918.7 | 1231.8 |
| I-55 | 1.2 | 2.8 | 16.7 | 57.4 | 78.1 | 5.6 | 24.6 | 203.9 | 586.3 | 820.3 |
| I-64 | 0.9 | 2.3 | 31.6 | 102.1 | 136.9 | 2.9 | 19.0 | 344.9 | 985.6 | 1352.3 |
| I-70 | 1.9 | 4.2 | 44.1 | 127.0 | 177.2 | 5.3 | 34.4 | 451.2 | 1241.9 | 1732.9 |
| I-170 | 0.4 | 0.9 | 13.0 | 48.2 | 62.6 | 2.9 | 15.3 | 152.8 | 484.1 | 655.1 |
| I-270 | 0.6 | 4.9 | 58.1 | 212.0 | 275.6 | 4.7 | 52.9 | 570.2 | 1784.6 | 2412.3 |
| Total | 7.0 | 18.4 | 188.2 | 645.8 | 859.4 | 29.1 | 179.9 | 1994.6 | 6001.1 | 8204.7 |

### 4.3.3 Consistency with Previous Study

In the previous study, a crash reduction benefit of $30,000 per crash was used. For this study, more recent numbers for valuation of crashes from AASHTO discounted to present values and updated percentages of crash severities collected from 2000-2008 are used. The updated values resulted in more than a doubling of the crash reduction benefit to approximately $72,350 per crash. The increase in value of benefit, the greater coverage of MA to include all the freeways in St. Louis, and the inclusion of incident generated secondary crashes results in the significant increase in B/C over the previous study. Thus, this increase is not attributable to a change in methodology even though there is an improvement in the accuracy of extracting secondary crashes from the MUAR reports.

Appendix B presents the annual secondary crash statistics for each freeway in St. Louis and shows the number of incident-caused secondary crashes which are caused by non-crash incidents such as parked motor vehicles, animals, and other non-fixed objects. (E.g. objects from vehicles, fallen tree). In the years 2000 to 2008, such non-crash incident-caused secondary crashes accounted for 33.9% of secondary crashes. In contrast to primary crashes, such incidents are conceivably less burdensome for MA to handle.

# 5. MA MOBILITY ASSESSMENT METHODOLOGY

Everyday, MA operators patrol St. Louis freeways to assist in clearing the roadways from incidents such as debris on the road, accident, disabled vehicles etc. With a roadway closed, any delay that occurs will increase non-linearly. For example, if a roadway is blocked for a certain period of time then with every minute passing, the delay of the each vehicle waiting is compounded by another minute. So clearing the roadways quickly will reduce the delay significantly. MA operators by patrolling the freeways are able to respond quickly and clear (or assist in clearing) the roadways in a timely manner.

## *5.1 Data Needs*

The amount of delay reduced by this program can be computed by estimating the cumulative delay caused by all of the incidents with and without MA. To compute this, the following data are needed:

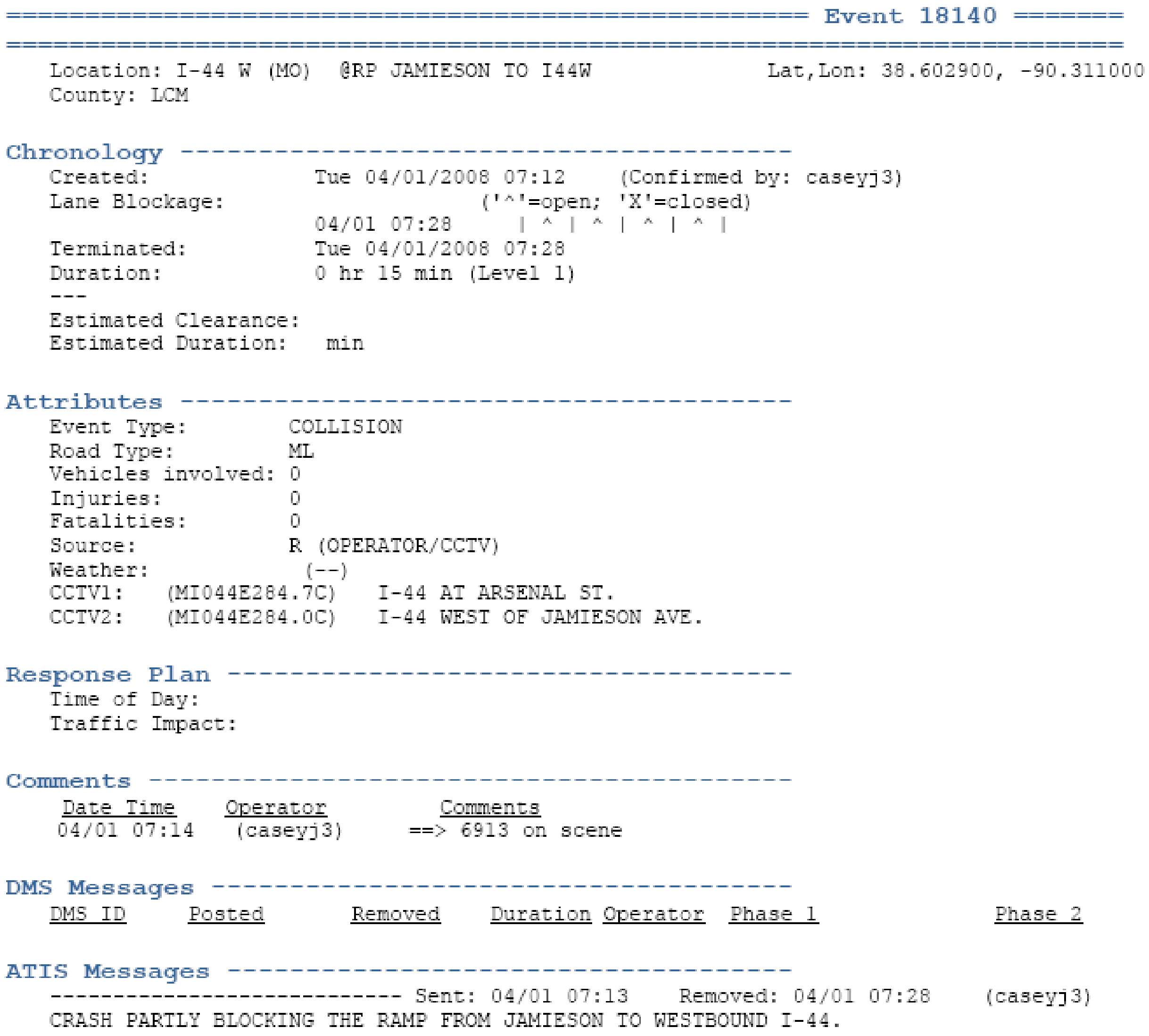
a) Incident specific details such as the type of incident, number of vehicles involved, location and time of incident
b) Traffic characteristics at the time of incident such as volume and speed
c) Response and clearance information of MA and non-MA scenario i.e. how fast is the response in both the scenarios and how long it takes to clear the incident.

Using the first two types of data, one can understand how much delay the incident will cause over time and the third helps in understanding how soon the incident can be mitigated.

### 5.1.1 Incident Data

MA operators keep a detailed paper log of incidents that includes type of incident, location, time and duration of assist. But all this information is not transferred to an electronic format. Only the summary of these incidents, such as the number of incidents per zone in the am and pm are recorded. By not converting this detailed information from paper logs to electronic format, one has to depend on other data sources for a less labor intensive data extraction.

Two other sources that keep an electronic incident log are Traffic.Com and Gateway Guide. These two sources maintain data of incidents in slightly different formats as shown in Table 5.1.1.1 and Figure 5.1.1.1. Although Traffic.com provides Latitude and Longitude of incident location, it does not provide the direction of freeway incidents. So, Gateway Guide, which contains the direction and more detailed information, was chosen for data processing.



```
=================================================== Event 18140 =======
=======================================================================
   Location: I-44 W (MO)  @RP JAMIESON TO I44W           Lat,Lon: 38.602900, -90.311000
   County: LCM

Chronology ---------------------------------------
   Created:             Tue 04/01/2008 07:12    (Confirmed by: caseyj3)
   Lane Blockage:                    ('^'=open; 'X'=closed)
                        04/01 07:28     | ^ | ^ | ^ | ^ |
   Terminated:          Tue 04/01/2008 07:28
   Duration:            0 hr 15 min (Level 1)
   ---
   Estimated Clearance:
   Estimated Duration:   min

Attributes ---------------------------------------
   Event Type:        COLLISION
   Road Type:         ML
   Vehicles involved: 0
   Injuries:          0
   Fatalities:        0
   Source:            R (OPERATOR/CCTV)
   Weather:            (--)
   CCTV1:   (MI044E284.7C)   I-44 AT ARSENAL ST.
   CCTV2:   (MI044E284.0C)   I-44 WEST OF JAMIESON AVE.

Response Plan ------------------------------------
   Time of Day:
   Traffic Impact:

Comments -----------------------------------------
    Date Time    Operator        Comments
    04/01 07:14   (caseyj3)     ==> 6913 on scene

DMS Messages -------------------------------------
   DMS ID     Posted      Removed    Duration Operator  Phase 1             Phase 2

ATIS Messages ------------------------------------
   ---------------------------- Sent: 04/01 07:13    Removed: 04/01 07:28    (caseyj3)
   CRASH PARTLY BLOCKING THE RAMP FROM JAMIESON TO WESTBOUND I-44.
```

**Figure 5.1.1.1 Gateway Guide Incident Log**

**Table 5.1.1.1 Sample Incident Log from Traffic.Com**

| | Sample Incident 1 | Sample Incident 2 | Sample Incident 3 |
|---|---|---|---|
| Lat | 38.634 | 38.634 | 38.633 |
| Long | -90.142 | -90.142 | -90.144 |
| Zone | null | Null | null |
| Start Date | 4/2/2008 | 4/2/2008 | 4/2/2008 |
| Start Time | 04:09:00 | 04:09:00 | 04:09:00 |
| End Date | 4/2/2008 | 4/2/2008 | 4/2/2008 |
| End Time | 06:15:08 | 06:20:41 | 06:23:54 |
| Criticality | critical | Critical | critical |
| Type | ACCIDENT | ACCIDENT | ACCIDENT |
| Location | I-55/I-70 | I-55/I-70 | I-55/I-70 |
| Description | approaching I-64 - accident blocking all lanes - ambulance, fire department, police on the scene | approaching I-64 - accident blocking all lanes - ambulance, fire department, police on the scene ALTERNATE: traffic can exit onto I-64 eastbound | at I-64 - accident blocking all lanes - ambulance, fire department, police on the scene ALTERNATE: traffic can exit onto I-64 eastbound |

### 5.1.2 Traffic Flow Data

The traffic flow characteristics such as volume and speed were not available during the previous study. So, the hourly traffic volumes generated by MoDOT for planning purposes was used for estimating the demand on the St. Louis freeway sections. Now, the St. Louis freeway system has an extensive network of detectors from which volume, speed and occupancy data can be extracted at an interval as small as 30 seconds; and this information from the nearest detector can be used for estimating the traffic flow characteristics at the time of incident. In the previous study, due to lack of real time traffic information, the researchers had to depend on capacity reduction factors from other regions to estimate the traffic delay over time.

### 5.1.3 Response and Clearance Information

MA's average response time of 20 minutes, as reported on MoDOT website, is used for this study. For the non-MA scenario, the response time is assumed to be 35 minutes, which is same as the earlier evaluation. This value was obtained from surveys conducted by J.D. Power and Associates, an independent consumer research firm (Lawlor, 2003). This value represents the lowest average or the best performing private responders. The clearance is assumed to vary from 10 minutes to 20 minutes for both MA and non MA.

## *5.2 Assessment Methodology*

The real time traffic flow data is used for estimating the delays due to incidents. The utilization of this information, as opposed to using historical data or factors from other cities, will help in building a model that is more representative of actual delay. But the real time data provides the information only for “with MA” scenario and does not provide for “without MA” scenario. So this methodology has two steps:

1) Estimate Delay of actual incident (i.e. with MA scenario)
2) Estimate non MA delay based on MA delay

### 5.2.1 Delay with MA

Gateway Guide’s electronic incident logs were used for extracting the incidents in the year 2008. The incident fields pertaining to location, type and time of the incident were extracted from each of these logs and cross referenced with the 5 minute volume information that was processed from the freeway detector data.

Figure 5.2.1.1 shows an illustration of speed data from multiple detectors. This particular example shows the impact of two incidents which happened on I-270 NB near Page Avenue. The first incident was a collision that was reported at 3:05 pm and subsequently a stolen vehicle car chase that ended near Page Ave at 3:25 pm. The impact of these incidents can be seen on the upstream detectors (i.e. mile markers 15.4, 14.8 and 13.6). This example shows how the detector data can be used for understanding the impacts of incidents.

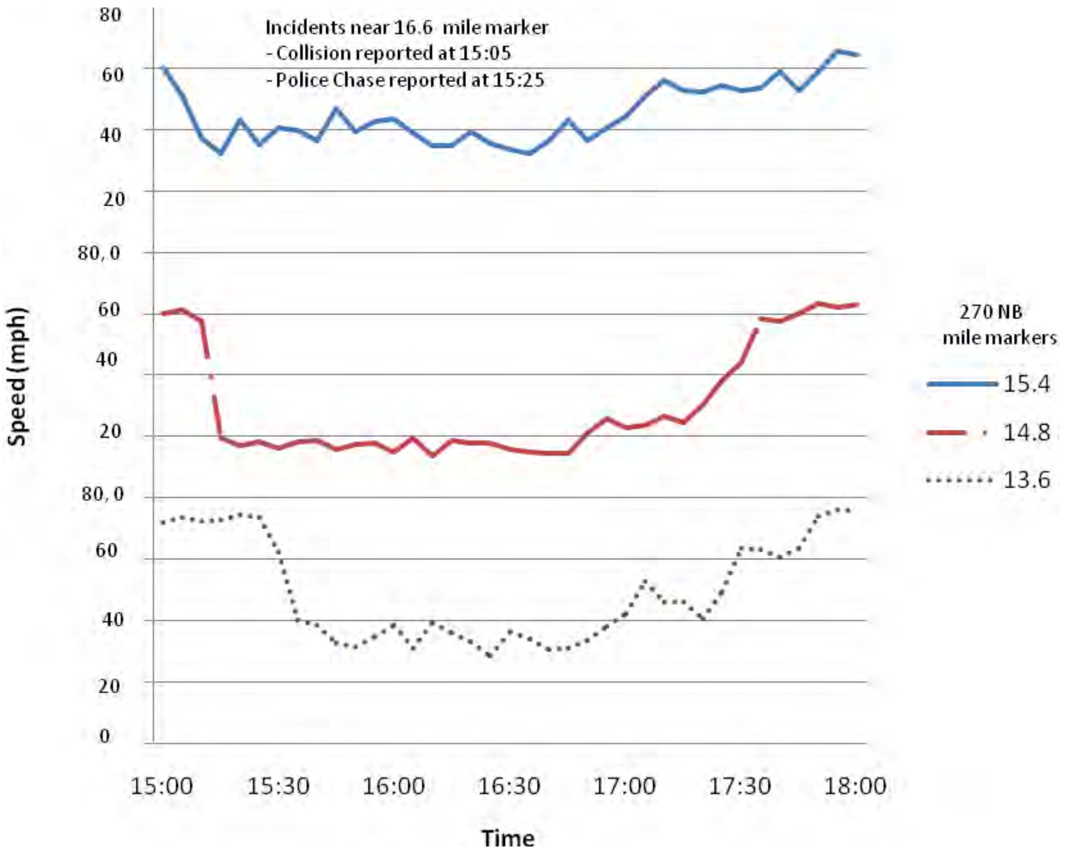
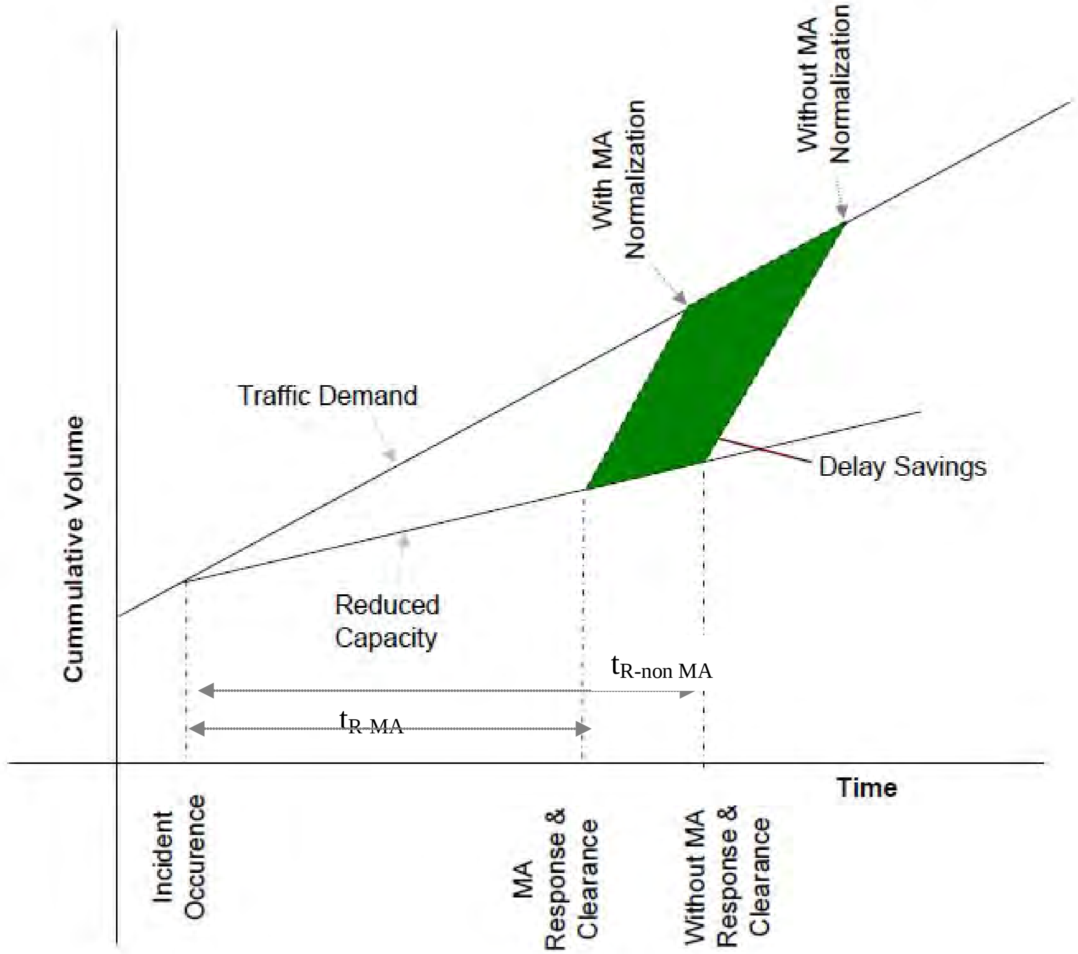


**Figure 5.2.1.1 I-270 North Bound Speeds during an Incident**

The total delay of the incidents is calculated by estimating the number of vehicles impacted by each incident and multiplying it by the increased travel times due to the incident. This delay then reflects the amount of delay experienced by the users. Using this information, the expected delay without a program like MA will be estimated based on the methodology from the next section.

### 5.2.2 Delay without MA

The delay in non-MA scenario is estimated as a factor of MA scenario. Figure 5.2.2.2 shows a cumulative volume and time diagram. The diagram shows that after the incident occurrence, the capacity is reduced, thus delay is accumulated since the arriving traffic can not be serviced. But if the clearance occurs sooner, then there is a delay reduction or savings. The total delay of an incident, like the one shown in Figure 5.2.2.2 can be computed as follows



λ = Traffic Demand
$\mu_R$ = Reduced Capacity

For an incident, the delays with and without MA can be represented as follows

$$\text{Total Delay with MA, } TD_{MA} = 0.5*(t_{R\text{-}MA}{}^{2})*(\lambda-\mu_{R}) \quad (5.2.1.2)$$

$$\text{Total Delay without MA, } TD_{non\ MA} = 0.5*(t_{R\text{-}non\ MA}{}^{2})*(\lambda-\mu_{R}) \quad (5.2.1.3)$$

From equations 5.2.1.2 and 5.2.1.3, the today delay without MA can be calculated as

$$TD_{non\ MA=}\ TD_{MA} * [t_{R\text{-}non\ MA}{}^{2} / t_{R\text{-}MA}{}^{2}] \quad (5.2.1.4)$$

Incident duration consists of response time and clearance time. The response times of MA and non-MA are assumed as 20 minutes and 35 minutes, and the clearance time is assumed to vary from 10 to 20 minutes for both the scenarios. Applying this information to equation 5.2.1.4 gives the following range of total delays

$$\begin{aligned} TD_{non\ MA} &= TD_{MA} * [(35+\text{clearance time})^{2} / (20+\text{clearance time})^{2}] \\ &= TD_{MA} * [(35+10)/(20+10)]^{2} \text{ to } TD_{MA} * [(35+20)/(20+20)]^{2} \\ &= 2.25\ TD_{MA} \text{ to } 1.89\ TD_{MA} \qquad (5.2.1.5) \end{aligned}$$

Therefore the delay savings with a MA program would be 1.25 to 0.89 times of total delay with MA program.

# 6. MA MOBILITY ASSESSMENT RESULTS

In the year 2008, there were about 6,000 incidents that were recorded in the Gateway Guide Incident logs. Table 6.1 shows the number of each type of incident for each freeway in St. Louis. These incidents did not include those that were coded as Roadwork, Utility and Arterial Incidents.

**Table 6.1 Year 2008 Freeway Incident Logs from Gateway Guide**

| | COLLISION | STALL | OTHER | FIRE | DEBRIS | Total |
|---|---|---|---|---|---|---|
| I-70 | 1017 | 440 | 233 | 27 | 7 | 1724 |
| I-270 | 798 | 459 | 175 | 32 | 10 | 1474 |
| I-44 | 492 | 550 | 176 | 13 | 10 | 1241 |
| I-55 | 338 | 141 | 93 | 14 | 4 | 590 |
| I-64 | 196 | 102 | 52 | 10 | 4 | 364 |
| I-170 | 150 | 67 | 37 | 7 | 3 | 264 |
| I-255 | 25 | 10 | 8 | 1 | 0 | 44 |
| Total | 3016 | 1769 | 774 | 104 | 38 | 5701 |

About 83% of these consisted of either Collision or Stall. From this dataset, 14 weekdays were sampled in the month of April for the interstate I-270 for a detailed investigation of the incident delays. I-270 data was chosen for three reasons:

a) It has one of the highest incident rates
b) It has most of the detectors working in year 2008
c) The cost of data processing was shared with another MoDOT project.

The total delay on I-270 from the 14 weekdays was estimated as 782 vehicle hours. This value was extrapolated to 250 working days as follows

Total Delay on Interstate 270 = 250*782 /14 = 13,964 vehicle hours

Most of the above data was observed from Collision incidents. Assuming if the I-270 data is representative of the region, then the total yearly delay can roughly be estimated as follows:

Approximate delay = (3059/798)*13964 = 53,528 vehicle hours

Without MA the delay would be 2.25 times to 1.89 times of MA delay. So the delay savings ranges from 66,910 vehicle hours to 47,640 vehicle hours. When translated to monetary value using a value of $23.82/hr, the savings is around $ 1.59 Million to $ 1.13 Million. Adding the mobility benefit to the safety benefit, the total annual benefit of $79,394 is obtained. The total mobility and safety B/C is **38.25:1**.

# 7. CONCLUSION

After a detailed analysis of St. Louis crash records for the years 2000 to 2008, the results show that the Motorist Assist Program (MA) in St. Louis provides tremendous safety and mobility benefits to the region. The benefit-cost ratio (B/C) is estimated to be 38.25:1. This reflects the reduction of secondary crashes using actual average annual secondary cashes of 859 for 2000 to 2008. The crash reduction factor of 1.259 was estimated using data from 1987 to 1990 and 1993 to 1996 which are the years immediately proceeding and following the implementation of MA. The B/C also reflects a $1.13 million savings in mobility benefits or reduced delay.

An interesting by product of the study is the discovery that secondary crash characteristics are on the average more severe than primary. The percentage of fatal crashes is 0.829% for secondary while it is 0.337% for primary. But the percentage of PDO crashes is 75.25% for secondary while it is 73.20% for primary. Since fatal crashes are the costliest crashes, overall secondary crashes are costlier than primary crashes. Secondary crashes tend to be more severe with regards to more fatal crash occurrences while having a slightly higher PDO crash occurrences and less injury crash (minor and major) occurrences.

The estimated per crash cost for secondary crashes was found to be $72,350 in 2009 dollars. National accepted values for the valuation of fatal, injury, and PDO crashes from the AASHTO Redbook were used. Due to the lack of previous knowledge, one could only speculate as to why there are both more fatal and PDO secondary crashes as compared with primary. Perhaps, one reason why there are more fatal crashes is because of the sudden encounter with the back of an unexpected queue at high speed and low volume conditions. Another reason could be there are more PDOs because of a higher incidence of low severity rear end crashes in high volume stop-and-go traffic caused by a primary incident. Even though the exact cause of the difference cannot be pinpointed at this point, the difference is clearly evident in the data, found to be statistically significant, and is based on approximately 65,000 crashes of which there are around 7,500 secondary crashes. The data set is large and is from almost all the freeways in the St. Louis region and from almost a full decade. There is every reason to believe that the difference is systematic and not random.

There is certainly other methodology that could have been used for evaluating MA. The literature review describes other methodology such as the use of micro-simulation and mathematical modeling. Each methodology has its plusses and minuses and practical constraints. The strength of a study based on actual crash reports is that no assumptions are made in terms of driver car-following behavior such as in simulation or shock wave speeds such as in mathematical modeling. One weakness is that it is difficult to explain the reasons why the numbers are such without using other variables to control for other factors. And unlike simulation, no sensitivity analysis can be easily performed. The University of Missouri is interested in continuing to analyze the causes for the difference between primary and secondary crash characteristics as the results will help to advance and improve incident management. The transportation engineering community has only recently begun to focus on the study of the nature of secondary crashes due to the availability of more detailed forms of safety data and the ability of performing data fusion with other data sources such as traffic data, incident reports, and media reports. The hope is that such investigations will reveal practical strategies to mitigate further the effects of primary incidents.

# APPENDIX A. ANNUAL PRIMARY AND SECONDARY CRASHES IN ST. LOUIS

The following figures show the annual primary (vertical scale on the right) and secondary (vertical scale on the left) crashes. The figures from each freeway look very different by visual inspection, but the correlation of the primary to the secondary crash is visually obvious. No analysis was conducted to explain the differing curves from each freeway.

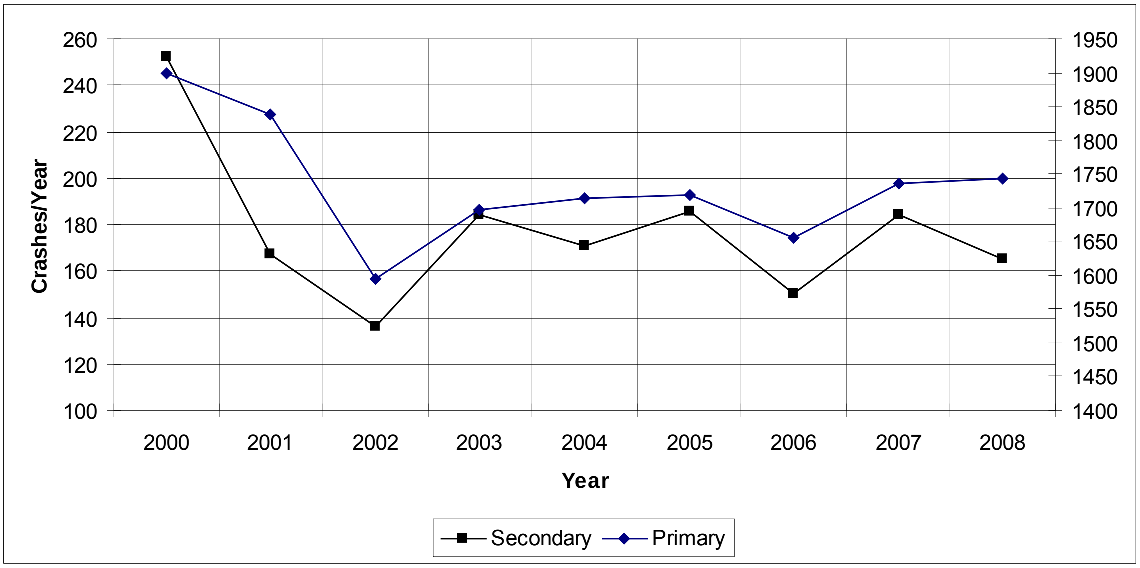


Figure A1. I-70

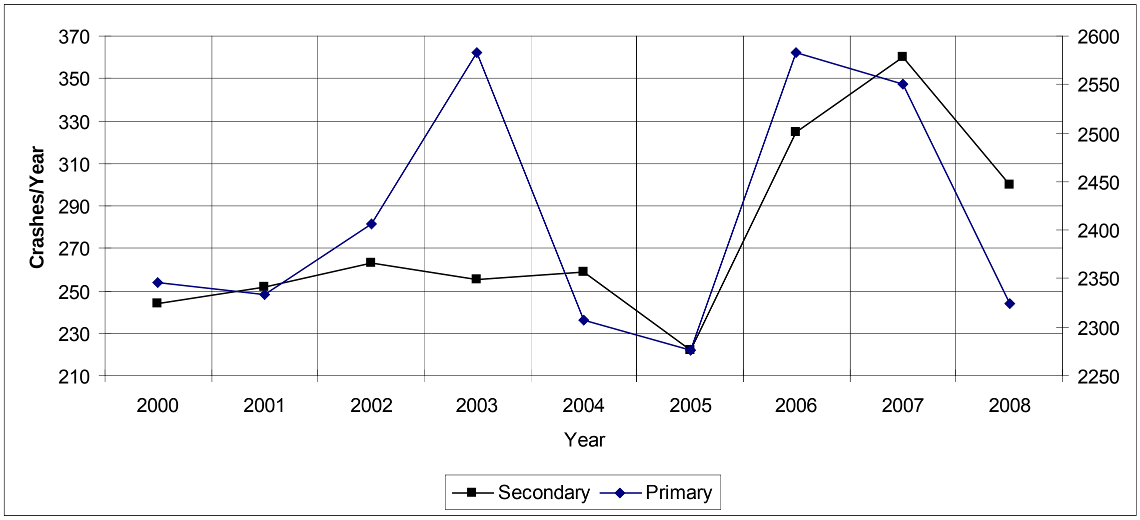


Figure A2. I-270

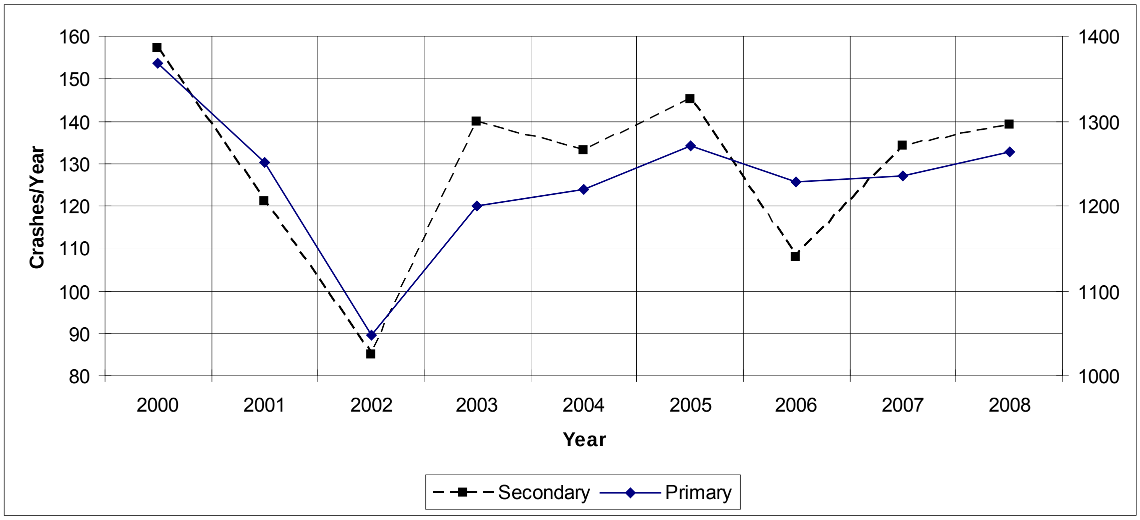


Figure A3. I-44

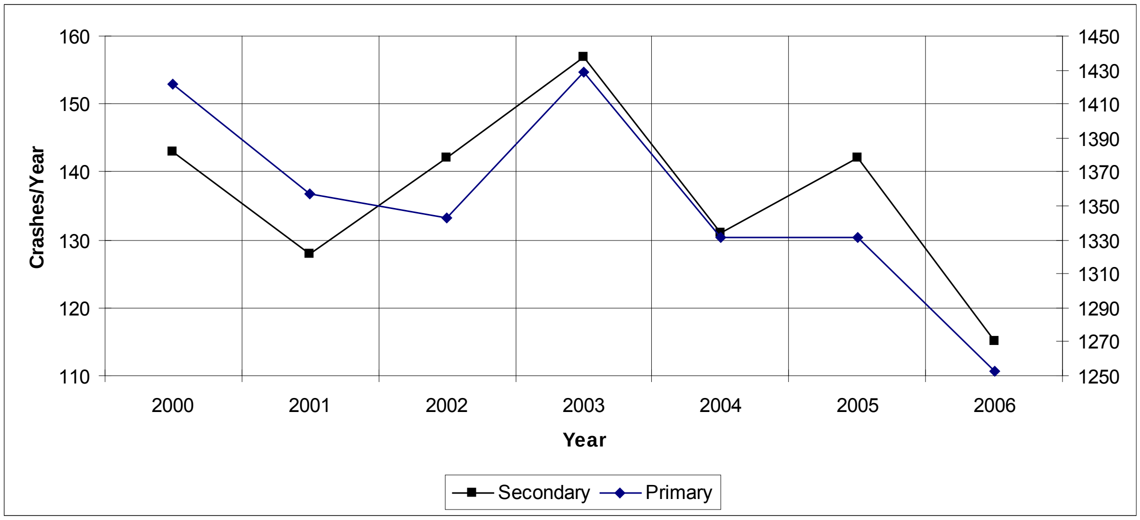


Figure A4. I-64

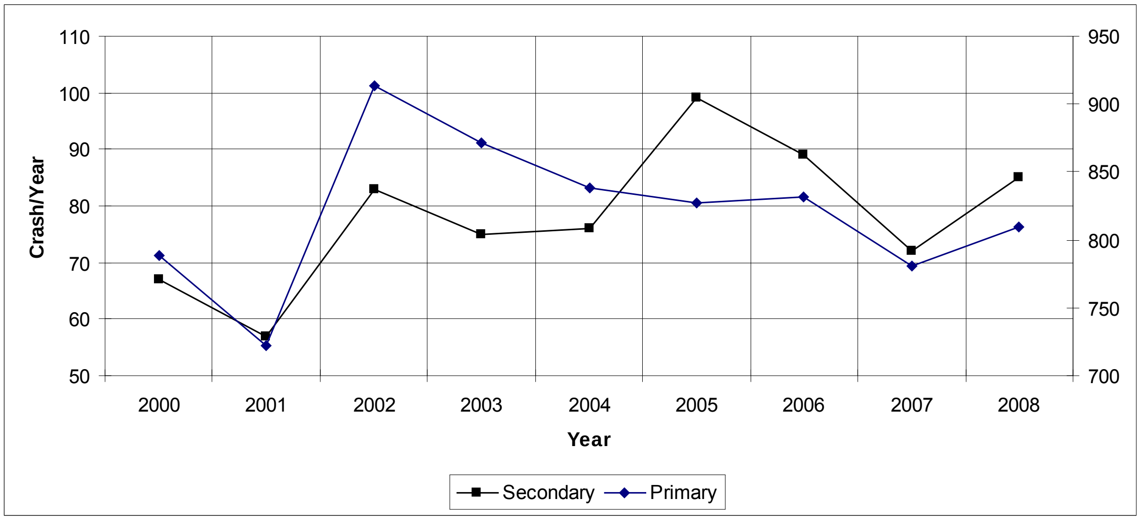


Figure A5. I-55

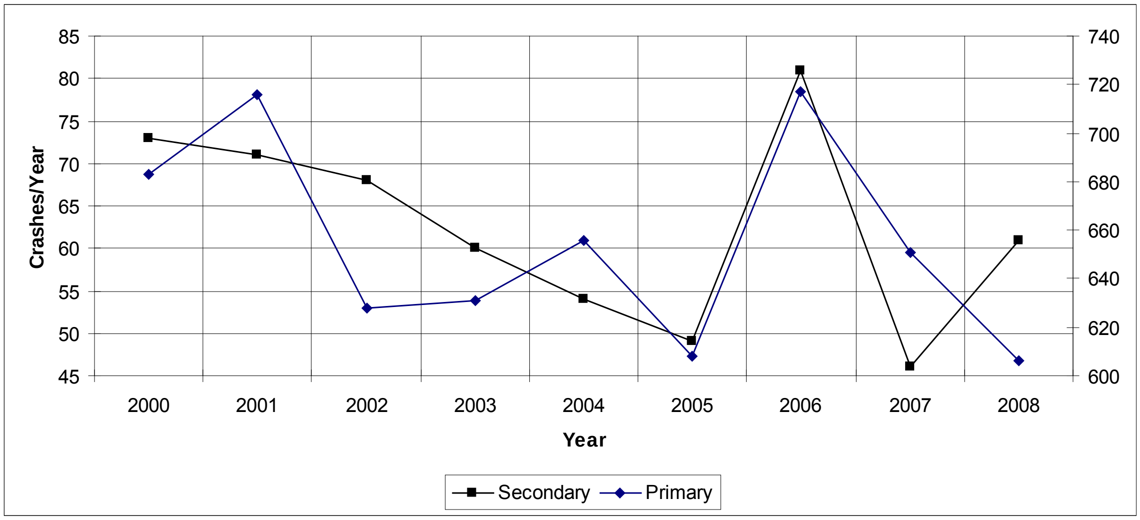


Figure A6. I-170

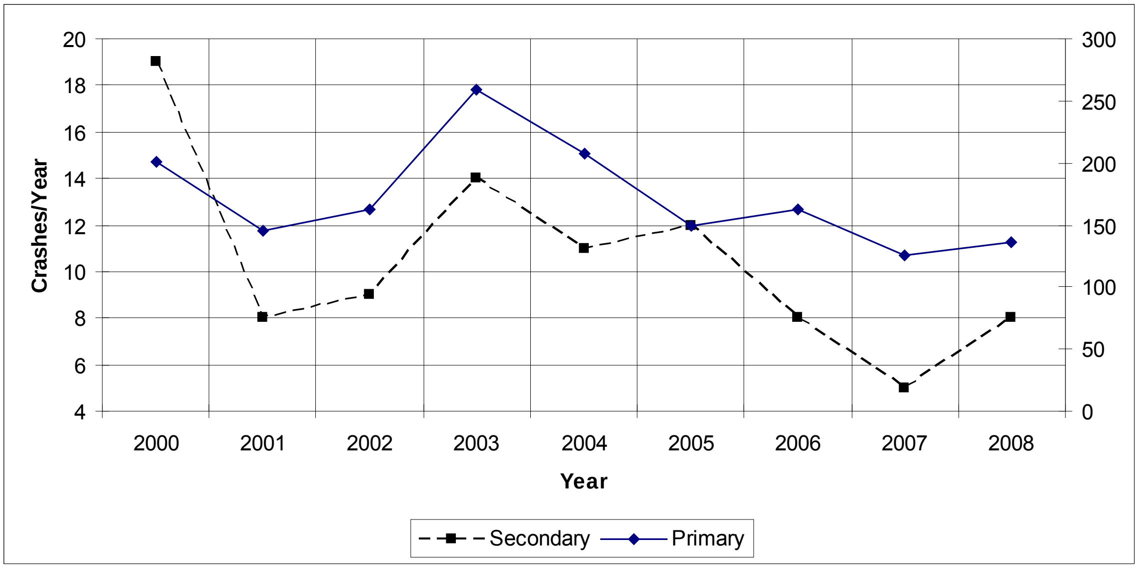


Figure A7. I-255

# APPENDIX B. SECONDARY CRASHES BY SEVERITY IN ST. LOUIS

The following tables present the annual secondary crash statistics for each freeway in St. Louis. Incident-caused secondary crashes are ones caused by non-crash incidents such as parked motor vehicles, animals, and other non-fixed objects. (E.g. objects from vehicles, fallen tree). The sum of the fatal, disabling injury, minor injury, and PDO columns should equal the number of non-redundant secondary crashes.

**Table B1. I-70**

| Year | Incident Caused Secondary Crashes | Fatal | Disabling Injury | Minor Injury | PDO | Non-redundant Secondary Crashes |
|---|---|---|---|---|---|---|
| 2000 | 77 | 3 | 7 | 67 | 175 | 252 |
| 2001 | 66 | 2 | 3 | 42 | 120 | 167 |
| 2002 | 58 | 1 | 3 | 32 | 100 | 136 |
| 2003 | 82 | 3 | 6 | 52 | 123 | 184 |
| 2004 | 64 | 2 | 2 | 38 | 129 | 171 |
| 2005 | 64 | 1 | 2 | 43 | 140 | 186 |
| 2006 | 53 | 1 | 3 | 37 | 109 | 150 |
| 2007 | 47 | 0 | 8 | 50 | 126 | 184 |
| 2008 | 45 | 4 | 4 | 36 | 121 | 165 |
| Totals | 556 | 17 | 38 | 397 | 1143 | 1595 |
| Average | 61.78 | 1.89 | 4.22 | 44.11 | 127 | 177.22 |
| Std. Dev. | 12.55 | 1.27 | 2.22 | 10.77 | 21.31 | 32.58 |

**Table B2. I-270**

| Year | Incident Caused Secondary Crashes | Fatal | Disabling Injury | Minor Injury | PDO | Non-redundant Secondary Crashes |
|---|---|---|---|---|---|---|
| 2000 | 96 | 1 | 2 | 57 | 184 | 244 |
| 2001 | 86 | 0 | 2 | 58 | 192 | 252 |
| 2002 | 70 | 0 | 4 | 46 | 213 | 263 |
| 2003 | 83 | 0 | 2 | 58 | 195 | 255 |
| 2004 | 93 | 0 | 11 | 44 | 204 | 259 |
| 2005 | 76 | 1 | 5 | 44 | 172 | 222 |
| 2006 | 86 | 2 | 5 | 75 | 243 | 325 |
| 2007 | 60 | 1 | 7 | 75 | 277 | 360 |
| 2008 | 70 | 0 | 6 | 66 | 228 | 300 |
| Totals | 720 | 5 | 44 | 523 | 1908 | 2480 |
| Average | 80.00 | 0.56 | 4.89 | 58.11 | 212.00 | 275.56 |
| Std. Dev. | 11.84 | 0.73 | 2.93 | 12.14 | 32.75 | 43.94 |

**Table B3. I-44**

| Year | Incident Caused Secondary Crashes | Fatal | Disabling Injury | Minor Injury | PDO | Non-redundant Secondary Crashes |
|---|---|---|---|---|---|---|
| 2000 | 77 | 3 | 4 | 29 | 121 | 157 |
| 2001 | 67 | 0 | 4 | 28 | 89 | 121 |
| 2002 | 54 | 4 | 5 | 16 | 60 | 85 |
| 2003 | 71 | 4 | 3 | 30 | 103 | 140 |
| 2004 | 67 | 1 | 3 | 27 | 102 | 133 |
| 2005 | 72 | 0 | 1 | 28 | 116 | 145 |
| 2006 | 41 | 2 | 4 | 16 | 86 | 108 |
| 2007 | 55 | 4 | 2 | 33 | 95 | 134 |
| 2008 | 55 | 0 | 4 | 16 | 119 | 139 |
| Totals | 559 | 18 | 30 | 223 | 891 | 1162 |
| Average | 62.11 | 2.00 | 3.33 | 24.78 | 99.00 | 129.11 |
| Std. Dev. | 11.50 | 1.80 | 1.22 | 6.80 | 19.38 | 21.63 |

**Table B4. I-64***

| Year | Incident Caused Secondary Crashes | Fatal | Disabling Injury | Minor Injury | PDO | Non-redundant Secondary Crashes |
|---|---|---|---|---|---|---|
| 2000 | 39 | 1 | 4 | 28 | 110 | 143 |
| 2001 | 36 | 2 | 1 | 28 | 97 | 128 |
| 2002 | 37 | 1 | 3 | 40 | 98 | 142 |
| 2003 | 33 | 0 | 3 | 34 | 120 | 157 |
| 2004 | 27 | 0 | 2 | 29 | 100 | 131 |
| 2005 | 18 | 1 | 2 | 35 | 104 | 142 |
| 2006 | 29 | 1 | 1 | 27 | 86 | 115 |
| Totals | 219 | 6 | 16 | 221 | 715 | 958 |
| Average | 31.29 | 0.86 | 2.29 | 31.57 | 102.14 | 136.86 |
| Std. Dev. | 7.27 | 0.69 | 1.11 | 4.86 | 10.75 | 13.46 |

*Starting in the third quarter in 2007, the I-64 re-construction had a significant effect on traffic volumes. Thus the data from 2007 and 2008 are not included, as they do not represent normal conditions.

**Table B5. I-55**

| Year | Incident Caused Secondary Crashes | Fatal | Disabling Injury | Minor Injury | PDO | Non-redundant Secondary Crashes |
|---|---|---|---|---|---|---|
| 2000 | 31 | 1 | 2 | 17 | 47 | 67 |
| 2001 | 37 | 1 | 0 | 13 | 43 | 57 |
| 2002 | 46 | 2 | 5 | 16 | 60 | 83 |
| 2003 | 32 | 0 | 1 | 16 | 58 | 75 |
| 2004 | 40 | 1 | 1 | 17 | 57 | 76 |
| 2005 | 46 | 2 | 7 | 22 | 68 | 99 |
| 2006 | 35 | 2 | 4 | 25 | 58 | 89 |
| 2007 | 26 | 1 | 0 | 14 | 57 | 72 |
| 2008 | 34 | 1 | 5 | 10 | 69 | 85 |
| Totals | 327 | 11 | 25 | 150 | 517 | 703 |
| Average | 36.33 | 1.22 | 2.78 | 16.67 | 57.44 | 78.11 |
| Std. Dev. | 6.73 | 0.67 | 2.54 | 4.53 | 8.44 | 12.48 |

**Table B6. I-170**

| Year | Incident Caused Secondary Crashes | Fatal | Disabling Injury | Minor Injury | PDO | Non-redundant Secondary Crashes |
|---|---|---|---|---|---|---|
| 2000 | 19 | 2 | 2 | 20 | 49 | 73 |
| 2001 | 20 | 0 | 0 | 16 | 55 | 71 |
| 2002 | 16 | 0 | 0 | 10 | 58 | 68 |
| 2003 | 16 | 0 | 3 | 11 | 46 | 60 |
| 2004 | 19 | 0 | 1 | 13 | 40 | 54 |
| 2005 | 11 | 2 | 0 | 14 | 33 | 49 |
| 2006 | 24 | 0 | 1 | 15 | 65 | 81 |
| 2007 | 7 | 0 | 1 | 8 | 37 | 46 |
| 2008 | 17 | 0 | 0 | 10 | 51 | 61 |
| Totals | 149 | 4 | 8 | 117 | 434 | 563 |
| Average | 16.56 | 0.44 | 0.89 | 13.00 | 48.22 | 62.56 |
| Std. Dev. | 5.03 | 0.88 | 1.05 | 3.71 | 10.38 | 11.67 |

**Table B7. I-255**

| Year | Incident Caused Secondary Crashes | Fatal | Disabling Injury | Minor Injury | PDO | Non-redundant Secondary Crashes |
|---|---|---|---|---|---|---|
| 2000 | 16 | 0 | 0 | 1 | 18 | 19 |
| 2001 | 3 | 0 | 0 | 2 | 6 | 8 |
| 2002 | 5 | 0 | 0 | 0 | 9 | 9 |
| 2003 | 5 | 0 | 0 | 2 | 12 | 14 |
| 2004 | 5 | 0 | 2 | 2 | 7 | 11 |
| 2005 | 6 | 0 | 1 | 1 | 10 | 12 |
| 2006 | 4 | 0 | 1 | 1 | 6 | 8 |
| 2007 | 3 | 0 | 0 | 0 | 5 | 5 |
| 2008 | 3 | 0 | 0 | 1 | 7 | 8 |
| Totals | 50 | 0 | 4 | 10 | 80 | 94 |
| Average | 5.56 | 0.00 | 0.44 | 1.11 | 8.89 | 10.44 |
| Std. Dev. | 4.07 | 0.00 | 0.73 | 0.78 | 4.08 | 4.16 |

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