Performance Evaluation and Benefit Analysis for CHART

– Coordinated Highways Action Response Team –

in
Year 2006

(Final report)

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PERFORMANCE EVALUATION OF CHART
- THE REAL-TIME INCIDENT MANAGEMENT SYSTEM (YEAR 2006) -

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EXECUTIVE SUMMARY

- **Objectives**

This report presents the performance evaluation study of CHART in Year 2006, including operational efficiency and resulting benefits. The research team at the Civil Engineering Department of University of Maryland, College Park has conducted the annual CHART performance analysis over the past eight years for Maryland State Highway Administration (MSHA).

Similar to previous studies, the focus of this work is to evaluate the effectiveness of Maryland CHART's ability to detect and manage incidents on major freeways and highways. Resulting benefits from the incident management are equally essential and also assessed.

The study consisted of two phases. Phase 1 focused on defining the objectives, identifying the available data, and developing the methodology. The core of the second phase was to assess the efficiency of the incident management program and to estimate the resulting benefits from the 2006 CHART incident operations data. As some information essential for efficiency and benefit assessment was not available in the CHART-II database, this study presents only those evaluation results that can be directly computed from the incident management data or derived with statistical methods.

- **Available Data for Analysis**

Upon a request made by MSHA, COSMIS began the performance evaluation for CHART operations in 1996. During the evaluation, the 1994 incident management data from the Traffic Operations Center were reviewed but not used due to various reasons. Thus, conclusions drawn were mostly based on either information from other states or from nationwide averaged data published by the Federal Highway Administration.

To ensure a better evaluation quality and also in view of the Statewide Operations Center (SOC) opening in August of 1995, members associated with the evaluation study concluded that reliable analysis should be based on *actual performance data from the CHART program*. Hence in 1996, the University of Maryland (Chang and Point-Du-Jour, 1998) was contracted to work jointly with MSHA staff in collecting incident management data and subsequently analyze the data.

This original study and evaluation analysis was inevitably faced with the difficulty of having **insufficient** information for analysis since this was the first time CHART had to collect all previous performance records for a scrupulous evaluation.

The evaluation for the 1997 CHART performance had the advantage of having relatively substantial information. The information collected were, incident management records from the SOC, TOC-3 (positioned in the proximity of the Capital Beltway), and TOC-4 (sited near the Baltimore Beltway) over the entire year as well as 1997 Accident Report Data from Maryland State Police for secondary incident analysis.

Unlike previous studies, the quality and quantity of data available for performance evaluation has increased considerably since 1999. This is a result of CHART's realization of the need to keep an extensive operational record in order to justify the costs, and to evaluate the benefits of the emergency response operations. Due to CHART's efficient data collection, there was an increase in documentation of lane-closure related incidents from 2,567 in 1997 to 21,055 in 2006.

The table below shows total emergency response operations that have been keenly documented from 2000 to 2006

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Incidents only	8,687	9,313	13,752	18,068	19,127	20,515	21,055
Total	34,891	26,008	32,814	38,523	40,539	41,196	44,043

It should be noticed that CHART may have responded to more emergency service requests than those reported in the database. This setback may be due to inefficient recording of incidents by control center operators. This drawback though has been tackled with the implementation of the CHART-II online information system.

Evolution of Evaluation Work

CHART has consistently worked on improving its data recording for both major and minor incidents in the past eight years; which accounts for the substantial improvements in data quality and quantity. The evaluation work has also been advanced in response to the improved data availability. It has become imperative to assess the quality of data used and to only use reliable data in the benefit analysis. Thus from 1999, the performance evaluation reports included data quality analysis. This aims at ensuring a continued advancement in quality of incident related data so as to reliably estimate all potential benefits of CHART Operations.

From February 2001, all incident requests for emergency assistance have been recorded in the CHART-II information system irrespective of whether CHART responded or ignored the request and this has significantly enriched the available data. In the current CHART database system, most incident related data can be generated directly for computer processing except that incident-location-related information remains documented in a text format which cannot be processed automatically with a data analysis program.

Distribution of Incidents

The evaluation methodology was created to utilize all available data sets that are considered to be of acceptable quality. An analysis of incident characteristics by incident duration, and number of blocked lanes is initially conducted.

The analysis results indicate that in Year 2006 there were a total of 2,989 severe incidents resulting in one-lane blockage, 3,659 severe incidents causing two-lane closures, and about 2,548 severe incidents blocking more than two lanes. In addition, there were a total of 25,631 shoulder incidents caused by either disabled vehicles or minor incidents. A comparison of lane-blockage incident data over the past seven years is summarized below:

A list of incidents by lane blockage type from Year 2000 to Year 2006.

	2000	2001	2002	2003	2004	2005	2006
Shoulder	27370	17593	21107	23399	24518	23,748	25,631
1 lane	3195	2357	2268	3015	3110	3,094	2,989
2 lanes*	2169	1407	1684	2443	2891	3,193	3,659
3 lanes*	478	403	571	801	870	1,078	1,245
≥ 4 lanes*	347	432	636	849	1055	1,127	1,303

* Counts Shoulder lane as one lane

Most of those incidents were distributed along six major commuting corridors. Namely, I-495/95 which experienced a total of 7,881 incidents in Year 2006; I-695, I-95, US-50, MD-295 and I-270 with 10,009, 4,024, 4,273, 1,417, and 1,536 incidents, respectively. CHART managed an average of 27 emergency requests per day on I-695 alone and 22, 11, 12, 4 and 4 responses for I-495/95, I-95, US-50, MD-295 and I-270, respectively. The distribution of incidents on those major commuting corridors between 2000 and 2006 is tabulated below:

Summary of incident distribution on major freeway corridors

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
I-495/95	11,404	9,524	9,652	9,936	10,288	9,840	7,881
I-695	7,704	5,165	7,916	8,938	9,277	9,536	10,009
I-270	1,767	1,277	1,474	1,582	1,375	986	1,536
I-95	2,779	2,296	3,211	4,568	5,852	5,629	4,024
US-50	829	1,730	1,795	1,984	2,505	3,285	4,273
MD-295	1,484	1,103	1,381	1,591	1,462	1,858	1,417

However, it should be mentioned that, most incidents on the major commuting freeways did not block traffic for more than one hour. For instance, the ratio of disabled vehicles and incidents which had their durations shorter than 30 minutes was about 80%. This observation can be attributed to the nature of the incidents and more probably to the efficient response of CHART. The distribution of incident/disabled vehicle duration from 2000 to 2006 is summarized below:

The distribution of incident/disabled vehicle duration from Year 2000 to 2006

Duration(Hr)	2000	2001	2002	2003	2004	2005	2006
$D < 0.5$	7,057	8,581	8,693	11,480	19,418	25,430	29,699
$1 > D \geq 0.5$	2,138	969	1,002	1,656	2,569	3,562	4,300
$2 > D \geq 1$	743	356	446	784	1,095	1,385	1,669
$D \geq 2$	518	227	347	672	1,173	1,133	1,623

In brief, it is apparent that the highway networks served by CHART remain plagued by a high frequency of incidents with their durations ranging from 10 to over 120 minutes. Those incidents were one of the primary contributors to traffic congestion in the entire region, especially on the major commuting highway corridors such as, I-95, I-270, I-495/95, and I-695.

Efficiency of Operations

Detection, Response and Traffic Recovery are the three vital features associated with the efficiency of an incident management program. Unfortunately, data needed for the execution of detection and response time analysis are not yet available under the CHART data system. MSHA patrols and Maryland State Police (MSP) remain the main sources of incident detection and response data.

The average response time is the time that elapsed from the reception of an emergency request to the time of arrival of the emergency response unit. The 2006 data indicate 11.17, 14.09 and 9.19 minutes of response time for TOC-3, TOC-4 and SOC, respectively. As shown in the table below, CHART has demonstrated a steady improvement in its response time over the past seven years:

The evolution of response times by center from Year 2000 to Year 2006

Response time (min)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
TOC-3	14.96	13.90	13.85	11.67	11.45	11.75	11.17
TOC-4	15.43	14.53	13.65	13.09	13.57	14.15	14.09
SOC	19.14	13.70	13.51	7.24	8.55	8.48	9.19
Weighted Average	**15.22**	**13.84**	**13.10**	**11.50**	**11.38**	**11.47**	**11.51**

To better understand the contribution of the incident management program, the study compares the average duration of incidents CHART responded to and those managed by other agencies. For instance, for shoulder-lane-blockage incidents that SHA Patrol did not respond to, the average duration was about 15 minutes more than the ones they responded to.

The duration of incidents managed by CHART response units averaged 22.92 minutes, shorter than the average duration of 32.45 minutes for those incidents responded by other agencies. On average, CHART operations in Year 2006 resulted in about 29% reduction in the average incident duration.

Performance improvement of CHART operations from Year 2000 to Year 2006 is summarized below:

Comparison of the average incident duration with and without CHART response

Year	With CHART (min)	Without CHART (min)
2000	33	77
2001	29	51
2002	28	39
2003	40	49
2004	38	45
2005	21.93	28.65
2006	22.92	32.45

Resulting Benefits

The benefits attributed to CHART's operations that were estimated directly from the available data include assistance to drivers and reductions in driver delay time, fuel consumption, emissions, and secondary incidents. CHART responded to a total of 21,055 lane blockage incidents in 2006, and assisted 22,988 highway drivers who may otherwise have caused incidents or rubbernecking delays to the highway traffic. CHART's contribution to incident duration reduction also resulted in a reduction of 291 potential secondary incidents. In addition, efficient removal of stationary vehicles and large debris on travel lanes by CHART patrol units may have prevented 544 potential lane-changing-related collisions in 2006, as approaching vehicles under those conditions will be forced to perform unsafe mandatory lane changes.

CORSIM, a traffic simulation program produced by FHWA was used in estimating the direct benefits of reductions in delay time and fuel consumption. It was determined that CHART's services in 2006, caused a reduction in delay of 37.53 million vehicle-hours as well as a 6.34 million gallon reduction in fuel consumption. A comparison of direct benefits from 2000 to 2006 is summarized below:

Comparison of direct benefits from Year 2000 to 2006

	Total Direct Benefits (million)	# of Incidents/ disabled vehicles
2000	$378.41	34,891
2001	$402.75	26,008
2002	$467.97	32,814
2003	$498.70	38,523
2004	$518.25	40,539
2005	$577.79 (864.31*)	41,196
2006	$709.85 (1092.35*)	44,043

* New results based on the U.S Census Bureau data for Year 2005

Conclusions and Recommendations

Grounded on the previous research experience, this study has conducted a rigorous evaluation of CHART's performance in the year of 2006 and resulting benefits under the constraints of data availability and quality. Overall, CHART has made significant progress in recording more reliable incident reports, especially after the implementation of the CHART-II Database.

However, much remains to be done in terms of collecting more data and extend the operations to major local arterials if resources are available to do so. For example, the data associated with the potential impacts of major incidents on local streets has not been collected by CHART. Without such information, one may substantially under estimate the benefits of CHART operations, as most incidents causing lane blockage on major commuting freeways are likely to spill back its congestion to neighboring local arterials if the traffic queue formation speed is faster than the pace of the incident clearance progress. By the same token, a failure to responding to major accidents in local arterials, such as MD355, may also significantly degrade the traffic conditions in I-270. Effectively coordinating with county agencies on both incident management and operational data collection is one of the major tasks to be done by CHART.

With respect to the performance, CHART has maintained nearly at the same level of efficiency in responding to incidents and driver assistance requests in recent years. The average response time in Year 2006 was 5.76 minutes, which is very similar to that observed in 2005. In view of the worsening congestion and the increasing number of incidents in the Washington-Baltimore region, it is commendable that CHART can keep its performance efficiency with the approximately same level of resources.

The main recommendations based on the performance of CHART in 2006 are listed below:

- Allocating more resources to CHART for incident response and traffic management to improve the performance of the response teams so that they can effectively contend with the ever-increased congestion and accompanied incidents.
- Coordinating with county traffic agencies to extend the CHART operations to major local routes, and including the data collection as well the performance benefits in the annual CHART review.
- CHART's quality evaluation report should be made available to the operators for their continuous improvement of response operations.
- Training sessions should be carried out to instruct operators on how to effectively record critical performance related data
- The data structure used in the CHART-II system for recording incident location should be improved to eliminate the current laborious and complex procedures.
- Average response time should be reduced by increasing freeway service patrols and assigning patrol locations, based on both the spatial distribution of incidents along freeway segments and the probability of an incident occurring.
- Efficiently integrating Police accident data into CHART-II incident response database in order to have a complete representation of statewide incident records.

- Incorporating the benefits of delay and fuel consumption due to reduced potential secondary incidents in the CHART benefit evaluation.

Note that comprehensive evaluation results of the CHART performance over the past five years are available on the Web site (http://chartinput.umd.edu)

CHAPTER1
INTRODUCTION

CHART (Coordinated Highways Action Response Team) is the highway-incident management system of the Maryland State Highway Administration. It was initiated in the mid-80s as “The Reach the Beach Program” and was subsequently expanded as a statewide program. The Statewide Operations Center (SOC), an integrated traffic control center for the state of Maryland, has its headquarters in Hanover, Maryland. The SOC is supported by a three satellite Traffic Operations Centers (TOC), of which one is seasonal. CHART’s current network coverage consists of statewide freeways and major arterials.

CHART has four major functions: traffic monitoring, incident response, traveler information, and traffic management. Incident response and traveler information systems have received increasing attention from the general public, media, and transportation experts.

In 1996, incident data was collected and used in the pilot evaluation analysis conducted by the University of Maryland in conjunction with MSHA staff (Chang and Point-Du-Jour, 1998). As this was the first time previous records were to be analyzed, researchers inevitably were faced with the difficulty of having a database with insufficient information.

The 1997 CHART performance evaluation was much more extensive than the previous year’s. The researchers were able to obtain a relatively richer set of data. The data used were obtained from incident management reports gathered in 12months from the SOC, TOC-3 (located in the proximity of the Capital Beltway), and TOC-4 (situated near the Baltimore Beltway). In addition to these data, accident reports from Maryland State Police were also available for secondary incident analysis.

There has definitely been an incredible improvement in data used for the evaluations since 1999. This is as a result of CHART’s recognition of the need to keep an extensive operational record in order to justify the costs and evaluate the benefits of the emergency response operation. The data available for analysis of lane-closure incidents increased from 5,000 reports in 1999 to 21,055 reports in 2006. A summary of total emergency response operations documented from 2000 to 2006 is presented in Table 1.1.

Table 1.1 Total Number of Emergency Response Operations

Records	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Incidents	8,687	9,313	13,752	18,068	19,127	20,515	21,055
Disabled Vehicles	20,428	16,274	19,062	20,455	21,412	20,681	22,988
Total	29,115	25,007	32,814	38,523	40,539	41,196	44,043

The objective of this study is to evaluate the effectiveness of CHART's incident detection, response, and traffic management operations on interstate freeways and major arterials. This assessment also includes CHART benefits estimation, which is an essential part of the study since support of MSHA programs from the general public and state policymakers is largely dependent on the benefits the state obtains from its ongoing programs. In order to conduct a comprehensive analysis using available data to ensure the reliability of the evaluation results, the evaluation study has been divided into three principal tasks:

Task 1: Assessment of Data Sources and Data Quality – involves identifying data sources, evaluating their quality, analyzing available data, and classifying missing parameters.

Task 2: Statistical Analysis and Comparison – entails performing comparisons based on data available in 2005 and 2006 with an emphasis on these target areas: incident characteristics, incident detection efficiency, distribution of detection sources, incident response efficiency, and effectiveness of incident traffic management.

Task 3: Benefit Analysis – entails analyzing reduction of total delay times, fuel consumption, emissions and secondary incidents due to CHART/SHA operations, as well as the reduction in potential accidents due to efficient removal of stationary vehicles in travel lanes by the CHART/SHA response team.

The subsequent chapters are structured as follows

Chapter 2 assesses the quality of data available for the 2006 CHART performance evaluation. This includes total available incident reports, percentage of missing data for each critical performance parameter, and a comparison of data quality of 2006 with that of 2005.

Chapter 3 outlines the statistical analysis of incident data characteristics such as distributions of incidents and disabled vehicles by road name, by location on road, by 'weekday and weekend', by lane-blockage type and by lane-blockage duration. A comparison of the average incident duration incurred by different types of incidents is also included in the analysis.

Chapter 4 provides a detailed report on the efficiency and effectiveness of incident detection. Issues discussed are detection rate, distribution of detection sources for various types of incidents and driver requests for assistance. The chapter also touches on an evaluation of incident response efficiency. The efficiency rate is based on the difference between incident report time and the arrival time of emergency response units. Also, the assessment of incident clearance efficiency is based on the difference between the arrival time of the emergency response units and the incident clearance time.

Chapter 5 estimates the direct benefits associated with CHART's operations. Parameters used for the estimates are the reductions in fuel consumption delays, emissions, secondary incidents, and potential accidents. CHART patrol unit also respond to a significant number of driver assistance requests and these services result in direct benefits to drivers and minimizes potential rubbernecking delays on highways.

Chapter 6 summarizes key performance statistics to facilitate the review and comparison of CHART's performance over the past years. The chapter ends with concluding comments and recommendations for future evaluation.

CHAPTER 2
DATA QUALITY ASSESSMENT

This chapter assesses the quality of data available in the CHART 2006 performance evaluation, and compares this data with data from CHART 2005

2.1 Analysis of Data Availability

In 2006, CHART recorded a total of 44,043 emergency response cases. These are categorized into two groups: incidents and disabled vehicles. A summary of the total available incident reports for the years 2004, 2005 and 2006 is shown in Table 2.1.

Table 2.1 Comparison of Available Data for 2004, 2005, 2006

Available Records		**2004**		**2005**		**2006**	
		Records	Total (%)	Records	Total (%)	Records	Total (%)
CHART II Database	Disabled Vehicles	21,412	52.8	20,681	50.2	22,988	52.2
	Incidents	19,127	47.2	20,515	49.8	21,055	47.8
Total		40,539	100	41,196	100	44,043	100

2.2 Analysis of Data Quality

More than 10 million records in 24 tables from the CHART II database have been filtered to obtain key statistics for a detailed evaluation of the data quality. Figures 2.1 and 2.2 illustrate the comparison of the quality of data recorded in 2005 and 2006.

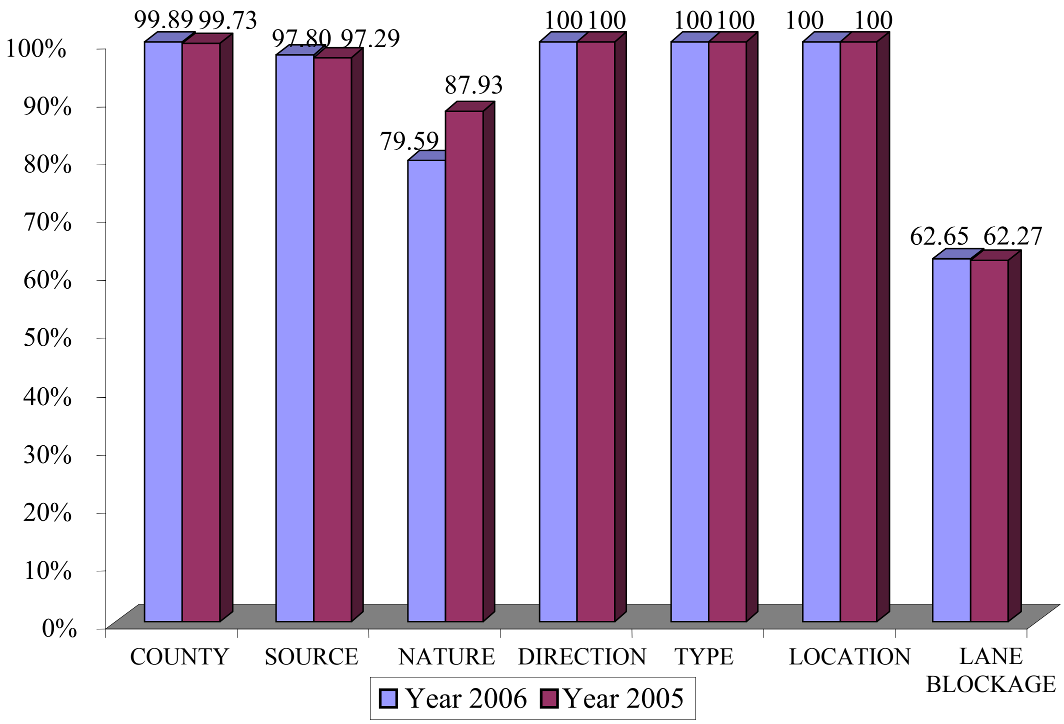


Figure 2.1 Summary of Data Quality for Critical Indicators

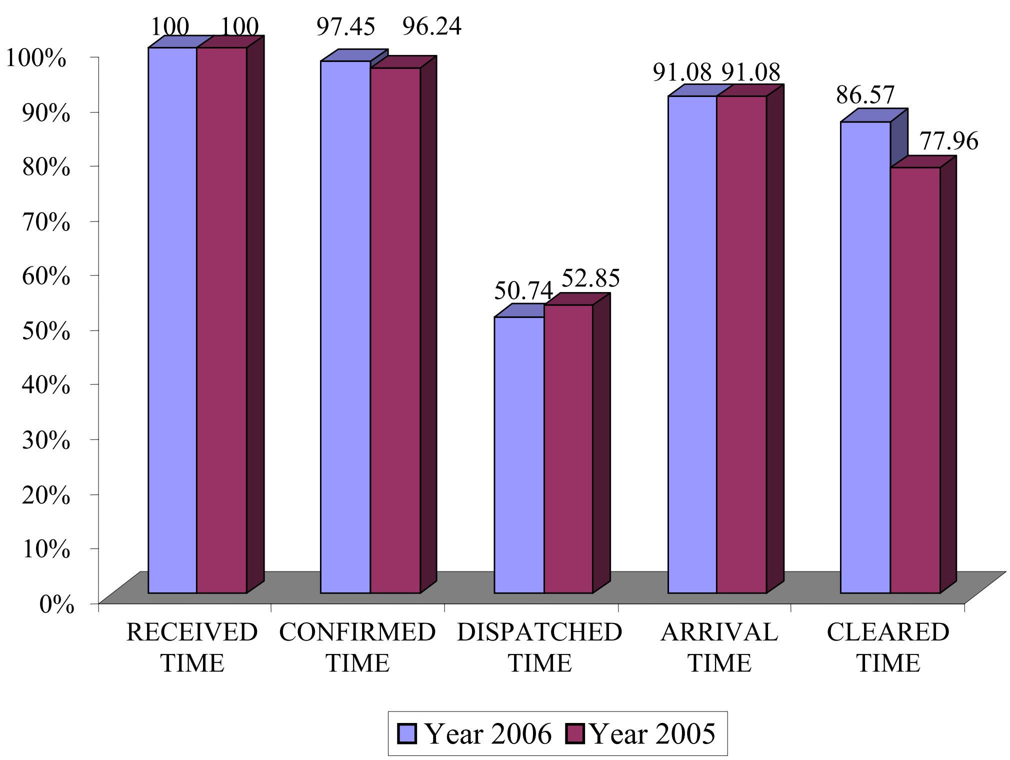


Figure 2.2 Summary of Data Quality for Time Indicators

Nature of Incidents/Disabled Vehicles

Here, data is classified based on the nature of incidents, such as vehicle on fire, collision-personal injury, and collision-fatality. CHART's records on disabled vehicles are also categorized as abandoned vehicles, tire changes and gas shortage. As shown in Figure 2.1, about 80% of emergency response reported in 2006 recorded the nature of incidents.

Detection Sources

As shown in F i g ure 2.1, about 98% of total emergency responses recorded in 2006 contain the source of detection, which is slightly more than the previous year's data. In 2006, about 96% of incidents reported and 99.45% of the disabled vehicles reported have a definitive detection source.

Operational Time-Related Information

To evaluate the efficiency and effectiveness of emergency response operations, CHART 2006 used five time parameters for performance measurements: "Received Time", "Dispatched Time", "Arrival Time", "Cleared Time", and "Confirmed Time". The data quality analysis with respect to these performance parameters is illustrated in Figure 2.2. The figure indicates that the quality of data for "Received Time" is sufficient for reliable analysis. The quality of data of "Confirmed Time", "Dispatched Time", "Arrival Time" and "Cleared Time" has shown gradual improvements over the years.

Type of Reports

The total number of incidents/disabled vehicles managed by each operation center in 2006 is summarized in Table 2.2. Overall, CHART responded to a total of 21,055 incidents in 2006. Over the same period, the response team also attended to 22,988 disabled vehicle requests.

Table 2.2 Emergency Assistance Reported in 2006

Operation Center	TOC3	TOC4	SOC	TOC5	AOC	OTHER	TOTAL
Disabled Vehicles	6,550	10,438	704	821	245	4,230	**22,988**(20,681)
Incidents	5,058	6,562	3,198	192	2,469	3,576	**21,055**(20,515)
Total	11,608	17,000	3,902	1,013	2,714	7,806	**44,043**(41,196)

Note: numbers in parenthesis are corresponding 2005 data

Location and Road Name Associated with Each Response Operation

The location and road name information associated with each emergency response operation is used to analyze the spatial distribution of incidents/disabled vehicles, and to identify freeway segments that incur frequent incidents. As shown in Figure 2.1, all incident response reports have documented location information. This is a feature that has always been properly recorded over the years. However, the location information associated with each response operation is structured in a descriptive text format that cannot be processed automatically with a computer program. Hence road names and highway segments have to be manually located and inputted into the evaluation system.

Table 2.3 shows the percentage of data with valid location information and road name for incidents and disabled vehicles in the CHART II Database for 2006. Note that only 96% of highway segments that contain incident locations can be identified. The remaining 4% of incident locations are either unclear or not specified, and therefore, cannot be used for reliable performance analysis.

Table 2.3 Data Quality Analysis with Respect to Road and Location

Data Quality	Incident	Disabled Vehicles	Total
Location	100%	100%	100%
Road	94%	98%	96%

Lane/Shoulder Blockage Information

To compute additional delays and fuel consumption cost incurred by each incident, it is essential to know the number of lanes (including shoulder lanes) blocked as a result of the incident. Analysis on all available data in 2006 shows that up to 62.65% of emergency response reports incurred a lane/shoulder blockage. This value is slightly higher than the 62.27% in 2005.

In summary, there have been improvements in the documentation of CHART's performance and recording of operations-related information in 2006. The use of the CHART II Database has had a noticeable positive impact on data quality improvement, but there is still room for improvement, as shown in the above statistics of data quality evaluation. Finally, CHART operators should be made aware of their contribution to mitigation of traffic congestion, driver assistance and the overall improvement in the driving environment.

CHAPTER 3

ANALYSIS OF DATA CHARACTERISTICS

The evaluation study starts with a comprehensive analysis of the spatial distribution of incidents/disabled vehicles and their key characteristics to improve the efficiency of incident management.

3.1 Distribution of Incidents and Disabled Vehicles by Day and Time

The research team analyzed the differences between the distribution of incidents/disabled vehicles during weekdays and weekends. As shown in Table 3.1, a good number (about 92%) of incidents/disabled vehicles in 2006 occurred on weekdays. Thus, more resources and personnel are required on weekdays than on weekends to manage the incidents/disabled vehicles more effectively.

Table 3.1 Distribution of Incident/Disabled Vehicles by Day

Center	TOC3		TOC4		TOC5		SOC		Other*		Total	
Year	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**
Weekdays	98%	98%	100%	99%	28%	45%	64%	69%	87%	75%	92%	91%
Weekends	2%	2%	0%	1%	72%	55%	36%	31%	13%	25%	8%	9%

* Includes DIST6, RAVENS TOC and REDSKINS TOC

As defined by the 1999 CHART performance evaluation, peak hours in this study are from 7:00 AM to 9:30 AM and from 4:00 PM to 6:30 PM. Table 3.2 illustrates that about 40% of incidents/disabled vehicles reported in 2006 occurred during peak hours which is slightly higher than the same observation made in 2005.

Table 3.2 Distribution of Incident/Disabled Vehicles by Peak and Off-Peak Periods

Center	TOC3		TOC4		TOC5		SOC		Other*		Total	
Year	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**	**2006**	**2005**
Peak**	44%	42%	45%	46%	13%	23%	20%	22%	35%	26%	40%	39%
Off-Peak	56%	58%	55%	54%	87%	77%	80%	78%	65%	74%	60%	61%

* Includes DIST6, RAVENS TOC and REDSKINS TOC

** 7:00 AM ~ 9:30 AM and 4:00 PM ~ 6:30 PM

3.2 Distribution of Incident and Disability Vehicles by Road and Location

Figure 3.1 gives a comparison of the frequency distribution between 2005 and 2006 and Figure 3.2 depicts the frequency distribution of incidents and disabled vehicles for 2006,

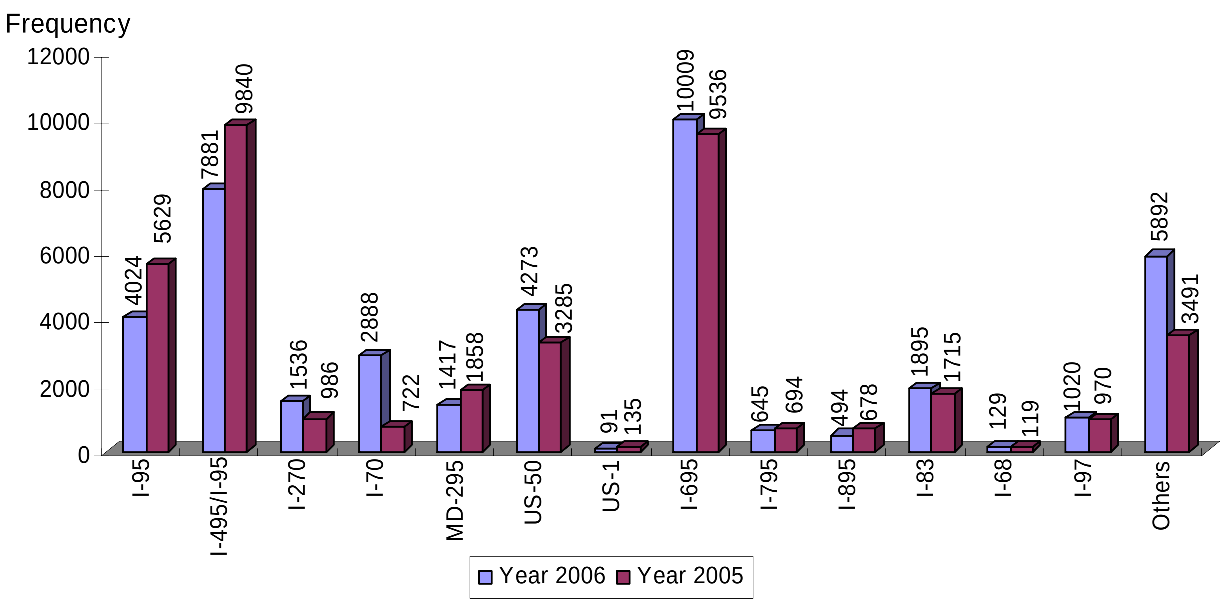


Figure 3.1 Distributions of Incident/Disabled Vehicles by Road Name in 2006 &2005

Based on the statistics shown above, the roadways with high incident frequencies for 2006 are I-695 (Baltimore Beltway), I-495/95 (Capital Beltway), US-50, I-95 (from the Delaware border to the Capital Beltway), I-270 and MD-295. I-695 experienced a total of 10,009 incidents/disabled vehicles in 2006 whilst I-495/95 had 7881 incidents/ disabled vehicles within the same period. US-50, I-95, I-270 and MD-295 were plagued with 4,273 4,024, 1,536 and 1,417 incidents/disabled vehicles, respectively.

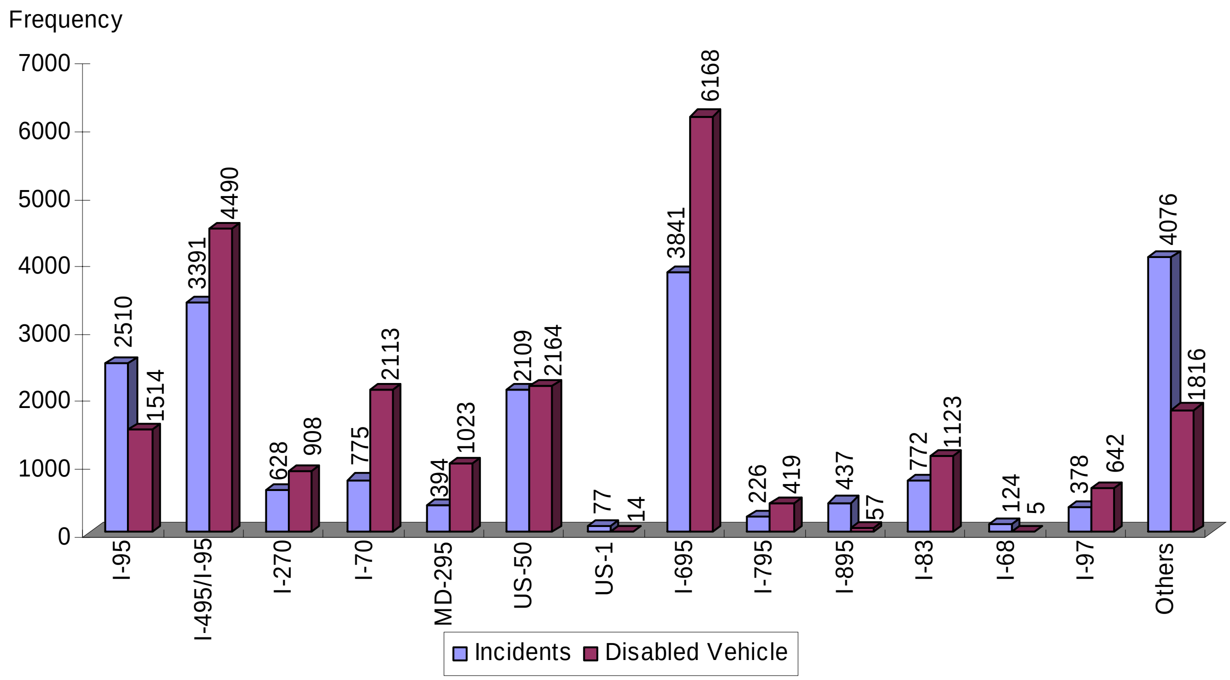


Figure 3.2 Distributions of Incident/Disabled Vehicles by Road Name in 2006

I-95, I-270 and US50 are connected to I-495/95, and are the main contributors of traffic congestion on I-495 during commuting periods. Due to the high traffic volumes on I-495, any incident is likely to have a spillback of vehicles onto I-95, I-270 and US50 causing congestion on those three freeways as well. The interdependent nature of incidents between the primary commuting freeways should be taken into account when prioritizing and implementing incident management strategies. To better allocate patrol vehicles and response units to hazardous hi g hway segments, the distribution of incidents/disabled vehicles between two consecutive exits was employed as an indicator in the analysis.

Figure 3.3 shows the distribution of incidents and disabled vehicles by location on I-695 in 2006 whilst Figure 3.4 compares these values with the 2005 values. The high-incident segments are from Exits 23 to 24 and Exits 22 to 23 (215 and 203, respectively). Both segments are in close proximity to I-83. Exits 11 to12 had the third largest number of incidents and it is close to I-95. The two high frequencies of disabled vehicles (about 720 cases) were recorded on the segments between Exits 21and 22 and Exits 22and 23, which are close to the I-83 interchange.

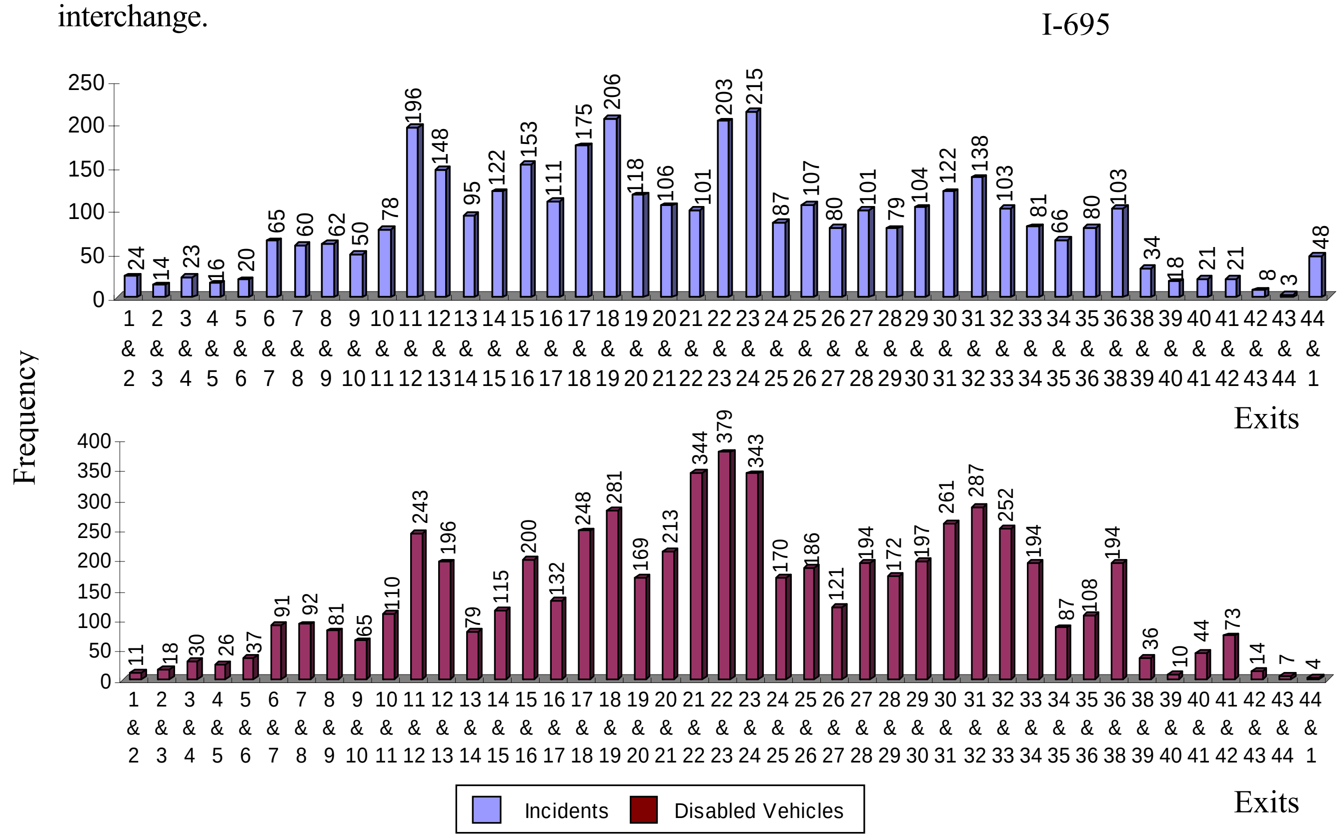


Figure 3.3 Distributions of Incidents/Disabled Vehicles by Location on I-695

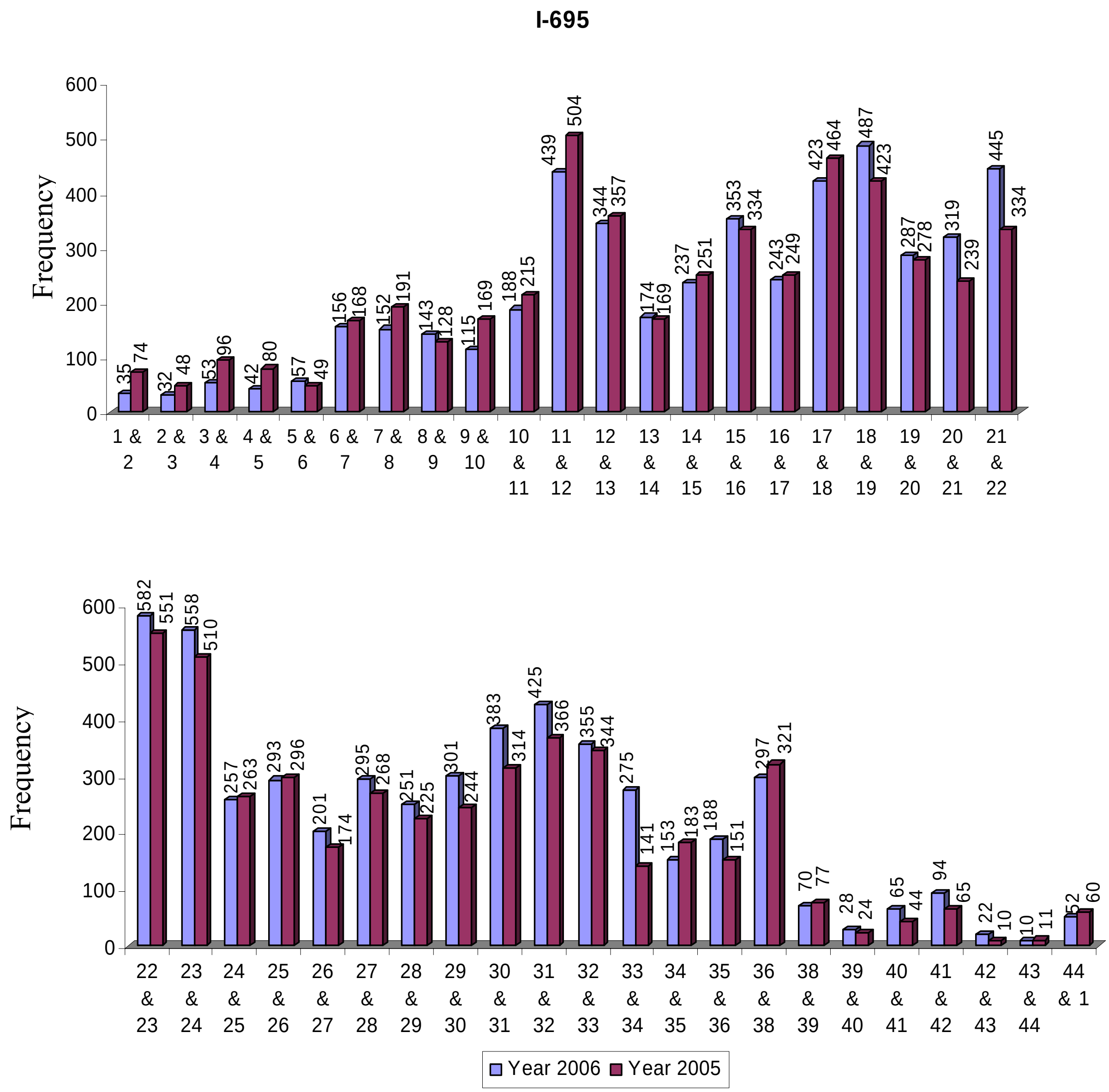


Figure 3.4 Comparisons of Incidents/Disabled Vehicles Distributions by Location on I-695

The subsequent figures present the comparison between 2005 and 2006 data, as well as the geographical distribution of incidents and disabled vehicles on I-495/95.

The comparison with the previous year data is illustrated in Figure 3.6. From Figure 3.5, it can be observed that the highest frequency of incidents (234 cases) occurred between Exits 31and 33 of I-495. The location with the highest frequency of disabled vehicles (276 cases) occurred between Exits 2 and 3, and also between Exits 4 and 7.

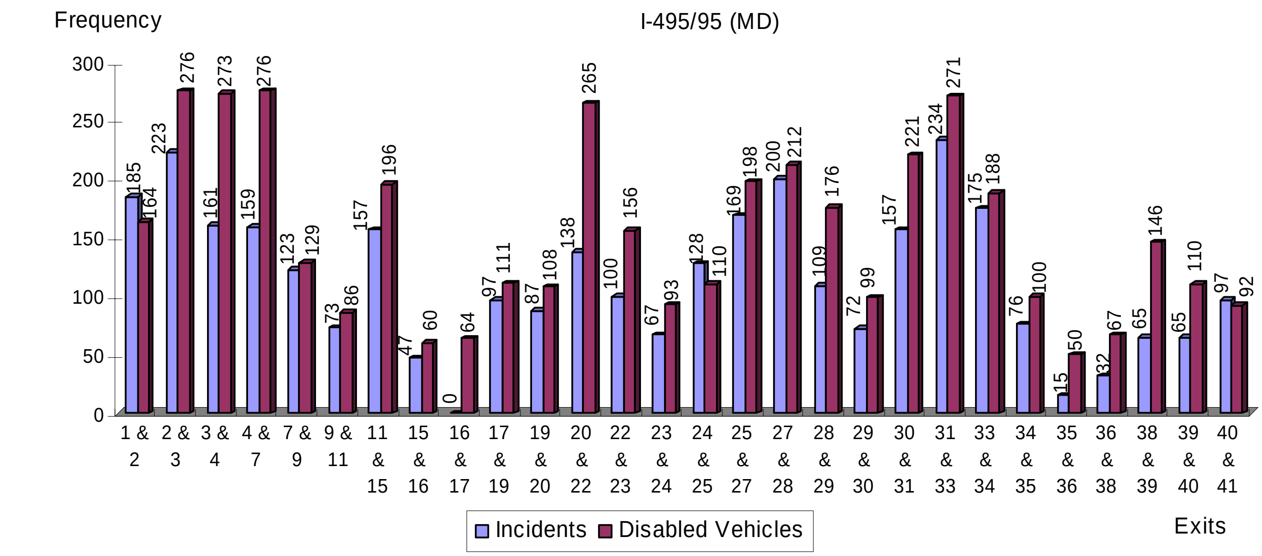


Figure 3.5 Distributions of Incident/Disabled Vehicles by Location on I-495/I-95

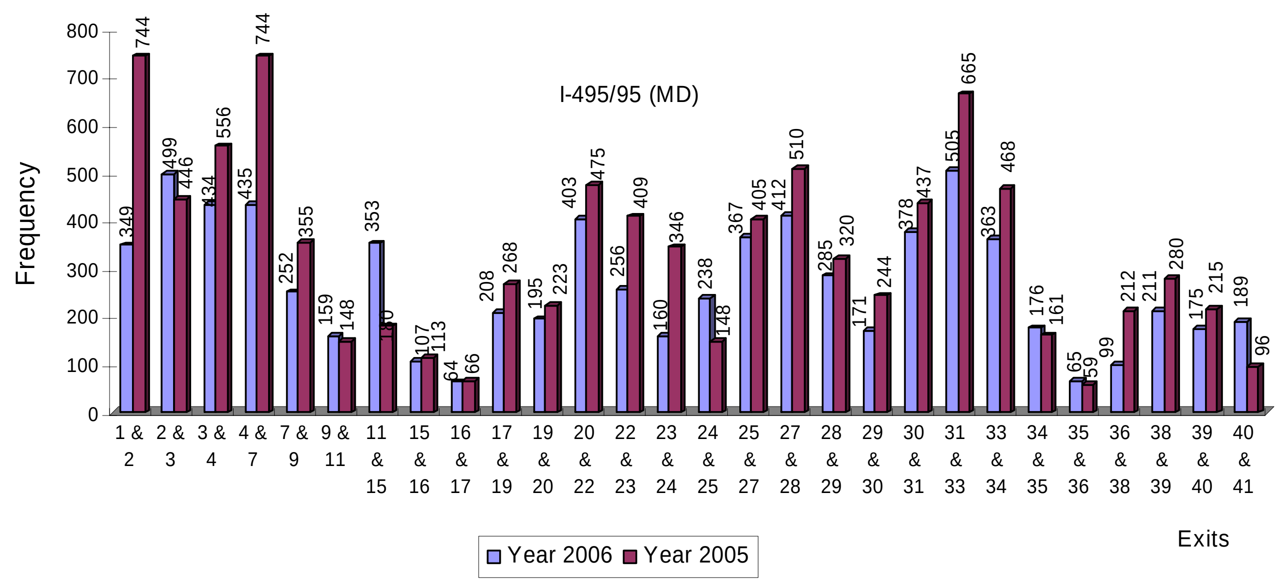


Figure 3.6 Comparison of Incident/Disabled Vehicles Distribution by Location on I-495/I-95

Figure 3.7 shows the distribution of incidents and disabled vehicles by location on I-95, and Figure 3.8 compares this distribution between data obtained in 2005 and 2006. As shown in Figure 3.7, the highest number of incidents occurred between Exits 55 and 56 (656 cases), which is close to the I-95/I-895interchange.The segments between Exits 47 and 49 experienced a high number of disabled vehicles (315 cases).

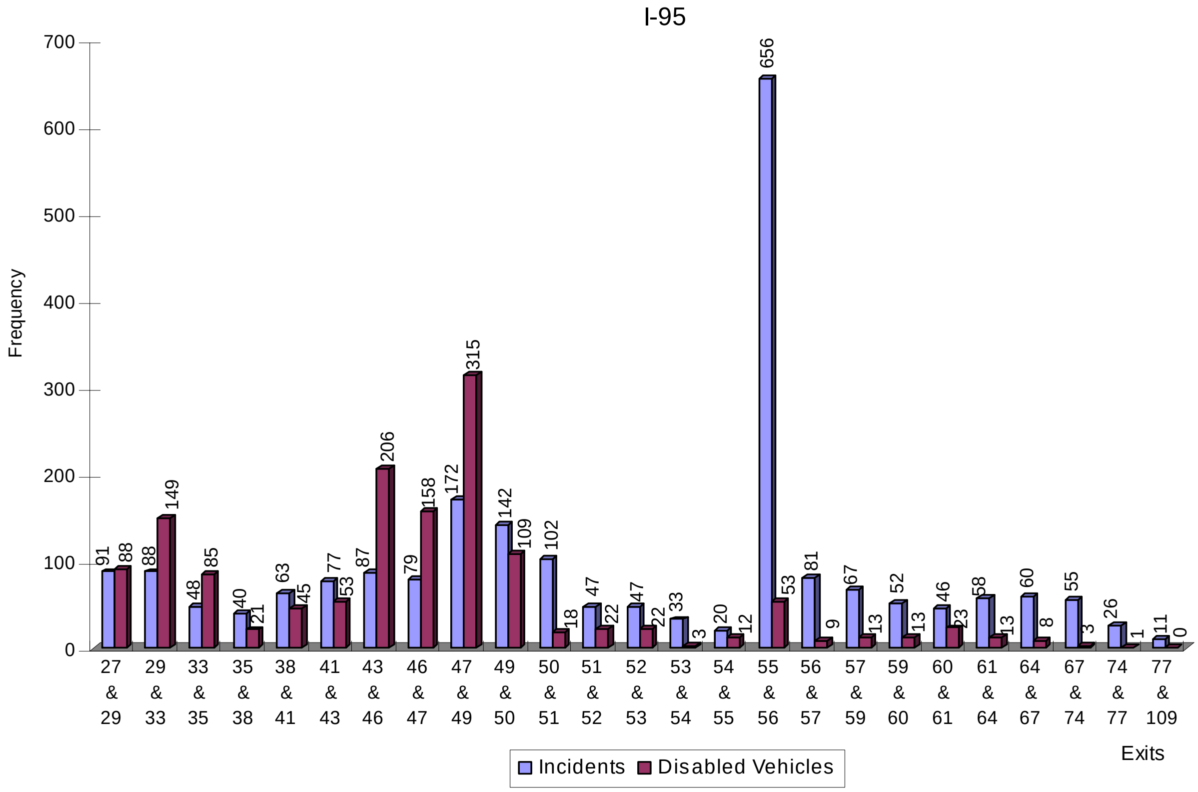


Figure 3.7 Distributions of Incidents/Disabled Vehicles by Location on I-95

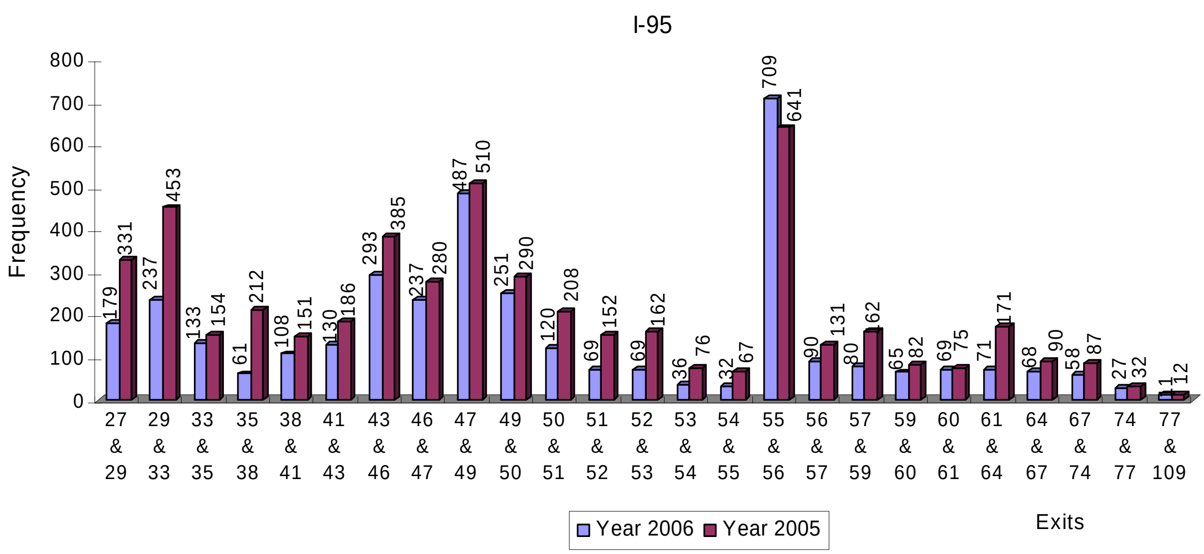


Figure 3.8 Comparison of Incidents/Disabled Vehicles Distribution by Location on I-95

The incidents and disabled vehicles recorded in 2006 for the I-95 segment between Exits 55 and 56 recorded the maximum number of incident responses, with a total frequency of 709. The segment on I-95 between Exits 47 and 49 (between I-195 and I-695) sustained the second largest number of incidents/disabled vehicles requests (487) in 2006. These trends are very similar to that observed in 2005.

Figure 3.9 represents the spatial distribution of incidents/disabled vehicles data on I-270 for 2006. A comparison is made in Figure 3.10 between 2006 and 2005 data.

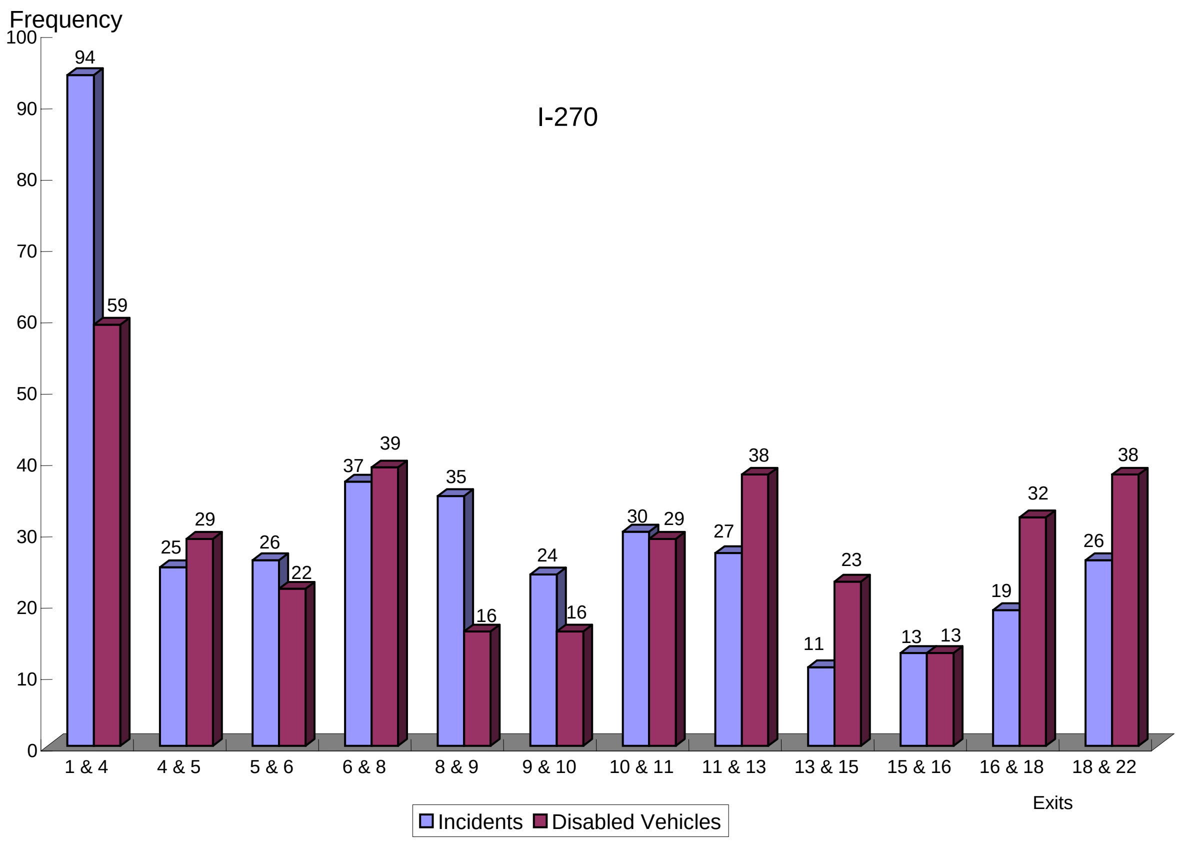


Figure 3.9 Distributions of Incident/Disabled Vehicles by Location on I-270

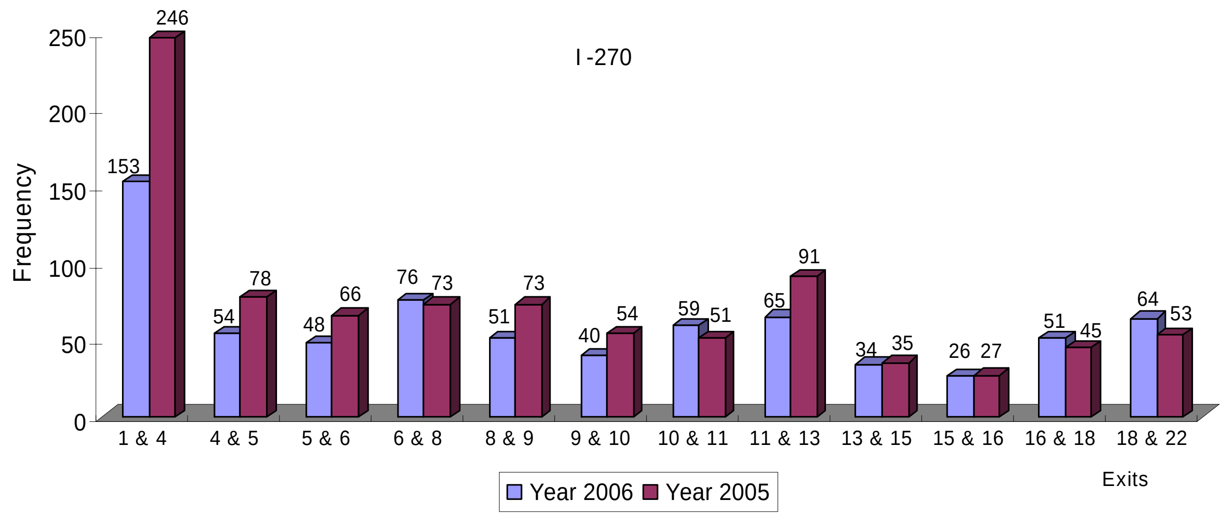
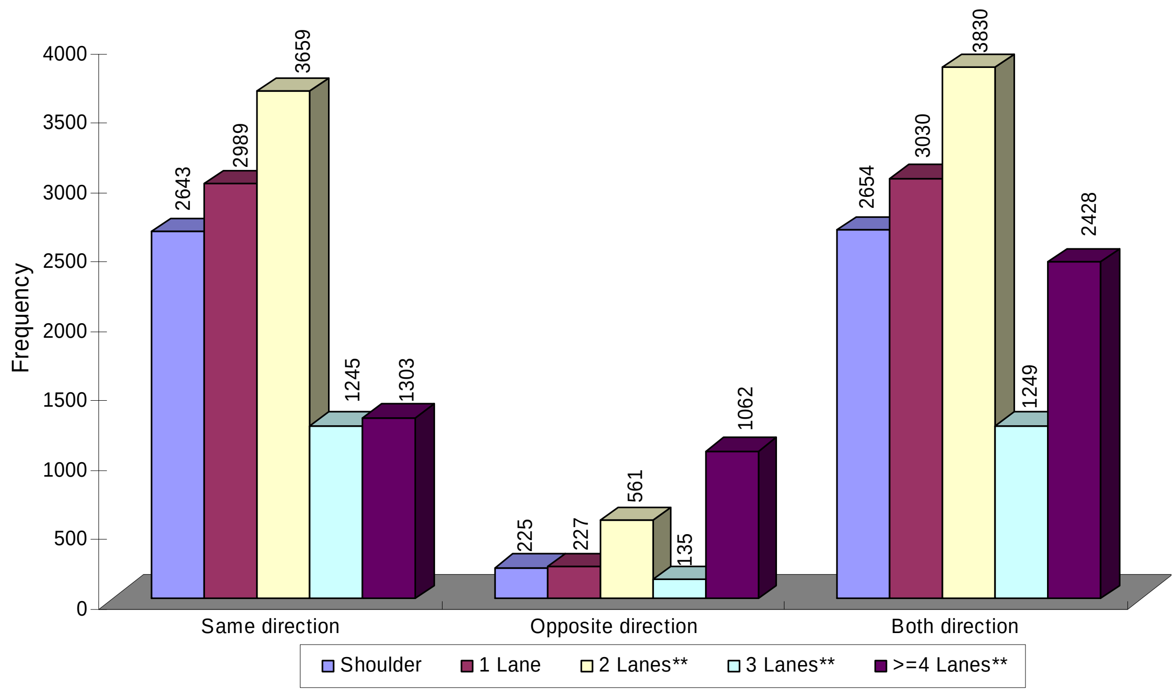


Figure 3.10 Comparisons of Incident/Disabled Vehicles Distributions by Location on I-270

The segment between Exits 1 and 4 on I-270 in F i g ure 3.9 experienced the highest numbers of incidents and disabled vehicles (94 and 59 respectively). In Figure 3.10, the 2006 data recorded less incidents/disabled vehicles than in 2005 except at the location between Exits 6 and 8, 10 and 11, 16 and 18, and Exits 18 and 22.

3.3 Distribution of Incidents and Disabled Vehicles by Lane Blockage Type

Figure 3.11 illustrates the distribution of incidents by lane blockage in 2006. Most of the incidents incurred two-lane blockages. The comparison of 2006 incidents/disabled vehicles distribution by lane blockage with 2005 data is illustrated in Figure 3.12. Note that all reported disabled vehicles are classified as shoulder lane blockages.



Note: * Not including "Disabled Vehicles"
** Also includes Shoulder Lane Blockages

Figure 3.11 Distributions of Incidents by Lane Blockage

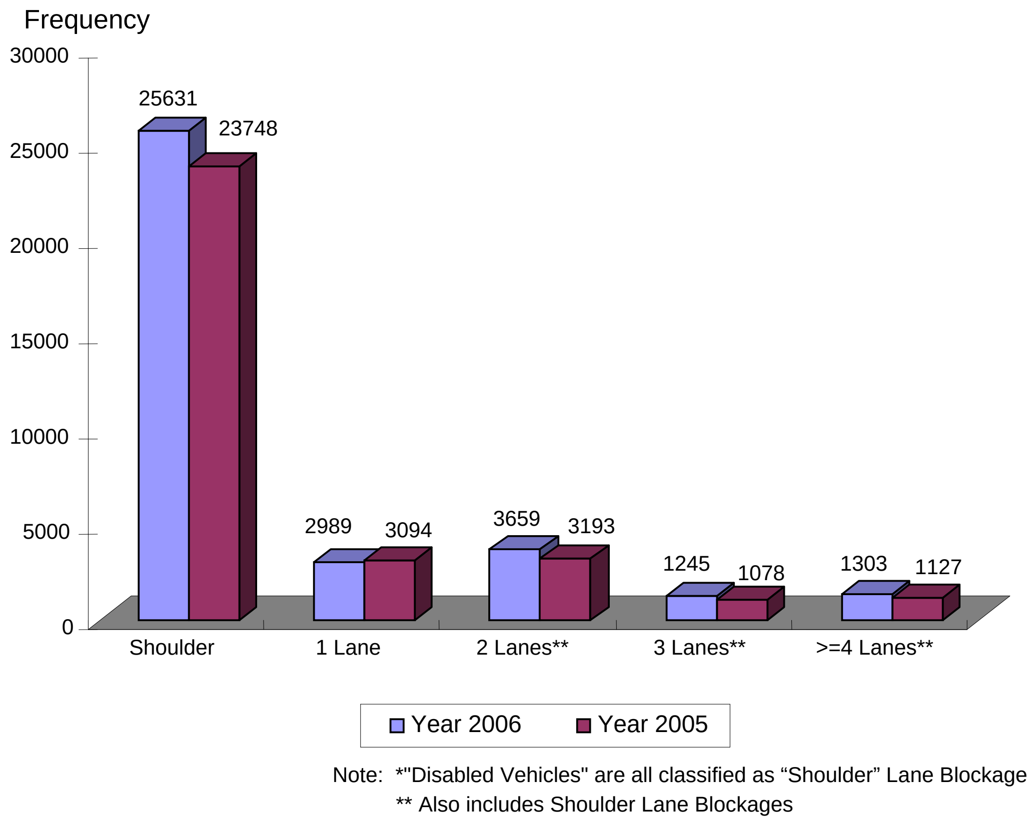


Figure 3.12 Comparisons of Incidents/Disabled Vehicle Distributions by Lane blockage

Figures 3.13 and 3.14 depict a comparison of lane blockage incidents between 2005 and 2006 for major roads in the Washington Metropolitan and Baltimore Areas

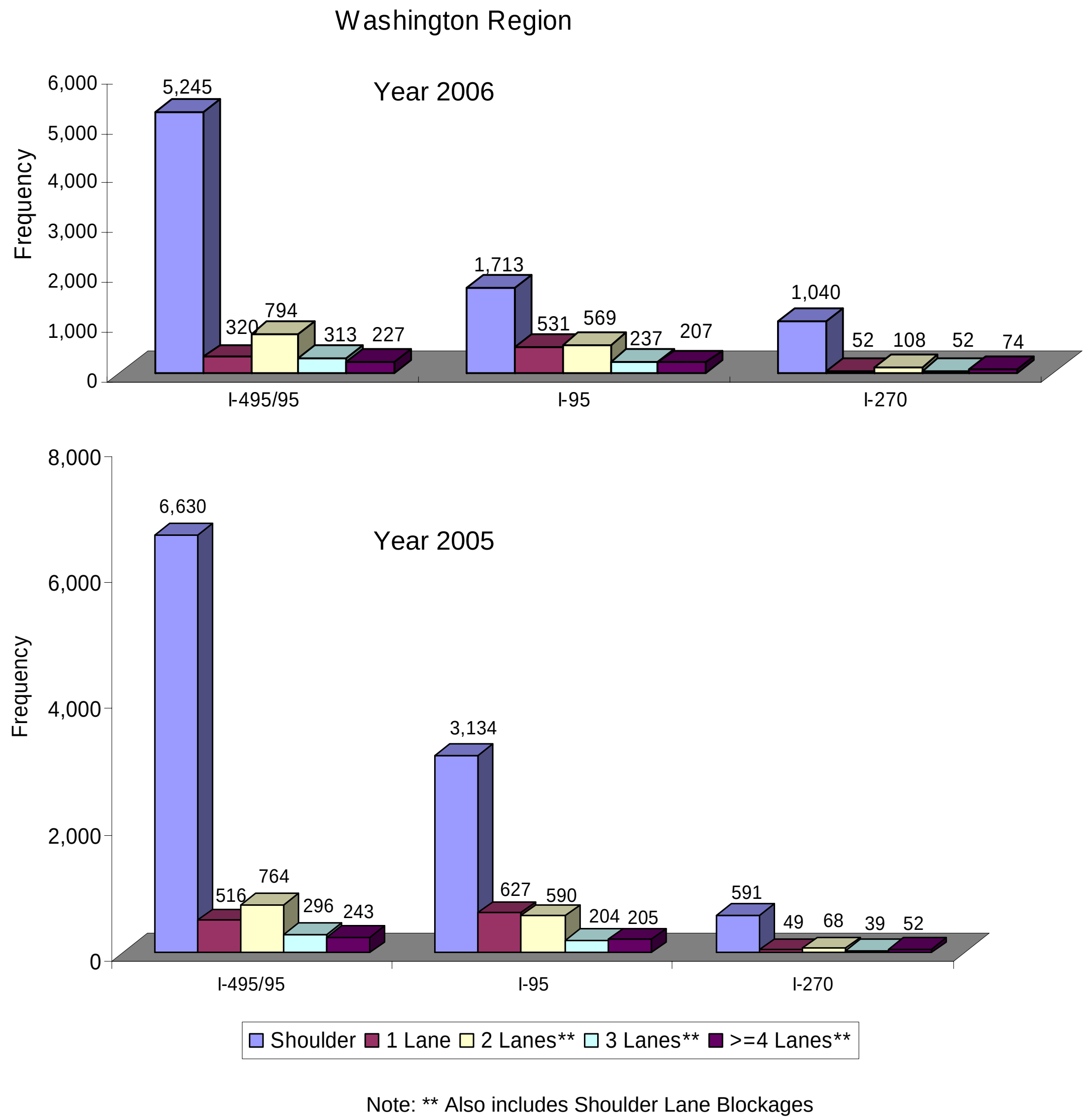


Figure 3.13 Distribution of Lane Blockages Incurred on Major Freeways in the Washington Area

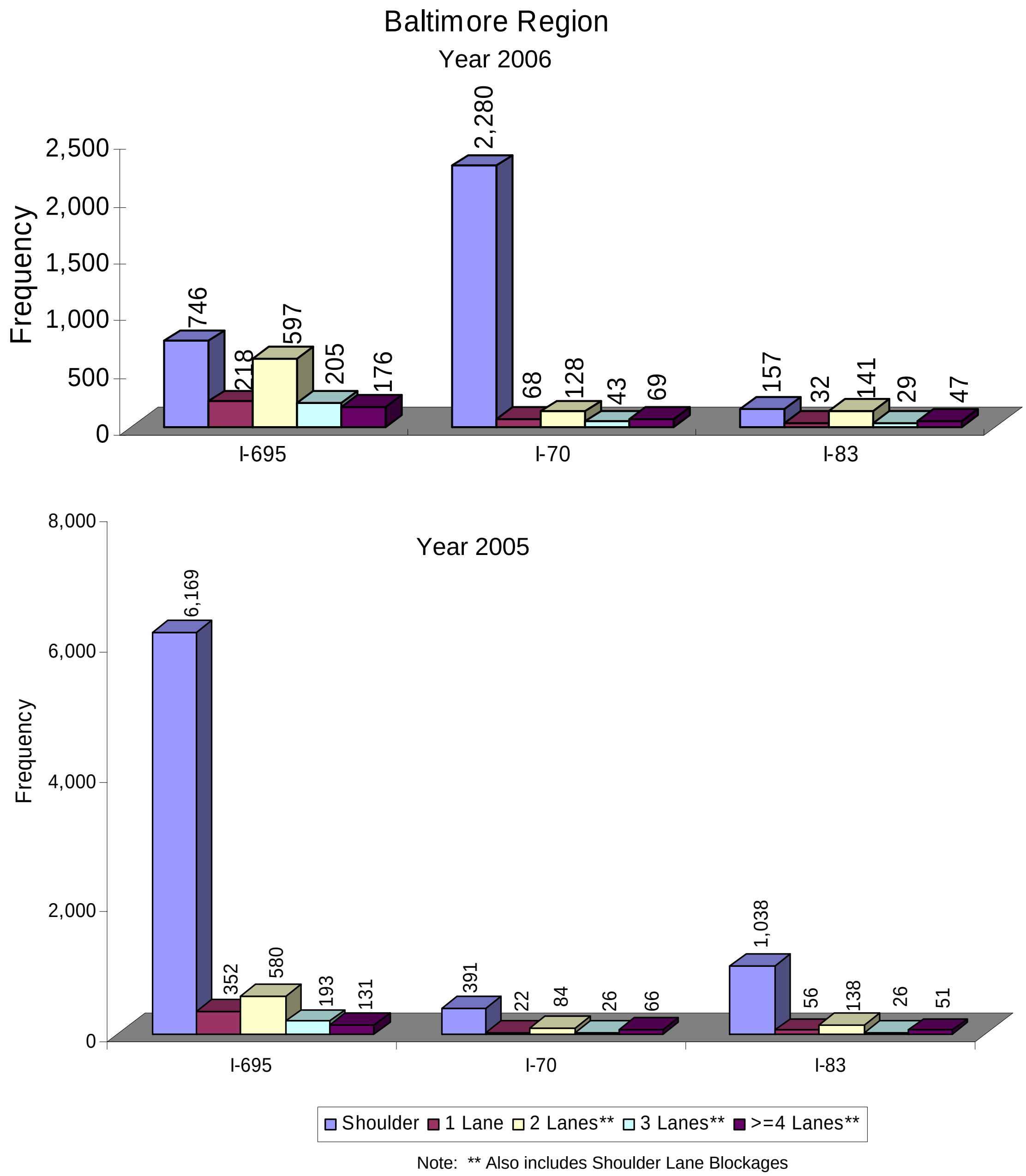
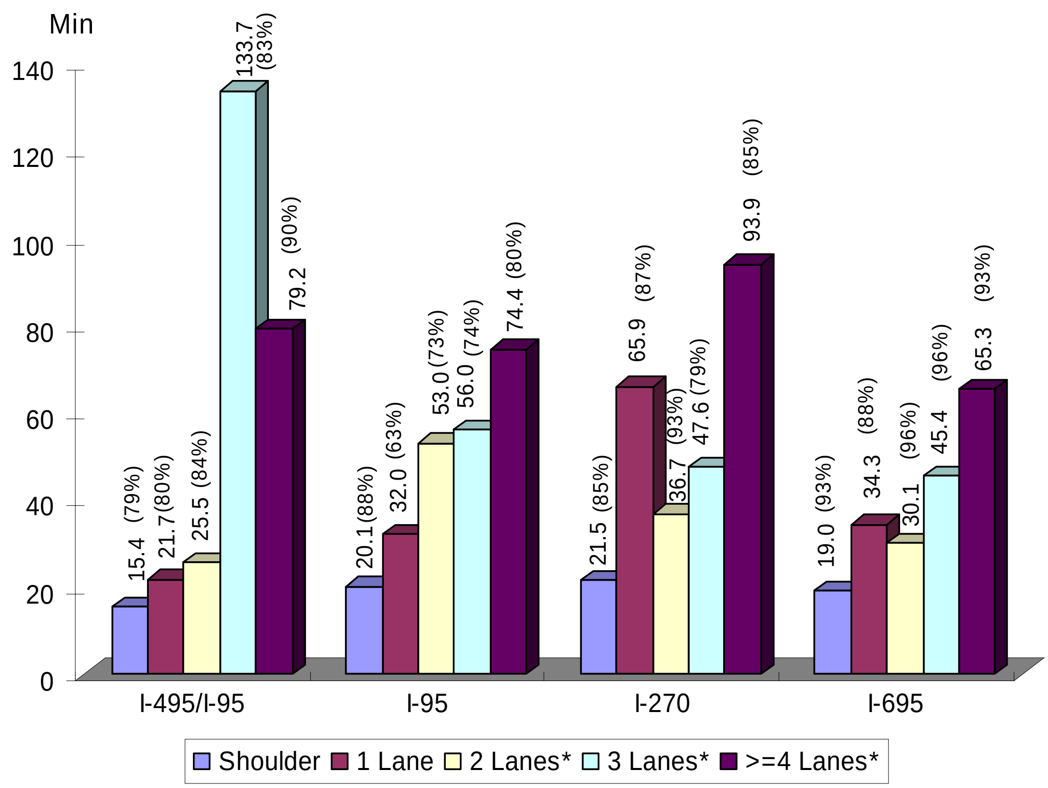


Figure 3.14 Distribution of Lane Blockages Incurred on Major Highways in the Baltimore Region

Note that disabled vehicles caused most of the shoulder lane blockages. Most of the disabled vehicles were as a result of driver assistance requests due to flat tire, minor mechanical problems, or gas shortages.

3.4 Distribution of Incidents and Disabled Vehicles by Blockage Duration

Lane blockage analysis naturally leads to the comparison of incident duration distribution. Fi g ure 3.15 illustrates a relation of lane blockages and their average duration on each major freeway.



Note: * Also includes Shoulder Lane Blockages
The number in each parenthesis shows the percentage of data available

Figure 3.15 Distribution of Lane Blockages and Road

It is painfully obvious that CHART's highway network has been plagued with high incident frequencies of duration ranging from 10 minutes to more than 2 hours. The incidents are clearly one of the primary contributors to traffic congestion in the entire region, especially on the major commuting-hi g hway corridors of I-495, I-695, I-270, and I-95. It is imperative therefore to continuously improve traffic management and incident response systems.

As shown below, most disabled vehicles did not block traffic for more than half an hour. 81% incidents and disabled vehicles had duration of less than 30 minutes.

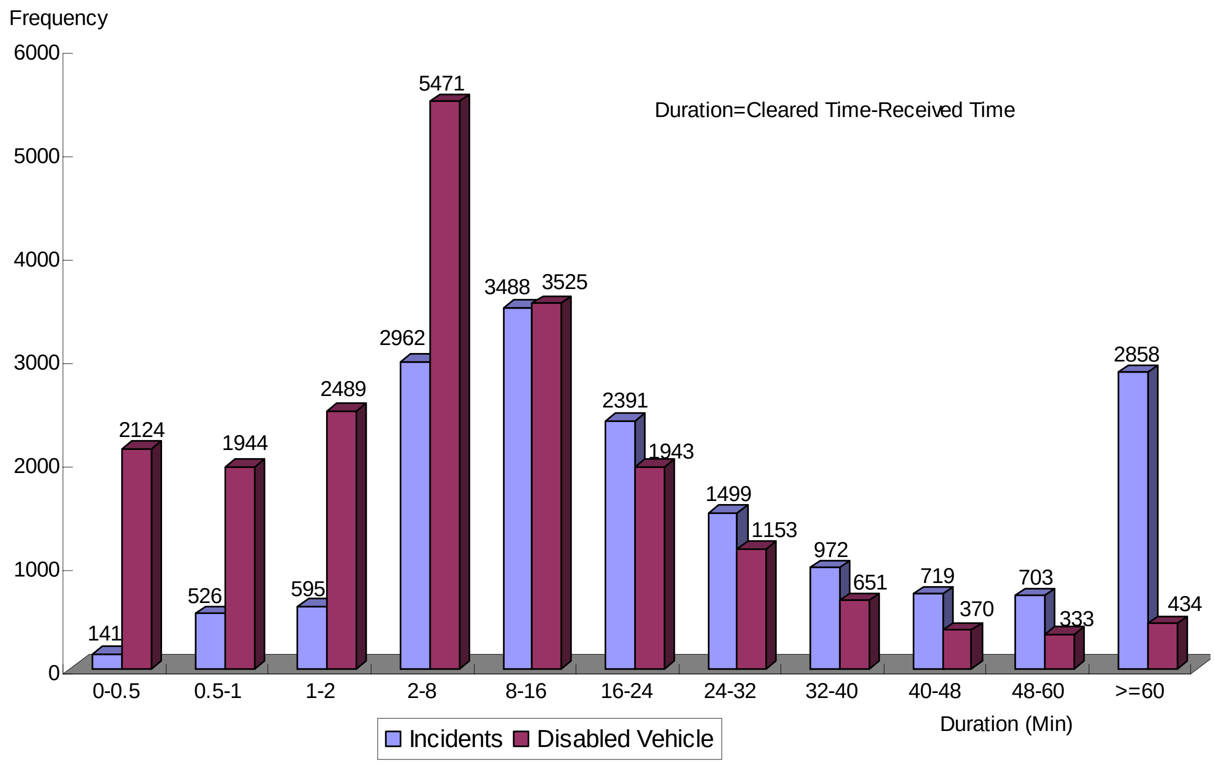


Figure 3.16 Distributions of Incidents/Disabled Vehicles by Duration

Although most incidents in 2006 were not severe, their impacts were si g nificant during peak hours. Clearing the blockages did not require special equi p ments, and the incident duration was highly dependent on the travel time of the incident response units.

F i g ure 3.17 presents the distribution of records in 2006 and its comparison with 2005 data. About 13%, 15% and 11% of reported incidents/disabled vehicles managed by TOC-3, TOC-4 and TOC-5 respectively had blocked traffic duration of more than 30 minutes. For SOC, about 64% of reported incidents duration was more than 30 minutes. It is inferred that only 20% of reports CHART responded to lasted more than 30 minutes in 2006.

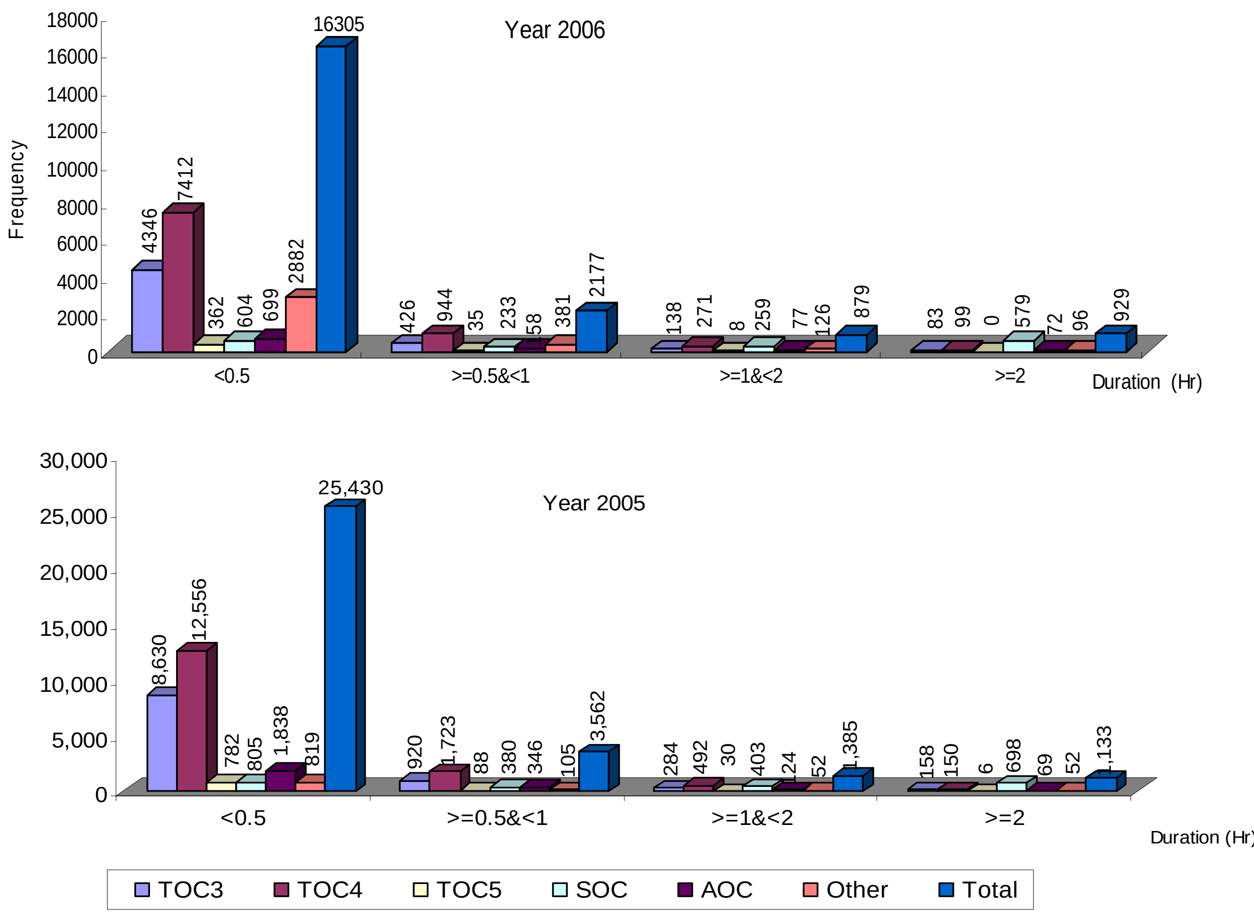


Figure 3.17 Comparison of Incidents/Disabled Vehicles Distribution by Duration

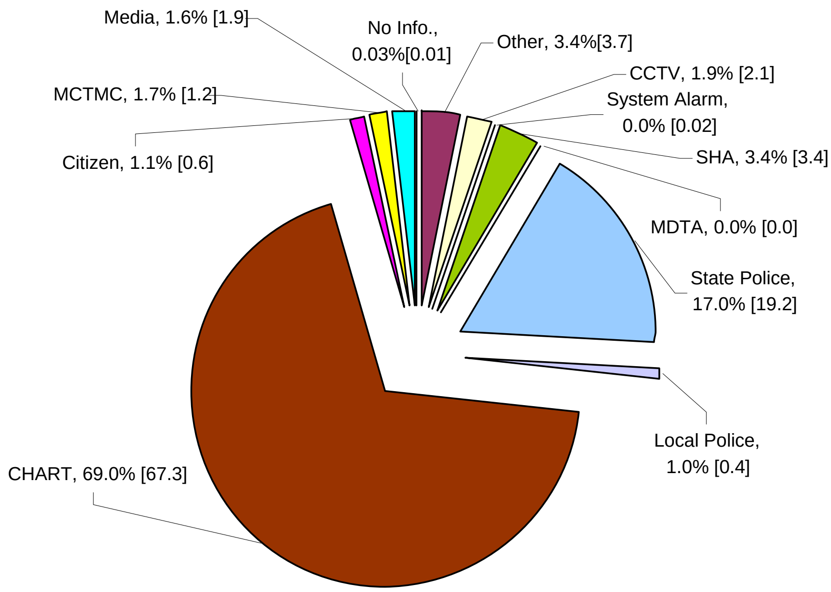
CHAPTER 4
EVALUATION OF EFFICIENCY AND EFFECTIVENESS

4.1 Evaluation of Detection Efficiency and Effectiveness

An automatic incident detection system is yet to be implemented by CHART. Therefore it has no means of evaluating the detection and false-alarm rates. At this point, there is also no way to determine the time taken by the traffic control centers to detect an incident from various sources after its onset. As such, the evaluation of detection efficiency and effectiveness is focused only on the incident response rate and distribution of detection sources.

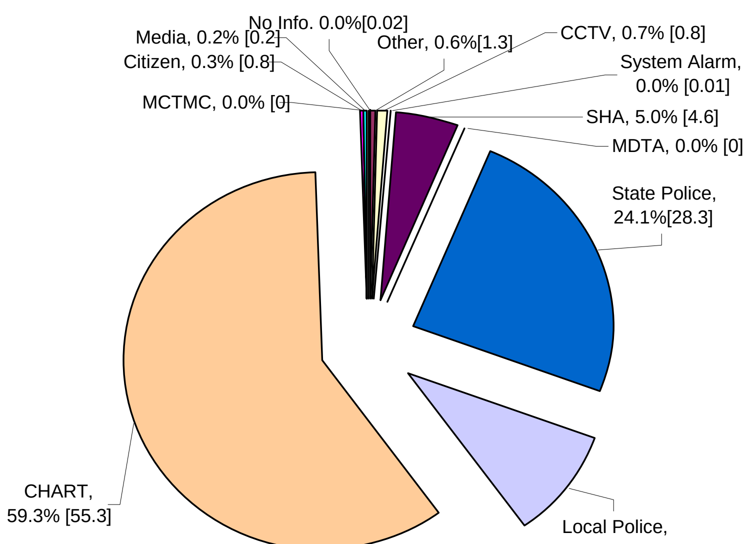
The response rate is defined as the ratio of the total number of traffic incidents reported to CHART control center to those managed by the CHART/MSHA emergency response teams. Based on 2006 incident management records, the overall response rate was about 70%. As in the previous year, existing incident reports do not specify the reasons for ignoring some requests. It appears that most of the ignored incidents happened during very light traffic periods or were not severe enough to cause any significant traffic blockage or delay. Notwithstanding the lack of an automated incident detection system, CHART has maintained an effective coordination system with state and municipal agencies that deal with traffic incidents and congestion.

Figures 4.1 and 4.2 illustrate the distributions of Incident/Disabled Vehicles by Detection Source for control centers TOC 3 and TOC 4 respectively.



Note: Numbers in [ ] show the percentages from Year 2005

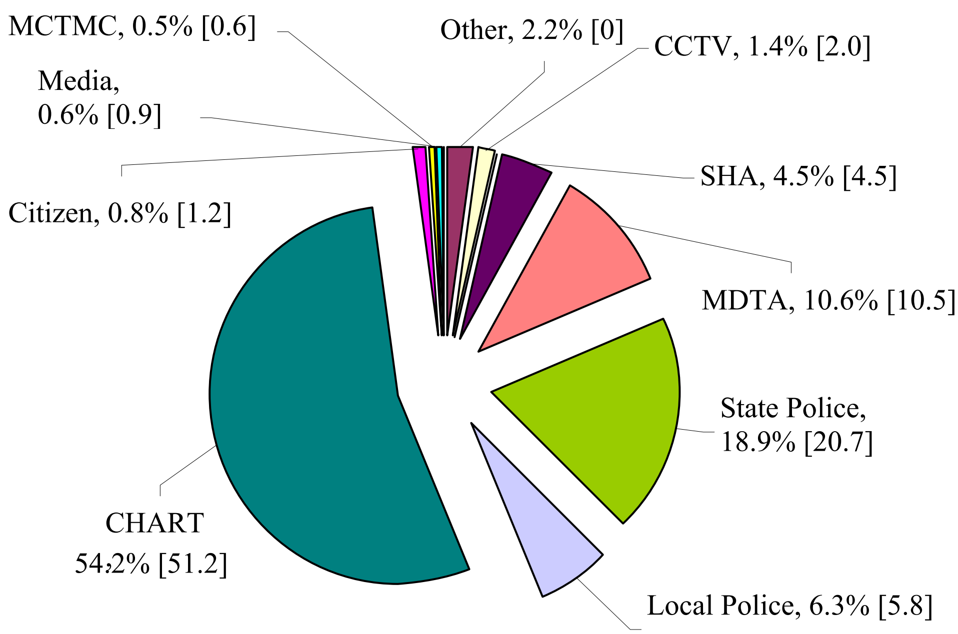
Figure 4.1 Distributions of Incident/Disabled Vehicles by Detection Source for TOC 3



Note: Numbers in [ ] show the percentages from Year 2005

Figure 4.2 Distributions of Incident/Disabled Vehicles by Detection Source for TOC 4

With respect to the distribution of all detection sources, the statistics in Fi g ure 4.3 clearly show that in 2006 about 54.2% of incidents were detected by MSHA/CHART patrols, which is higher than that recorded in 2005. About 18.9% were reported by the Maryland State Police (MSP), slightly lower than the figure 20.7% in 2005. Note that the numbers in parentheses indicate the 2005 statistics.



Note: Numbers in [ ] show the percentages from Year 2005

Figure 4.3 Distributions of Incident/Disabled Vehicles by Detection Sources

4.2 Analysis of Response Efficiency

The distributions of response times and incident durations were used to analyze the efficiency of incident response**.** The response time is defined as the interval between the onset of an incident and the arrival of response units. Since the actual start time of incidents are unknown, the response time used in this analysis is based on the difference between the time the Response Center received a request and the time of arrival of response unit at the incident site.

The average response time for incidents in 2006 is given in Fi g ure 4.4. The average response time in 2006 was 11.51 minutes, slightly higher than that of 2005 (11.47 minutes)

Response Time= Arrival Time-Received Time

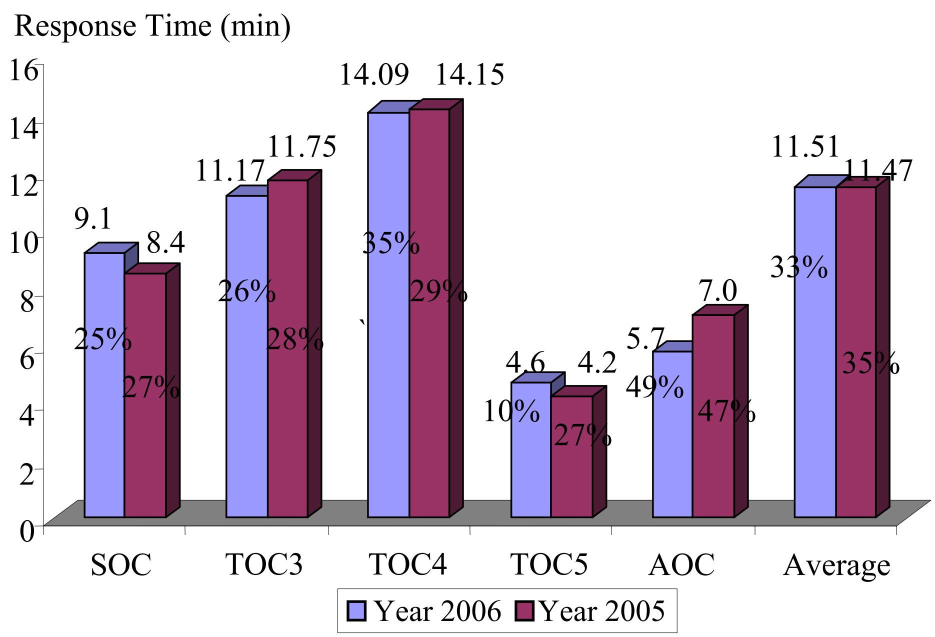


Figure 4.4 Average Response Time Distributions

4.3 Reduction in Incident Duration

A very important performance indicator is the reduction in average incident duration due to the operations of CHART. Theoretically, a before-and-after analysis would be the most effective way to evaluate CHART's effects on incident duration. However, there is no incident-management-related data prior to CHART to aid in any meaningful assessment. Due to this shortcoming, the alternative used is computing average incident clearance time in 2006 for ignored incidents and those CHART responded to.

Since CHART's incident management team responded to most incidents in 2006, the data for CHART-ignored Incidents is very limited.

As shown in Table 4.1, the average duration for clearing an incident with and without the assistance of CHART was about 22.92 minutes versus 32.45 minutes. Note that the analysis did not take into account data with duration greater than 2hours and outside the range of (mean ± two standard deviations). Also, incidents with durations less than 1 minute were excluded for the analysis. Based on the results shown in Table 4.1, it seems that with the assistance of CHART/MSHA response units, the time i t took to clear an incident was reduced. On the average, CHART contributed to about 29% reduction in blockage duration reduction in incident duration has certainly contributed si g nificantly to savings on travel time, fuel consumption, and related socio-economic costs. Note that the statistics shown in Table 4.1 are likely to be biased as only about 87% of incident reports contain all the information(reported received time and cleared time) required for incident duration computation. Data quality remains a critical issue to be addressed by CHART.

Table 4.1 Comparison on Incident Durations for Various Types of Lane Blockages

Duration= Cleared Time-Received Time

Blockage	With SHA Patrol		Without SHA Patrol	
	Duration (min)	Frequency	Duration (min)	Frequency
Shoulder	17.37	1979	32.59	26
1 lane	23.25	4583	29.36	121
2 lanes	35.89	1552	38.16	70
3 lanes	42.18	355	44.85	13
>=4 lanes	49.38	212	54.40	9
Unknown	19.02	5944	28.37	95
Weighted Average	22.92 (21.93)	14625*	32.45 (28.65)	334*

Note: 1. "Duration" is computed by the qualified samples with durations within mean±2×deviation and less than 2 hours

2. "Duration" less than 1 minute is excluded for the analysis

3. The number in each parenthesis shows the result of year 2005

*4. The number indicated with * denote the total number of available cases for this comparison*

CHAPTER 5
BENEFITS FROM CHART'S INCIDENT MANAGEMENT

Due to the poor quality of recorded data, CHART's benefit assessment has always been based on benefits that are directly measurable or quantifiable based on incident reports. These direct benefits, both to roadway users and the entire community, are classified as:

- assistance to drivers;
- reduction in secondary incidents;
- reduction in driver delay time;
- reduction in vehicle operating hours;
- reduction in fuel consumption; and
- reduction in emissions.

Some other intangible impacts, such as vitalizing the local economy and increasing network mobility, are not included in this benefit analysis.

5.1 Assistance to Drivers

The public has been very appreciative of the prompt assistance given to drivers by CHART's incident management units. The prompt response by CHART's has directly contributed to minimizing the potential rubbernecking effects on traffic, particularly during peak hours, where incidents can cause excessive delays. Therefore, despite the difficulties in precisely quantifying this benefit, it is undoubtedly one of the major direct benefits.

The distribution of assistance to drivers (alias Disabled Vehicles in the CHART II Database) by request type in Years 2005 and 2006 is depicted in Fi g ure 5.1. The distribution of assistance to drivers by TOC-3 and TOC-4 are illustrated in F i g ures 5.2 and 5.3, respectively.

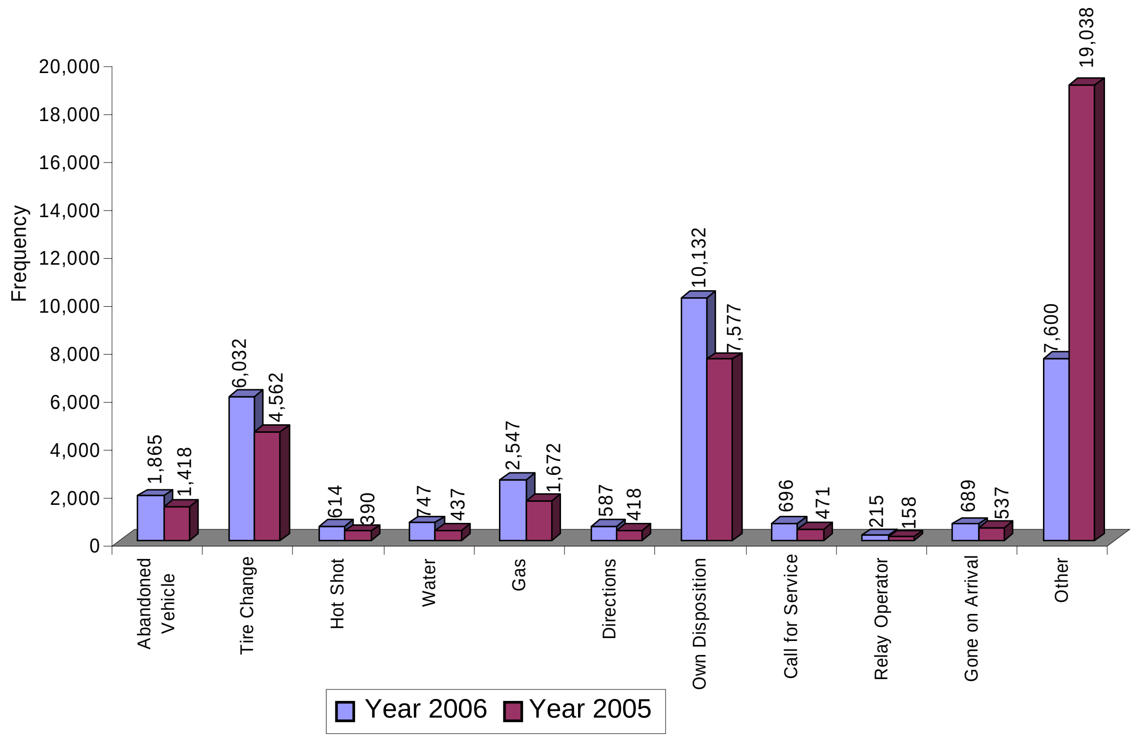


Figure 5.1 Nature of Driver Assistance Requests in 2005 and 2006

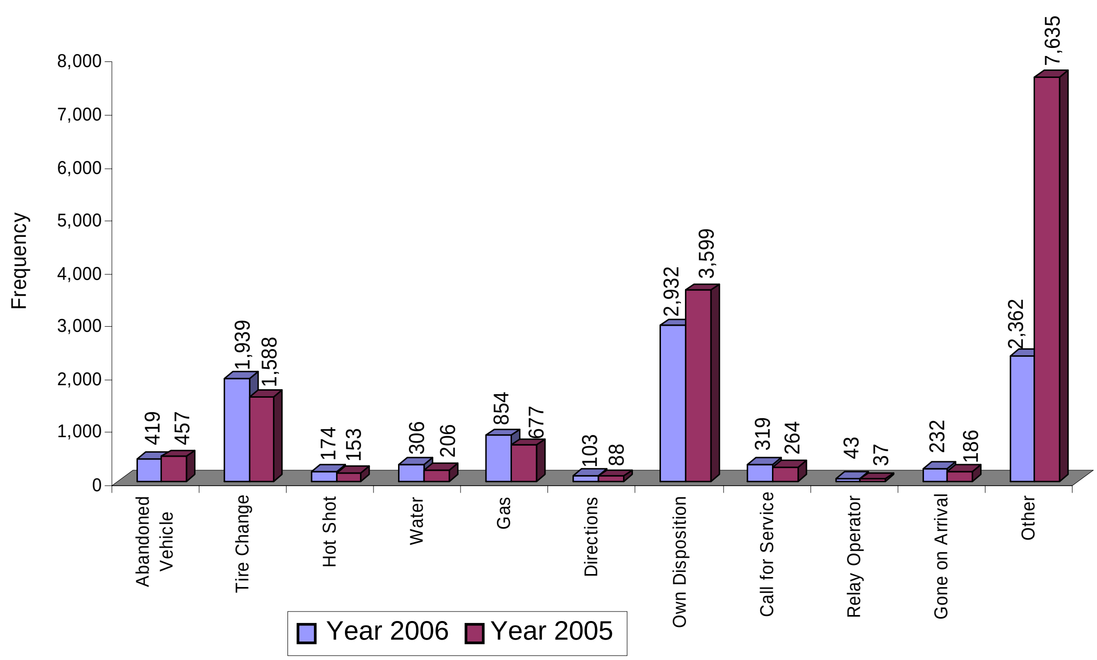


Figure 5.2 Nature of Driver Assistance Requests for TOC 3

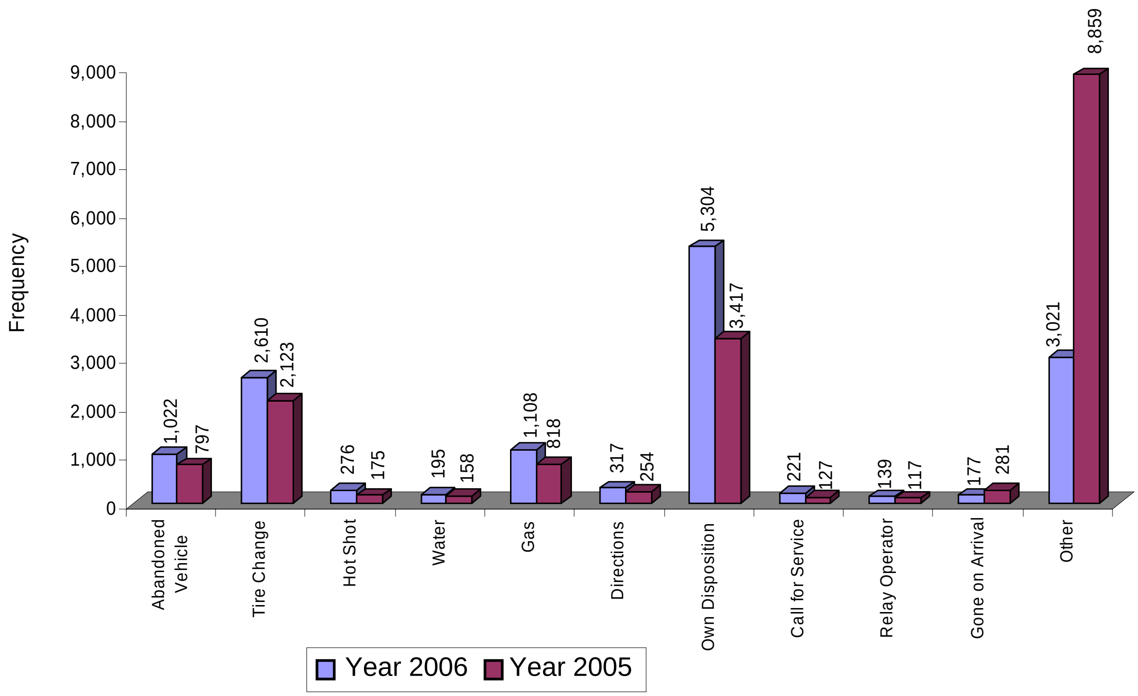


Figure 5.3 Nature of Driver Assistance Requests for TOC 4

The type of driver assistance accounted for includes flat tires, shortage of gas, or mechanical problems in 2006. Out of the 22,988 assistance requests, a total of 8,579 were related to “out of gas” and “tire changes”, significantly more than the number in 2005 (6,234 cases).

5.2 Potential Reduction in Secondary Incidents

It is recognized that major accidents induce a number of relatively minor secondary incidents. This may be as a result of the dramatic change in traffic conditions such as the rapid spreading of queue lengths and the substantial drop in traffic speed. Some incidents are caused as a result of rubbernecking effects. Hence, an efficient removal of incident blockage is also beneficial in reducing potential secondary incidents.

Grounded on the experience gained from previous works, this study has adopted the following definition for secondary incidents:

- Incidents that occur within two hours from the onset of a primary incident and also within two miles downstream of the location of the primary incident.

- Incidents that happen half a mile either downstream or upstream of the primary incident location in the opposite direction, occurring within half an hour from the onset of the primary incident.

Figure 5.4 shows the distribution of incidents classified as secondary incidents by our definition using the accident database of the Maryland State Police Department for Year 2006. Notably, there were 699 secondary incidents in 2006. A linear correlation is assumed between the number of secondary incidents and incident duration and the reduction in secondary incidents due to CHART's operations are estimated as follows:

- Number of reported secondary incidents: 699
- Estimated number of secondary incidents without CHART resulted in a 29.37% reduction of incident duration and is calculated as:

  699/ (1-0.2937) = 990 incidents
- The number of potentially reduced incidents due to CHART/MSHA operations: 990- 699 = 291 secondary incidents

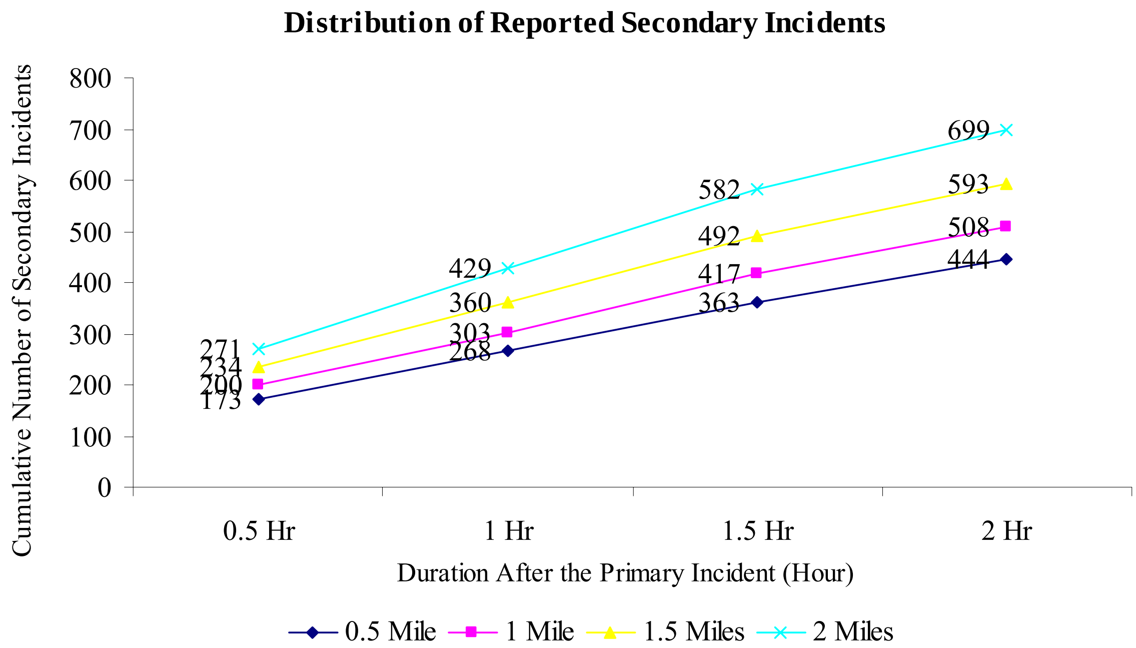


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Figure 5.4 Distributions of Reported Secondary Incidents

Note that the 291 secondary incidents may have further prolonged the primary incident duration, resulting in an increase in congestion, fuel consumption and travel time. These associated benefits are not computed in this report due to data limitation but will be investigated in future studies.

5.3 Estimated Benefits due to Efficient Removal of Stationary Vehicles

Drivers are forced to perform undesirable lane-changing maneuvers because of lane-blockages around incident sites. Considering that improper lane changing is a prime contributor of traffic accidents, prolonged obstruction removal increases risk of accidents. Thus, CHART/MSHA's removal of stationary vehicles in travel lanes may directly alleviate potential lane-changing-related accidents around incident sites.

The estimated results for potential incident reduction for selected freeways are reported in Table 5.1. Note that this estimation was made using peak period data. Off-peak data was not used because it is known not to have any correlation with lane-changing-maneuvers and accidents. A detailed description of the estimation methodology can be found in the previous CHART performance evaluation reports.

Table 5.1 Reduction of Potential Incidents due to CHART Operations

Road Name		I-495/95	I-95	I-270	I-695	I-70	I-83	MD-295	US-50	Total
Mileage		41	63	32	44	13	34	30	42	
No. Potential Incident Reduction	2006	158	142	21	118	29	35	10	31	544
	2005	139	97	15	116	22	26	5	32	452
	2004	112	81	16	104	20	20	14	17	384
	2003	171	92	20	147	9	39	7	25	510
	2002	107	105	10	71	12	10	5	23	343

* The analysis has excluded the outlier data (i.e., mean ± 2 standard deviation)

5.4 Direct Benefits to Highway Users

The benefits obtained as a result of reduction in delay and fuel consumption are summarized in the following tables. Table 5.2 shows the benefits calculated using the previous unit rates and Table 5.3 shows the benefits calculated for the Year 2006 using the updated unit rates obtained from the Year 2005 U.S Census Bureau. To convert delays to monetary value for commercial vehicles, we multiply delays by the value of time factors (19.58$/hr for driver and 45.4$/hr for cargo).

<table>
<tr><th colspan="2">Reduction due to Chart</th><th>Amount</th><th>Unit rate</th><th>Dollar (million)</th></tr>
<tr><td rowspan="3">Delay (M veh-hr)</td><td rowspan="2">Truck</td><td rowspan="2">2.446 (2.386)</td><td>$19.58 truck drivers' cost</td><td>47.89 (46.72)</td></tr>
<tr><td>$45.40/hour (cargo's cost)</td><td>111.04 (108.33)</td></tr>
<tr><td>Car</td><td>35.091 (26.276)</td><td>$14.34(car driver's cost)</td><td>503.20 (376.80)</td></tr>
<tr><td colspan="2">Fuel Consumption (M gallon)</td><td>6.336 (4.838)</td><td>$1/gal</td><td>6.34 (4.84)</td></tr>
<tr><td rowspan="3">Emission (tons)</td><td>HC</td><td>490.72 (487.63)</td><td>6,700/ton</td><td rowspan="3">41.37 (41.11)</td></tr>
<tr><td>CO</td><td>5,511.54 (5,476.90)</td><td>6,360/ton</td></tr>
<tr><td>NO</td><td>235.02 (233.54)</td><td>12,875/ton</td></tr>
<tr><td colspan="2">Total</td><td colspan="3">709.85 (577.79)</td></tr>
</table>

Table 5.2 Total Direct Benefits to Highway Users in 2006 Using Previous Unit Rates

Note: 1.The number in each parenthesis shows the results in Year 2005

<table>
<tr><th colspan="2">Reduction due to Chart</th><th>Amount</th><th>Unit rate</th><th>Dollar (million)</th></tr>
<tr><td rowspan="3">Delay (M veh-hr)</td><td rowspan="2">Truck</td><td rowspan="2">2.446 (2.386)</td><td>$19.58 truck drivers' cost</td><td>47.89 (46.72)</td></tr>
<tr><td>$45.40/hour (cargo's cost)</td><td>111.04 (108.33)</td></tr>
<tr><td>Car</td><td>35.091 (26.276)</td><td>$25.06(car driver's cost)[2]</td><td>879.37 (658.48)</td></tr>
<tr><td colspan="2">Fuel Consumption (M gallon)</td><td>6.336 (4.838)</td><td>$2/gal[2]</td><td>12.67 (9.68)</td></tr>
<tr><td rowspan="3">Emission (tons)</td><td>HC</td><td>490.72 (487.63)</td><td>6,700/ton</td><td rowspan="3">41.37 (41.11)</td></tr>
<tr><td>CO</td><td>5,511.54 (5,476.90)</td><td>6,360/ton</td></tr>
<tr><td>NO</td><td>235.02 (233.54)</td><td>12,875/ton</td></tr>
<tr><td colspan="2">Total</td><td colspan="3">1092.35 (864.31)</td></tr>
</table>

Table 5.3 Total Direct Benefits to Highway Users in 2006 Using Updated Unit Rates

Note: 1.The number in each parenthesis shows the results in Year 2005

2. The car driver’s cost and fuel price are updated based on the information from the U.S Census Bureau in Year 2005

The estimated reductions in vehicle emissions were based on parameters provided by MDOT and on the total delay reduction. Using the cost parameters shown in Table 5.3(DeCorla-Souza, 1998), the above reduction in emissions resulted in a total savings of 41.37 million dollars. Thus, CHART/MSHA’s activities in Year 2006 generated a total savings of 1092.35 million dollars, more than the benefits of 864.31 million dollars in Year 2005.

In addition to the above savings, a reduction in emissions due to reduced running time in the Baltimore and Washington regions have been computed. The results are summarized in Tables 5.4.

Table 5.4(a) Delay and Emissions Reductions for Trucks due to CHART/MSHA Operations for Washington and Baltimore Regions

Trucks		Total by Chart		Washington Region		Baltimore Region	
		Year 2006	Year 2005	Year 2006	Year 2005	Year 2006	Year 2005
Annual Delay Reduction	hour	2,445,865	2,386,080	658,954	768,708	1,786,911	1,617,373
Daily Delay Reduction	hour	9,407	9,177	2,534	2,957	6,873	6,221
Emission Reduction							
HC reduction	ton/day	0.123	0.120	0.049	0.052	0.074	0.068
	$/day	823.97	803.83	330.39	345.57	493.58	458.26
CO reduction	ton/day	1.381	1.348	0.554	0.579	0.827	0.768
	$/day	8,784.84	8,570.11	3,522.51	3,684.33	5,262.34	4,885.79
NO reduction	ton/day	0.059	0.057	0.024	0.025	0.035	0.033
	$/day	758.32	739.78	304.07	318.03	454.25	421.75
Total	$/day	10,367.13	10,113.72	4,156.96	4,347.93	6,210.16	5,765.79

Table 5.4 (b) Delay and Emissions Reductions for Cars due to CHART/MSHA Operations for Washington and Baltimore Regions

Cars		Total by Chart		Washington Region		Baltimore Region	
		Year 2006	Year 2005	Year 2006	Year 2005	Year 2006	Year 2005
Annual Delay Reduction	hour	35,090,766	26,276,118	12,748,222	9,997,882	22,342,544	16,278,235
Daily Delay Reduction	hour	134,964	101,062	49,032	38,453	85,933	62,609
Emission Reduction							
HC reduction	ton/day	1.764	1.321	0.707	0.568	1.057	0.753
	$/day	11,821.42	8,851.93	4,740.10	3,805.48	7,081.32	5,046.45
CO reduction	ton/day	19.817	14.839	7.946	6.379	11.871	8.460
	$/day	126,035.93	94,376.25	50,537.32	40,572.74	75,498.61	53,803.51
NO reduction	ton/day	0.845	0.633	0.339	0.272	0.506	0.361
	$/day	10,879.54	8,146.64	4,362.43	3,502.28	6,517.11	4,644.37
Total	$/day	148,736.89	111,374.82	59,639.85	47,880.50	89,097.04	63,494.33

As shown in Tables 5.4a and 5.4b, the daily delay reductions for the Washington region in 2006 were 2,534 hours/day and 49,032 hours/day for trucks and cars respectively, compared to the 2,957 hours/day for trucks and 38,453 hours/day for cars recorded in Year 2005. The delay reduction for trucks in the Baltimore region increased from 6,221 hours/day in Year 2005 to 6,873 hours/day in 2006 and increased from 62,609 hours/day in Year 2005 to 85,933 hours/day in 2006, for cars.

The overall reduction in emissions (i.e., cars and trucks) for the entire region was 159,104$/day and 121,489$/day for Year 2006 and 2005, respectively.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Grounded on the previous research experience, this study has conducted a rigorous evaluation of CHART's performance in the year of 2006 and resulting benefits under the constraints of data availability and quality. Overall, CHART has made significant progress in recording more reliable incident reports, especially after the implementation of the CHART-II Database.

However, much remains to be done in terms of collecting more data and extend the operations to major local arterials if resources are available to do so. For example, the data associated with the potential impacts of major incidents on local streets has not been collected by CHART. Without such information, one may substantially under estimate the benefits of CHART operations, as most incidents causing lane blockage on major commuting freeways are likely to spill back its congestion to neighboring local arterials if the traffic queue formation speed is faster than the pace of the incident clearance progress. By the same token, a failure to responding to major accidents in local arterials, such as MD355, may also significantly degrade the traffic conditions in I-270. Effectively coordinating with county agencies in both incident management and operational data collection is one of the major tasks to be done by CHART.

With respect to the performance, CHART has maintained nearly at the same level of efficiency in responding to incidents and driver assistance requests in recent years. The average response time in Year 2006 was 5.76 minutes, which is almost same as 5.77 minutes, observed in Year 2005. In view of the worsening congestion and the increasing number of incidents in the Washington-Baltimore region, it is commendable that CHART can keep its performance efficiency with the approximately same level of resources.

In brief, CHART operations by MSHA in Year 2006 have yielded significant benefits by assisting drivers, and reducing delay times, fuel consumption, as well as emissions. Some more indirect benefits could be estimated if appropriate data of traffic conditions before and after incidents are collected during each operation. Such benefits include impacts related to secondary incidents, potential impacts on neighboring roadways, and reduction in stress to drivers on major commuting corridors. In addition, an in-depth analysis of the nature of incidents and their spatial distribution may offer insight into developing safety-improvement measures for the highway network covered by CHART.

6.2 Recommendations and Further Development

The main recommendations based on the performance of CHART in Year 2006 are listed below:

- Allocating more resources to CHART for incident response and traffic management to improve the performance of the response teams so that they can effectively contend with the ever-increased congestion and accompanied incidents.
- CHART's quality evaluation report should be made available to the operators for their continuous improvement of response operations.
- Coordinating with county traffic agencies to extend the CHART operations to major local routes and including the data collection as well the performance benefit in the annual CHART review.
- Training sessions should be carried out to instruct operators on how to effectively record critical data associated with incident response performance.
- The data structure used in the CHART-II system for recording incident location should be improved to eliminate the current laborious and complex procedures.
- The average response time should be reduced by increasing freeway service patrols and assigning patrol locations based on both the spatial distribution of incidents along freeway segments and the probability of an incident occurring.
- Efficiently integrating Police accident data into CHART incident response database in order to have a complete representation of statewide incident records.

- Incorporating the benefits of delay and fuel consumption due to reduced potential secondary incidents into CHART benefit evaluation.

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