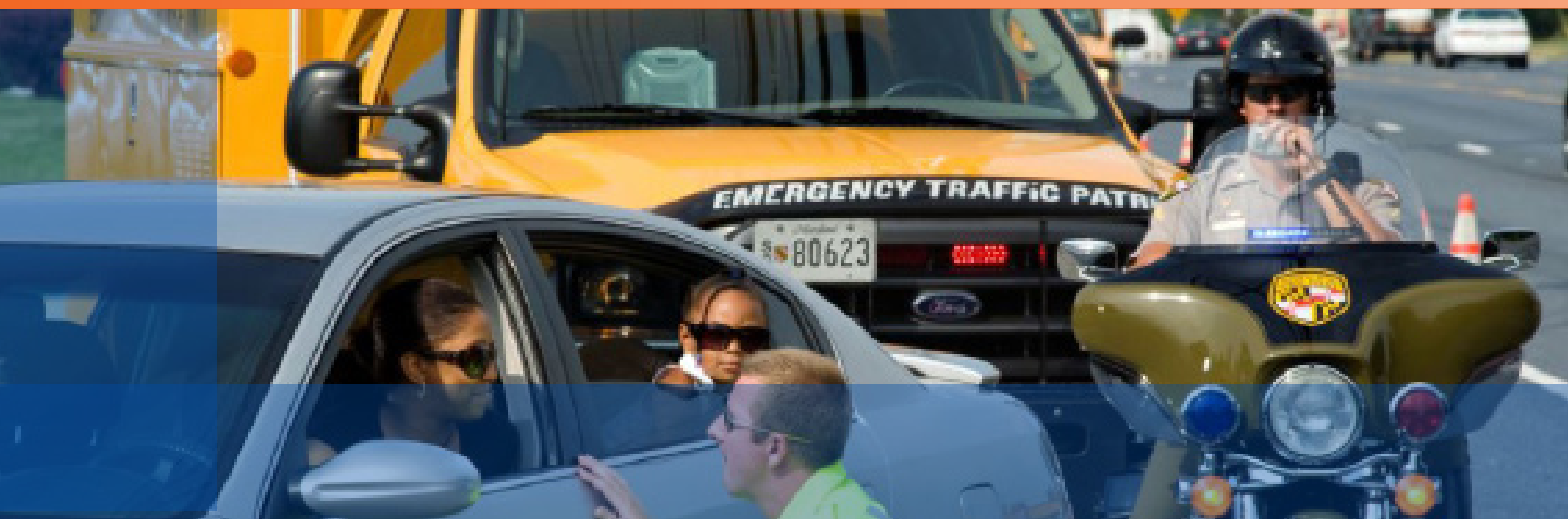
Performance Evaluation and Benefit Analysis for CHART in Year 2021

– Coordinated Highways Action Response Team –

November 2022

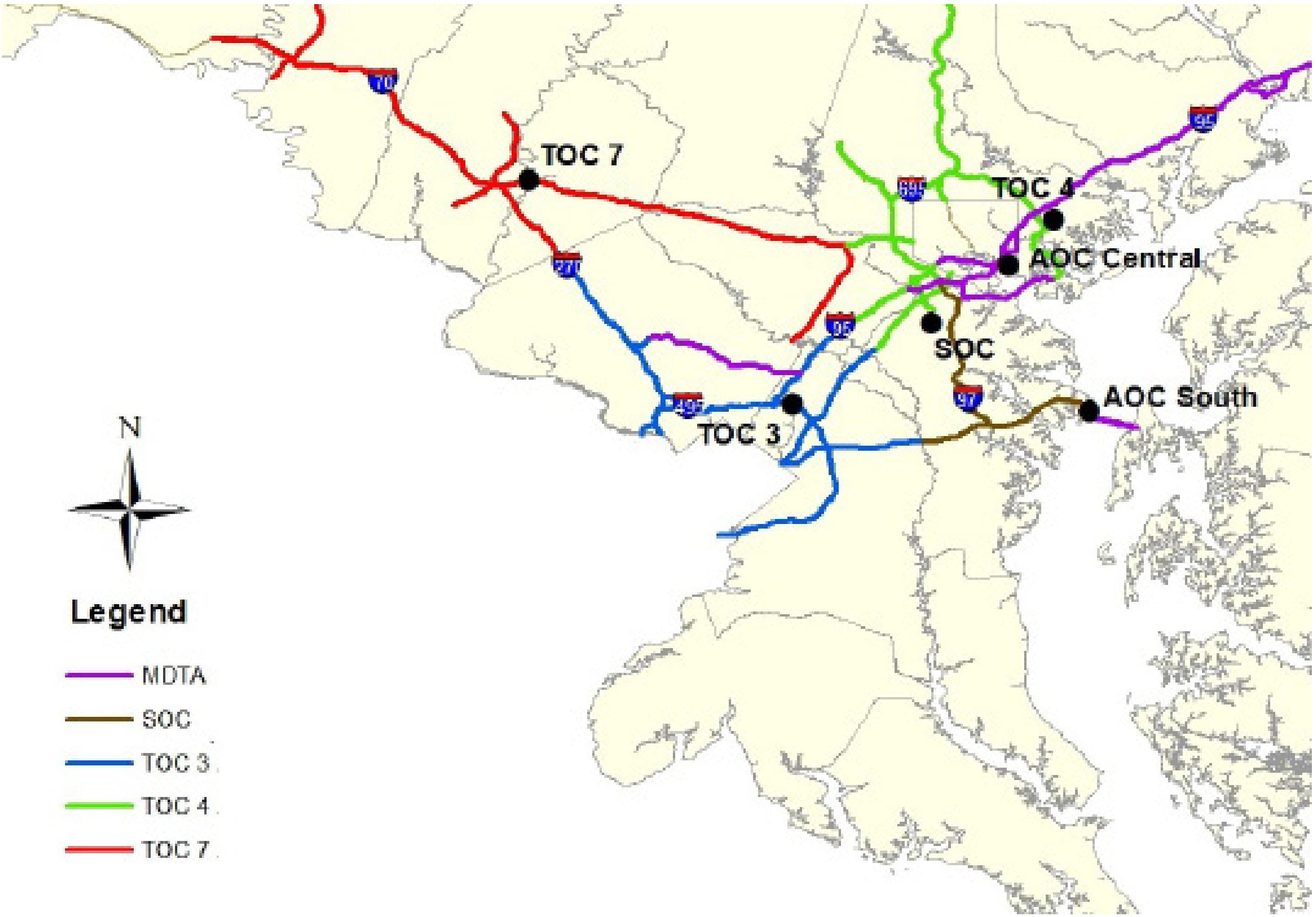


Department of Civil and Environmental Engineering
The University of Maryland, College Park

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

Office of Transportation Mobility and Operations
Maryland Department of Transportation
State Highway Administration

Performance Evaluation of CHART
The Real-Time Incident Management System (Year 2021)



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EXECUTIVE SUMMARY

Objectives

This report presents the performance evaluation study of the Coordinated Highways Action Response Team (CHART) for the Year 2021, including its operational efficiency and resulting benefits. The research team at the Civil and Environmental Engineering Department of the University of Maryland, College Park (UM), has conducted the annual CHART performance analysis over the past 24 years for the Maryland State Highway Administration (MDOT SHA).

Similar to previous studies, the focus of this task was to evaluate the effectiveness of CHART's ability to detect and manage incidents on major freeways and highways. Assessing the benefits resulting from incident management was equally essential. In addition, this annual report has extended the analysis of incident duration distributions on major highways for better understanding of the incident characteristics and management.

The study consisted of two phases. Phase 1 focused on defining objectives, identifying the available data, and developing the methodology. The core of the second phase involved assessing the efficiency of the incident management program and estimating the resulting benefits using the 2021 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 MDOT SHA, COSMIS began evaluating CHART operations performance in 1996. During the initial evaluation, the 1994 incident management data from the Traffic Operations Center (TOC) were reviewed but for various reasons were not used. Thus, the conclusions drawn were based mostly on information either from other states or from nationwide averaged data published by the Federal Highway Administration.

To better the evaluation quality and also in view of the fact that the Statewide Operations Center (SOC) has been opened in August of 1995, those associated with the evaluation study concluded that the analysis should be based on actual performance data from the CHART program. Hence, in 1996, the UM research team (Chang and Point-Du-Jour, 1998) was contracted to work jointly with MDOT SHA staff to compile and conduct the research with respect to CHART performance using the available data.

This original study and evaluation analysis inevitably faced 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 1997 CHART performance evaluation had the advantage of having relatively substantial information. The collected information comprised incident management records from the Statewide Operations Center (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 the Maryland State Police (MSP) for secondary incident analysis.

Unlike previous studies, the quality and quantity of data available for performance evaluation have been increased considerably since 1999. This results from CHART reflect the need to keep an extensive operational record in order to justify its costs to operate the emergency incident response program and estimate the resulting benefits. Due to CHART's efficient data collection, the documentation of lane-closure-related incidents increased from 2,567 in 1997 to 38,275 in 2021.

Table E.1 shows the total number of emergency response operations assiduously documented from 2017 to 2021:

Table E.1 Total Number* of Emergency Response Records from 2017 to 2021

	2017	2018	2019	2020	2021	Δ (2021-2020)
Incidents only	37,100 (30,335)	41,247 (34,692)	38,383 (31,750)	34,590 (26,702)	38,275 (29,546)	10.65% (10.65%)
Total	81,299 (72,381)	88,138 (79,956)	79,506 (71,233)	70,115 (60,665)	76,722 (65,839)	9.42% (8.53%)

**Note: 1. Total includes incidents and disabled vehicles (i.e., assists to drivers).*
2. Number in the parenthesis shows the incidents or assists responded by CHART.

It should be noticed that CHART has responded to more incidents this year than last year. This may be due to an increase in the networkwide incidents.

Evolution of the Evaluation Work

CHART has consistently worked to improve its data recording for both major and minor incidents over the past two decades, achieving substantial improvements in data quality and quantity. The evaluation work has also been advanced by the increased level of data availability. Since the quality of available data is critical to a reliable estimate of CHART's performance and contributing benefits, the performance evaluation reports have included data quality analysis from 1999 to ensure continued advancement in the quality of incident-related data.

From February 2001, all incidents requesting emergency assistance have been recorded in the CHART-II information system, regardless of CHART's involvement or not. This has significantly enriched the available data for analysis. 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 that cannot be processed automatically with a data analysis program.

Distribution of Incidents/Disabled Vehicles

The evaluation methodology was created to use all available data sets of acceptable quality. An analysis of incident/disabled vehicle characteristics by its duration and number of blocked lanes was firstly conducted in this annual CHART benefit analysis study.

As shown in Table E.2, the results of 2021 incident data indicate that there were a total of 3,290 incidents resulting in one-lane blockage, 9,328 incidents causing two-lane closures, and 5,534 incidents blocking three or more lanes. Either disabled vehicles or minor incidents caused a total of 45,258 shoulder blockages. A comparison of the lane-blockage incidents and disabled vehicles data over the past five years is summarized in Table E.2:

Table E.2 List[1] of Incidents/Disabled vehicles by Lane Blockage Type

	2017	2018	2019	2020	2021	Δ (2021-2020)
Shoulder[2]	51,115	54,630	48,485	41,409	45,258	9.30%
1 lane	3,727	3,948	3,480	3,221	3,290	2.14%
2 lanes[3]	8,383	9,589	8,823	8,205	9,328	13.69%
3 lanes[3]	2,859	3,086	2,965	2,780	3,062	10.14%
≥ 4 lanes[3]	2,114	2,458	2,301	2,331	2,472	6.05%

** Note: 1. This analysis is based only on the samples with complete information for identifying the lane blockage status.*
2. Shoulder Lane Blockages include events that have disabled vehicles (i.e., assists to drivers).
3. A shoulder lane blockage is counted as one lane blockage (e.g., 2-lane blockage can either be two travel lanes or one travel lane and one shoulder blockage).

Most of those incidents/disabled vehicles were distributed along six major commuting corridors: I-495/95, which experienced a total of 12,068 incidents/disabled vehicles in 2021; I-695, I-95, US-50, I/MD-295, and I-270 with 8,585, 12,838, 7,807, 3,120, and 4,484 incidents/disabled vehicles, respectively. The distributions of incidents/disabled vehicles on those major commuting corridors between 2017 and 2021 are shown in Table E.3:

Table E.3 Summary* of Incidents/Disabled vehicles Distribution on Major Freeway Corridors

	2017	2018	2019	2020	2021	Δ (2021 - 2020)
I-495/95	12,570	11,807	10,589	10,339	12,068	16.72%
I-695	12,249	11,752	10,705	8,025	8,585	6.98%
I-95	11,259	15,619	14,729	12,937	12,838	-0.77%
US-50	8,053	7,940	7,208	6,492	7,807	20.26%
I/MD-295	3,459	3,578	3,152	2,694	3,120	15.81%
I-270	4,998	5,086	4,892	4,058	4,484	10.50%

** This analysis is based on incidents and disabled vehicles having the information of their event locations recorded in the database.*

Freeway segments experiencing most incidents and disabled vehicle assists during the AM and PM hours in 2021 are shown in Table E.4. The highest frequency of incidents occurred on the I-95 southbound segment between Exits 56 and 57, and the I-95 northbound segment between Exits 55 and 56 in AM and PM peaks, respectively. The inner loop of I-495 between Exits 13 and 15 and the inner loop of I-495 between Exits 34 and 36 ranked the first with the respect to the number of disabled vehicle assists in 2021 in AM and PM peak hours.

Table E.4 Top 10 Freeway Sections with the Most Incidents/Disabled Vehicles in 2021

	Incidents				Disabled vehicles			
	AM Peak		PM Peak		AM Peak		PM Peak	
1	I-95 S	Exits 56&57	I-95 N	Exits 55&56	I-495 IL	Exits 13&15	I-495 IL	Exits 34&36
2	I-95 N	Exits 55&56	I-95 N	Exits 67&74	I-495 OL	Exits 3&4	I-95 N	Exits 67&74
3	I-695 IL	Exits 43&44	I-95 S	Exits 56&57	I-95 N	Exits 61&62	I-495 OL	Exits 4&7
4	I-495 OL	Exits 27&28	I-695 IL	Exits 11&12	I-95 S	Exits 67&74	I-495 IL	Exits 13&15
5	I-95 N	Exits 67&74	I-95 S	Exits 67&74	I-95 N	Exits 67&74	I-495 OL	Exits 16&17
6	I-95 S	Exits 67&74	I-70 E	Exits 87&91	I-495 IL	Exits 22&23	I-495 OL	Exits 3&4
7	I-95 S	Exits 50&52	I-695 IL	Exits 43&1	I-495 OL	Exits 11&13	I-95 S	Exits 67&74
8	I-95 N	Exits 74&77	I-695 IL	Exits 25&26	I-495 OL	Exits 16&17	US 50 E	Exits 16&22
9	I-95 N	Exits 64&67	I-95 S	Exits 50&52	I-495 OL	Exits 25&28	I-695 IL	Exits 11&12
10	I-495 OL	Exits 17&20	I-95 N	Exits 74&77	I-495 OL	Exits 4&7	I-495 IL	Exits 7&9

** This analysis is based on incidents and disabled vehicles having the information of their event locations recorded in the database.*

It should be mentioned that most incidents/disabled vehicles on major commuting freeways did not block traffic for more than one hour. For instance, about 72 percent of incidents/disabled vehicles had durations shorter than 30 minutes in 2021. This observation can be attributed to the nature of the incidents and, more probably, to the efficient response of CHART. The distributions of incidents/disabled vehicle duration from 2017 to 2021 are summarized in Table E.5:

Table E.5 Distribution* of Incidents/Disabled Vehicle Duration from 2017 to 2021

Duration(Hrs)	2017	2018	2019	2020	2021
D < 0.5	76%	74%	73%	73%	72%
0.5 ≤ D < 1	14%	15%	16%	15%	15%
1 ≤ D < 2	6%	6%	7%	7%	8%
2 ≤ D	4%	5%	5%	5%	5%

** This analysis is based on incidents and disabled vehicles (i.e., assists to drivers) which have complete information for the event duration.*

In brief, it is apparent that the highway networks served by CHART are still plagued by a high frequency of incidents with durations ranging from 10 to over 120 minutes. Those incidents were 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 performance indicators associated with an incident management program. Unfortunately, data needed for the detection and response time analysis are not yet available under the CHART data system. MDOT SHA patrols and MSP remain the main sources of incident detection and response.

The average response time is defined as the average time from receiving an emergency request to the arrival of an emergency response unit. Table E.6 shows the average response times of 12.64, 14.03, 11.83, 14.67 and 9.45 minutes for TOC-3, TOC-4, TOC-7, SOC and Authority Operations Center (AOC), respectively, in 2021. The results indicate that TOC-3, TOC-4, and TOC-7 took slightly longer response times in 2021 than in 2020. Note that incidents/disabled vehicles included in this analysis were responded by various units, including CHART and non-CHART agencies.

Table E.6 Evolution of Response Times by Center from 2017 to 2021

Response Time (mins)	2017	2018	2019	2020	2021		
					During OH	After OH	Overall
TOC-3	12.33	13.00	12.99	12.17	12.64 (3,960)	12.33 (15)	12.64 (3,975)
TOC-4	13.17	14.01	13.40	12.98	14.01 (4,911)	17.39 (28)	14.03 (4,939)
TOC-7	10.24	11.46	11.38	11.42	11.72 (3,020)	12.43 (551)	11.83 (3,571)
ESTO	6.95	7.12	6.84	N/A	N/A	N/A	N/A
SOC	13.34	13.78	13.93	14.32	14.67 (5,724)	N/A	14.67 (5,724)
AOC	7.66	8.74	8.99	9.03	9.45 (8,057)	N/A	9.45 (8,057)
OTHER	6.84	8.91	11.68	2.53	3.52 (2)	9.71 (9)	8.58 (11)
Weighted Average	**11.44**	**11.99**	**11.88**	**11.64**	**12.24 (25,674)**	**12.62 (603)**	**12.25 (26,277)**

** Note: The number in each parenthesis indicates the available samples with acceptable quality for analysis.*

1. *This analysis is based on the data of incidents and disabled vehicles (i.e., assists to drivers) which have indicated the responsible operation center and response times.*
2. *This analysis includes those sample data which have response times between 1 minute and 60 minutes.*
3. *Events included in this analysis were responded by various units, including CHART, fire boards, state/local polices, private towing companies, etc.*
4. *OH stands for Operational Hours: TOCs operate 5 a.m. – 9 p.m. Monday through Friday. TOC-3 and TOC-4 began operating seven days a week (5 a.m. - 9 p.m.) as of August 30th, 2017. SOC and AOC operate on a 24 hour/seven-days-a-week basis.*
5. *ESTO's response records are absorbed by SOC as of Oct 6th, 2019.*

The results in Table E.7 reveal that incidents are likely to be responded more promptly than disabled vehicles during both operational and non-operational hours by most operation centers.

Table E.7 Comparisons of CHART Response Performance during and after Operational Hours

Response Time (mins)	Operational Hours		Non-operational Hours		Total		
	Incident	Disabled Vehicle	Incident	Disabled Vehicle	Incident	Disabled Vehicle	Sub-total
TOC-3	12.14 (2,878)	15.52 (1,104)	10.30 (10)	14.08 (5)	12.13 (2,888)	15.52 (1,109)	13.07 (3,997)
TOC-4	13.84 (3,585)	17.46 (1,422)	14.69 (16)	18.97 (9)	13.84 (3,601)	17.47 (1,431)	14.88 (5,032)
TOC-7	12.28 (2,377)	12.03 (626)	12.58 (411)	13.63 (137)	12.33 (2,788)	12.32 (763)	12.32 (3,551)
SOC	14.25 (4,949)	19.77 (1,681)	N/A	N/A	14.25 (3,724)	19.77 (1,681)	15.97 (5,405)
AOC	7.60 (5,476)	12.22 (2,221)	N/A	N/A	7.60 (5,476)	12.22 (2,221)	8.93 (7,697)
OTHER	3.52 (2)	N/A	6.03 (8)	39.08 (1)	5.53 (10)	39.08 (1)	8.58 (11)
Weighted Average	**11.55 (18,042)**	**15.26 (9,337)**	**12.49 (445)**	**14.12 (152)**	**11.57 (18,487)**	**15.55 (7,206)**	**12.69 (25,693)**

** Note: The number in each parenthesis indicates the data availability.*

1. *This analysis is based on the records of incidents and disabled vehicles (assistance to drivers) which have the information of the responsible operation center and response times.*
2. *This analysis includes those sample data which have CHART response times between 1 minute and 60 minutes.*
3. *Events included in this analysis were responded by CHART.*
4. *Operational Hours: TOCs operate 5 a.m. – 9 p.m. Monday through Friday, TOC-3 and TOC-4 began operating seven days a week (5 a.m. - 9 p.m.) as of August30, 2017, SOC and AOC operate on a 24 hour/seven-days-a-week basis.*

Also, the 2021 data show that CHART's response operations are more efficient when incidents are more severe and cause lane blockages. In general, more severe incidents, especially involving in fatalities or heavy vehicles, demand longer clearance times.

Analysis of Incident Durations

To better understand the contributions of the incident management program, this study compared the average duration of incidents to which CHART responded with those managed by other agencies. For example, the difference on the average duration for one-lane-blockage incidents between with and without CHART involvement is about 11.47 minutes. (See Table 4.1)

The average duration of incidents managed by CHART response units in 2021 was 26.31 minutes, shorter than the average duration of 37.82 minutes for those incidents by other agencies. Such a difference of about 30.45 percent in 2021, is slightly lower than the same statistics computed with the data in previous year. Performance comparisons of CHART operations from years 2017 to 2021 are summarized in Table E.8:

Table E.8 Comparison of Average Incident Duration* with and without CHART Response

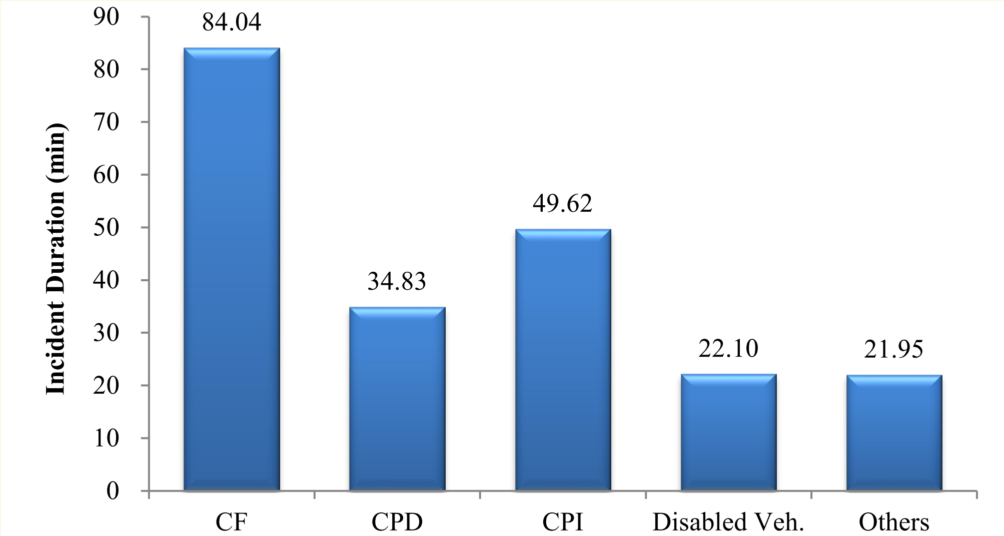
Year	With CHART (mins)	Without CHART (mins)
2017	24.01	34.88
2018	25.42	33.08
2019	25.75	33.91
2020	25.35	37.02
2021	26.31	37.82

** Note: 1. This analysis is based on incident records which have included the information of event duration, lane blockage, and response units.*
2. This analysis includes those sample events which have incident durations between 1 minute and 120 minutes.
3. The numbers are the weighted average of incidents with different lane blockages, including shoulder only blockage.

For effective and efficient traffic management after incidents, responsible agencies can convey the information to travelers by updating the variable message signs. They can also estimate the resulting queue length and assess the need to implement detour operations and any other control strategies to mitigate congestion. To maximize the effectiveness of those operational strategies, a reliably predicted/estimated incident duration will certainly play an essential role.

Hence, this study conducted a statistical analysis of incident duration distributions, which provides some further insights into the characteristics of incidents under various conditions. In this analysis, the distributions of average incident duration are identified by predefined categories, including Nature, County, County and Nature, Weekdays and Weekends, Peak and Off-Peak Hours, CHART Involvement, and Roads.

The average duration of incidents involving fatalities (CF) was 84 minutes, shorter than the average of 92 minutes in year 2020. Incidents with property damage (CPD) and personal injuries (CPI) lasted, on average, 35 and 50 minutes, respectively (see Figure E.1). The average duration of disabled vehicle incidents was 22 minutes, like those classified as “Others” (e.g., debris, vehicles on fire, police activities, etc.) which experienced an average duration of approximately 22 minutes.



** Notes:*

1. *This analysis is based on incidents which have included the information of event duration and nature.*
2. *This analysis includes those sample data which have incident durations between 1 minute and 120 minutes.*

Figure E.1 Distribution of the Average Incident Durations by Nature

Resulting Benefits

The benefits due to CHART operations were estimated directly from the available data, including assists to drivers and reductions in delay times, fuel consumption, emissions, and secondary incidents. In 2021, CHART responded to a total of 29,546 (out of 38,275) lane blockage incidents, and assisted 36,293 (out of 38,447) highway drivers who may otherwise have caused incidents or rubbernecking delays to highway traffic. In addition, the efficient removal of stationary vehicles and large debris from travel lanes by CHART patrol units may have prevented 984 potential lane-changing-related collisions in 2021, as vehicles approaching those conditions would have been forced to perform unsafe mandatory lane changes.

CORSIM, a traffic simulation program produced by the Federal Highway Administration (FHWA), was used to estimate the direct benefits attributed to delay reduction, and it was discovered that various factors may affect the resulting delay, including traffic and heavy vehicle volumes, the number of lane closures, the number of incident responses, and incident durations (see Chapter 7 for further information on benefits estimate). For instance, several primary factors (such as AADT and gas price) have increased in 2021. The ratio in difference between incident durations of with and without CHART and the number of incidents eligible for benefit estimate exhibit a slight reduction in 2021. Overall, the delay reduction due to CHART's services in 2021 (39.74 million vehicle-hours) increased by 68.96 percent, compared to the performance in 2020 (23.52 million vehicle-hours). The collective impacts of all those key contributing factors have resulted in a net benefit increase, i.e., from $1,080.83M in 2020 to $1,875.25M in 2021. Comparison results of the direct benefits, estimated from the reduction in delay times, fuel consumptions, and emissions from 2017 to 2021, are summarized in Table E.9:

Table E.9 Comparison of Direct Benefits from 2017 to 2021

	Total Direct Benefits (million)[1,2,3,4]	# of Incidents Eligible for the Benefit Estimate[5]
2017	$1,465.62	29,986
2018	$1,311.89	33,243
2019	$1,393.38	30,793
2020	$1,080.83	28,513
2021	$1,875.25	31,253

** Note:*

1. *Results are based on the data of the corresponding year from the U.S Census Bureau and Energy Information Administration.*
2. *The direct benefits represent reductions from delay time, fuel consumptions, and emissions due to the CHART effective operations.*
3. *The direct benefits rely on numerous factors (i.e., traffic and heavy vehicle volumes, the number of lane blockages, the number of incidents responded, and incident durations).*
4. *The direct benefits are estimated based on the car delay reduction occurring over all roads covered by CHART and the truck delay reduction only occurring along major roads.*
5. *The direct benefits are estimated based only on the incidents causing travel lane closure(s).*

Most benefits were produced from delay reductions due to CHART's efficient incident response and management, especially along the major corridors which are the primary contributors to traffic congestion in Maryland. The estimated delay reduction due to CHART's services on I-95, I-495, I-270, I-695, I-70, and I-83 are 7.87, 4.34, 1.40, 5.64, 2.40, and 0.84 million vehicle-hours, respectively, in 2021. Such direct benefits for each major road in 2021 are summarized in Table E.10:

Table E.10 Direct Benefits for Major Roads in 2021 due to CHART operations

Roads	Total Direct Benefits (million)[1,2,3]	# of Incidents Eligible for the Benefit Estimate[4]
I-95	$381.26	5,203
I-495/95	$207.70	3,273
I-270	$65.63	969
I-695	$267.64	3,486
I-70	$116.06	1,601
I-83	$41.34	725
Others	$795.61	15,996
Total	**$1,875.25**	**31,253**

** Note:*

1. *Results are based on the data from the U.S Census Bureau and Energy Information Administration.*
2. *The direct benefits are estimated from the reductions in car/truck delay times, fuel consumptions, and emissions due to CHART's effective operations.*
3. *The direct benefits vary with some key factors, includig traffic and heavy vehicle volumes, the number of lane blockages, the number of incidents responded, and incident durations.*
4. *The estimated direct benefits are based only on those incidents causing travel lane closure(s).*

The main contributing factors used for estimating benefits are listed and tabulated below:

- The total number of incidents used for the benefit estimate increased by about 9.61 percent from year 2020 to year 2021 as shown in Table E.11.
- The ratio, reflecting the difference between incident durations with CHART and those without CHART, decreased from 28.41 percent in 2020 to 28.04 percent in 2021 as shown in Table E.12.
- Table E.13 shows that the adjusted AADT in 2021 increased on all major roads compared to 2020.
- Table E.14 shows that truck percentage decreased in year 2021 over most major roads in Maryland, on average by 4.63 percent.

Table E.11 The Total Number of Incidents Eligible for the Benefit Estimate from Year 2020 to Year 2021

	2020	2021	Δ('20 ~ '21) [2]
No. of Incidents [1]	28,513	31,253	9.61%

Note: 1.The incidents causing main lanes blockage are included. The incidents causing only shoulder lanes blockage are excluded for the benefit analysis.
2. The percentage change in No. of Incidents (X) from Year 2020 to Year 2021 is calculated as follows: $\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

Table E.12 Average Incident Duration with and without CHART from Year 2020 to Year 2021[1]

	With CHART (mins) (A)	Without CHART (mins) (B)	Difference (mins) (B-A)	Ratio in Difference ((B-A)/B)
2020	27.06	37.80	10.74	28.41%
2021	27.99	38.89	10.90	28.04%
Δ('20 ~ '21) [2]	3.44%	2.88%	1.53%	-1.31%

Note: 1. The analysis is based on those incidents causing main lane blockage, but not with those for shoulder lane blockage only.
2. The percentage change in incident duration (X) from Year 2020 to Year 2021 is calculated as follows: $\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

Table E.13 The adjusted AADT for Major Roads from Year 2020 to Year 2021

	Year	I-495	I-95	I-270	I-695	MD 295	US 50	US 1	I-83	I-70	Total
ΣAADT(vplph)*PHF	2020	10,502	6,827	6,127	9,316	3,600	2,082	4,115	2,293	2,843	47,706
	2021	11,912	7,981	6,987	10,586	4,087	2,342	4,746	2,434	3,162	54,237
Δ('20 ~ '21) (%)*		13.43	16.90	14.04	13.63	13.53	12.49	15.33	6.15	11.22	13.69

Note: The percentage change in the adjusted AADT (X) from Year 2020 to Year 2021 is calculated as follows: $\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

Table E.14 Truck percentage for Major Roads from Year 2020 to Year 2021

	Year	I-495	I-95	I-270	I-695	MD 295	US 50	US 1	I-83	I-70	Total
Truck %	2020	9.08	15.62	6.96	8.32	3.03	9.82	4.85	10.54	10.73	8.77
	2021	7.76	11.98	5.41	7.57	2.72	11.30	4.84	13.25	10.47	8.37
Δ('20 ~ '21) (%)*		-14.50	-23.31	-22.35	-9.01	-10.24	15.08	-0.23	25.68	-2.46	-4.63

Note: The percentage change in the truck percentage (X) from Year 2020 to Year 2021 is calculated as follows: $\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

The following procedures are used for performing sensitivity analyses:

- Identifying key factors contributing to the total CHART benefits, which are: traffic volume, the number of incidents resulting in lane blockage, incident duration with and without CHART involvements, truck percentage, value of time, and gas price;
- Computing the marginal impacts of each selected factor, using its 2021 value, but setting all other factors identical to those in 2020; and
- Following the same procedures to analyze the sensitivity of the total 2020 benefits with respect to each key factor.

The results of sensitivity analysis for each factor are shown in the Table E.15. The increase in the average adjusted AADT by 13.69 percent in 2021 contributed to an increase of 43.30 percent in the total benefit. The number of eligible incidents increased by 9.61 percent in 2021, resulting in the benefit increase of 6.54 percent. Note that a decrease of 1.31 percent in the performance difference between incident durations with CHART and those without CHART resulted in a 1.31 percent decrease in the total benefit. The total benefits increase by 2.97 percent due solely to an average increase of 5.14 percent in drivers' income (i.e., a proxy for time value).

Table E.15 Sensitivity Analysis of Key Factors Contributing to the Benefits (Unit: M dollars)

Benefits of the Previous Year (2020)			1,080.83
Key Factor		Δ('20 ~ '21)	Estimated Benefits
Sensitivity Analysis	Adjusted AADT	↑ 13.69 %	1,548.85(↑43.30 %)
	Number of incidents	↑ 9.61 %	1,151.53(↑6.54 %)
	Incident duration percentage difference between w/ and w/o CHART	↓ 1.31 %	1,066.68(↓1.31 %)
	Truck percentage	↓ 4.63 %	1,075.55(↓0.49 %)
	Monetary unit of gas price	↑ 32.65 %	1,084.61(↑0.35%)
	Monetary unit of time value	↑ 5.14 %	1,112.88(↑2.97%)
Benefits of the Current Year (2021)			**1,875.25(↑73.50%)**

Note: The number in each parenthesis shows the percentage of benefit change from year 2020.

Conclusions and Recommendations

Grounded in the lessons from the earlier studies, this study has conducted a rigorous evaluation of CHART's performance in 2021 and its resulting benefits under the constraints of data availability and quality. Overall, CHART has made significant progress in recording more reliable incident reports, especially after implementation of the CHART-II Database.

However, much remains to be done in terms of collecting more data and extending operations to major local arterials, if resources are available to do so. For example, data regarding the potential impacts of major incidents on local streets have not been collected by CHART. Without such information, one may substantially underestimate the benefits of CHART operations, as most incidents causing lane blockages on major commuting freeways are likely to spill congestion back to neighboring local arterials if traffic queues form more quickly than the progress of operations for incident clearance. Similarly, a failure to respond to major accidents on local arterials, such as MD-355, may also significantly degrade traffic conditions on I-270. Effectively coordinating with county agencies on both incident management and operational data collection is one of CHART's major tasks.

With respect to overall performance, CHART has maintained nearly the same level of efficiency in responding to incidents and driver assistance requests in recent years. The average incident response time in Year 2021 was 12.25 minutes (See Figure 4.5). In view of the worsening congestion and the increasing number of incidents in the Washington-Baltimore region, it is commendable that CHART can maintain its performance efficiency with approximately the same level of resources.

This study's main recommendations, based on the performance of CHART in 2021, are listed below:

- Develop and update a strategy to allocate CHART's resources between different response centers, based on their respective performance and efficiency so that they can effectively contend with the ever-increasing congestion and accompanying incidents both in urban and suburban areas.
- Coordinate with county traffic agencies to extend CHART operations to major local roads, and include data collection as well as performance benefits in the annual CHART review.
- Make CHART's data quality evaluation report available to the centers' operators for their continuous improvement on data recording and documentation.
- Implement training sessions to educate/re-educate operators on the importance of high-quality data, and discuss how to effectively record critical performance-related information.
- Improve the data structure used in the CHART-II system for recording incident locations to eliminate the current laborious and complex procedures.
- Document and re-investigate the database structure on a regular basis to improve the efficiency and quality of collected data.
- Document possible explanations for extremely short or long response and/or clearance times so that the results of performance analysis can be more reliable.
- Integrate police accident data efficiently with the CHART-II incident response database to have a complete representation of statewide incident records.
- Incorporate the delay and fuel consumption benefits from the reduced potential secondary incidents in the CHART benefit evaluation.

Please note that comprehensive evaluation results of CHART performance over the past ten years are available on the website (http://chartinput.umd.edu).

Summary of Key Findings from the 2021 CHART Performance Evaluation

- Both the number of statewide emergency responses and CHART responses increased significantly from Year 2020 to Year 2021 (9.42% and 8.53%, respectively), due likely to the recovery from the impact of COVID19.
- TOCs, AOC and SOC on average took slightly longer response times in 2021 than in 2020 to clear reported incidents.
- In 2021, the average incident duration with CHART was 26.31 minutes, shorter than the average of 37.82 minutes for those incidents responded by other agencies. The reduction in the average incident duration is about 30 percent. The average incident duration with CHART slightly increased from 25.35 minutes in 2020 to 26.31 minutes in 2021.
- Among major corridors, US-50 experienced the most significant increase in its incidents/disabled vehicle frequency in 2021, compared to 2020 (about 20%). The total incidents/disabled vehicles frequency on I-495/95 and I/MD-295 also increased by 16.72% and 15.81%, respectively.

Chapter 1

INTRODUCTION

CHAPTER 1
Introduction

CHART (Coordinated Highways Action Response Team) is the highway incident management system of the Maryland State Highway Administration (MDOT SHA). Initiated in the mid-80s as "Reach the Beach Program" it 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 four satellite Traffic Operations Centers (TOCs), of which one is seasonal. CHART's current network coverage consists of statewide freeways and major arterials.

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

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

CHAPTER 1
Introduction

The 1997 CHART performance evaluation, compared with 1996, was far more extensive. The researchers were able to obtain a relatively richer set of data, obtained from incident management reports gathered over twelve months from the SOC, TOC-3 (located near the Capital Beltway), and TOC-4 (situated near the Baltimore Beltway). In addition to these data, accident reports from the Maryland State Police (MSP) were also available for secondary incident analysis.

The data used for evaluations have improved significantly since 1999 because CHART recognized the need to keep an extensive operational record in order to justify the costs and estimate the benefits from the emergency response operations. The data available for analysis of lane-closure incidents increased from 5,000 in 1999 to 38,275 reports in 2021. A summary of total emergency response operations documented from 2017 to 2021 is presented in Table 1.1. CHART responded to 29,546 out of 38,275 recorded incidents, and 36,293 out of 38,447 recorded disabled vehicle requests in 2021.

Table 1.1 Total Number of Emergency Response Operation Records*

Records	2017	2018	2019	2020	2021
Incidents	37,100 (30,335)	41,247 (34,692)	38,383 (31,750)	34,590 (26,702)	38,275 (29,546)
Disabled Vehicles	44,199 (42,046)	46,891 (45,264)	41,123 (39,483)	35,525 (33,963)	38,447 (36,293)
Total	81,299 (72,381)	88,138 (79,956)	79,506 (71,233)	70,115 (60,665)	76,722 (65,839)

**Note: 1. "Incidents" indicate any events interrupting traffic flows on main lanes; "disabled vehicles" indicate assists to drivers; and "Total" is the sum of incidents and disabled vehicles.*
2. Numbers in each parenthesis show the incidents and assists by CHART.

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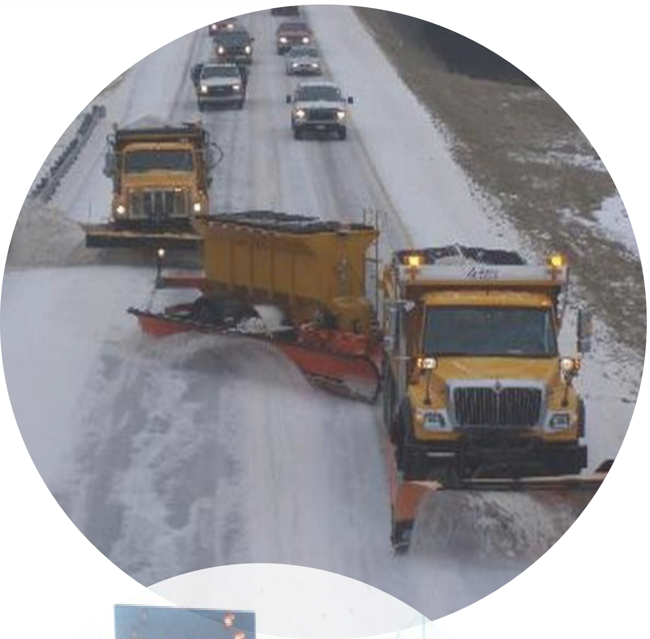

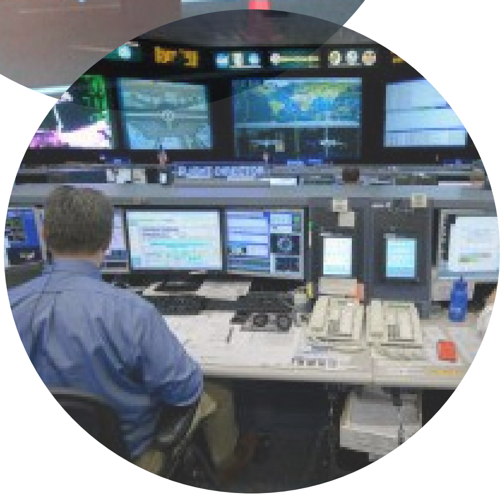

The objective of this study is to evaluate the effectiveness of CHART's incident detection, response, and traffic management operations on interstate freeways and major arterials. This assessment also includes an estimation of CHART benefits, an essential part of the study, since support of MDOT SHA programs from the general public and state policymakers largely depends 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 the following 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 2020 and 2021, with an emphasis on these target areas: incident characteristics, efficiency of incident detection, distribution of detection sources, efficiency of incident response, and effectiveness of incident traffic management.

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

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The subsequent chapters are structured as follows:

Chapter 2 assesses the quality of data available for the 2021 CHART performance evaluation. This includes the total available incident reports, the percentage of missing data for each critical performance parameter, and a comparison of 2021 data quality with that of 2020.

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. The analysis also includes a comparison of the average incident duration caused by different types of incidents.

Chapter 4 provides a detailed report on the efficiency and effectiveness of incident detection. Issues discussed are the detection rate, the distribution of detection sources for various types of incidents, and driver assists. The chapter also touches on an evaluation of incident response efficiency. The efficiency rate is based on the difference between the 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 discusses a statistical analysis of response times, which provides fundamental insight into the characteristics of response times under various conditions. In this analysis, the distributions of the average response time are identified by a range of categories, including the time of day, the incident nature, the pavement conditions, the lane blockage status, the involvement of heavy vehicles, and the involved regions.

Chapter 6 performs a statistical analysis of incident durations, similar to Chapter 5. In this analysis, the distributions of the average incident duration are identified by a range of categories, including nature, county, weekdays and weekends, peak and off-peak hours, CHART involvement, pavement conditions, the involvement of heavy vehicles, and the roads.

Chapter 7 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's patrol units also respond to a significant number of driver assistance requests, and these services provide direct benefits to drivers and minimize potential rubbernecking delays on highways.

Finally, Chapter 8 offers concluding comments and recommendations for future evaluations.

Chapter 2

DATA QUALITY ASSESSMENT

CHAPTER 2
Data Quality Assessment

This chapter assesses the quality of data available for the CHART 2021 performance evaluation and compares it with the data from CHART 2020.

2.1 Analysis of Data Availability

In 2021, CHART recorded a total of 76,722 emergency response cases. These are categorized into two groups: incidents and disabled vehicles. A summary of the total available incident reports for the years 2019, 2020, and 2021 is shown in Table 2.1.

Table 2.1 Comparison of Available Data for 2019, 2020, and 2021

Available Records		2019		2020		2021	
		Records	Ratios(%)	Records	Ratios(%)	Records	Ratios(%)
CHART II Database	Disabled Vehicles	41,123	51.7	35,525	50.7	38,447	50.1
	Incidents	38,383	48.3	34,590	49.3	38,275	49.9
Total		79,506	100	70,115	100	76,722	100

CHAPTER 2
Data Quality Assessment

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 2020 and 2021.

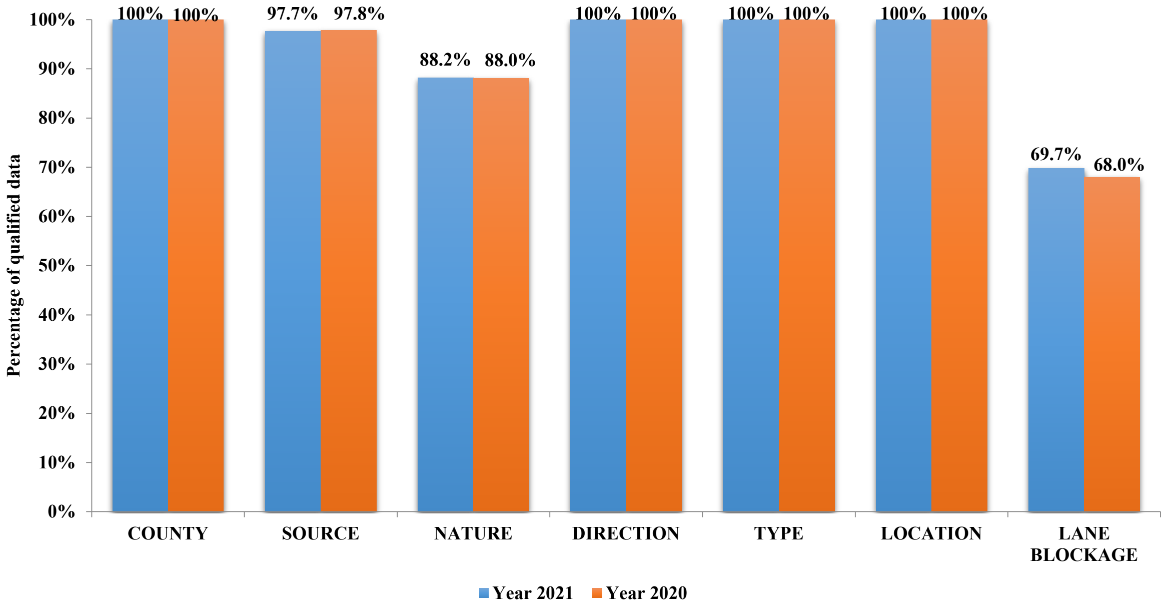

Figure 2.1 Summary of Data Quality with respect to Critical Indicators

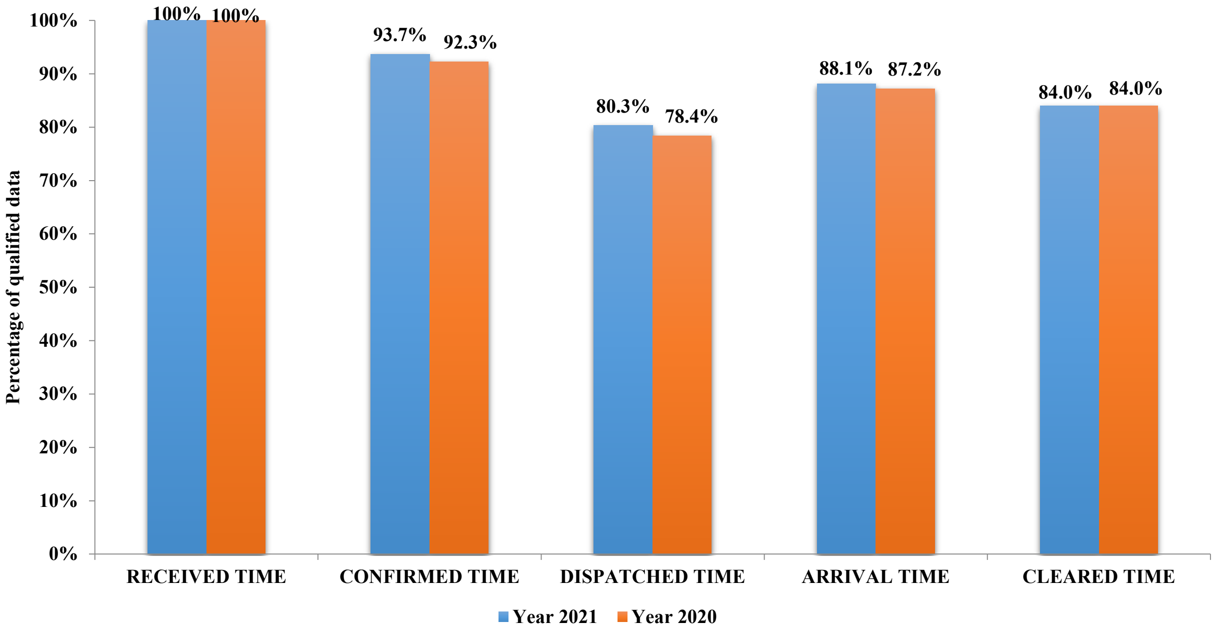

Figure 2.2 Summary of Data Quality with respect to Time Indicators

CHAPTER 2
Data Quality Assessment

Nature of Incidents/Disabled Vehicles

Data were classified based on the nature of the incidents, such as vehicle on fire, collision-personal injury, and collision-fatality. CHART's records for disabled vehicles are also categorized as abandoned vehicles, tire changes, and gas shortage. As shown in Figure 2.1, about 88.2 percent of emergency responses reported in 2021 recorded the nature of incidents/disabled vehicles, which is similar to that in 2020. Note that the location nature of disabled vehicles has been included in the CHART II database since January 2019.

Detection Sources

As Figure 2.1 shows, about 97.7 percent of all emergency responses recorded in 2021 contained the source of detection. In 2021, about 95.5 percent of incidents reported and 99.8 percent of the disabled vehicles reported had a definite detection source.

Operational Time-Related Information

To evaluate the efficiency and effectiveness of emergency response operations, CHART in 2021 used the following five parameters for performance measurements: "Received Time", "Dispatched Time", "Arrival Time", "Cleared Time", and "Confirmed Time". Figure 2.2 illustrates the data quality analysis with respect to these performance parameters. The information shown in the figure indicates that the quality of data for "Received Time", "Confirmed Time", and "Arrival Time" are sufficient for reliable analysis, while the data of "Dispatched Time" and "Cleared Time" should be improved to around 90 percent or higher availability.

CHAPTER 2
Data Quality Assessment

Type of Reports

The total number of incidents/disabled vehicles managed by each operation center in 2021 is summarized in Table 2.2. In 2021, most centers, except AOC, managed more incidents/disabled vehicles than in 2020. Overall, 38,275 incidents have been responded in 2020. Over the same period, the response team also attended to 38,447 disabled vehicle requests.

Table 2.2 Emergency Assistance Reported in 2021

Operation Center	TOC3	TOC4	SOC	TOC7	AOC	OTHER	TOTAL
Disabled Vehicles	10,296 (8,867)	6,994 (6,958)	7,342 (5,847)	7,130 (6,491)	6,625 (7,356)	60 (6)	38,447 (35,525)
Incidents	6,106 (6,243)	6,560 (6,356)	10,834 (8,863)	5,232 (3,977)	9,503 (9,146)	40 (5)	38,275 (34,590)
Total	16,402 (15,110)	13,554 (13,314)	18,176 (14,710)	12,362 (10,468)	16,128 (16,502)	100 (11)	76,722 (70,115)

Note: Numbers in each parenthesis are the corresponding data from 2020.

Location and Road Name Associated with Each Response Operation

The location and road name information associated with each emergency response operation was used to analyze the spatial distribution of incidents/disabled vehicles and to identify freeway segments that experience frequent incidents. As shown in Figure 2.1, almost all incident response reports have documented location information. This feature 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 must be manually located and entered into the evaluation system.

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Data Quality Assessment

Table 2.3 shows the percentage of data with road names and highway segment location information for incidents and disabled vehicles in the CHART II Database for 2021. Note that about 99.99 percent of data have information related to the locations, but about 59 percent of data can be used to identify the event sites (i.e., road names, direction, and exit numbers). For the remaining 41 percent of incidents/disabled vehicles data, the location information is 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
Road	99.21%	99.63%	99.42%
Location	99.99%	99.99%	99.99%
Valid Data for Road & Location	54.96%	63.20%	59.09%

Lane/Shoulder Blockage Information

To compute the costs of additional delays and fuel consumption caused by each incident requires the information of blocked lanes (including shoulder lanes) as a result of the incident. The analysis of all available data in 2021 shows that up to 69.7 percent of emergency response reports involved lane/shoulder blockage (see Figure 2.1), slightly higher than 68.0 percent in 2020.

In summary, in 2021, improvements have been made in documenting CHART's performance and recording operations-related information. The use of the CHART II Database has had a noticeable positive impact on data quality improvement, but room for improvement still exists, as shown in the above statistics on evaluating data quality. Finally, CHART operators should be made aware of their contributions to mitigation of traffic congestion, driver assistance, and overall improvement of the driving environment.

Chapter 3

ANALYSIS OF DATA CHARACTERISTICS

CHAPTER 3
Analysis of Data Characteristics

The evaluation study began 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 large number (about 79 percent) of incidents/disabled vehicles in 2021 occurred on weekdays. Thus, more resources and personnel are required on weekdays than on weekends to manage the incidents/disabled vehicles more effectively. Note that the percentage of weekend responses by TOC7 increased significantly while SOC experience a reduction in the percentage of weekend responses.

Table 3.1 Distribution of Incidents/Disabled Vehicles by Day

Center	TOC3		TOC4		TOC7	
Year	2021	2020	2021	2020	2021	2020
Weekdays	83%	86%	84%	85%	86%	98%
Weekends	17%	14%	16%	15%	14%	2%

Center	SOC		AOC		Other*		Total	
Year	2021	2020	2021	2020	2021	2020	2021	2020
Weekdays	72%	63%	75%	76%	40%	0%	79%	80%
Weekends	28%	37%	25%	24%	60%	100%	21%	20%

** Includes RAVENS TOC and REDSKINS TOC*

CHAPTER 3
Analysis of Data Characteristics

As defined by the 1999 CHART performance evaluation, peak hours in this study are from 7:00 a.m. to 9:30 a.m. and from 4:00 p.m. to 6:30 p.m. Table 3.2 indicates that 26 percent of incidents/disabled vehicles reported in 2021 occurred during peak hours, about the same level as in 2020.

Table 3.2 Distribution of Incidents/Disabled Vehicles during Peak and Off-Peak Periods

Center	TOC3		TOC4		TOC7	
Year	2021	2020	2021	2020	2021	2020
Peak**	31%	33%	31%	32%	31%	36%
Off-Peak	69%	67%	69%	68%	69%	64%

Center	SOC		AOC		Other*		Total	
Year	2021	2020	2021	2020	2021	2020	2021	2020
Peak**	16%	12%	24%	25%	16%	0%	26%	27%
Off-Peak	84%	88%	76%	75%	84%	100%	74%	73%

** Includes RAVENS TOC and REDSKINS TOC*

*** 7:00 a.m. ~ 9:30 a.m. and 4:00 p.m. ~ 6:30 p.m.*

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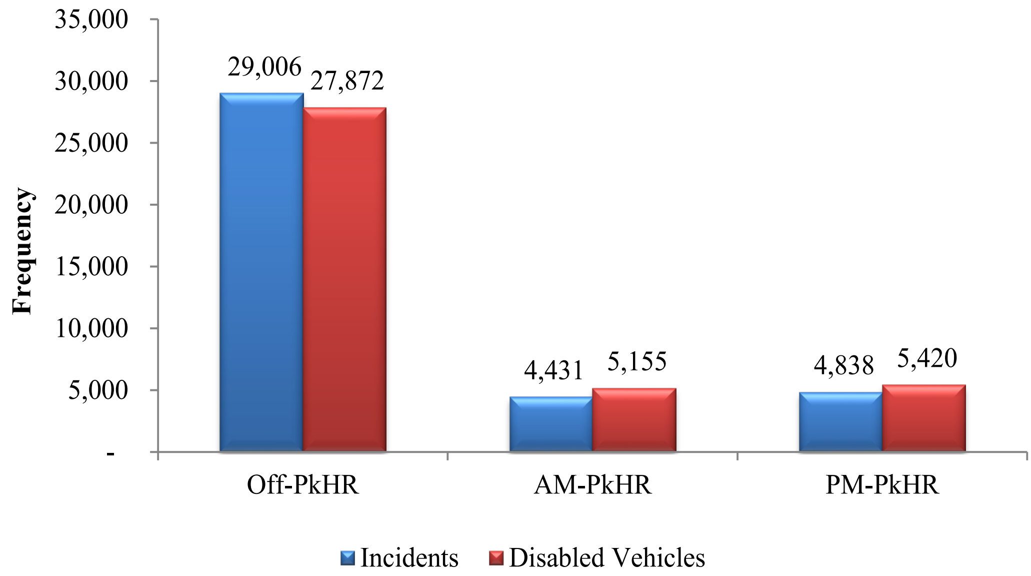
Figure 3.1 illustrates the distributions of incidents/disabled vehicles by time of day in more detail. The frequency of incidents in off-peak hours is much higher than in morning or evening peak hours, since there are many more such hours. More detailed information regarding distributions by time of day is presented in the Appendix A.



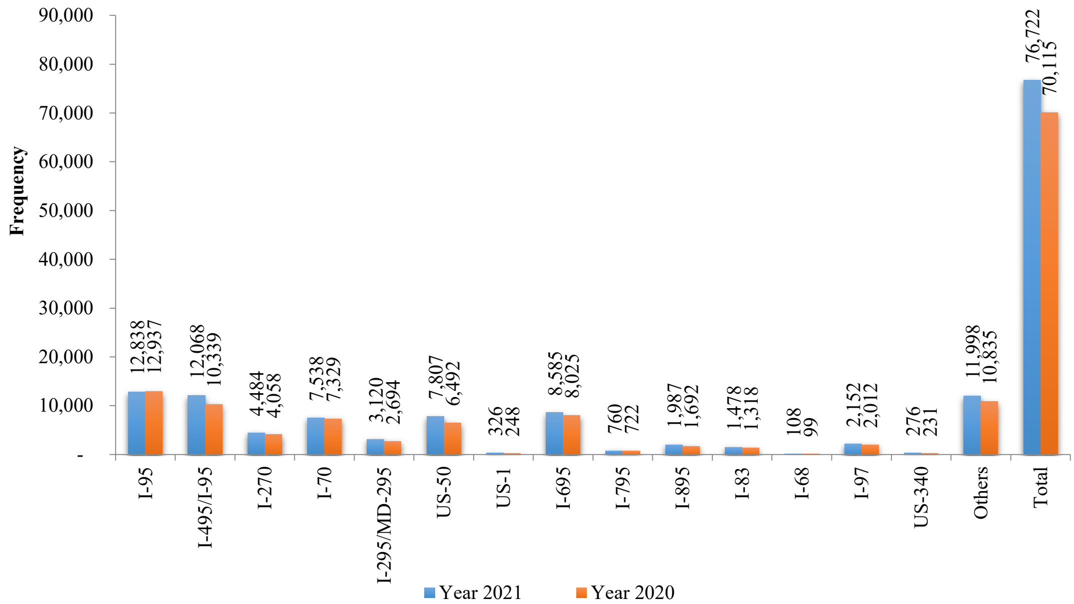
** Off-PkHR, AM-PkHR, and PM-PkHR stand for Off-Peak hours, AM-Peak hours, and PM-Peak hours, respectively.*

Figure 3.1 Distributions of Incidents/Disabled Vehicles by Time of Day in 2021

CHAPTER 3
Analysis of Data Characteristics

3.2 Distribution of Incidents and Disabled Vehicles by Road and Location

Figure 3.2 compares the frequency distribution by road between 2021 and 2020, and Figure 3.3 depicts the frequency distribution of incidents and disabled vehicles for 2021.



** "Total" includes incomplete data for road name and direction.*

Figure 3.2 Distributions of Incidents/Disabled Vehicles by Road in 2021 and 2020

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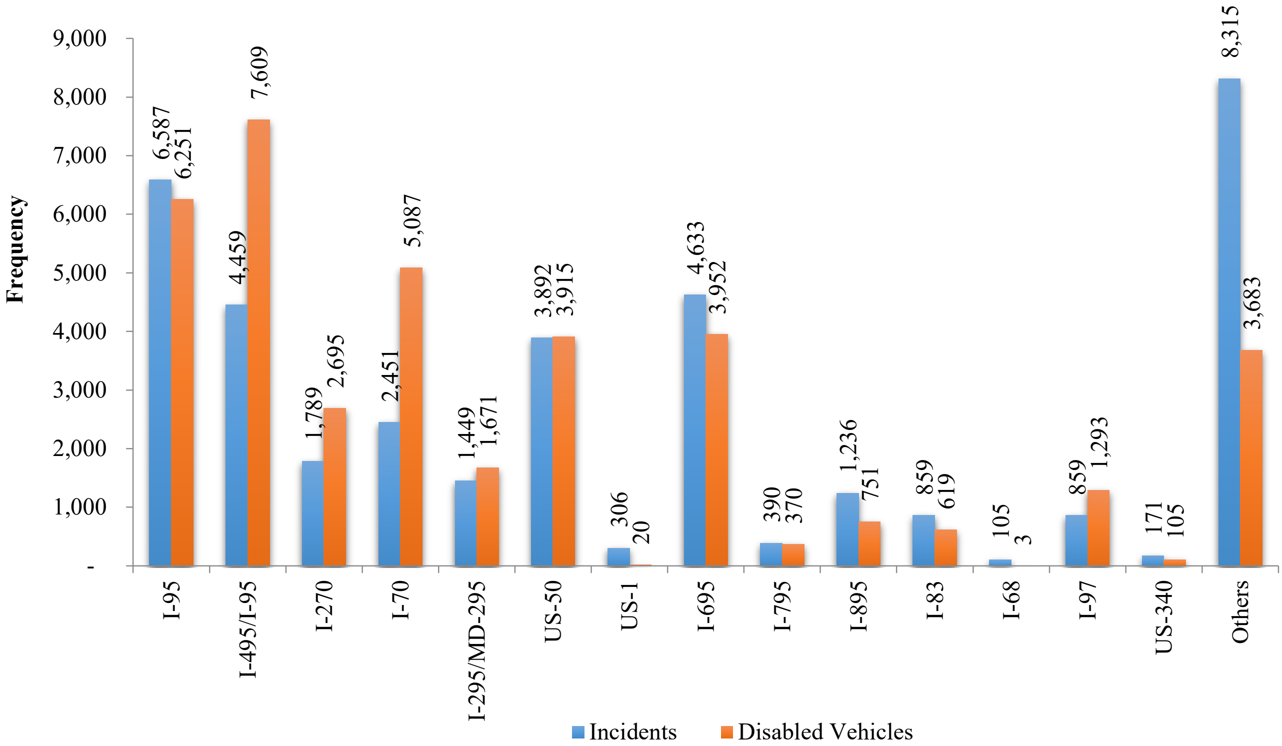
Analysis of Data Characteristics



** "Total" includes incomplete data for road name and direction.*

Figure 3.3 Distributions of Incidents/Disabled Vehicles by Road in 2021

Based on the statistics shown above, the roadways experiencing high incident frequencies for 2021 were I-95 (from the Delaware border to the Capital Beltway), I-695 (Baltimore Beltway), I-495/95 (Capital Beltway), US-50, I-70 and I-270. I-95 suffered from a total of 12,838 incidents/disabled vehicles in 2021, while I-695 had 8,585 incidents/disabled vehicles within the same period. I-495/95, US-50, I-70 and I-270 had 12,068, 7,807, 7,538, and 4,484 incidents/disabled vehicles, respectively. Note that a total of 697 incidents/disabled vehicles in 2021 CHART-II database lack the information of road names for further analysis.

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Analysis of Data Characteristics

Figures 3.4 and 3.5 present comparisons of frequency distributions by time of day on major roads in Maryland for incidents and disabled vehicles, respectively. As shown in these figures, more incidents occurred during p.m. peak hours than in a.m. peak hours on most major roads, except I-270 and I/MD-295.

I-95, I-270, and US-50 are connected to I-495/95 and are the main contributors of traffic congestion on I-495 during commuting periods. Due to its high traffic volume, any incident on I-495 is likely to cause a spillback of vehicles onto I-95, I-270, and US-50, causing congestion on those three freeways as well. The interdependent nature of incidents between the primary commuting freeways should be considered when prioritizing and implementing incident management strategies. To better allocate patrol vehicles and response units to hazardous highway segments, the distribution of incidents/disabled vehicles between two consecutive exits was employed as an indicator in the analysis.

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Analysis of Data Characteristics

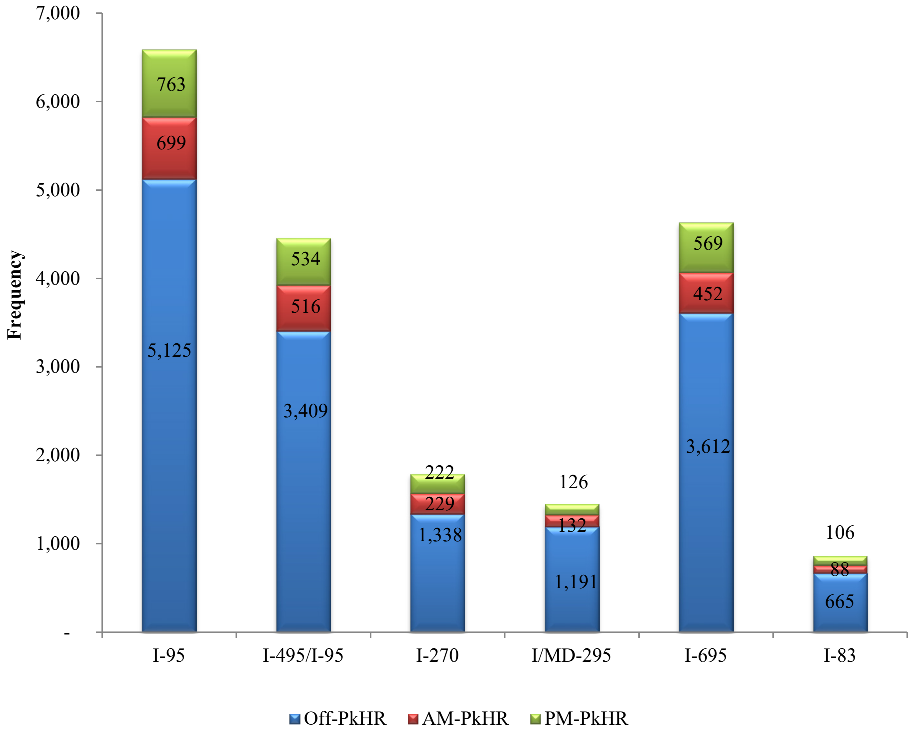


Figure 3.4 Distribution of Incidents by Time of Day on Major Roads in 2021

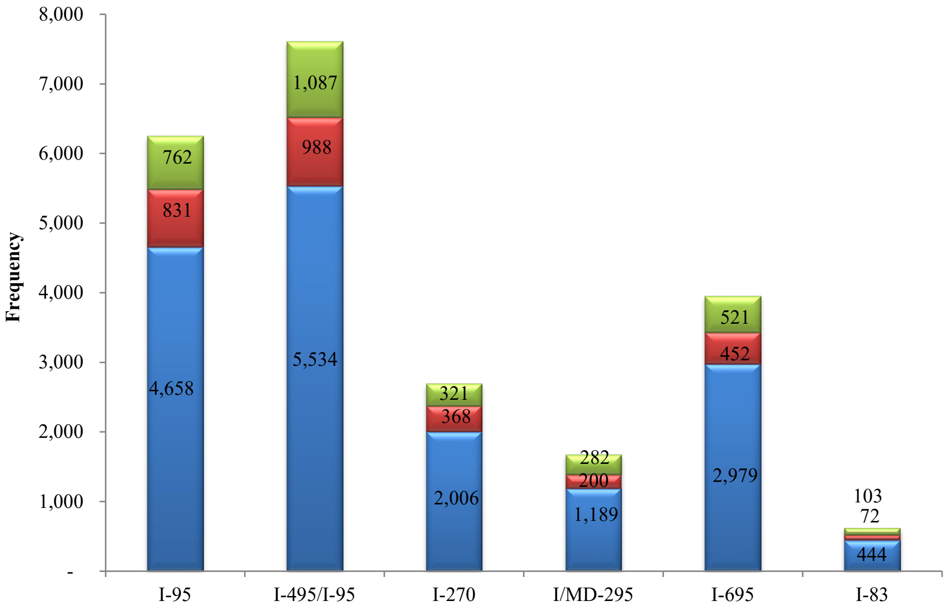
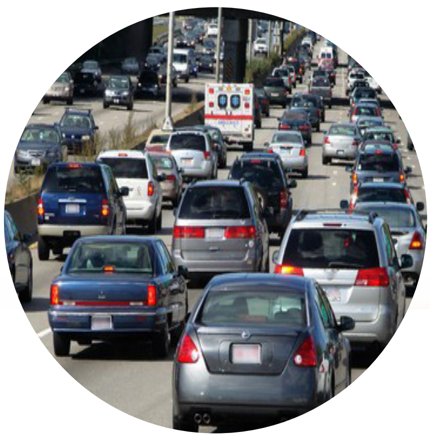


Figure 3.5 Distribution of Disabled Vehicles by Time of Day on Major Roads in 2021

CHAPTER 3
Analysis of Data Characteristics

Figure 3.6 shows the distribution of incidents and disabled vehicles by location on I-695 in 2021, while Figure 3.7 highlights the comparison with the results in 2020. Those segments of high incident frequency are from Exit 43 to 44, Exits 11 to 12, and Exit 17 to 18 (292, 250, and 231, respectively). Those two roadway segments near I-70 and I-95 between Exits 17 and 18, and Exits 11 and 12, experienced a high frequency of disabled vehicles (318 and 252 cases).

The subsequent figures show the comparison between 2021 and 2020 incident data, including the geographical distribution of incidents and disabled vehicles on I-495/95 interchanges. Figure 3.8 shows that the highest frequency of incidents (268 cases and 263 cases) occurred from Exits 28 to 29 and Exits 30 to 31 of I-495. The location, plagued by the highest frequency of disabled vehicles (503 cases), occurred on the roadway segment between Exits 4 and 7. A comparison with the data in 2020 is illustrated in Figure 3.9.



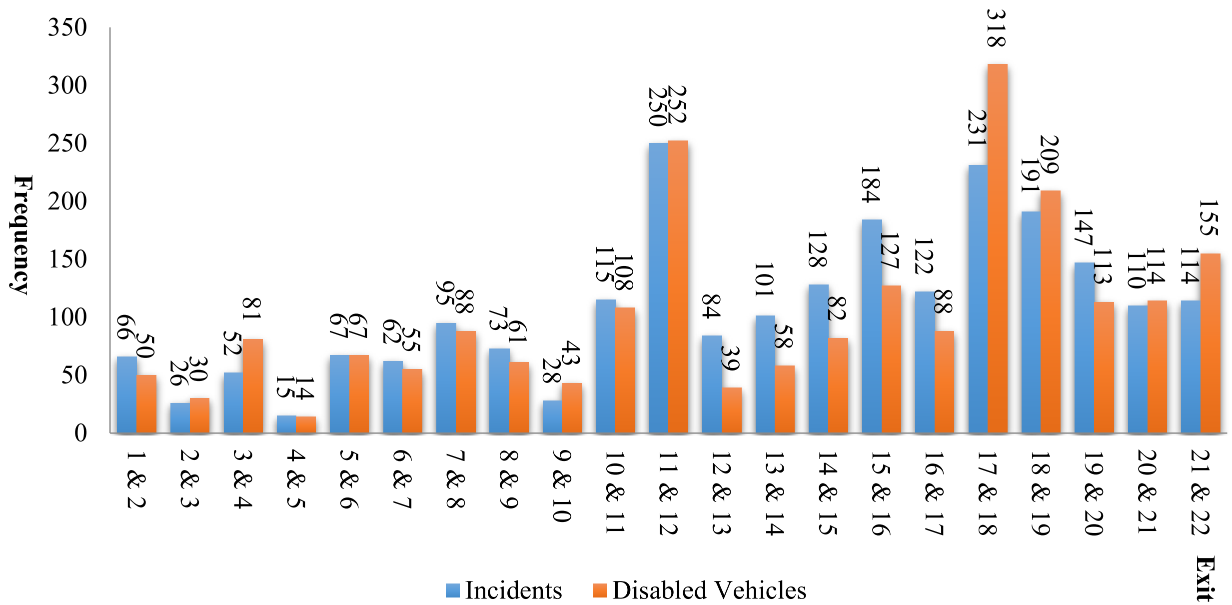


Figure 3.6 Distribution of Incidents/Disabled Vehicles by Location on I-695

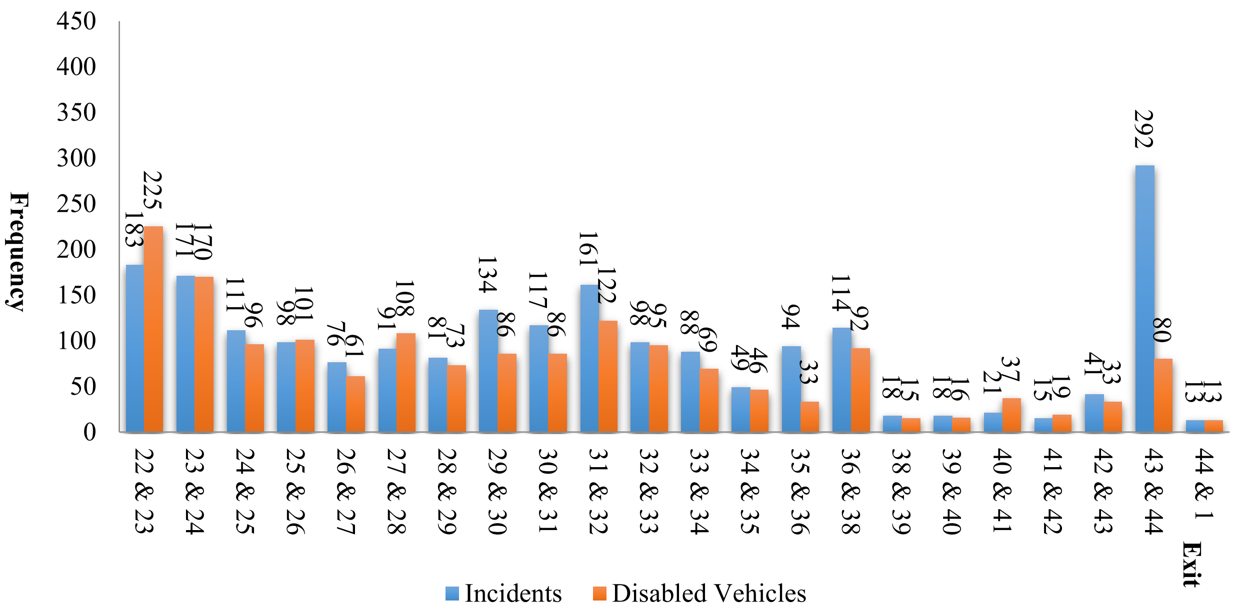


Figure 3.6 Distribution of Incidents/Disabled Vehicles by Location on I-695 (cont.)

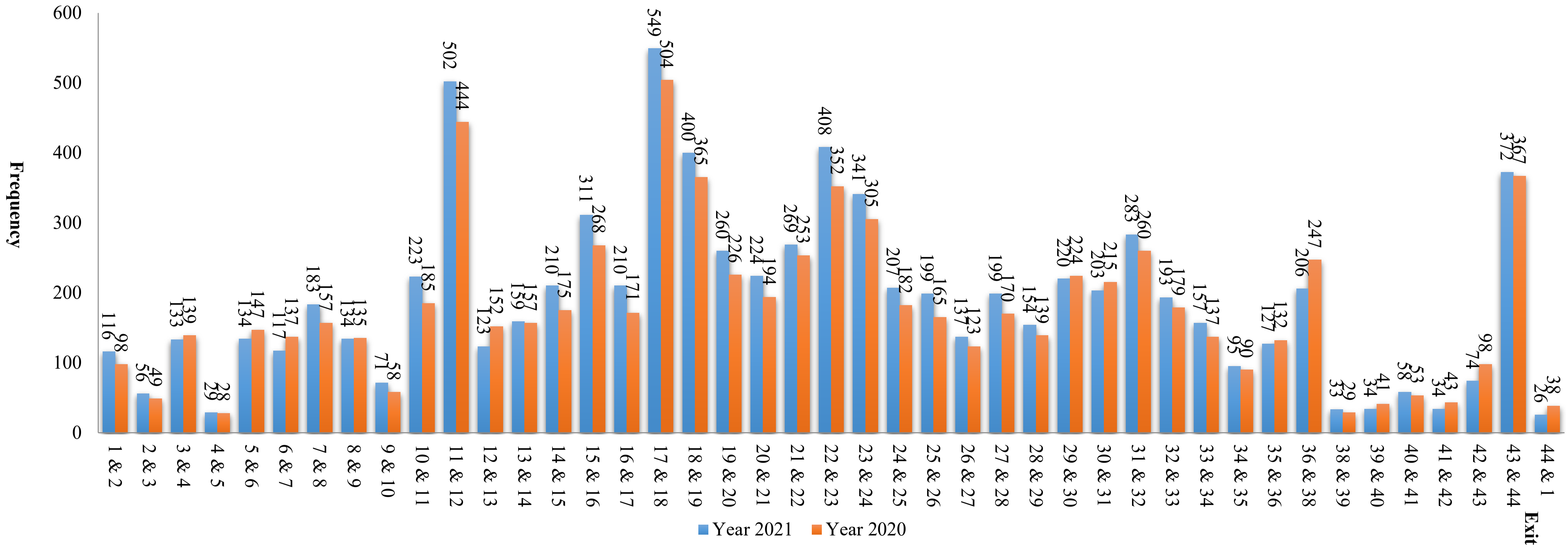


Figure 3.7 Comparisons of Incidents/Disabled Vehicles Distributions by Location on I-695

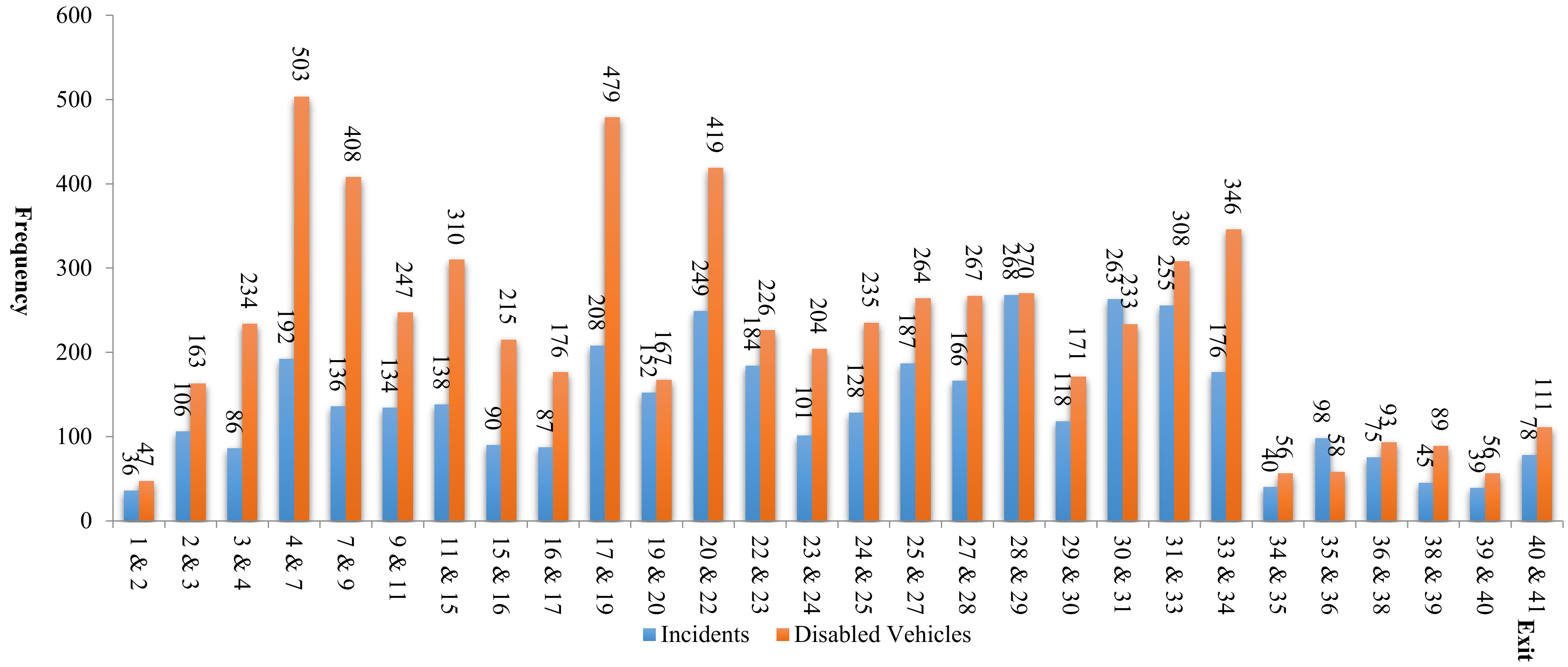


Figure 3.8 Distributions of Incidents/Disabled Vehicles by Location on I-495/I-95

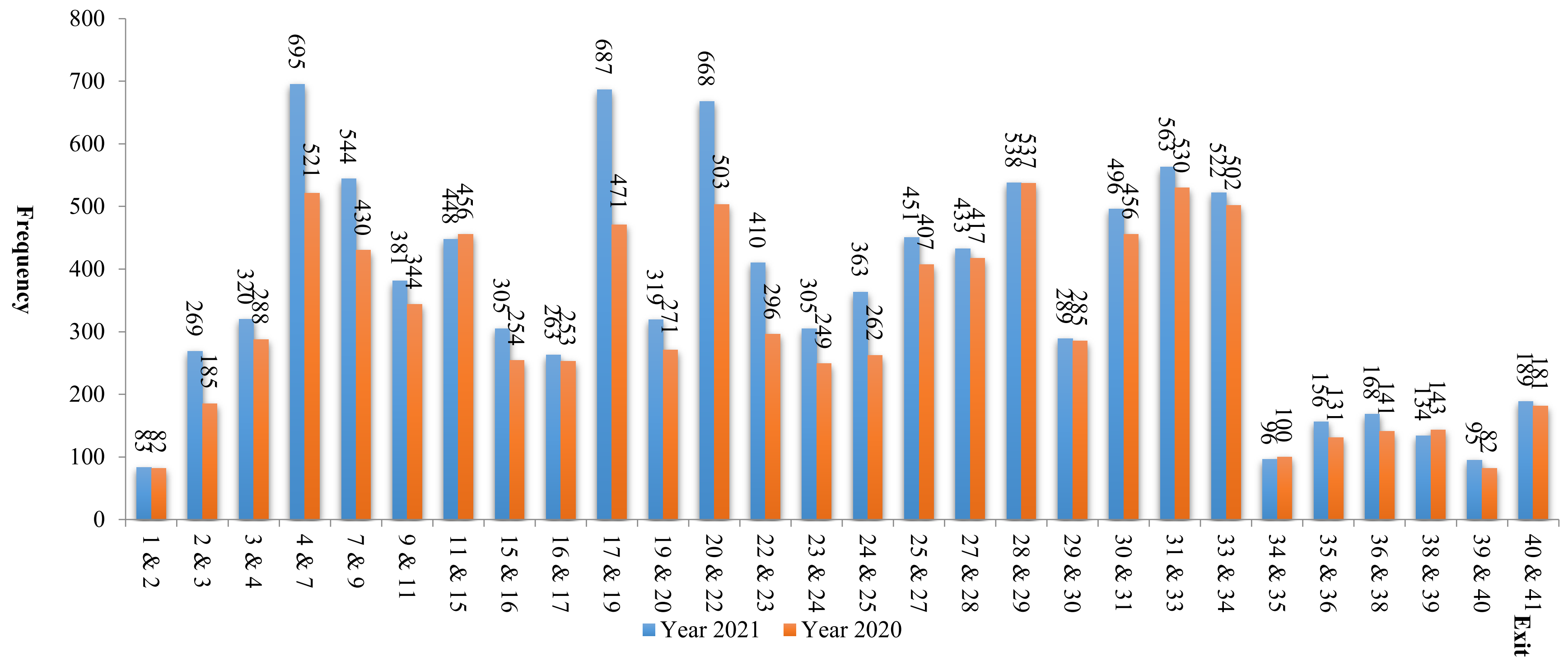


Figure 3.9 Comparisons of Incidents/Disabled Vehicles Distributions by Location on I-495/I-95

Figure 3.10 shows the distribution of incidents and disabled vehicles by location on I-95, and Figure 3.11 compares such distributions between 2021 and 2020. As shown in Figure 3.10, the highest number of incidents occurred at the following three segments: between Exits 67 and 74 (675 cases), Exits 55 and 56 (503 cases), Exits 56 and 57 (473 cases). Two segments (i.e., between Exits 67 and 74, and Exits 61 and 64) experienced the highest number of disabled vehicles (541 cases and 421 cases, respectively).

In 2021, the I-95 segment between Exit 67 and Exit 74 experienced the highest frequency of 1,216 incidents and disabled vehicles, revealing the same patterns as in 2018 (1,299 cases, ranked the 1st), 2019 (1,340 cases, ranked the 1st) and 2020 (1,193 cases, ranked the 1st). Those I-95 segments between Exits 53 and 59 were reported to experience fewer requests of responding to incident/disabled vehicles than in 2020, while those between Exits 67 and 93 experienced more.

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Analysis of Data Characteristics

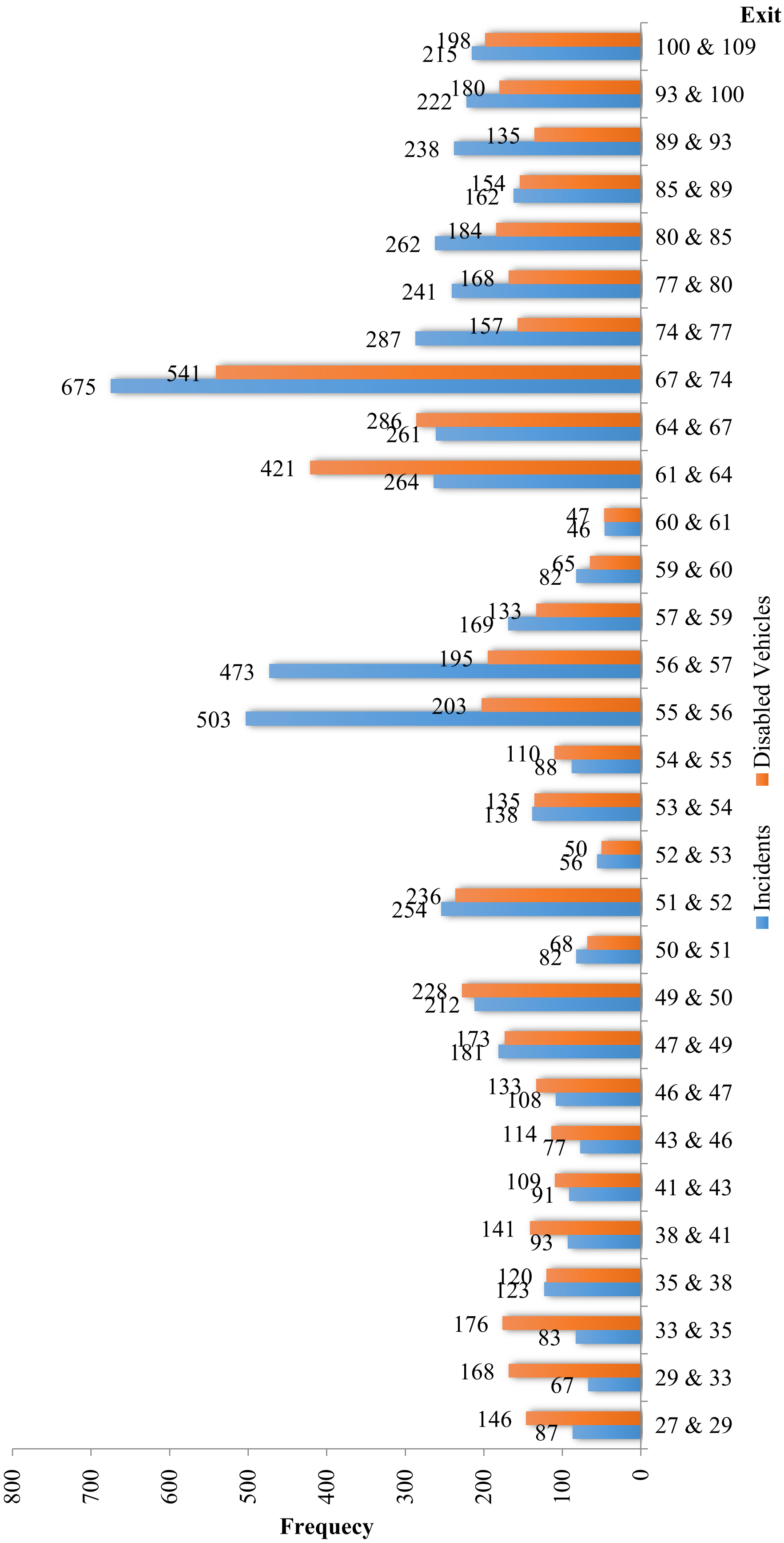


Figure 3.10 Distributions of Incidents/Disabled Vehicles by Location on I-95

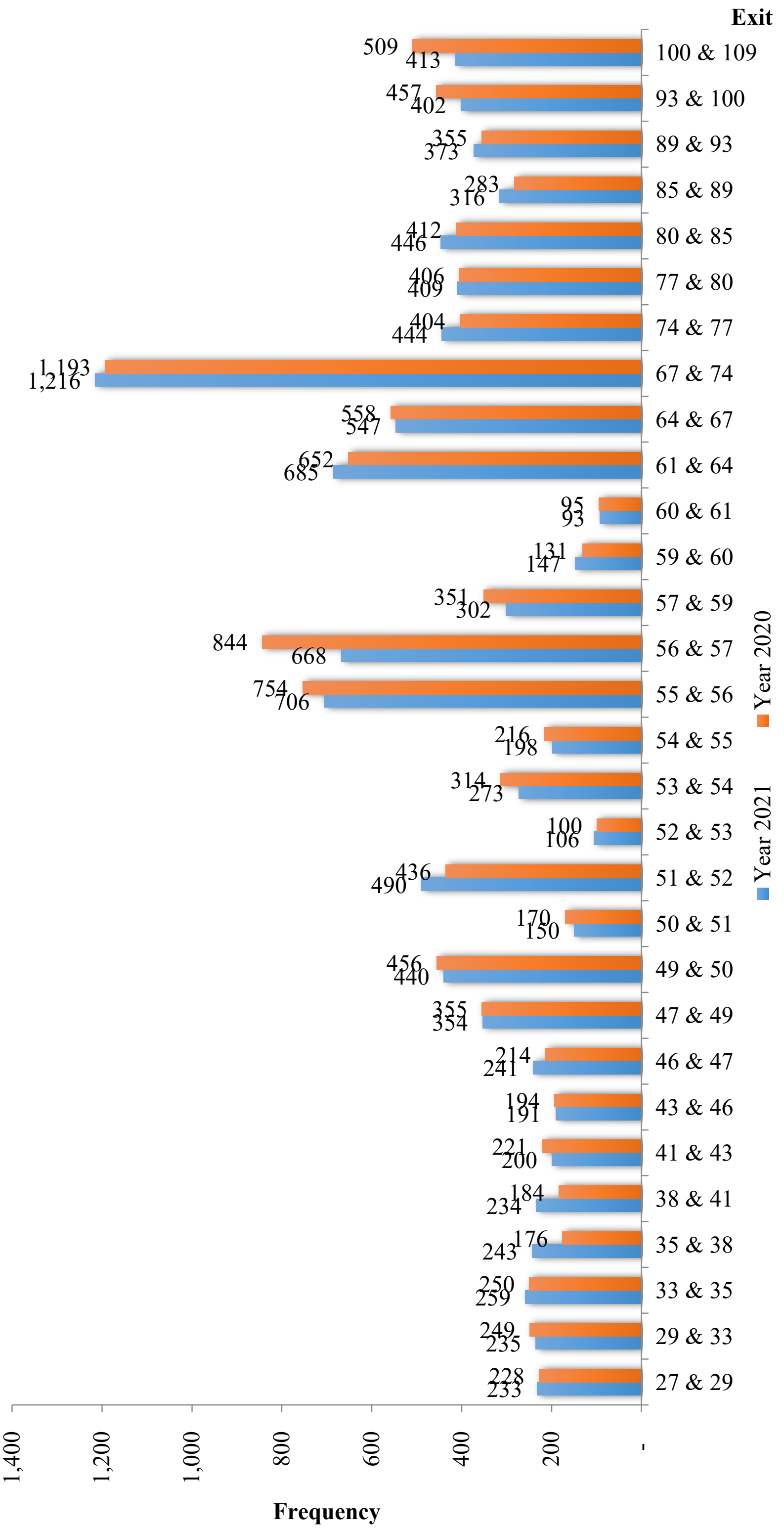


Figure 3.11 Comparisons of Incidents/Disabled Vehicles Distributions by Location on I-95

CHAPTER 3
Analysis of Data Characteristics

Figure 3.12 represents the spatial distribution of incidents/disabled vehicles data on I-270 in 2021. The segments between Exits 26 and 31 on I-270 experienced the highest numbers of incidents (197 cases) as well as the highest number of disabled vehicles (252 cases).

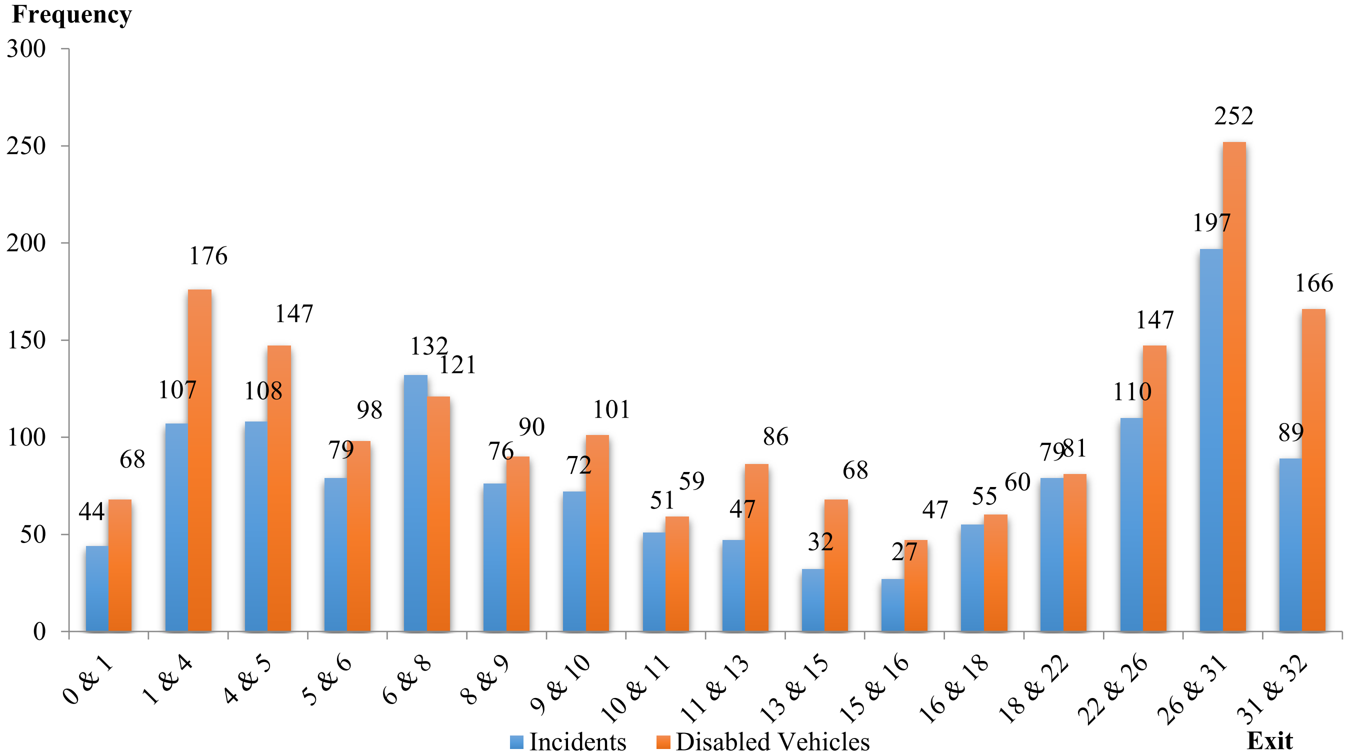


Figure 3.12 Distributions of Incidents/Disabled Vehicles by Location on I-270

CHAPTER 3
Analysis of Data Characteristics

Figure 3.13 shows a comparison of the distribution of incidents/disabled vehicles on I-270 between 2021 and 2020 data. Those segments from Exit 15 to Exit 32 show higher incident/disabled vehicles requests than those observed in 2020, while segments from Exit 10 to Exit 15 show lower response frequencies than 2020.

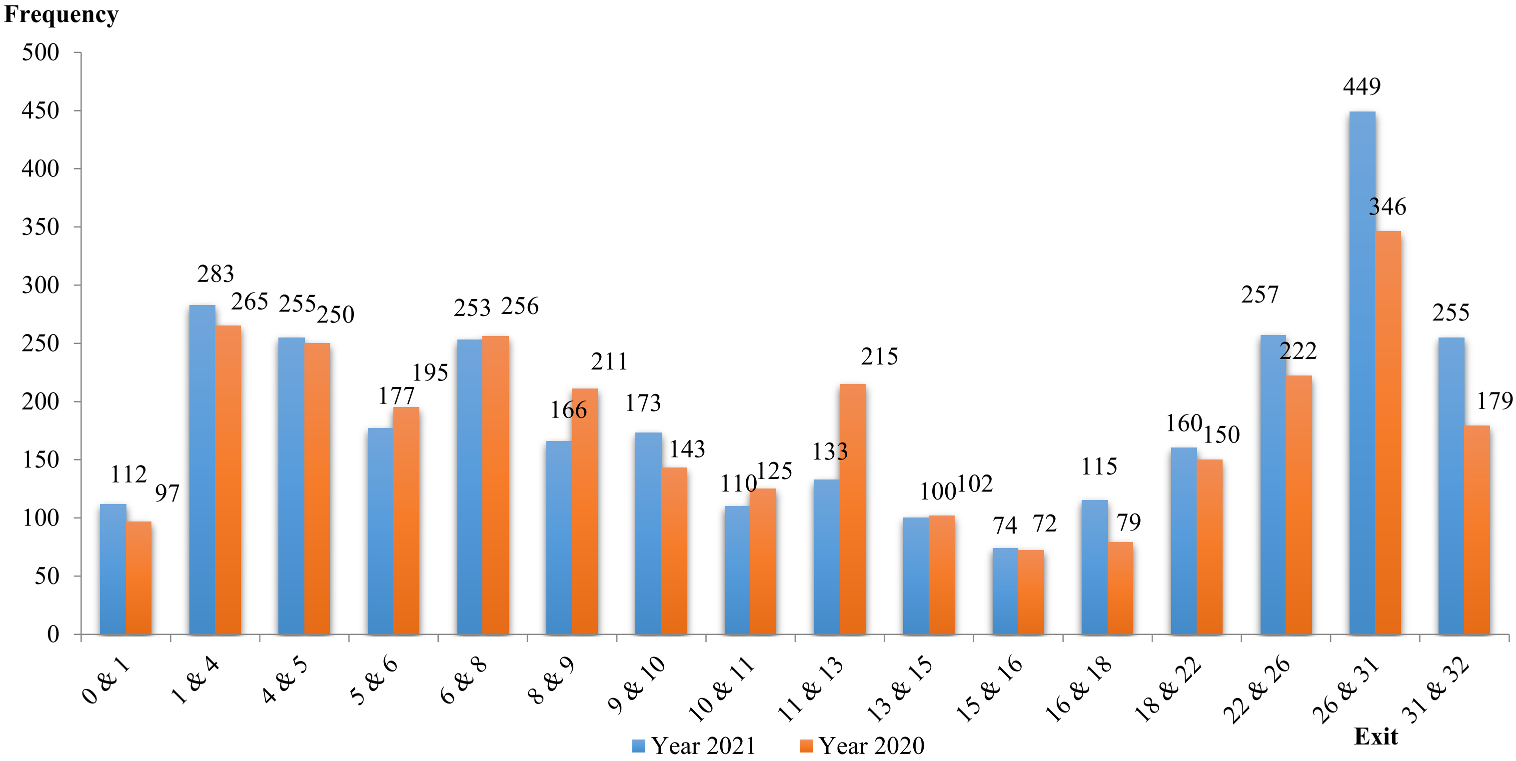
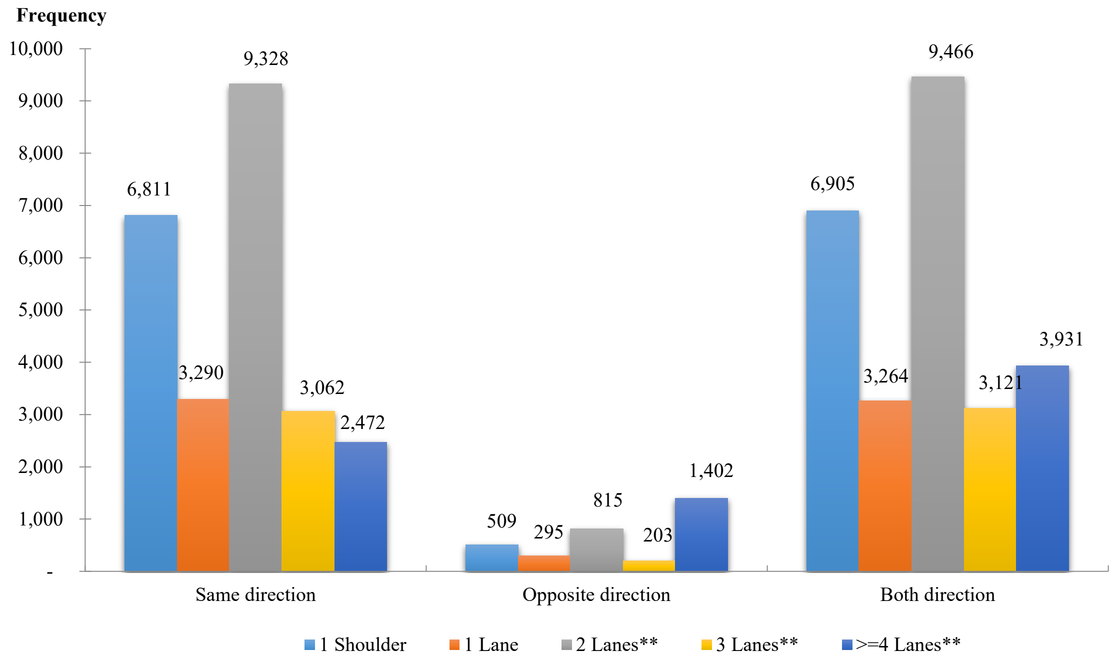


Figure 3.13 Comparisons of Incidents/Disabled Vehicles by Location on I-270

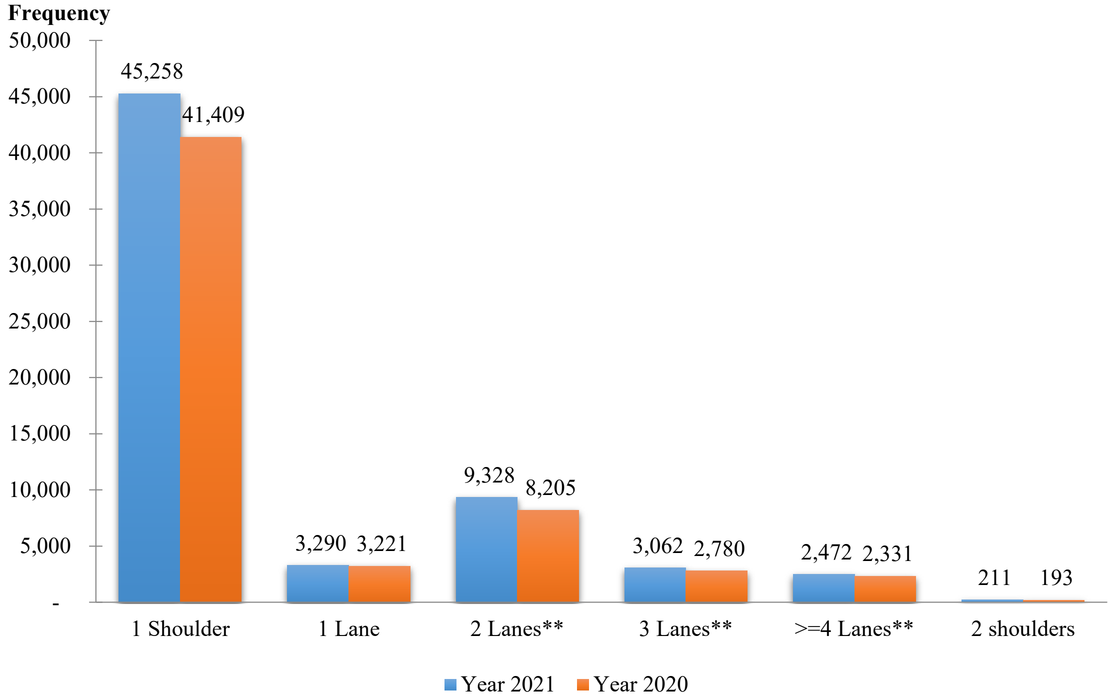
3.3 Distribution of Incidents and Disabled Vehicles by Lane Blockage Type

Figure 3.14 illustrates the distribution of incidents by lane blockage in 2021. A large portion of those incidents involved one-shoulder or two-lane blockages. The comparison of 2021 incidents/ disabled vehicles distribution by lane blockage with 2020 data is illustrated in Figure 3.15. Note that all reported disabled vehicles are classified as shoulder lane blockages in Figures 3.14 and 3.15.



*Note: *This analysis uses only incidents (not including "Disabled Vehicles")*
***Also includes Shoulder Lane Blockages*

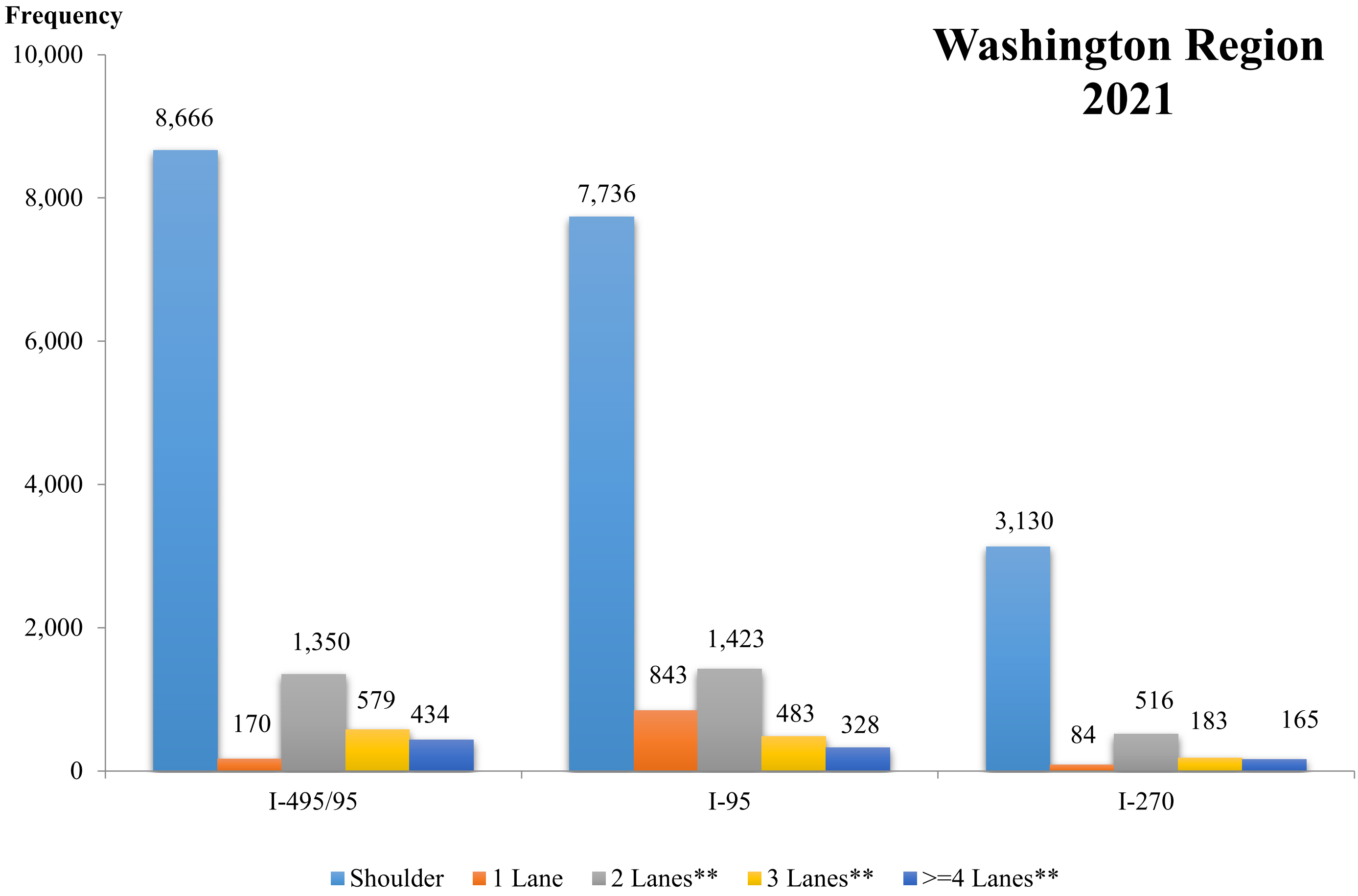
Figure 3.14 Distributions of Incidents by Lane Blockage



*Note: * Disabled Vehicles are all classified as Shoulder Lane Blockages.*
*** Also includes Shoulder lane blockages.*

Figure 3.15 Comparisons of Incidents/Disabled Vehicles Distributions by Lane Blockage

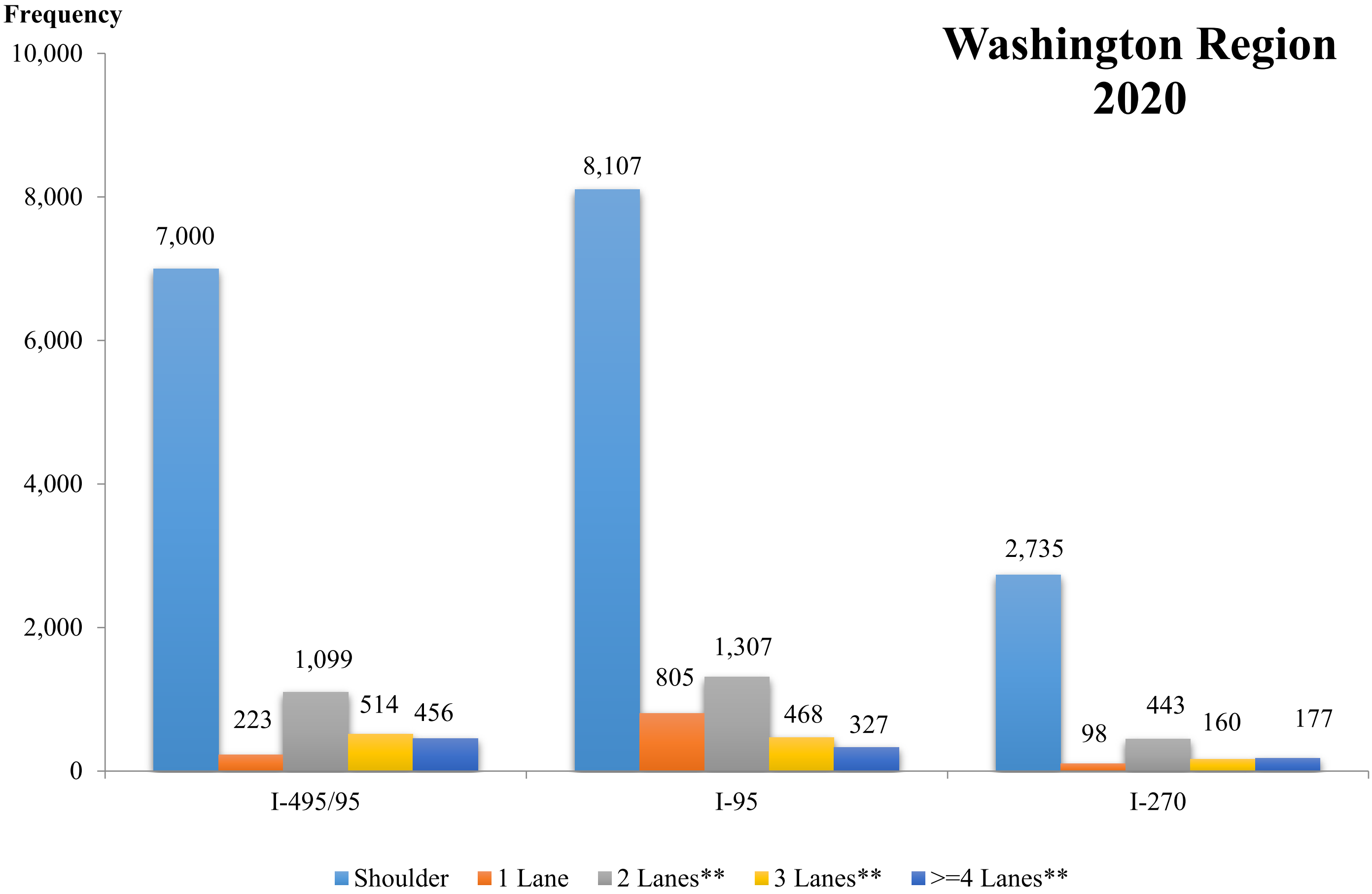
Figures 3.16 and 3.17 depict a comparison of lane blockage incidents between 2021 and 2020 for major roads in the Washington Metropolitan and Baltimore areas. In 2021, I-495/95 shows an increase in shoulder lane blockages and 2 or 3-lane blockages. Shoulder-lane-only blockages on all major roads in Baltimore Region increased in 2021. Compared to those in 2020, incidents of two-lane blockages on all major roads also increased in 2021.



*Note: *Disabled Vehicles are all classified as Shoulder Lane Blockages*

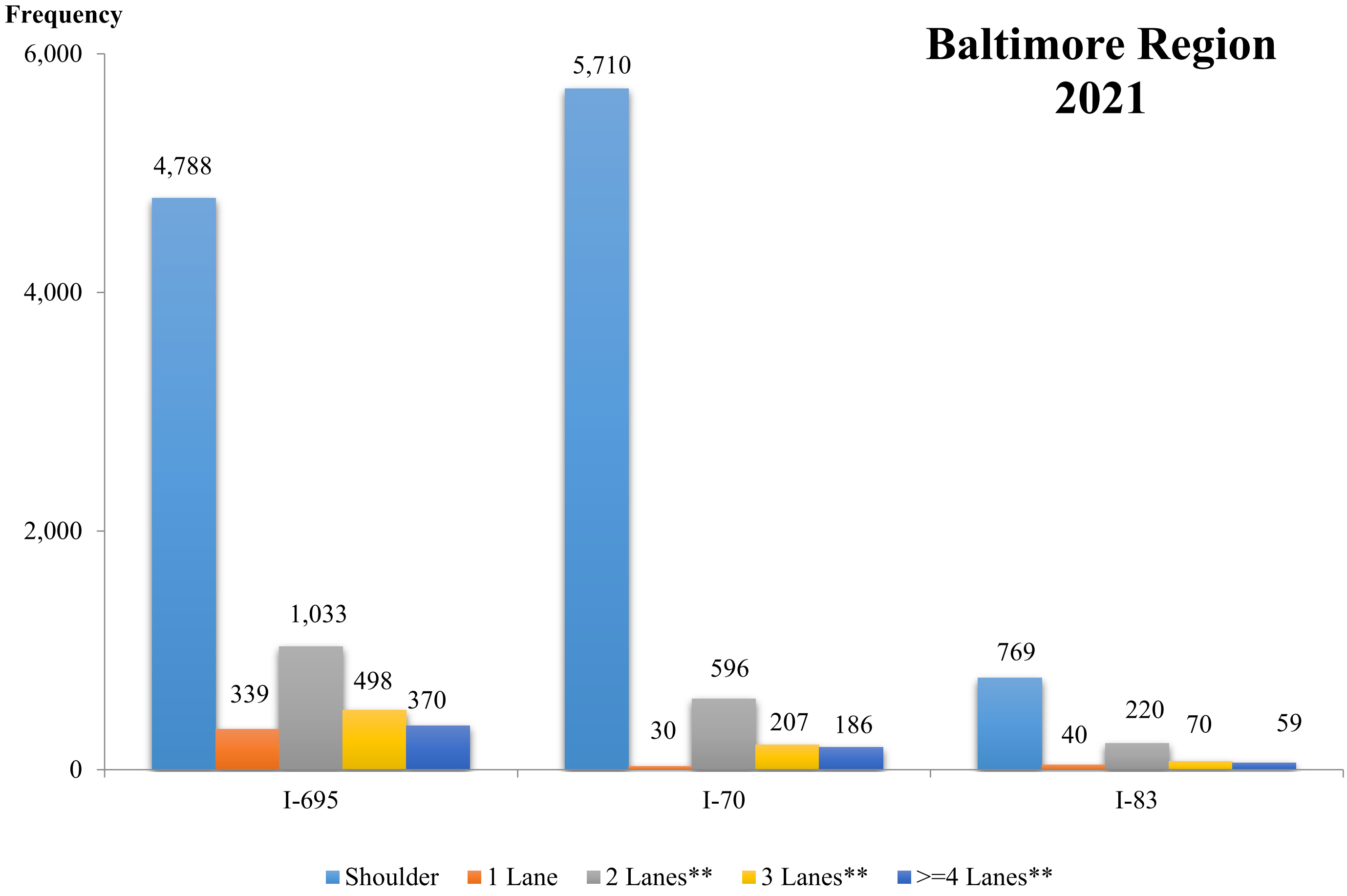
***Also includes Shoulder Lane Blockages*

Figure 3.16 Distributions of Lane Blockages Occurring on Major Freeways in the Washington Area



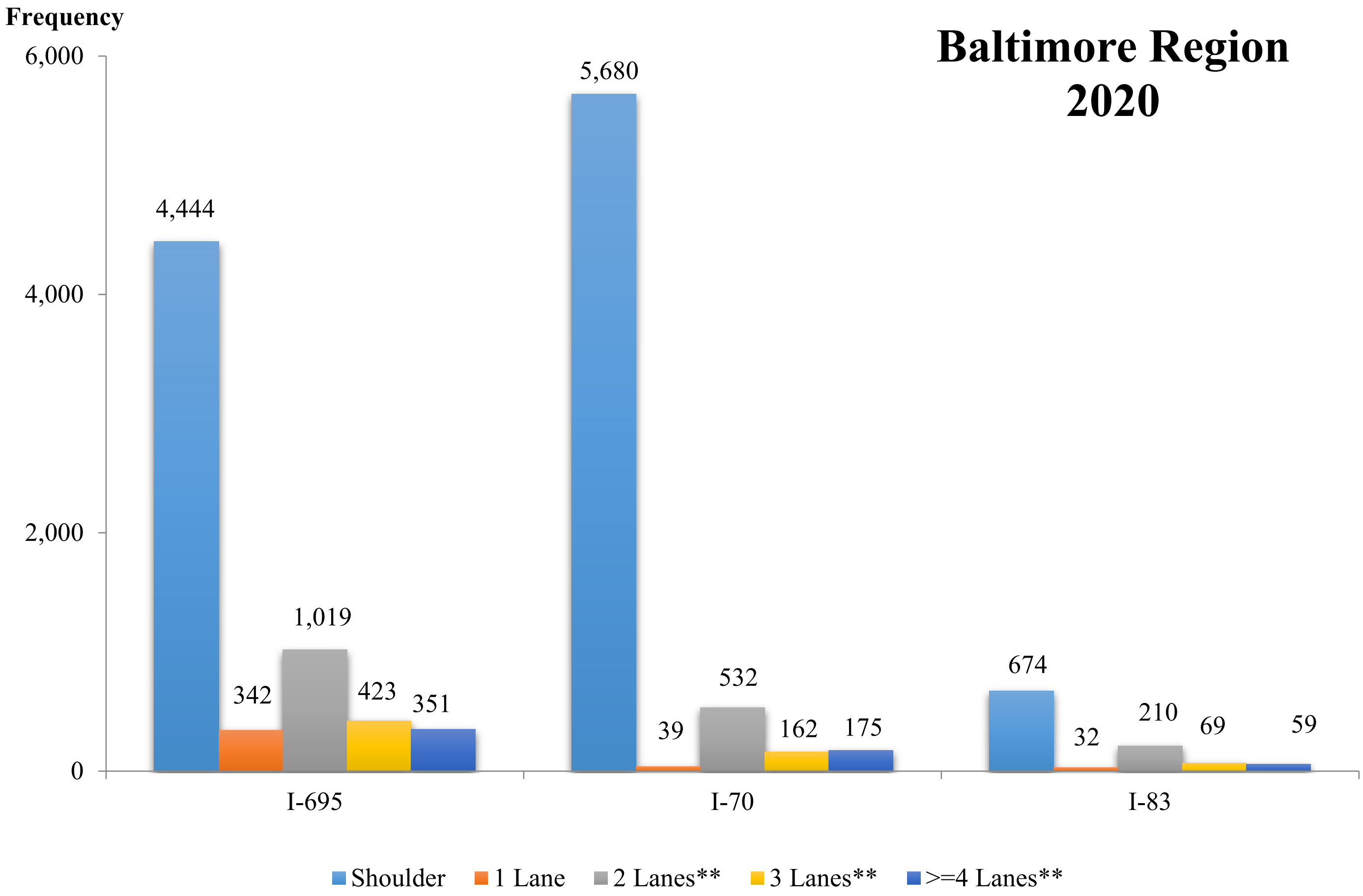
*Note: *Disabled Vehicles are all classified as Shoulder Lane Blockages*
***Also includes Shoulder Lane Blockages*

Figure 3.16 Distributions of Lane Blockages Occurring on Major Freeways in the Washington Area (cont.)



*Note: *Disabled Vehicles are all classified as Shoulder Lane Blockages*
***Also includes Shoulder Lane Blockages*

Figure 3.17 Distributions of Lane Blockages Occurring on Major Highways in the Baltimore Region



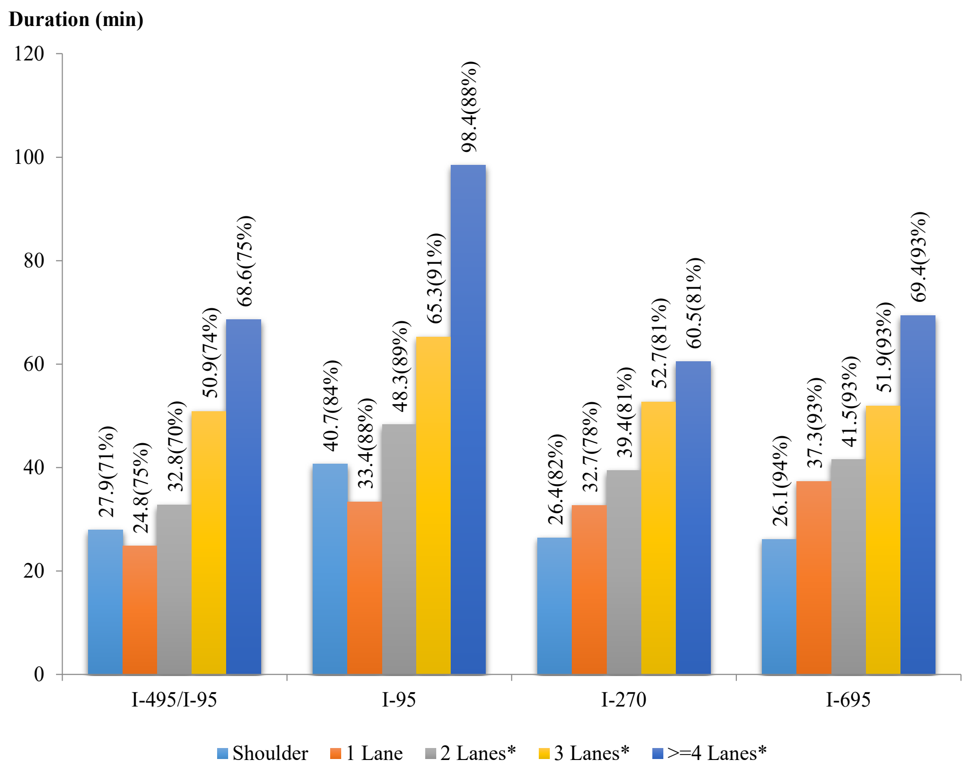
*Note: *Disabled Vehicles are all classified as Shoulder Lane Blockages*
***Also includes Shoulder Lane Blockages*

Figure 3.17 Distributions of Lane Blockages Occurring on Major Highways in the Baltimore Region (cont.)

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

3.4 Distribution of Incidents and Disabled Vehicles by Lane Blockage Duration

Lane blockage analysis naturally leads to the comparison of incident duration distribution. Figure 3.18 illustrates a relation between lane blockages and their average durations on each major freeway.



*Note: *Also includes shoulder lane blockages.*
***Numbers in each parenthesis show the percentage of data available.*

Figure 3.18 Incident Duration by Lane Blockages and Road

It is quite obvious that CHART's highway network has experienced a high frequency of incidents, ranging from twenty minutes to more than one hour in duration. These incidents are clearly primary contributors to traffic congestion in the entire region, especially on the major commuting highway corridors of I-495, I-695, I-270, and I-95, making it 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. About 66 percent of incidents and disabled vehicles had durations of less than 30 minutes.

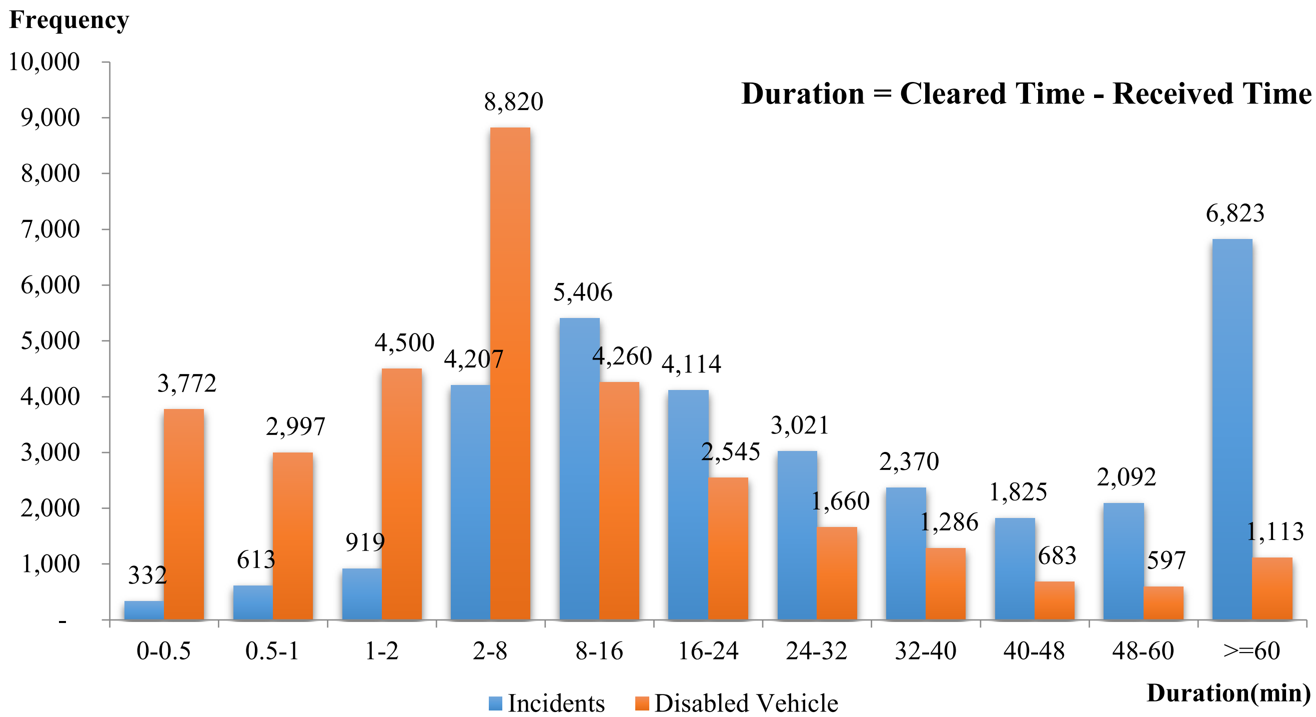
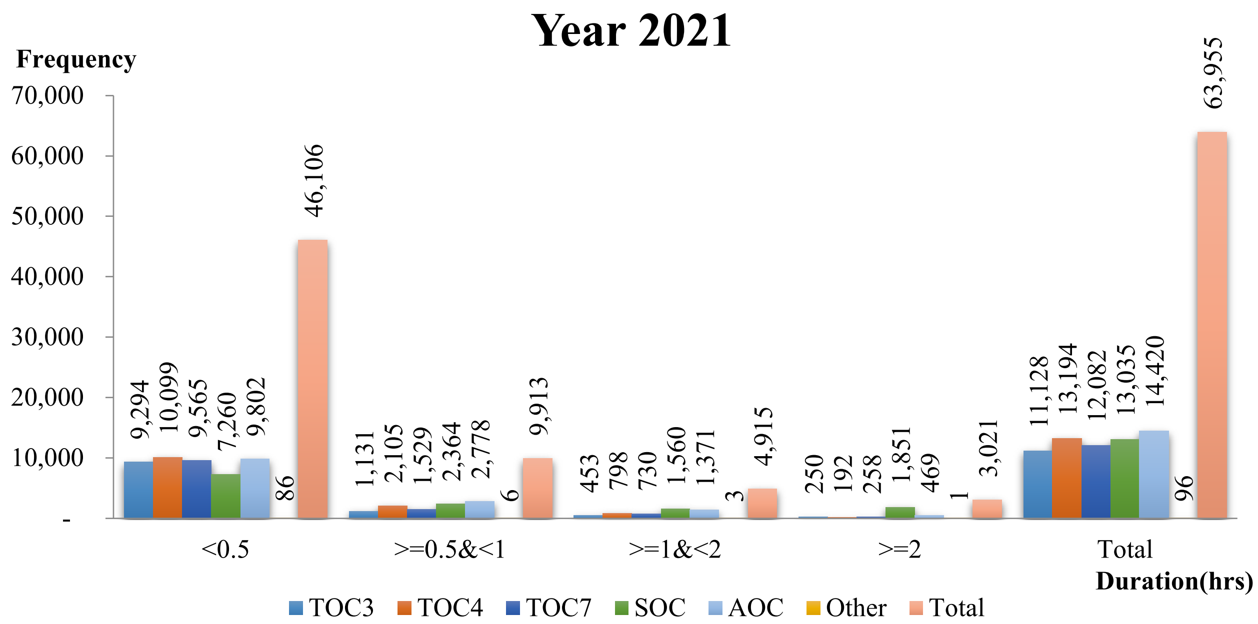


Figure 3.19 Distributions of Incidents/Disabled Vehicles by Duration in 2021

Although most incidents in 2021 were not severe, their impacts were significant during peak hours. Clearing the blockages did not require special equipment, and the incident duration was highly dependent on the travel time of the incident response units.

Figure 3.20 presents the distribution of records in 2021 and its comparison with 2020 data. About 16 percent, 23 percent, and 21 percent of reported incidents/disabled vehicles managed by TOC-3, TOC-4, and TOC-7, respectively, blocked traffic lasting longer than 30 minutes. For SOC, about 44 percent of reported incidents lasted longer than 30 minutes, the same level as in 2020.



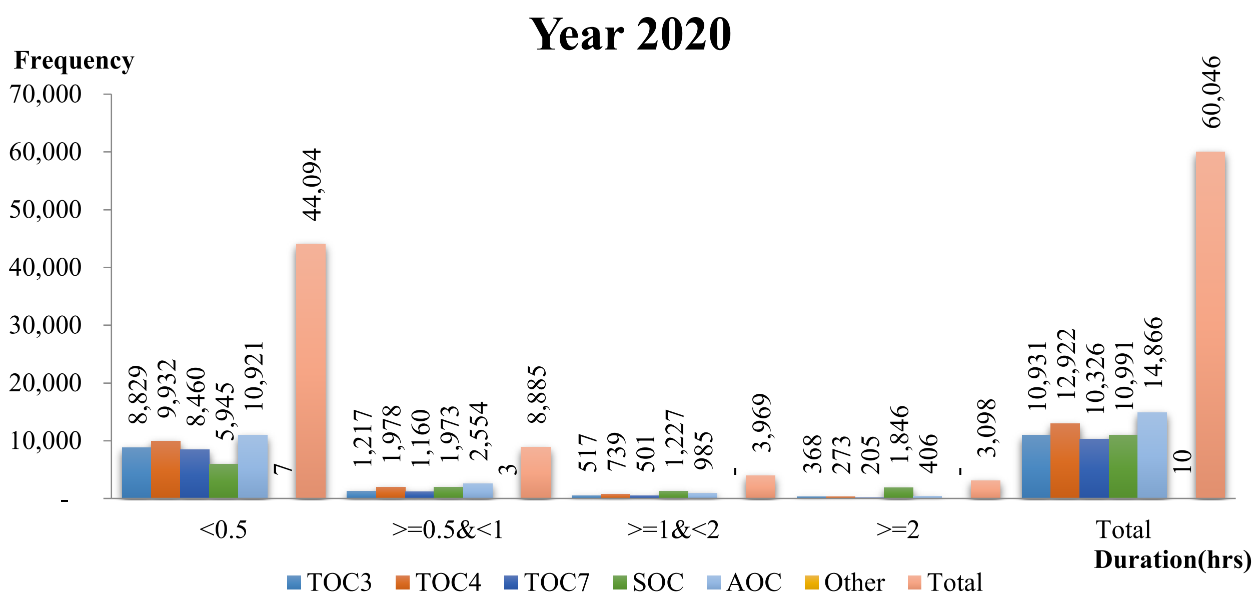


Figure 3.20 Comparisons of Incidents/Disabled Vehicles Distributions by Duration (hrs) and Operation Center

Chapter 4

EVALUATION OF EFFICIENCY AND EFFECTIVENESS

CHAPTER 4
Evaluation of Efficiency and Effectiveness

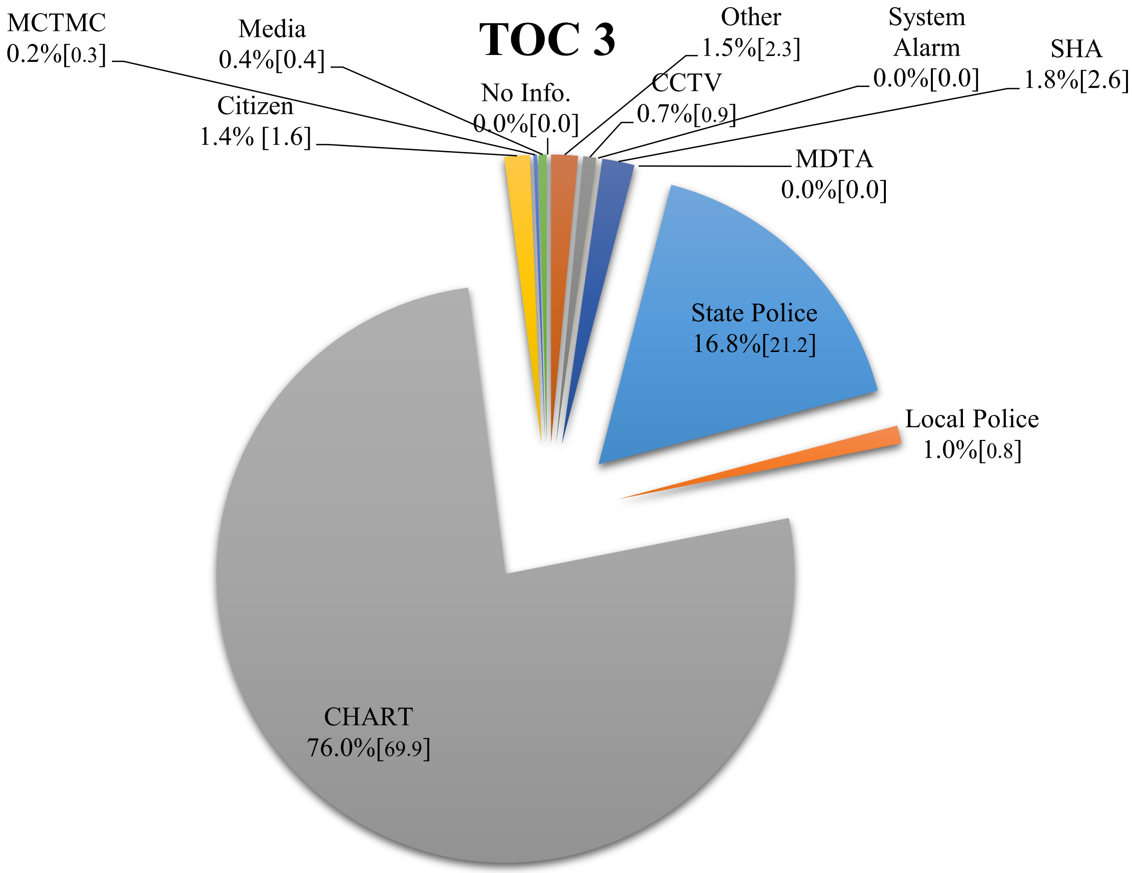
4.1 Evaluation of Detection Efficiency and Effectiveness

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

The response rate is defined as the ratio of the total number of traffic incidents/disabled vehicles reported to the CHART control center to those responded by the CHART emergency response teams. Based on the 2021 incident management records, the overall response rate was 90 percent. As in the previous year, existing incident reports did 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 sufficiently severe 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.

CHAPTER 4
Evaluation of Efficiency and Effectiveness

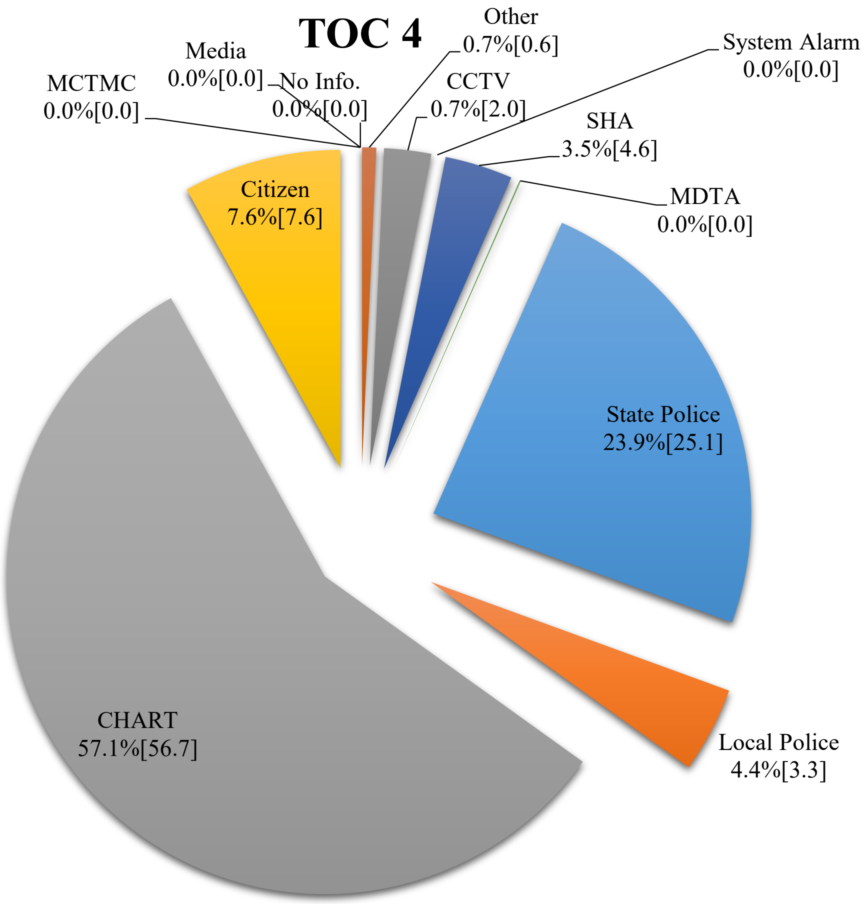
Figures 4.1, 4.2, and 4.3 illustrate the distributions of incidents/disabled vehicles by detection source for control centers TOC 3, TOC 4 and TOC7, respectively.



Note: 1. Numbers in [ ] show the percentages from Year 2020.

2. Actual frequencies for incidents/disabled vehicles detected by No info., system alarm, and MDTA in 2021 are 0, 2 and 0 in the CHART-II database.

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

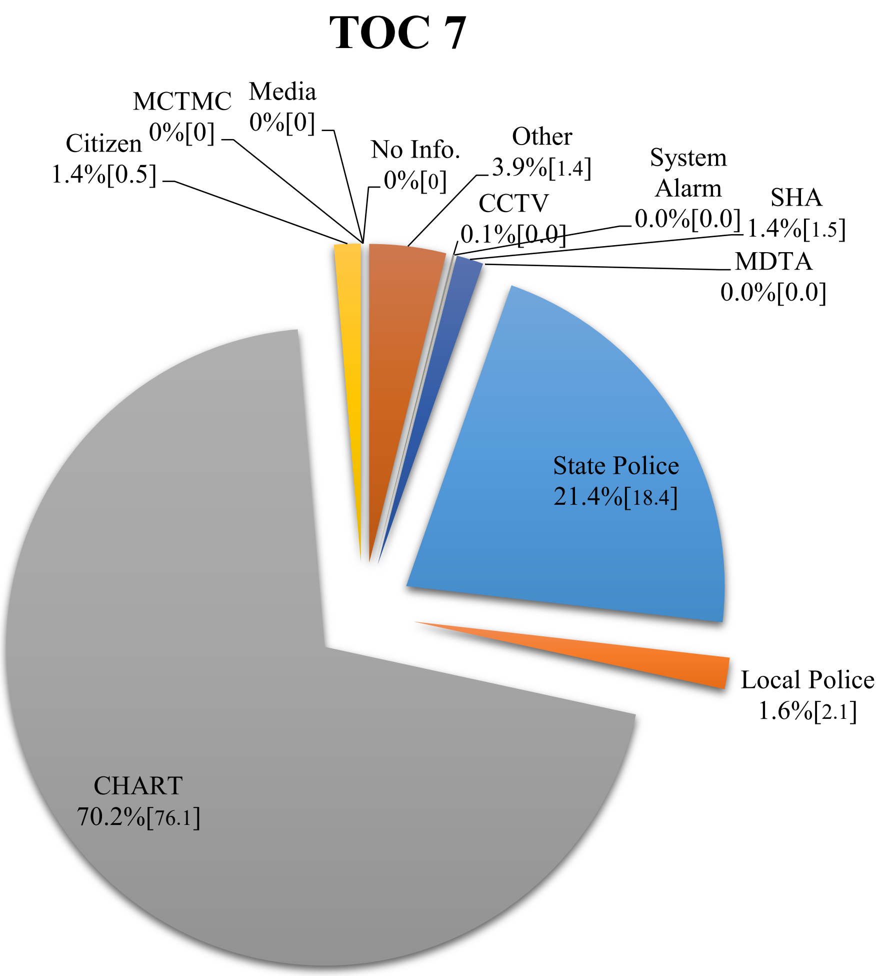


Note: 1. Numbers in [ ] show the percentages from Year 2020.

2. Actual frequencies for incidents/disabled vehicles detected by No info., System Alarm, MDTA, MCTMC, and Media in 2021 are 0, 0, 9, 0 and 0 in the CHART-II database.

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

CHAPTER 4
Evaluation of Efficiency and Effectiveness



Note: 1. Numbers in [ ] show the percentages from Year 2020.

2. Actual frequencies for incidents/disabled vehicles detected by No Info., System Alarm, MDTA, MCTMC, and Media in 2021 are 0, 1, 0, 0, and 0 in the CHART-II database.

Figure 4.3 Distributions of Incidents/Disabled Vehicles by Detection Source for TOC 7

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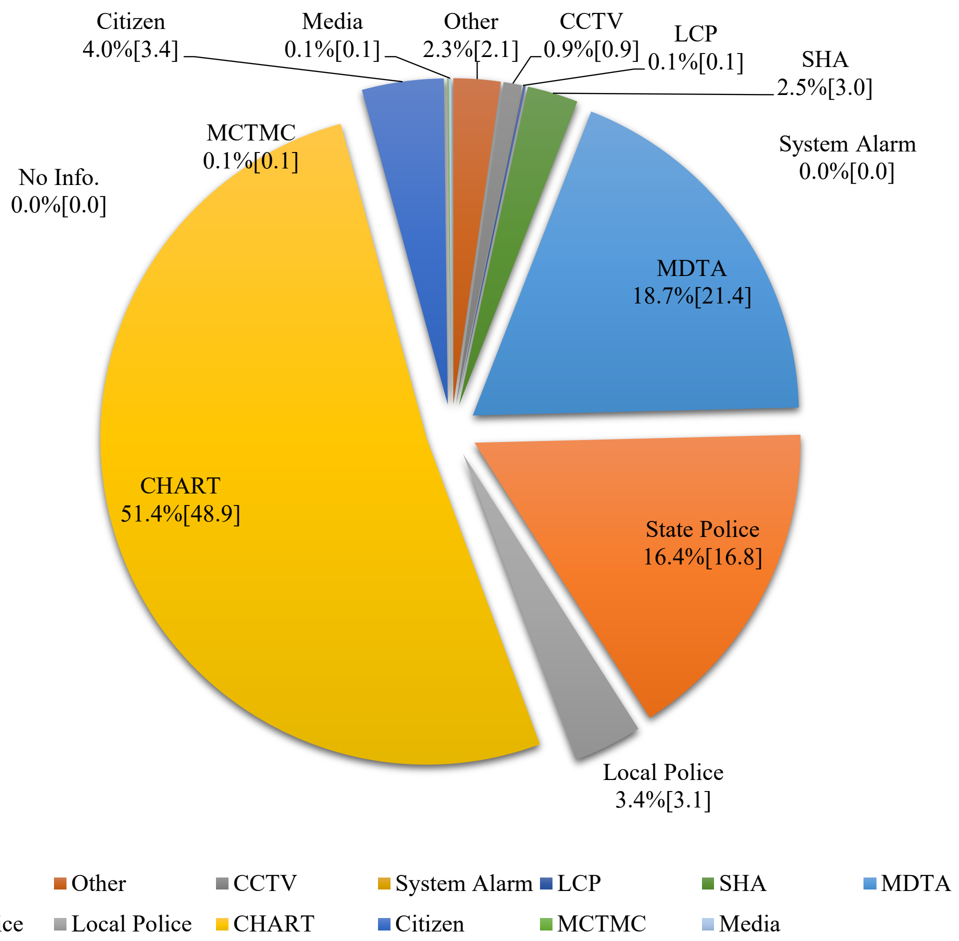
Evaluation of Efficiency and Effectiveness

With respect to the distribution of all detection sources, the statistics in Figure 4.4 clearly show that about 51 percent of incidents in 2021 were detected by MSHA/CHART patrols, slightly higher than in 2020. 19 percent were reported by the MDTA, slightly lower than that in 2020. About 16 percent were reported by the MSP, at the same level as that in 2020.



Note: 1. Numbers in [ ] show the percentages from Year 2020.

2. Actual frequency for incidents/disabled vehicles detected by No info. and System Alarm in 2021 is 0 and12 in the CHART-II database.

Figure 4.4 Distributions of Incidents/Disabled Vehicles by Detection Source

4.2 Analysis of Response Efficiency

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

The average response time for incidents/disabled vehicles in 2021 is given in Figure 4.5. The average response time in 2021 was 12.25 minutes, slightly slower than that of 2020 (11.64 minutes).

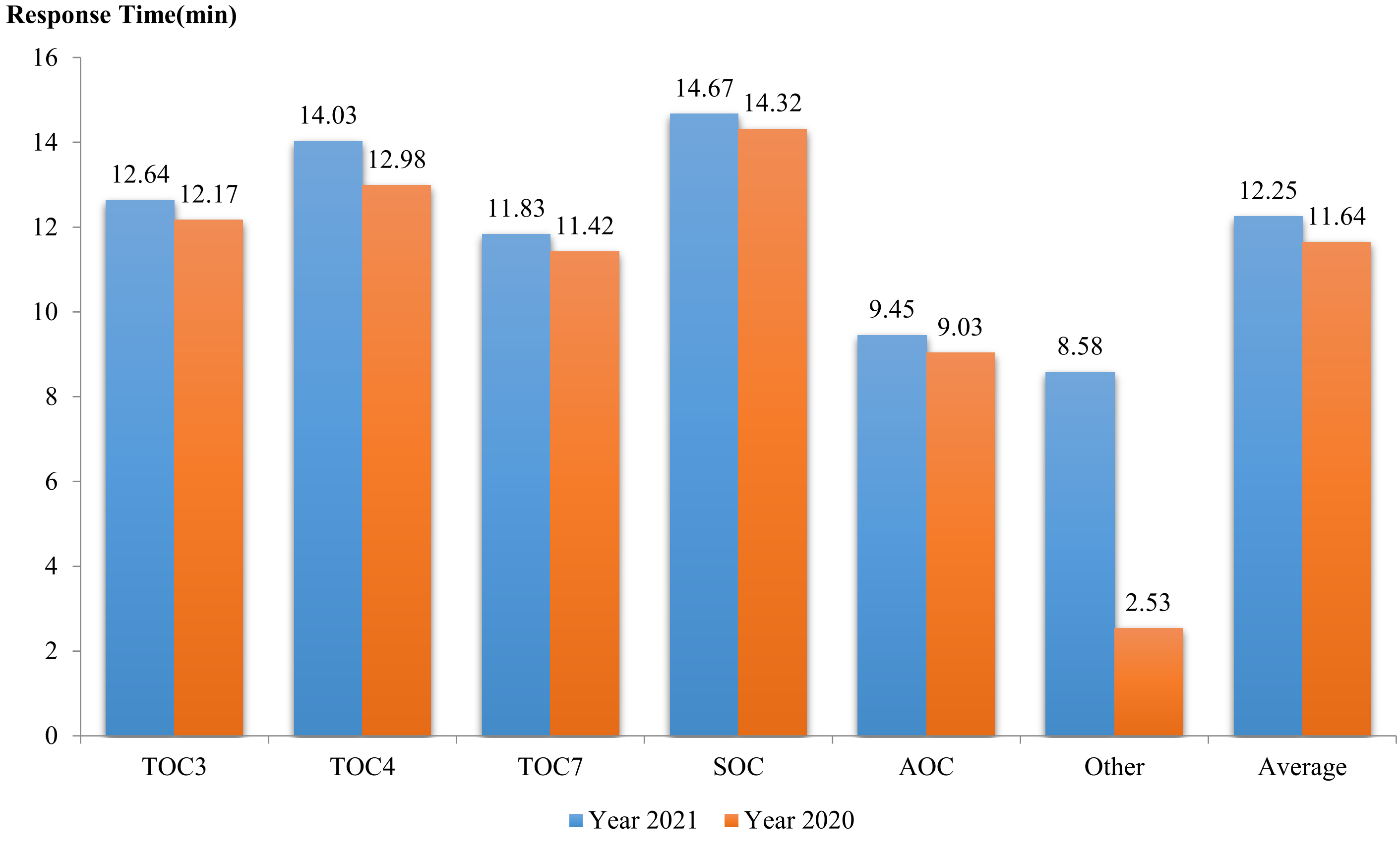


Figure 4.5 Distributions of Average Response Times to Incidents/disabled Vehicles

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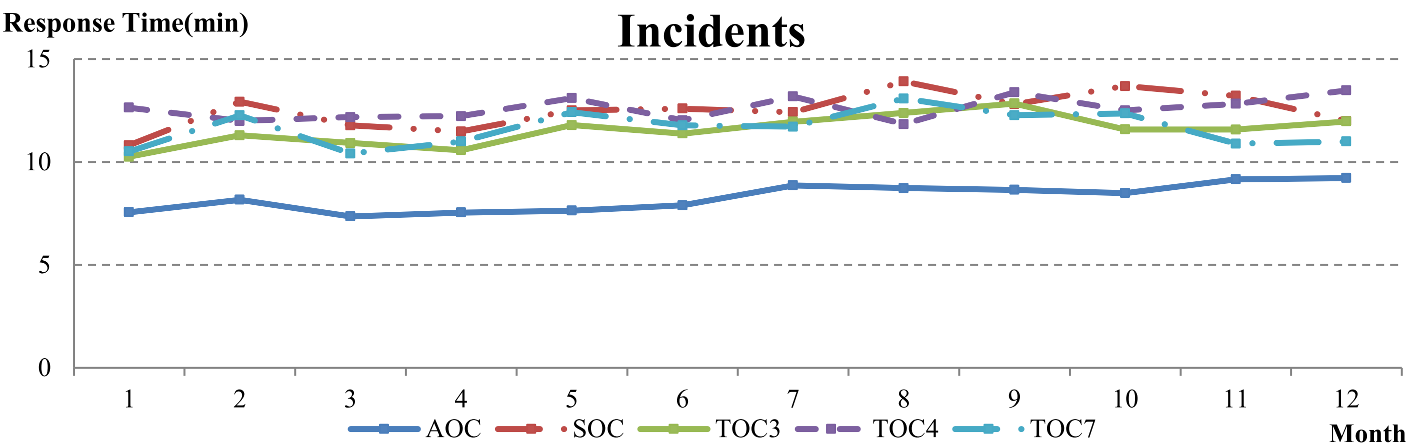
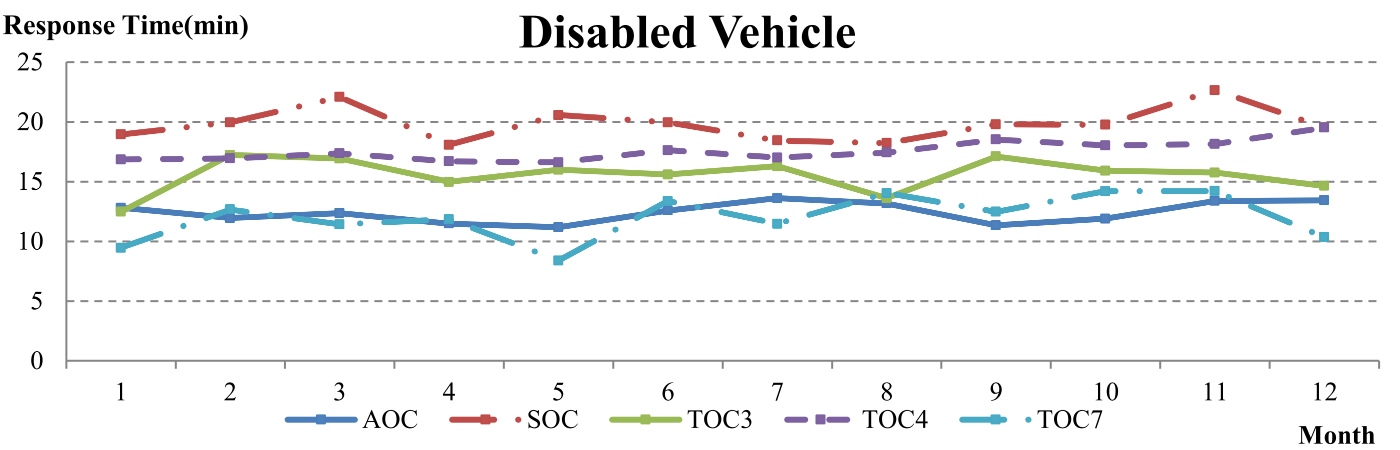
Evaluation of Efficiency and Effectiveness

In Figure 4.6 the average response times to incidents by TOC 3, TOC 4, TOC 7 and SOC are fairly consistent throughout the year and are between 10 and 14 minutes. AOC shows fairly quick and consistent response times between 7 and 9.2 minutes for incidents through year 2021. On the other hand, the response times for disabled vehicles range between 8 and 23 minutes. AOC and TOC 7 exhibited a relatively shorter response time for disabled vehicles throughout the year, compared to SOC, TOC 3, and TOC 4. Overall, the average response time for AOC is shorter than for most TOCs over the entire year for both incidents and disabled vehicles.



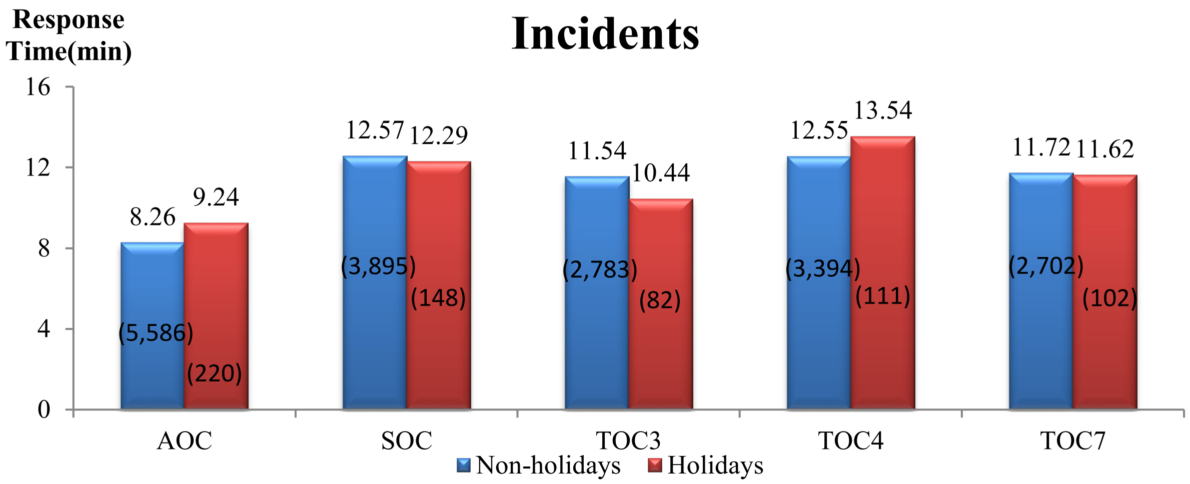


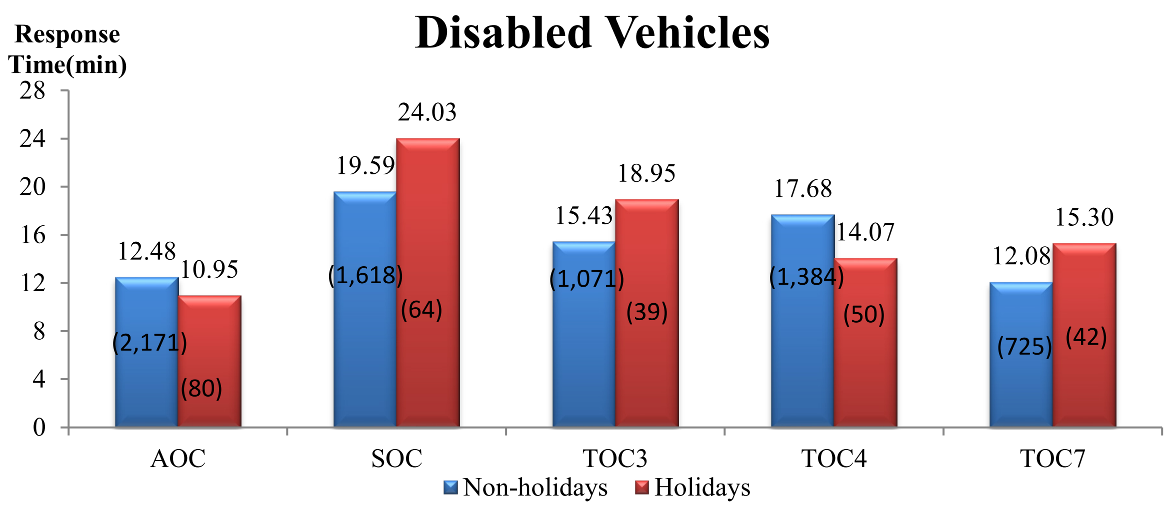
Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

Figure 4.6 Average Response Times for Operation Centers by Month in 2021

CHAPTER 4
Evaluation of Efficiency and Effectiveness

Figure 4.7 shows that most operation centers, except AOC and TOC 4, exhibited slightly faster response times for incidents occurred during holidays in 2021. Unlike other centers, TOC 4 and AOC showed shorter response times for disabled vehicles on holidays than on non-holidays.





Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

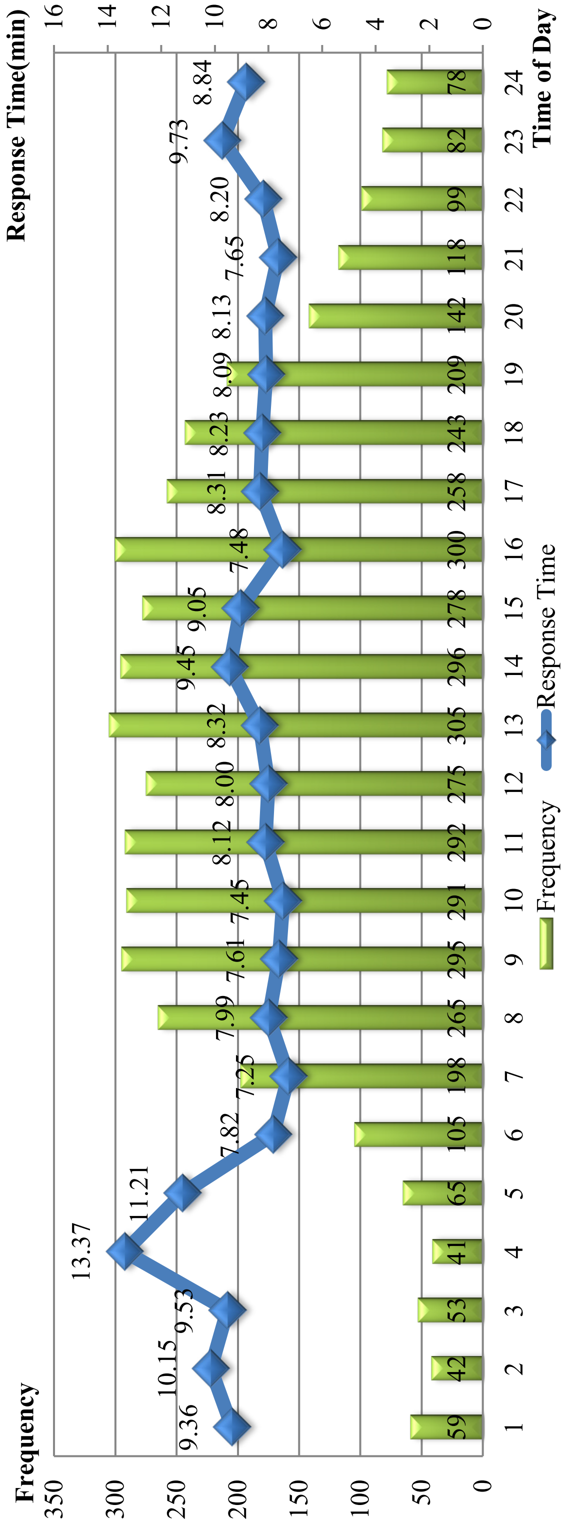
2. Numbers in each parenthesis show the data availability.

3. Holidays include New Year's Day, Martin Luther King Jr. Day, Washington's Birthday, Memorial Day, Independence Day, Labor Day, Columbus Day, Veterans Day, Thanksgiving Day, and Christmas Day

Figure 4.7 Average Response Times for Operation Centers on Holidays and Non-holidays in 2021

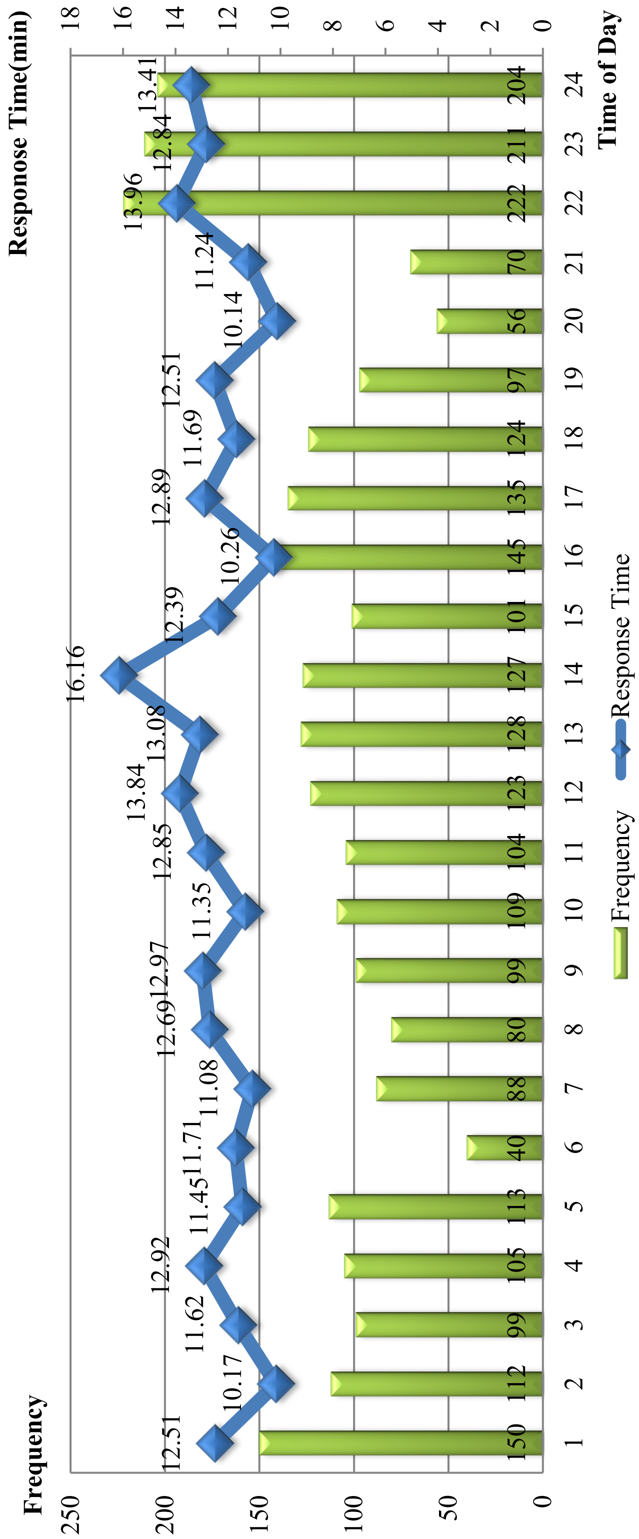
Figures 4.8 to 4.12 present the average response times by time of day during weekdays for each operation center. The bar graph represents the average incident frequencies to which the operation center responded, where the line graph illustrates its average response times by the time of day. Overall, AOC shows quite consistent response times during the daytime, and its response times for most cases during the night tend to be longer. On the other hand, the response times by SOC vary with the incidents responded to during the day. Since SOC operates as the backup of TOCs 3, 4 and 7 after their operational hours (5 a.m. - 9 p.m.), incident response frequencies during non-operational hours are much higher than those by major TOCs (see Figures 4.10 to 4.12).

The response times by TOC 3, TOC 4 and TOC 7 are quite consistent during their operational periods (5 a.m. – 9 p.m.). The responded incident frequencies by TOC 4 and TOC 7 also exhibit distinct patterns during p.m. peak hours.



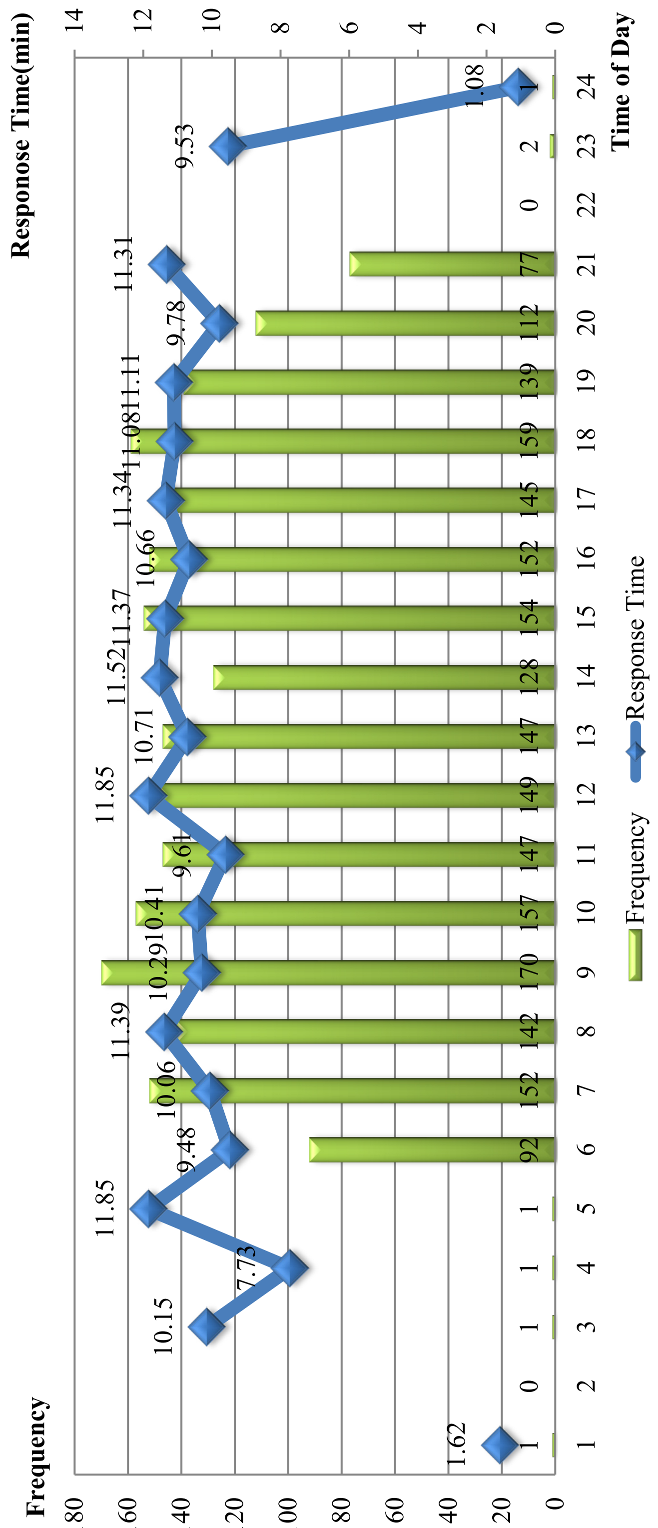
Note: Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

Figure 4.8 Average Response Times for AOC by Time of Day on Weekdays in 2021



Note: Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

Figure 4.9 Average Response Times for SOC by Time of Day on Weekdays in 2021

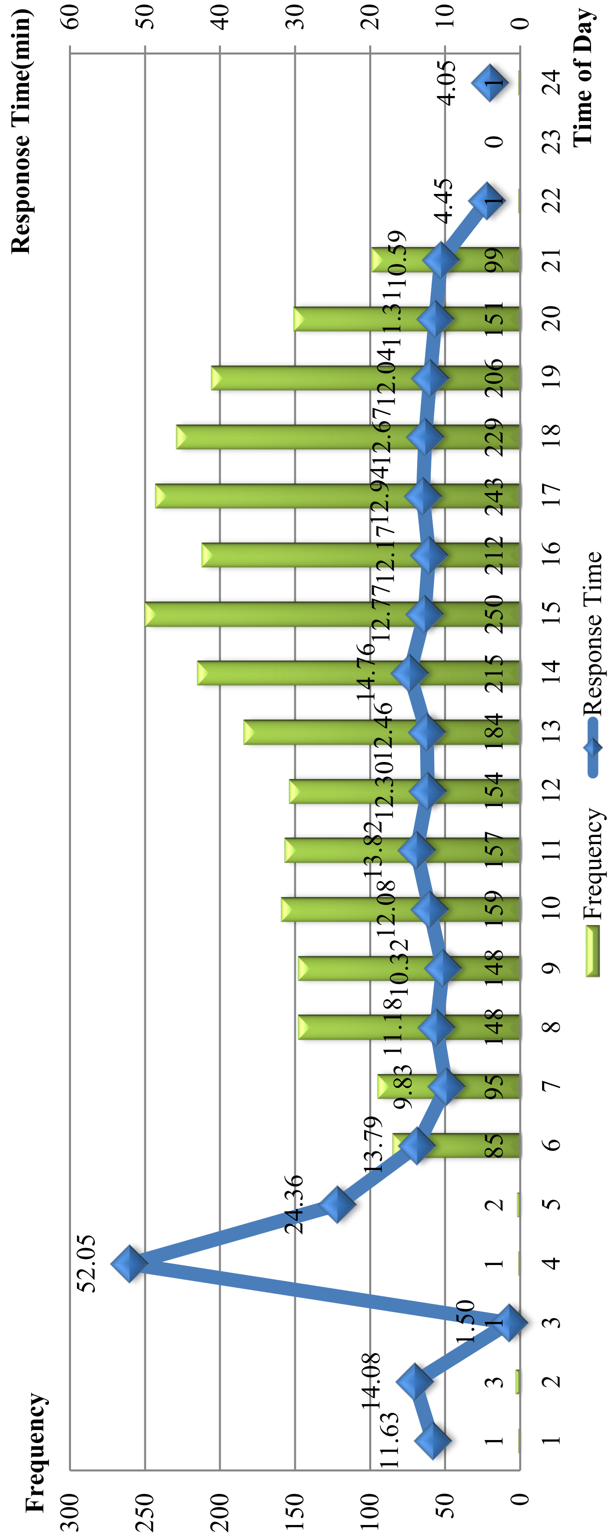


Note: Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

Figure 4.10 Average Response Times for TOC3 by Time of Day on Weekdays in 2021

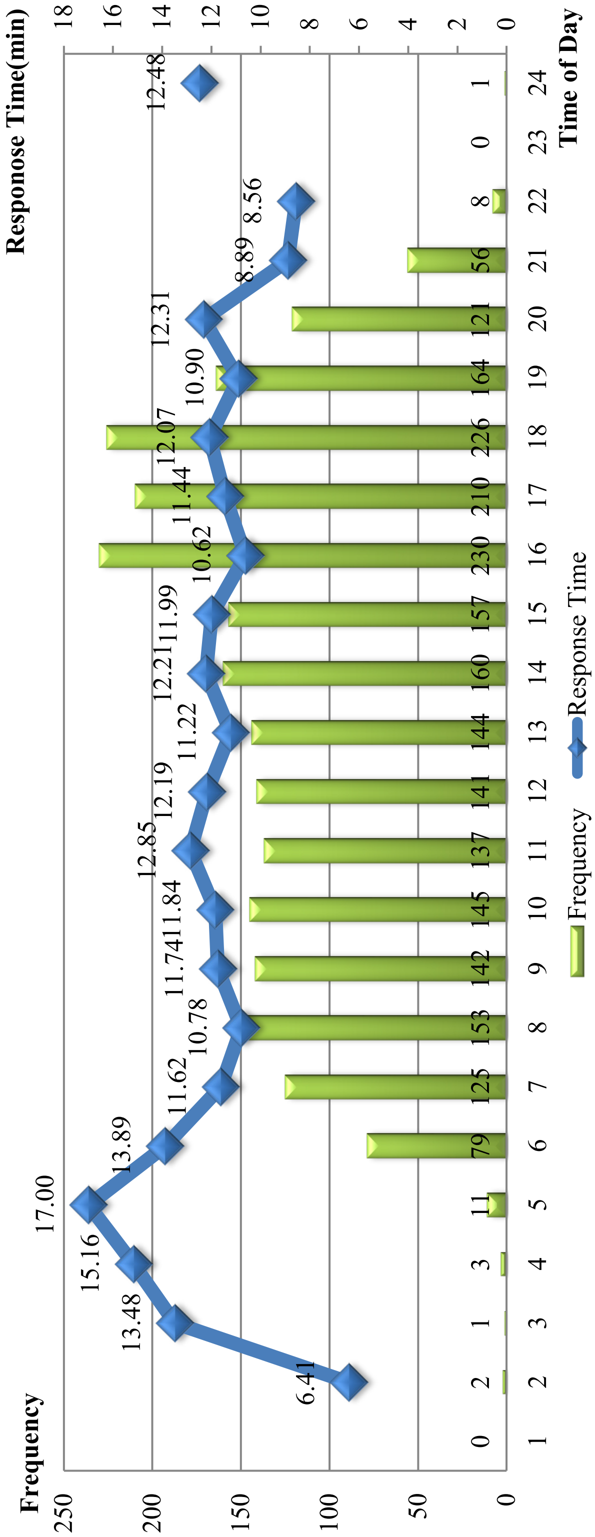
CHAPTER 4

Evaluation of Efficiency and Effectiveness



Note: Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

Figure 4.11 Average Response Times for TOC4 by Time of Day on Weekdays in 2021

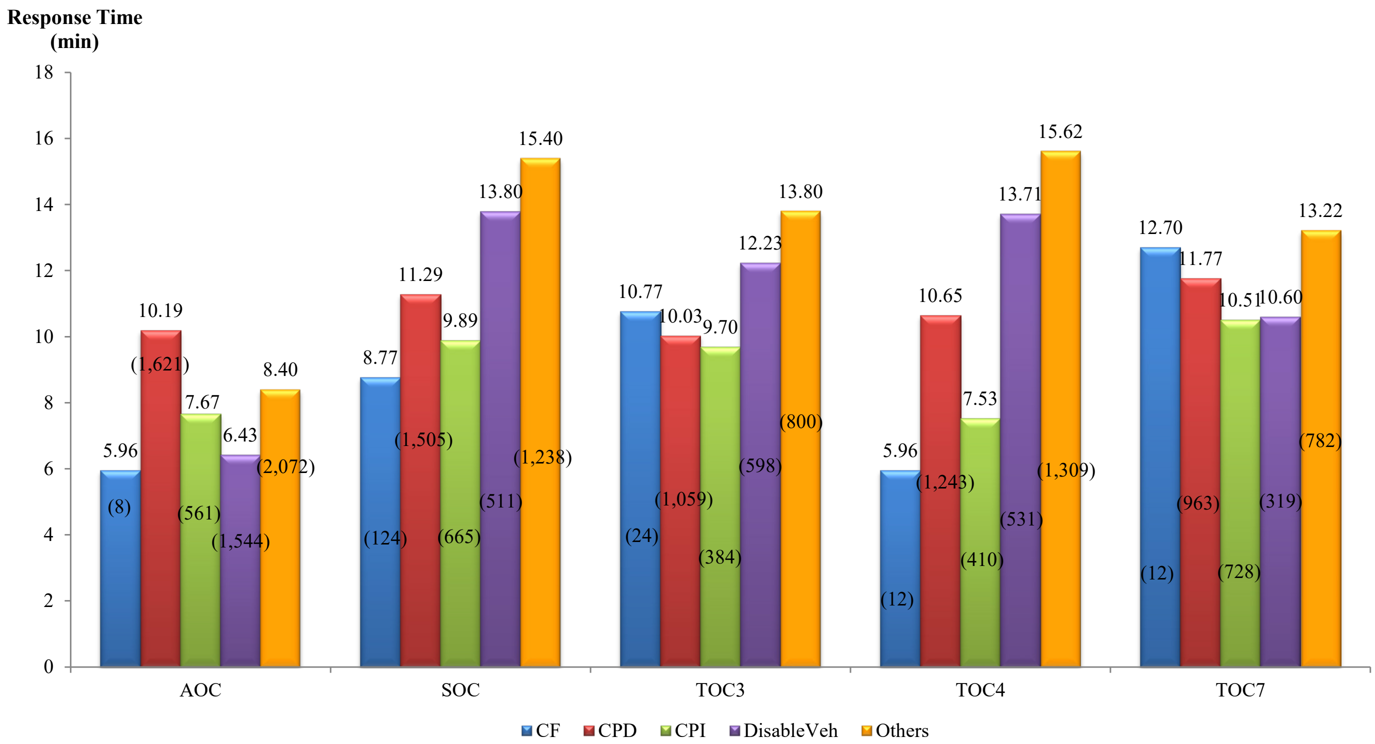


Note: Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

Figure 4.12 Average Response Time for TOC7 by Time of Day on Weekdays in 2021

CHAPTER 4
Evaluation of Efficiency and Effectiveness

Figure 4.13 shows a further analysis of response efficiency, where most operation centers demonstrated faster responses for incidents involving vehicle collision, injuries (CPI), and fatalities (CF) in 2021. On the other hand, most operation centers took relatively longer response times for disabled vehicles and other types of incidents, such as fire, debris, police activities, etc.

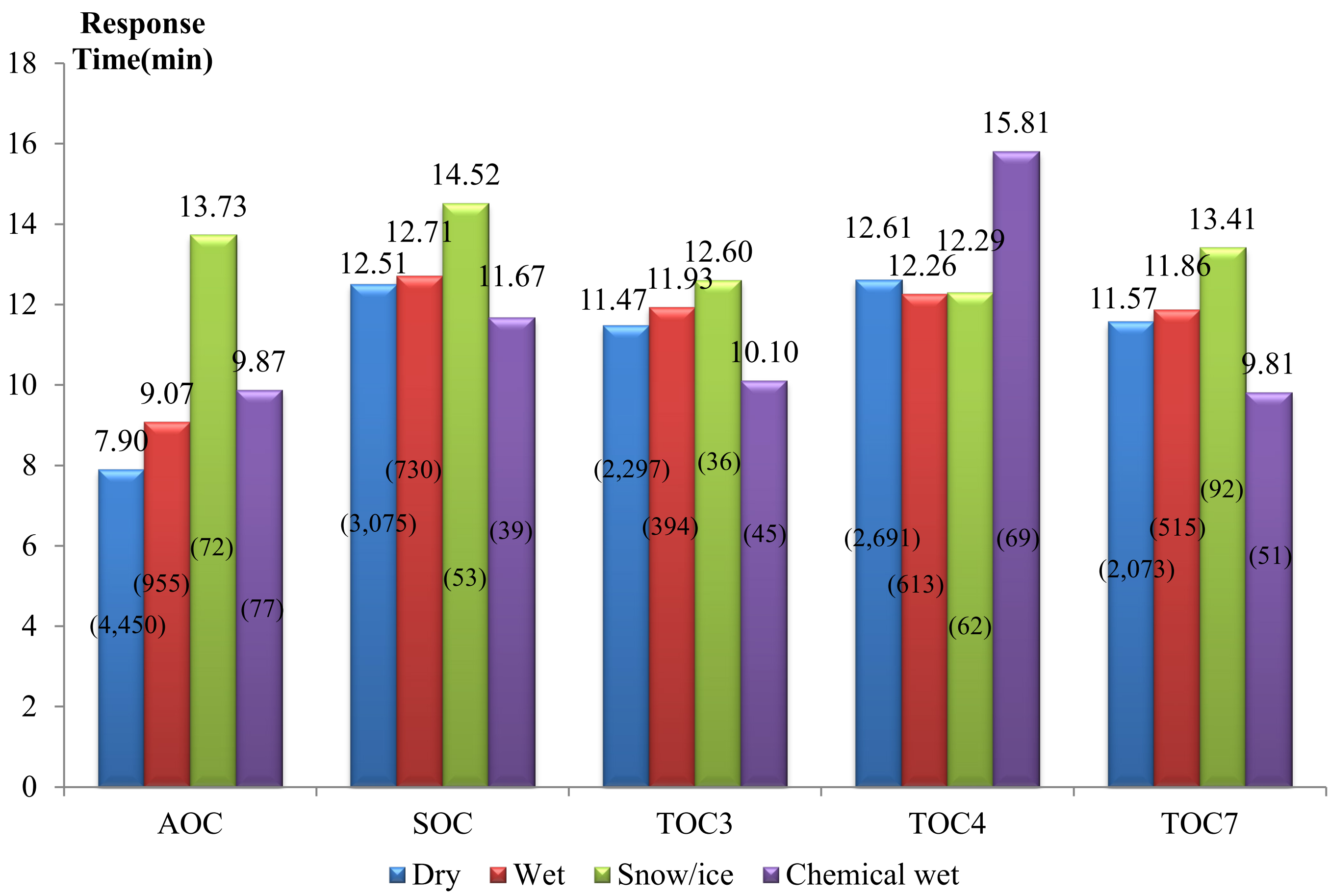


Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.
2. Numbers in each parenthesis show frequencies.
3. CF, CPD, and CPI represent collision-fatality, collision-property damage, and collision-personal injury, respectively.
4. Others include weather closures police activities, off-road activities, emergency roadwork, debris in roadway, and vehicles on fire.

Figure 4.13 Average Response Times for Operation Centers by Incident Nature in 2021

CHAPTER 4
Evaluation of Efficiency and Effectiveness

With respect to the pavement conditions, each operation center shows different response patterns under different pavement conditions. Overall, AOC tends to show a shorter average response time than any other operation center under most pavement conditions (See Figure 4.14).



Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.

2. Numbers in the parenthesis show the data availability for this analysis.

Figure 4.14 Average Response Times for Operation Centers by Pavement Conditions in 2021

CHAPTER 4

Evaluation of Efficiency and Effectiveness

Figures 4.15 through 4.19 present the response times for operation centers by detection source. The bar graph represents the available data to compute the average response times, while the line graph represents the computed average response times. The major detection source for AOC is MDTA, while the state police and CHART units detect the most incidents to which SOC responded. For SOC, on average, the incidents detected by CCTV and CHART units have relatively fast responses.

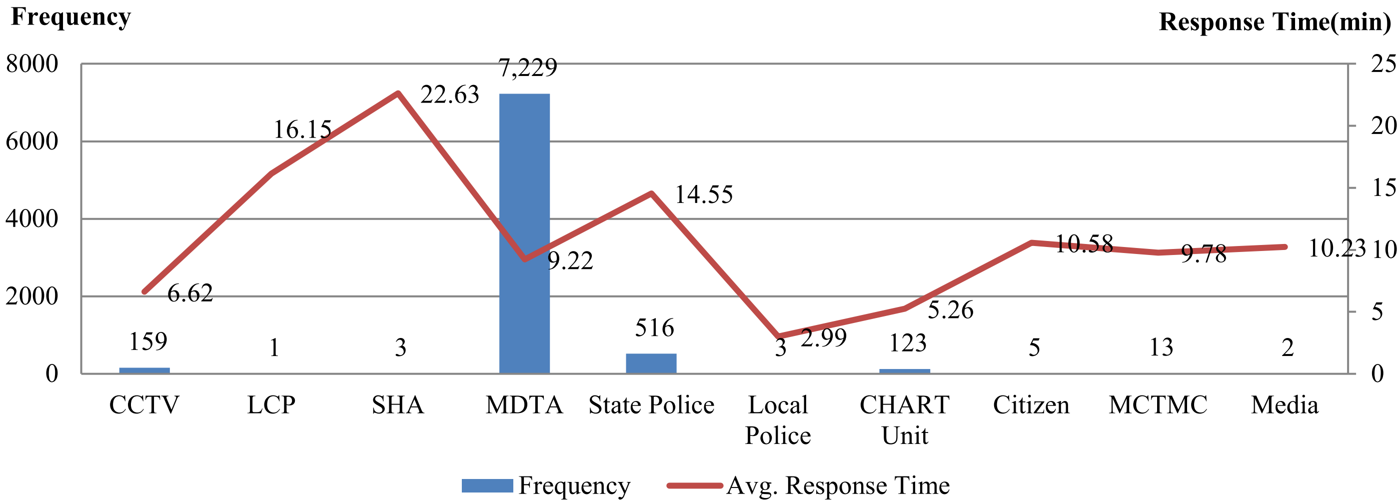


Figure 4.15 Average Response Times for AOC by Detection Source in 2021

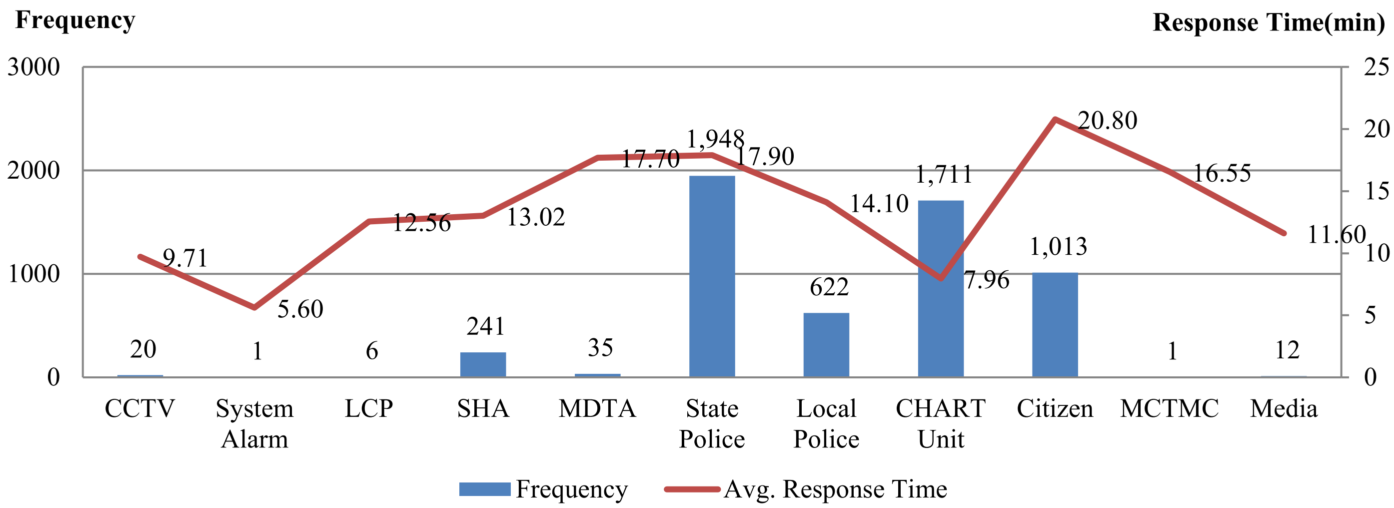


Figure 4.16 Average Response Times for SOC by Detection Source in 2021

As shown in Figure 4.17, 4.18 and 4.19, for TOCs 3 and 7, CHART and state police are the two major detection sources. In addition, the incidents detected by CHART response units have relatively shorter response time than those detected via most other sources in TOCs 3, 4, and 7.

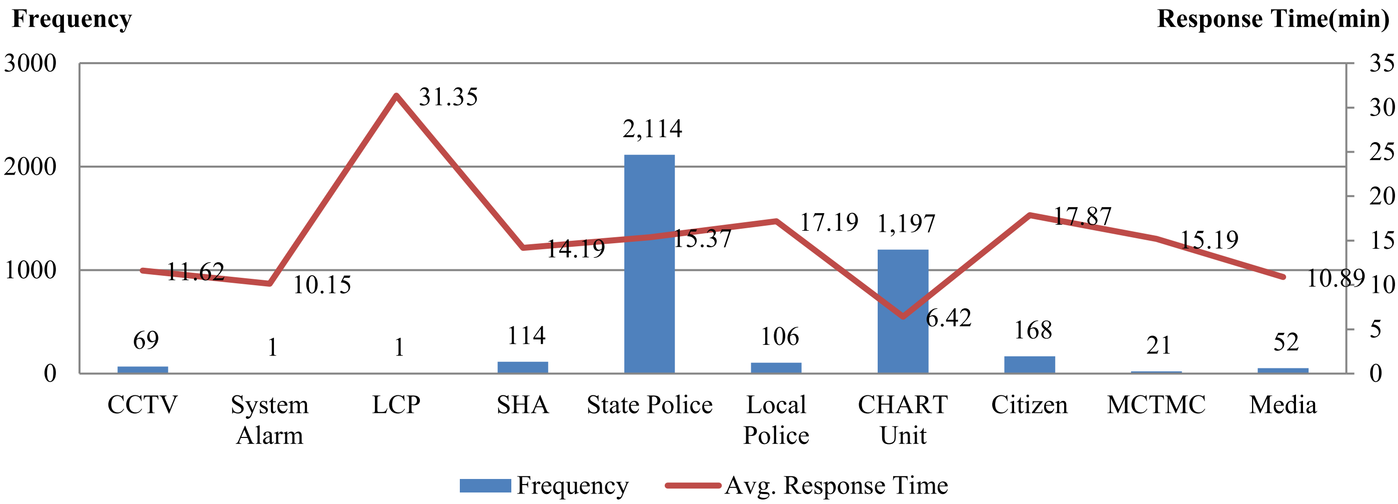


Figure 4.17 Average Response Times for TOC 3 by Detection Source in 2021

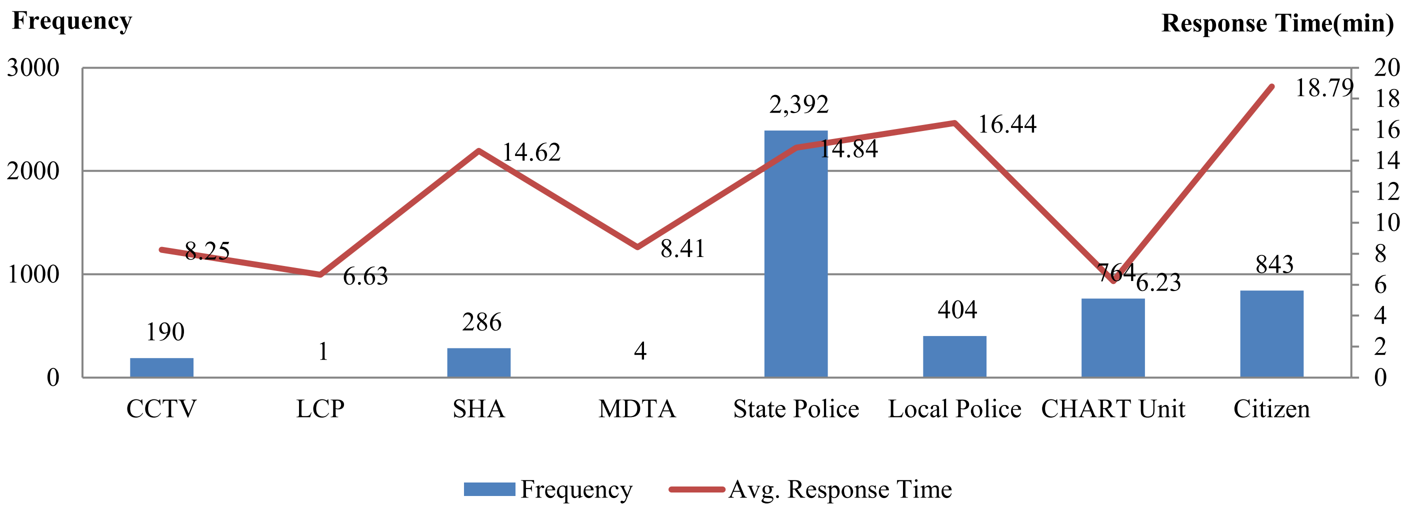


Figure 4.18 Average Response Times for TOC 4 by Detection Source in 2021

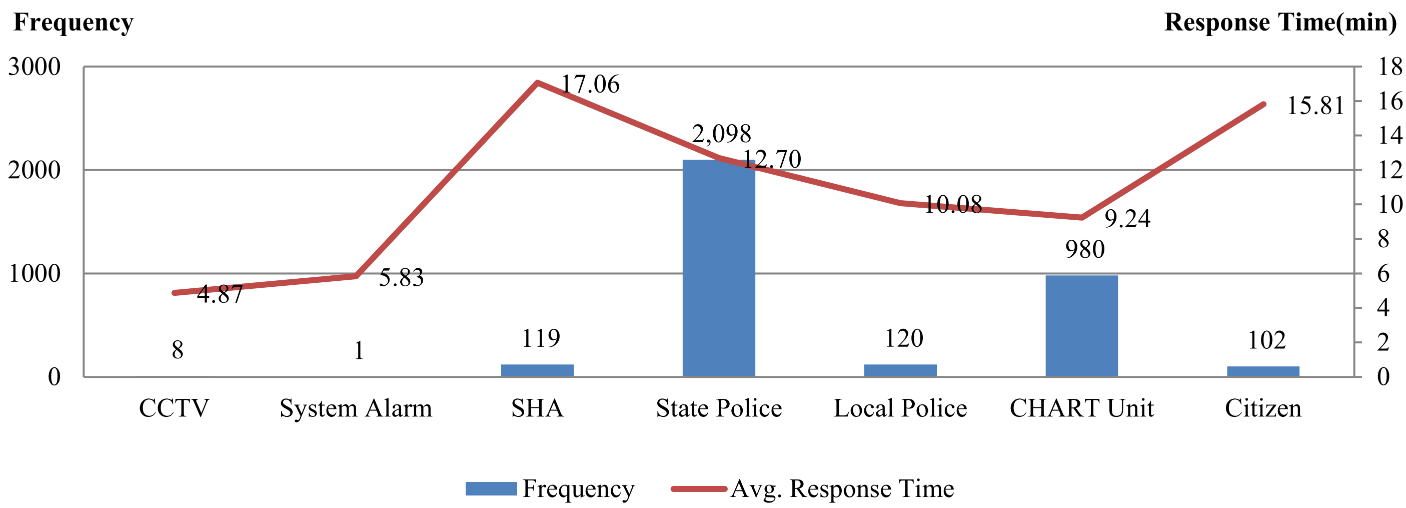
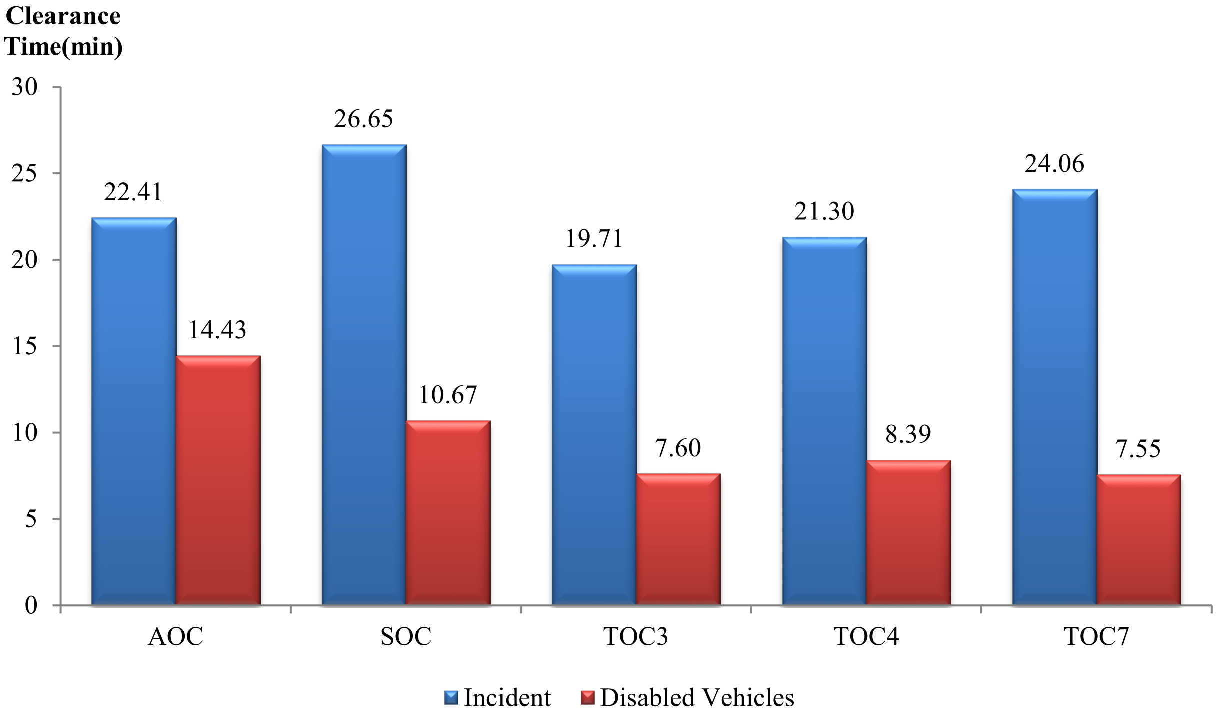


Figure 4.19 Average Response Times for TOC 7 by Detection Source in 2021

CHAPTER 4
Evaluation of Efficiency and Effectiveness

4.3 Analysis of Clearance Efficiency

As is well recognized, the efficiency of incident clearance could be varied by many factors. Figure 4.20 summarizes the clearance efficiency of incidents/disabled vehicles by operation center. The average clearance time by SOC is longer than any other for incidents. On the other hand, TOC 3 and TOC 7 show the smallest average clearance times for incidents and disabled vehicles, respectively. Further analyses of incident clearance times are presented in Chapter 6.



Note: Data only for incident duration between 1 minute and 120 minutes are used for this analysis.

Figure 4.20 Average Clearance Times by Operation Center in 2021

4.4 Reduction in Incident Duration

An essential 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, no incident-management-related data prior to CHART exists for any meaningful assessment. Hence, this study used the alternative of comparing average incident clearance times in 2021 for non-responded incidents and those to which CHART responded. Since CHART's incident management team responded to most incidents in 2021, the data for non-CHART incidents are very limited.

Table 4.1 shows the comparisons of incident durations with and without the response of CHART teams. In 2021, the average incident duration with CHART is 26.31 minutes, shorter than the average duration of 35.16 minutes. It seems clear that the assistance of CHART response units reduced the clearance time of reported incidents. On average, CHART in 2021 contributed to a reduction in blockage duration of about 28 percent, which has certainly contributed significantly to savings in travel times, fuel consumption, and related socioeconomic costs.

Note that incidents responded by CHART with durations of less than one minute and those without CHART responses lasting less than five minutes were excluded from the analysis. Incidents of "Unknown Lane Blockage" were redistributed to shoulder-only incidents and one-lane blockage incidents, which are mostly for minor incidents with the highest frequency.

CHAPTER 4
Evaluation of Efficiency and Effectiveness

Table 4.1 Comparisons of Incident Durations for Various Types of Lane Blockages in 2021 (Duration= Cleared Time-Received Time)

Blockage	With CHART Patrol		Without CHART Patrol		Incidents with CHART but took longer durations than the average duration of those without CHART (B)	
	Duration (min)	Sample Frequency (A)	Duration (min) (B)	Sample Frequency	Sample Frequency (C)	Percentage (C/A *100)
Shoulder	21.78	5,863	35.41	421	1,225	20.90%
1 lane	23.52	12,111	34.99	744	2,875	23.74%
2 lanes	40.34	2,624	49.09	154	404	15.40%
3 lanes	46.98	715	59.64	44	213	29.79%
>=4 lanes	50.06	365	64.85	16	105	28.77%
Weighted Average	26.31 (25.35)	21,678 (19,988)	37.82 (37.02)	**1,379 (1,298)**		
Unknown	17.20	6199	33.89	623		

Note: 1. Incidents with durations of less than 1 minute were excluded from the analysis.
2. Cases of "Unknown" blockage were redistributed into different blockage categories.
3. The numbers in parentheses show the results from year 2020.

Chapter 5

ANALYSIS OF RESPONSE TIMES

Chapter 5
Analysis of Response Times

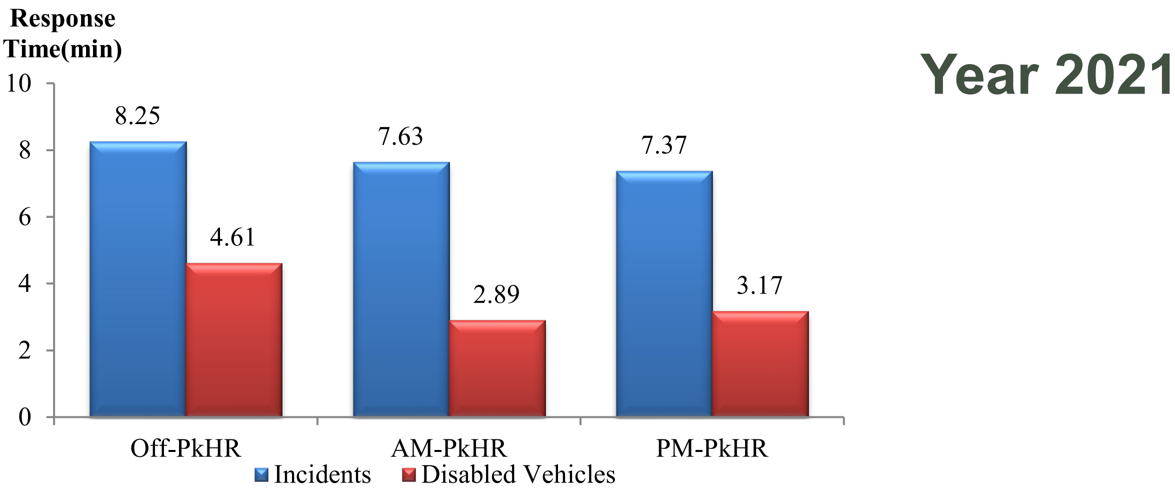
A large body of traffic studies has pointed out the critical role of efficient response to the total delay incurred by incidents, and concluded that an increase in incident response time may contribute to the likelihood of having secondary incidents (Bentham, 1986; Brodsky and Hakkert, 1983; Mueller et al., 1988). The study results by Sanchez-Mangas et al. (2009) show that a reduction of 10 minutes in emergency response time could result in 33 percent less probability of incurring vehicle collision and fatalities. Most studies conclude that dispatching emergency services units and clearing the incident scenes in a timely manner are the key tasks for minimizing incident impact (Kepaptsoglou et al., 2011: Huang and Fan, 2011).

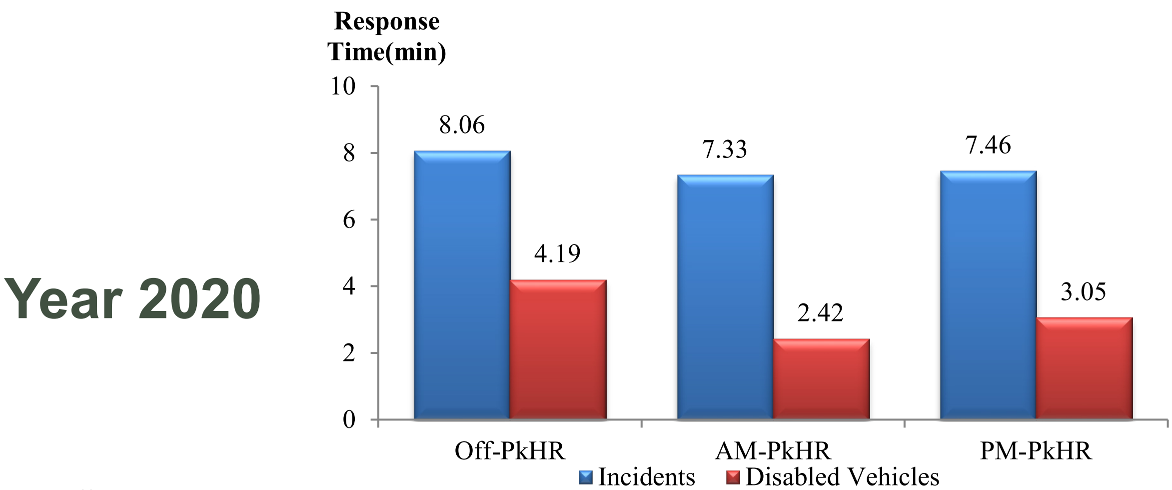
For these reasons, this chapter presents the results from the statistical analysis of incident response time; this analysis provides a fundamental insight into the characteristics of incident response times under various conditions.

Chapter 5
Analysis of Response Times

5.1 Distribution of Average Response Times by Time of Day

Figure 5.1 compares the response times by time of day in 2021 and 2020. In 2021, the average incident response times during off-peak and a.m. peak hours were slightly longer than those of 2020, while the average response time during p.m. peak hours were shorter than that in 2020. Also, the average response times to disabled vehicles in 2021 were slightly longer than those in 2020 regardless of the time of day. As expected, the response times to incidents and disabled vehicles during off-peak hours were longer than those during peak hours due likely to the resource constraints.



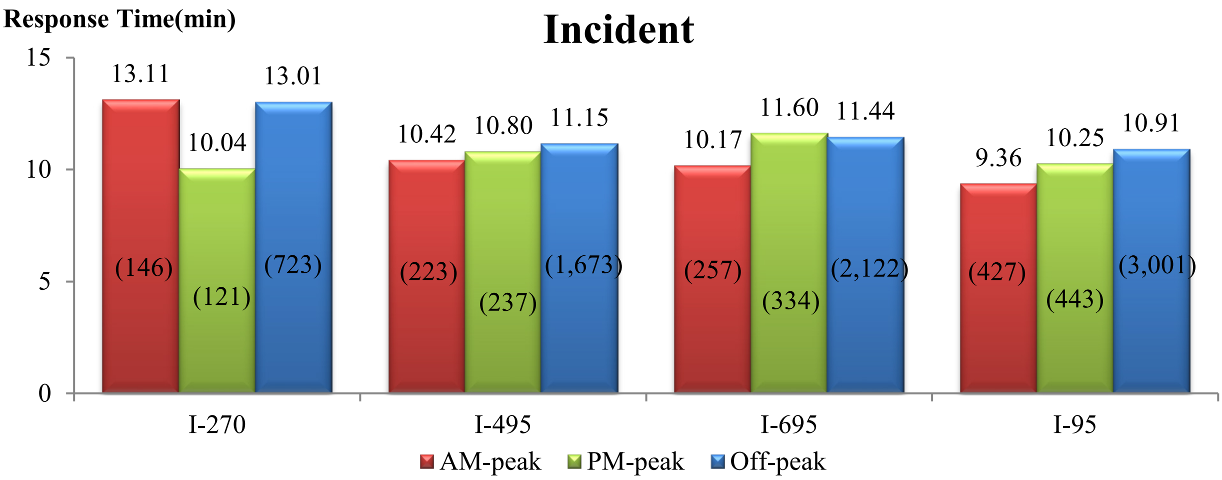


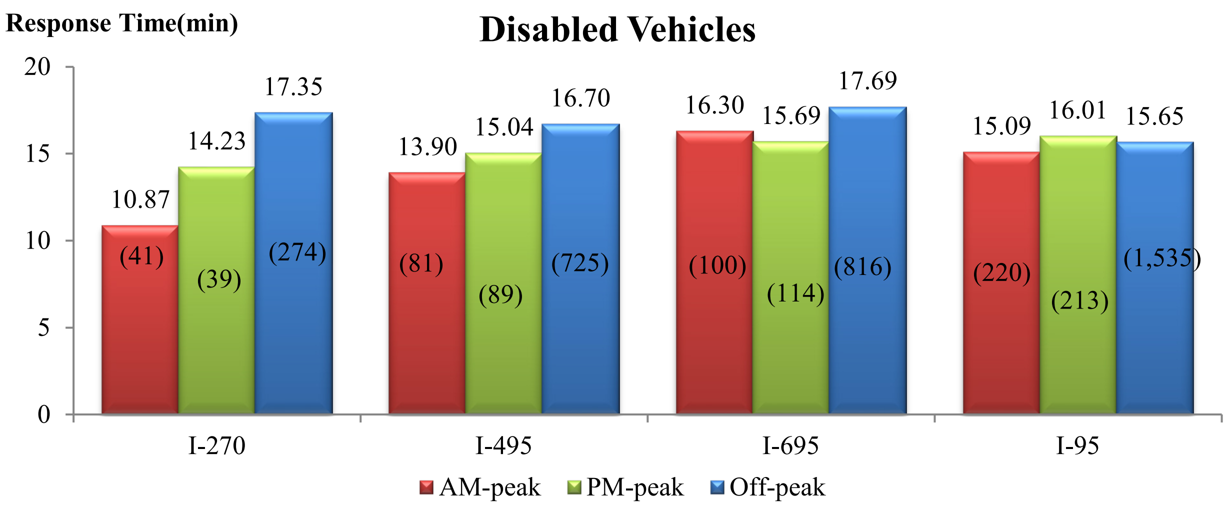
Note: Off-peak Hours include night times.

Figure 5.1 Distributions of Average Response Times by Time of Day in 2021 and 2020

Chapter 5
Analysis of Response Times

Figure 5.2 shows the average response times by different times of day on the major roads. Among those, the incidents on I-270 experienced the longest responses time during a.m. peak and off-peak hours, while incidents on I-95 received the shortest response times during those time periods. Regarding the average response times to disabled vehicles, those on I-695 and I-95 experienced the longest during am and pm peak hours, respectively.





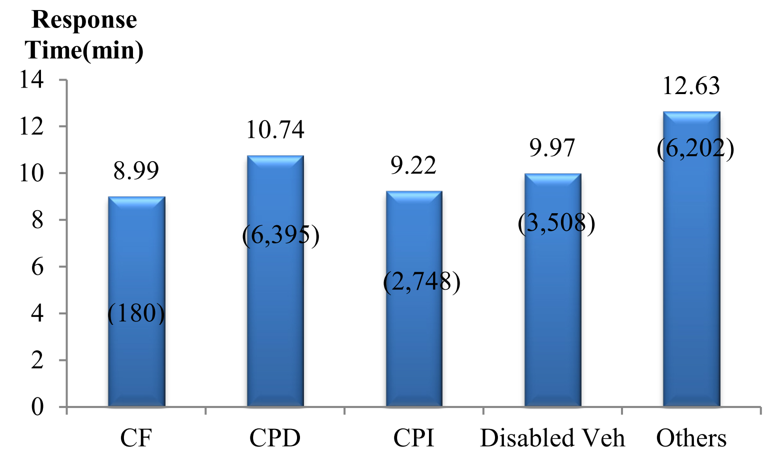
Note: 1. Data only for response times between 1 minute and 60 minutes are used for this analysis.
2. Numbers in each parenthesis show frequencies.

Figure 5.2 Distributions of Average Response Times for Roads by Time of Day in 2021

5.2 Distribution of Average Response Times by Incident Nature

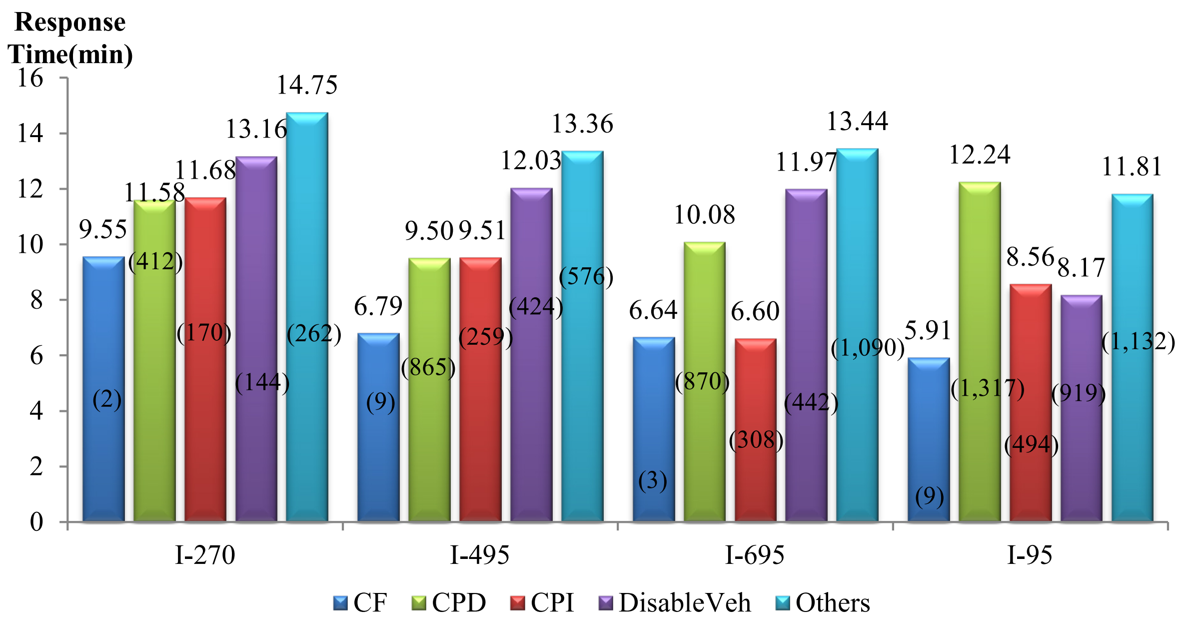
Figure 5.3 shows that the response times are likely to decrease for detected severe incidents. For instance, those incidents, causing any fatality or injuries (CF and CPI), usually lead to quicker responses than any other types of incidents.

A similar pattern of decreased response times as the incident becomes severe appears on most of the major corridors as shown in Figure 5.4.



Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.
2. Numbers in each parenthesis show frequencies.
3. CF, CPD, and CPI represent collision-fatality, collision-property damage, and collision-personal injury, respectively.
4. Others include police activities, off-road activities, emergency roadwork, debris in roadway, and vehicles on fire.

Figure 5.3 Average Response Time by Incident Nature in 2021



Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.
2. Numbers in each parenthesis show frequencies.

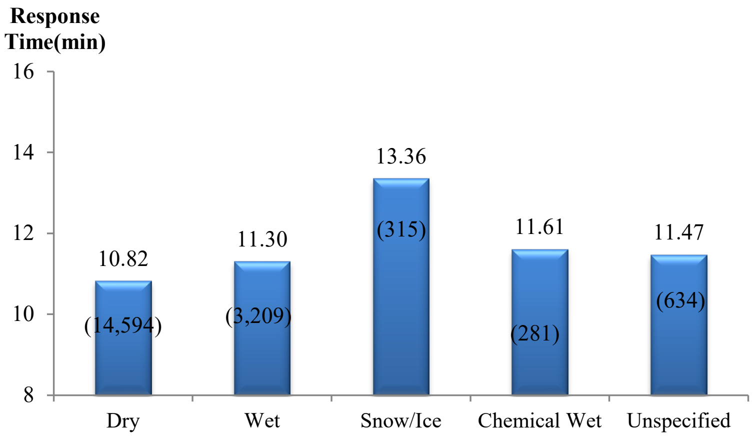
Figure 5.4 Average Response Time for Roads by Incident Nature in 2021

Chapter 5
Analysis of Response Times

5.3 Distribution of Average Response Times by Various Factors

This section presents the results of analysis on how other factors would influence the response times.

Figure 5.5 illustrates that the response times may vary with the pavement conditions. The responses are likely to be slower on snow/ice pavement, whereas they tend to be faster on a dry condition. The information on the weather conditions is usually unavailable in most incident databases.



Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.
2. Numbers in parentheses show frequencies.

Figure 5.5 Average Response Time by Pavement Condition in 2021

As shown in Figure 5.6, incidents causing lane closure are likely to be responded faster than those incidents without lane closure. Figures 5.4 and 5.6 illustrate that the response times are likely to be shorter for more severe incidents, such as those causing a fatality, an injury, or a lane closure.

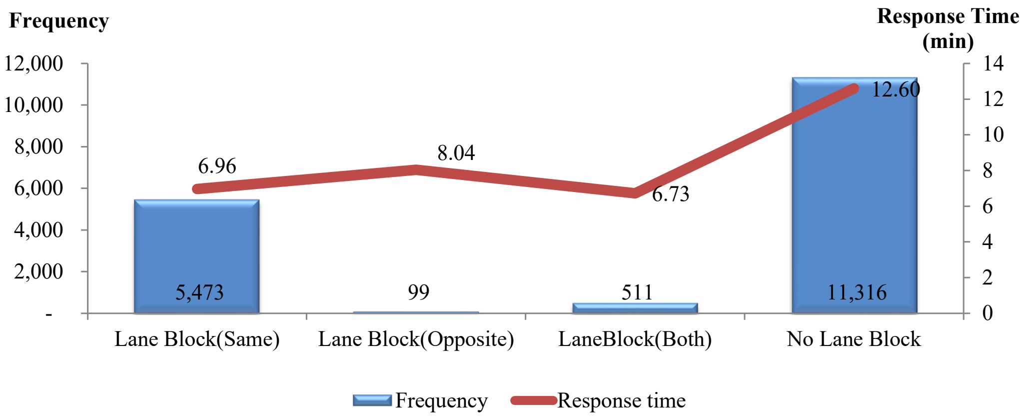
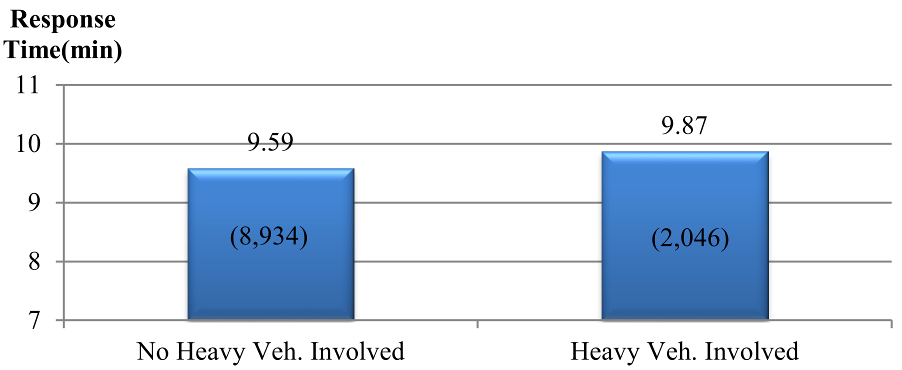


Figure 5.6 Average Response Time by Lane Blockage in 2021

Chapter 5
Analysis of Response Times

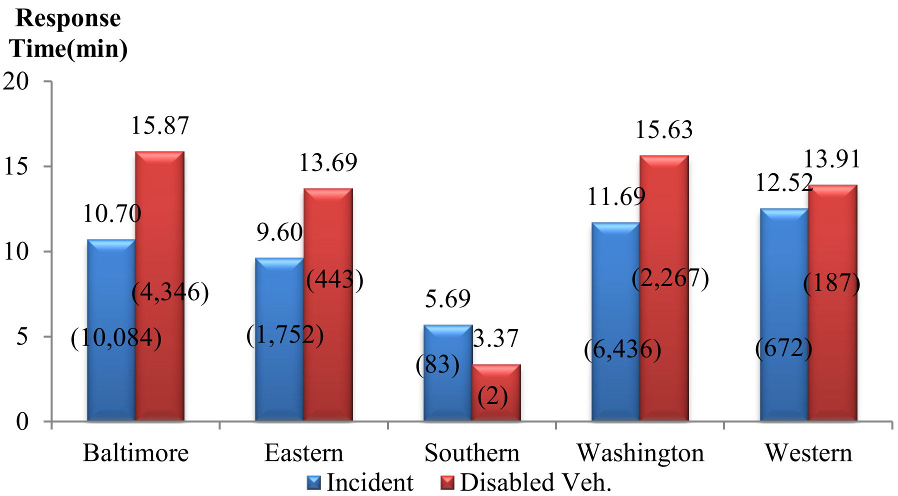
Figure 5.7 shows that incidents involving heavy vehicles, on average, experienced a similar response time as with only passenger cars.

Note that the response time may differ among regions, due to the discrepancy in the available resources and incident frequency among operation centers, including coverage area, incident rates, traffic volumes, etc. Figure 5.8 demonstrates that the response times were faster in suburban areas, including Eastern and Southern Maryland, than in the metropolitan areas, such as the Baltimore and Washington regions. Urban areas are more likely to have higher incident rates and heavier traffic volumes, which could impede the efficiency of response units. One can also notice that the responses for incidents were usually quicker than those for disabled vehicles in most regions.



Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.
2. Numbers in parentheses show frequencies.

Figure 5.7 Average Response Time by Heavy Vehicle Involvement in 2021



Note: 1. Incident data only for response times between 1 minute and 60 minutes are used for this analysis.
2. Numbers in parentheses show frequencies.
3. There is no record for disabled vehicles at Southern Maryland with valid information.

Figure 5.8 Average Response Time by Region in 2021

Chapter 6

ANALYSIS OF INCIDENT DURATIONS

Chapter 6
Analysis of Incident Durations

For effective and efficient traffic management after incidents, responsible agencies can convey information to travelers by updating variable message signs, estimating the resulting queue length, assessing the need to implement detour operations, and performing any other control strategies to mitigate congestion. To maximize the effectiveness of these operational measures, reliably predicted/estimated incident durations will certainly play an essential role.

This chapter presents the statistical results from the incident duration data; this analysis provides some critical insights into the characteristics of incident duration under various conditions. In this analysis, the distributions of average incident duration are classified by the following categories: Nature, County, County and Nature, Weekdays and Weekends, Peak and Off-Peak Hours, CHART Involvement, and Roads.

Chapter 6
Analysis of Incident Durations

6.1 Distribution of Average Incident Durations by Nature

In general, incidents are classified into two large groups, based on whether or not they involve collisions. The first group, incidents with collisions, consists of three types: collisions with fatalities (CFs), collisions with personal injuries (CPIs), and collisions with property damage (CPDs). The second group, incidents without collisions, includes incidents of various natures, such as disabled vehicles, debris in the roadway, vehicles on fire, police activities, etc. Table 6.1 summarizes the categories of incidents by their nature as used in the remaining analysis.

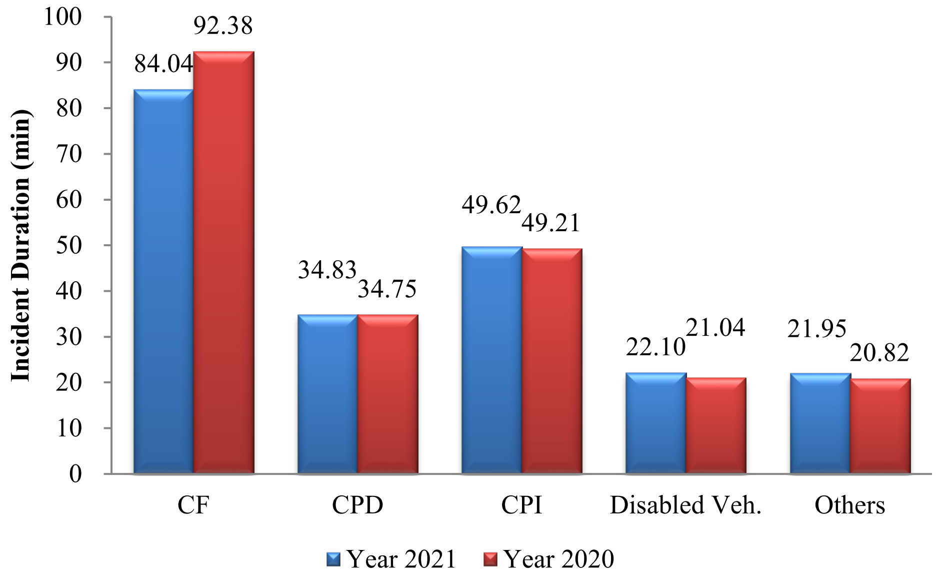
Note that Disabled Vehicles are defined as those disabled vehicles that interrupt the normal traffic flow on the main lanes. In the category of incidents without collision, most are Disabled Vehicles. In 2021, about 38 percent of incidents without collision were caused by Disabled Vehicles. A similar pattern was also observed in 2020. In contrast, the other types of non-collision incidents occurred in relatively low frequencies; therefore, the study classifies all such incident types as one category, i.e., Others, as shown in Table 6.1.

Table 6.1 Categories of Incident Nature

Incidents	With collisions	Collisions-Fatalities(CF)	
		Collisions-Property Damage(CPD)	
		Collisions-Personal Injuries(CPI)	
	Without collisions	Disabled Vehicles	
		Others	Police Activities
			Off-Road Activities
			Emergency Roadwork
			Debris in Roadway
			Vehicles on Fire
			Weather Closure, etc.

Chapter 6
Analysis of Incident Durations

Figure 6.1 summarizes the average incident duration for each type in 2021 and 2020. The statistical results indicate that the average incident duration for CFs is significantly higher than that for the other incident natures. Statistically, an incident that has resulted in a fatality can last more than an hour on average. In contrast, incidents caused by Disabled Vehicles, on average, were much shorter in duration. The average incident duration for CFs in 2021 shows a decrease compared to that in 2020.



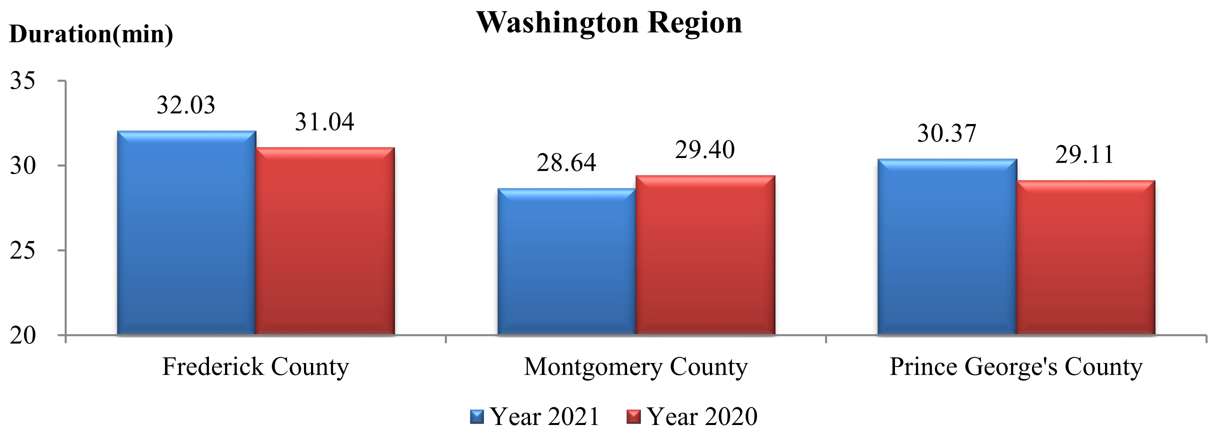
Note: 1. Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis
2. CF, CPD, and CPI represent collision-fatality, collision-property damage, and collision-personal injury, respectively.

Figure 6.1 Distribution of Average Incident Duration by Nature in 2021 and 2020

Chapter 6
Analysis of Incident Durations

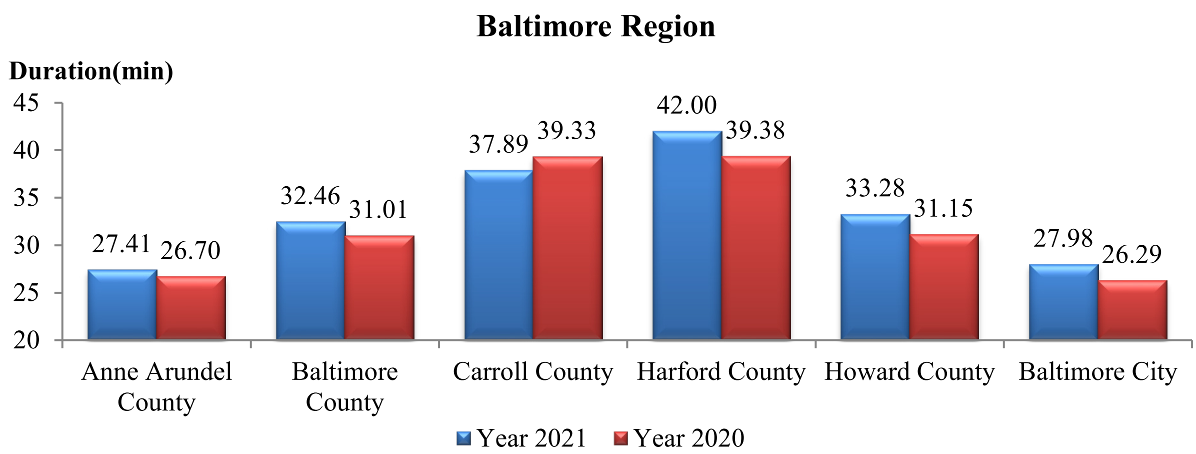
6.2 Distribution of Average Incident Durations by County and Region

The distribution of incident durations also varies between counties and regions. Figures 6.2 to 6.5 illustrate incident durations by county in regions in 2021 and 2020. In the Washington region, the area around Washington D.C. (Montgomery and P.G. Counties) has shorter incident durations than Frederick County, as shown in Figure 6.2. Figure 6.3 shows that the incidents especially around Carroll County and Harford County had longer durations than incidents occurring in other counties in the Baltimore region.



Note: Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis

Figure 6.2 Distribution of Average Incident Duration by County in Washington Region in 2021 and 2020

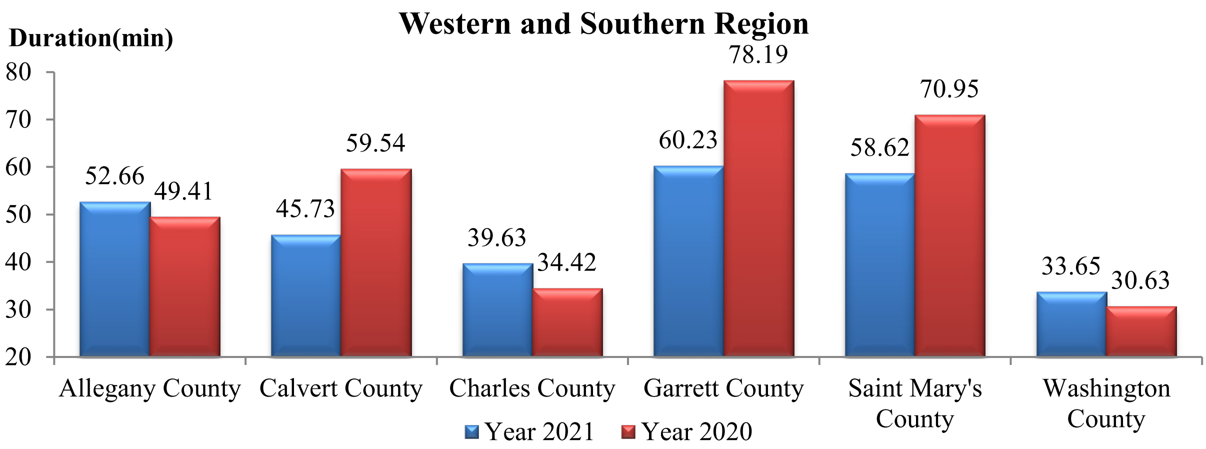


Note: Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis

Figure 6.3 Distribution of Average Incident Duration by County in Baltimore Region in 2021 and 2020

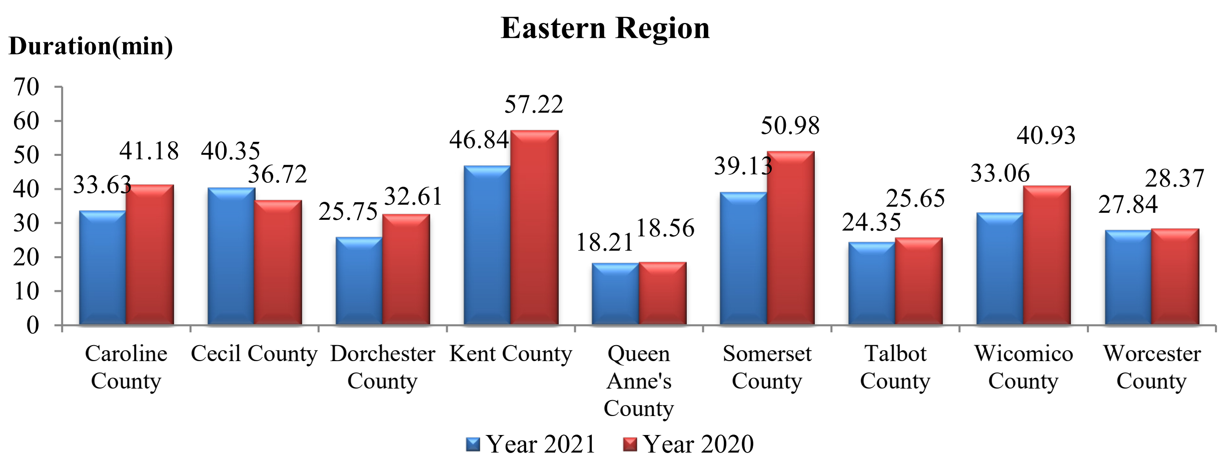
Chapter 6
Analysis of Incident Durations

Incidents that occurred in counties in western and southern Maryland mostly resulted in relatively longer durations. Figure 6.4 shows that the average incident duration in these areas is usually longer than thirty-f minutes, except for Washington County, which had the shortest average incident duration in western and southern Maryland in year 2021. Similarly, the incidents occurring in Queen Anne's County on the Eastern Maryland (Figure 6.5) are likely to result in shorter durations than those in any other areas of Eastern Shore. On the other hand, incidents occurred in Cecil County and Kent County on the Eastern Shore experienced the average incident duration of longer than forty minutes, respectively, in 2021.



Note: Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis

Figure 6.4 Distribution of Average Incident Duration by County in Western and Southern Regions in 2021 and 2020



Note: Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis

Figure 6.5 Distribution of Average Incident Duration by County on Eastern Region in 2021 and 2020

Chapter 6
Analysis of Incident Durations

Table 6.2 summarizes the average response times, clearance times, and incident durations by region. One can easily notice that incidents occurred in the Southern area took longer to be cleared than any other regions. On the other hand, the Eastern region took shorter time to clear the detected incidents, thus the average incident duration was relatively shorter than those in the other areas in Maryland in 2021.

Table 6.2 Summary of Incident Duration Components by Region

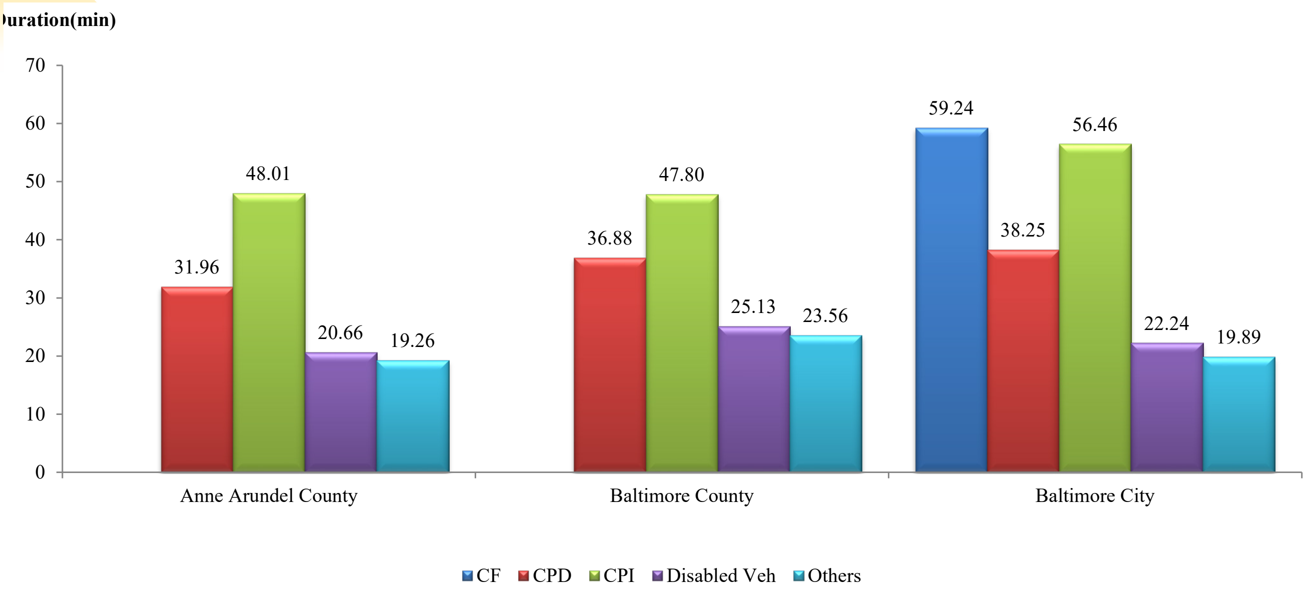
Region	Sample Frequency*	Avg. Response Time (mins)	Avg. Clearance Time (mins)	Avg. Incident Duration (mins)
Baltimore	12,128	7.77	23.12	30.90
Washington	7,603	7.63	22.83	30.45
Eastern	2,247	5.60	20.25	25.86
Western	886	8.62	26.05	34.67
Southern	68	6.75	36.03	42.79

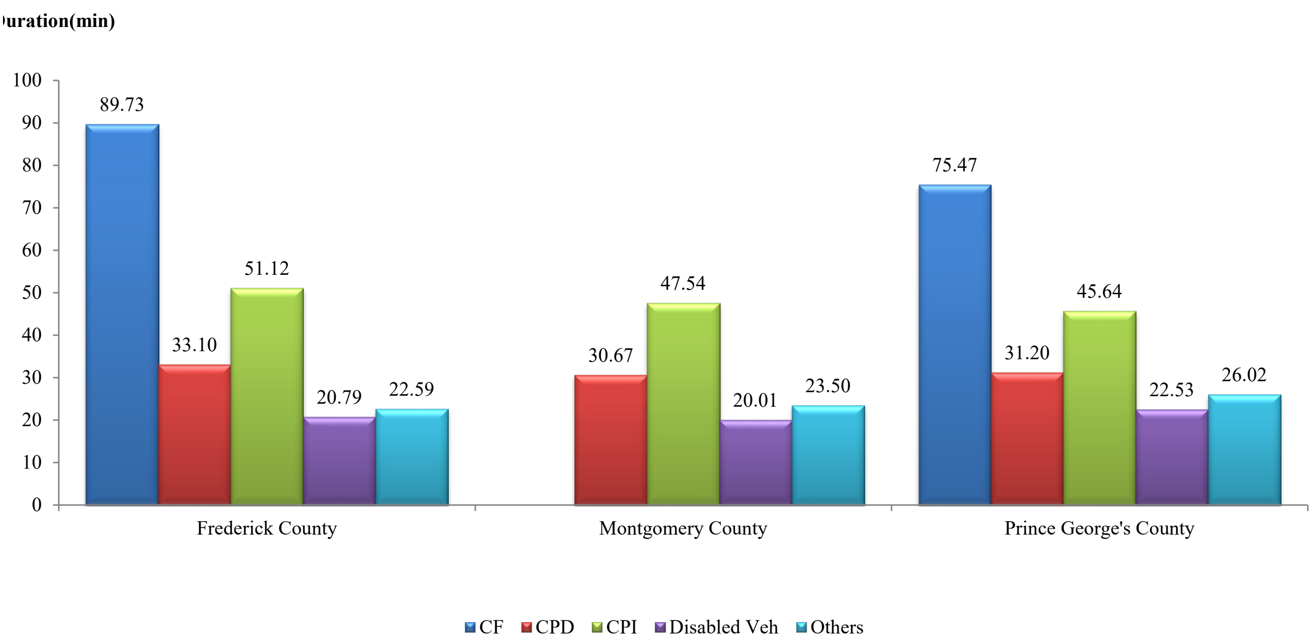
** Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis.*

Figure 6.6 compares incident durations by nature only for several major counties in Maryland. As shown in the figure, the average incident duration for CF in Baltimore City was shorter than in any other area. Among those counties, Prince George's County had the shortest duration for the incident with personal injury.

In most areas, the incident durations are highly likely to increase as the incident becomes more severe. For instance, the incidents with any fatality or personal injury showed the longest durations, followed by incidents with incidents with property damage.

Chapter 6
Analysis of Incident Durations





**Note: 1. Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis.*

2. CF, CPD, and CPI stand for collision-fatality incident, collision-property damage incident, and collision-personal injury incident, respectively.

Figure 6.6 Distribution of Average Incident Duration by County and Nature

6.3 Distribution of Average Incident Durations by Weekdays/Ends and Peak/Off-Peak Hours

As shown in Table 6.3, incidents occurred in weekends were likely to last longer than those on weekdays. This would be mostly due to the fact that fewer response teams are available during the weekends than during weekdays.

Table 6.3 Distribution of Average Incident Duration by Weekday and Weekend

	Year	Sample* Frequency	Avg. Response Time	Avg. Clearance Time	Avg. Incident Duration
Weekdays	2021	17,950	7.36	22.42	29.78
	2020	16,986	7.11	22.00	29.11
Weekends	2021	4,988	8.19	24.61	32.79
	2020	4,293	7.57	22.78	30.35

Note : 1. Incident records with the complete information for duration computation.
2. Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis.

Table 6.4 shows that the average clearance time during off-peak hours was longer than during peak hours. Consequently, the average duration for incidents occurring during off-peak hours was longer than for those during peak hours.

Table 6.4 Distribution of Average Incident Duration by Off-Peak and Peak Hours

	Year	Sample[1] Frequency	Avg. Response Time	Avg. Clearance Time	Avg. Incident Duration
Off-Peak	2021	17,322	7.72	23.36	31.08
	2020	15,822	7.28	22.45	29.73
Peak[2]	2021	5,616	6.98	21.47	28.45
	2020	5,457	6.95	21.32	28.27

Note : 1. Incident records with the complete information for duration computation.
2. Peak hours: 7:00 AM to 9:30 AM and 4:00 PM to 6:30 PM
3. Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis.

Chapter 6
Analysis of Incident Durations

6.4 Distribution of Average Incident Durations by CHART Involvement, Pavement Condition, Heavy Vehicle Involvement, and Road

Whether or not CHART responded to an incident is another significant factor affecting the distribution of incident durations. When CHART was involved in the incident recovery task, the incident duration was likely to be reduced. This observation indicates that CHART played an efficient role in shortening incident durations, reducing the delay caused by non-recurrent congestion.

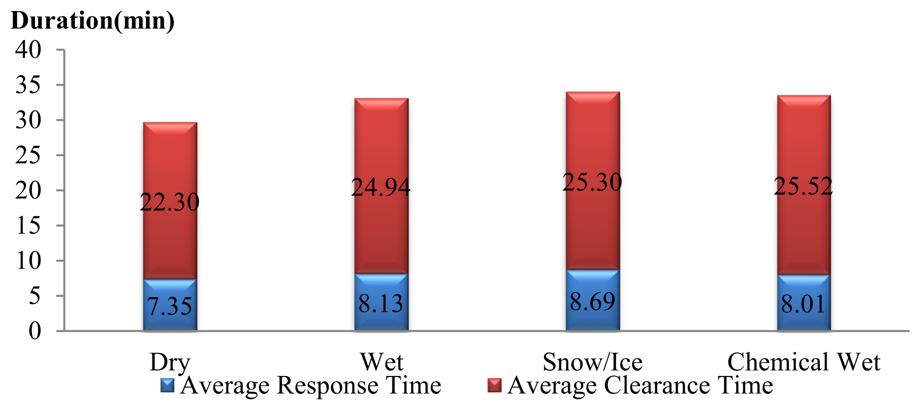
Table 6.5 Distribution of Average Incident Duration without and with CHART

	Year	Sample* Frequency	Avg. Response Time	Avg. Clearance Time	Avg. Incident Duration
w/o CHART	2021	919	16.34	31.73	48.07
	2020	900	15.16	31.85	47.01
w CHART	2021	22,019	7.17	22.53	29.70
	2020	20,379	6.85	21.73	28.58

Note: 1. Incident records with the complete information for duration computation.

2. Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis.

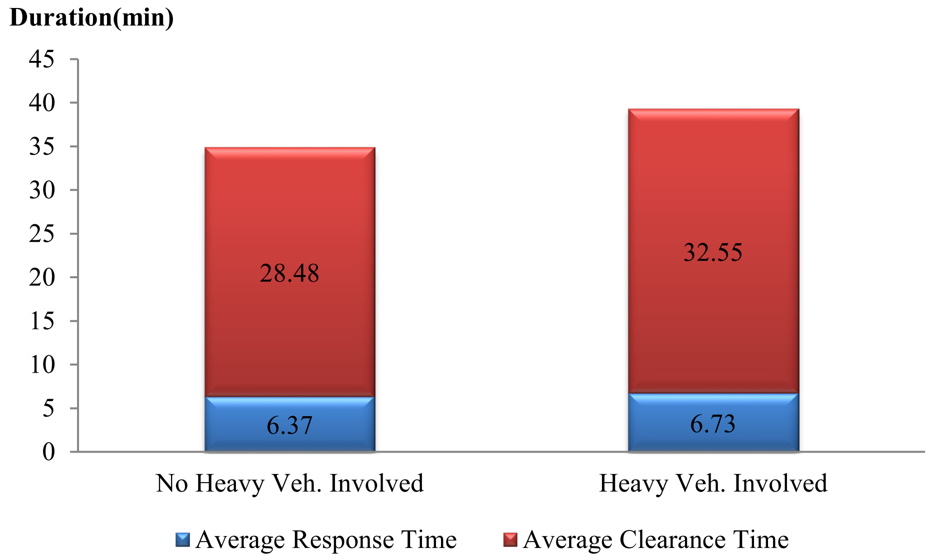
The response time and clearance time of incidents could vary with the pavement conditions. Figure 6.7 shows that the condition of Chemically Wet pavement such as an oil spill may result in a longer clearance time. Also, Wet, Snow/ice, and Chemical Wet pavement conditions seem to increase the clearance time when compared with those on the dry condition.



Note: Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis.

Figure 6.7 Distribution of Average Incident Duration by Pavement Condition

Figure 6.8 illustrates the influence of heavy vehicles on the average incident durations. In 2021, the clearance for incidents involved with heavy vehicles was likely to take longer times due to their resulting severity.



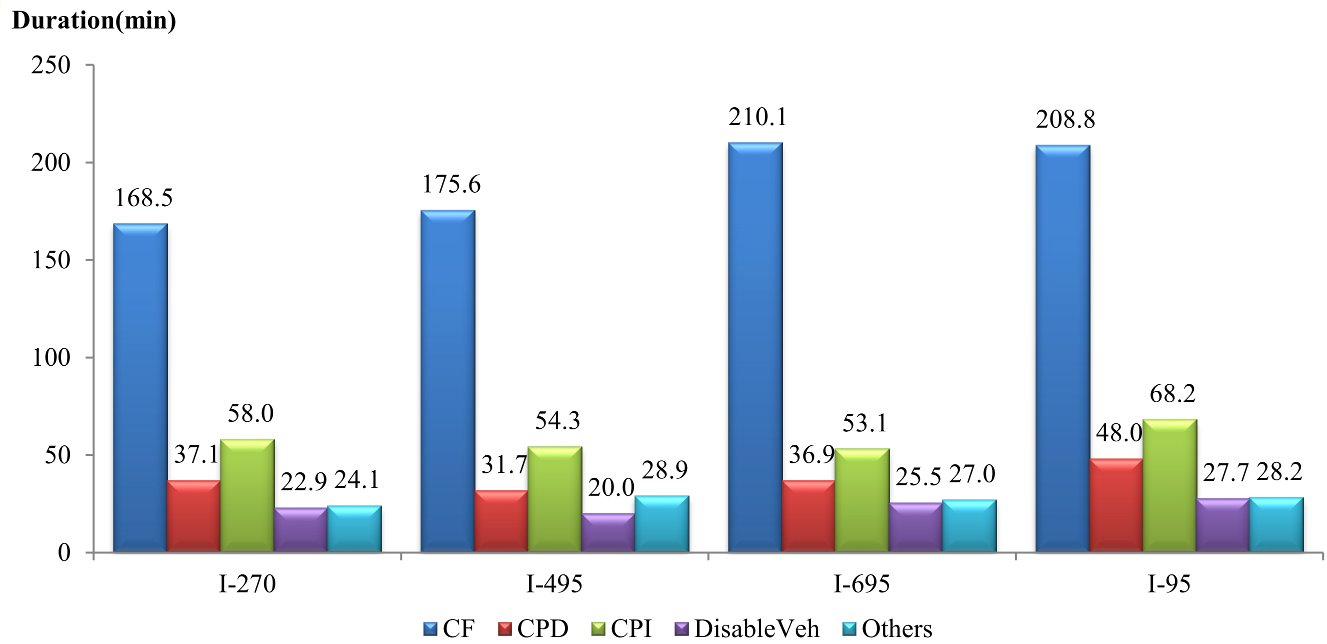
Note: Incident data only for incident duration between 1 minute and 120 minutes are used for this analysis.

Figure 6.8 Distribution of Average Incident Duration by Heavy Vehicle Involvement

Figure 6.9 shows the distribution of average incident durations by road and nature. Notably, the average incident duration of CFs was much longer than those for other incident types. Also, note that CF incidents occurring on I-270 seemed to exhibit the shortest average duration (i.e., 168.5 minutes) among those major roads.

Chapter 6

Analysis of Incident Durations



Note:
CF: Collision-fatality incident
CPD: Collision-property damage incident
CPI: Collision-personal injury incident

Figure 6.9 Distribution of Average Incident Duration by Road and Nature

Chapter 7

BENEFITS FROM CHART'S INCIDENT MANAGEMENT

Chapter 7

Benefits From CHART's Incident Management

Due to the data availability, the benefit assessment for CHART has always been limited to those directly measurable or quantifiable based on incident reports. These direct benefits, both to roadway users and to the entire community, are classified into the following categories:

- 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 revitalizing the local economy and increasing network mobility, are not included in this benefit analysis.

Chapter 7
Benefits From CHART's Incident Management

7.1 Assistance to Drivers

Since the inception of CHART, the public has expressed great appreciation for the timely assistance to drivers by the CHART incident management team. Prompt responses by CHART have directly contributed to minimizing the potential effects of rubbernecking on the traffic flows, particularly during peak hours, where incidents can cause excessive delays. Thus, providing assistance to drivers is undoubtedly one major direct benefit generated by the CHART program.

The distributions of assistance to drivers (labeled as Disabled Vehicles in the CHART II Database) by request type in Year 2021 and Year 2020 are depicted in Figure 7.1. Those assists offered by TOC 3, TOC 4, and TOC 7 are illustrated in Figure 7.2, Figure 7.3, and Figure 7.4, respectively.

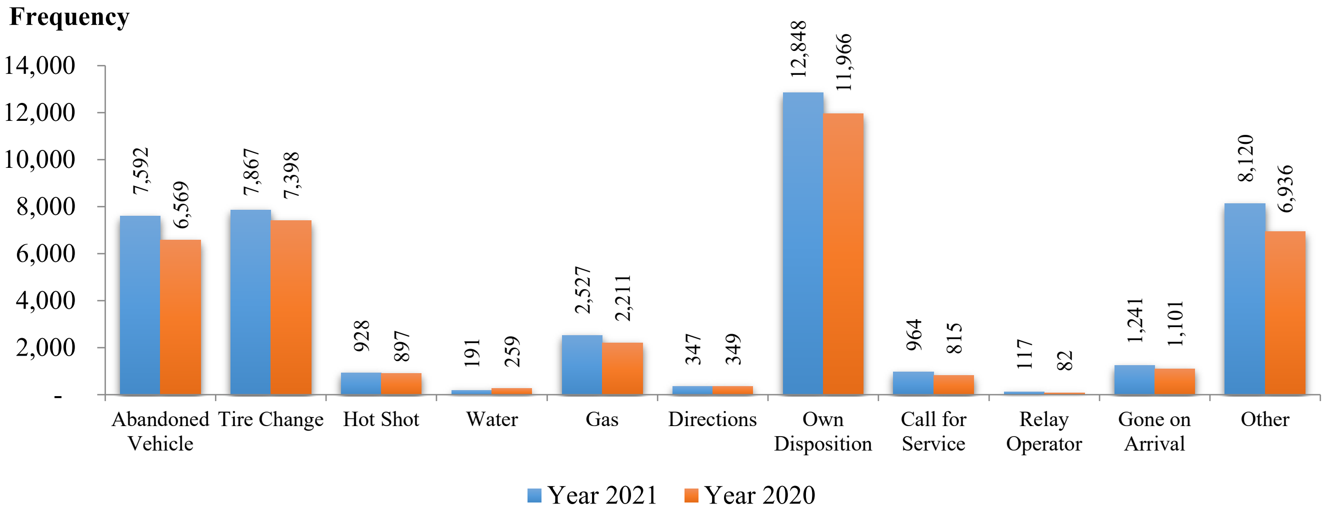


Figure 7.1 Classification of Driver Assistance Requests by Nature in 2021 and 2020

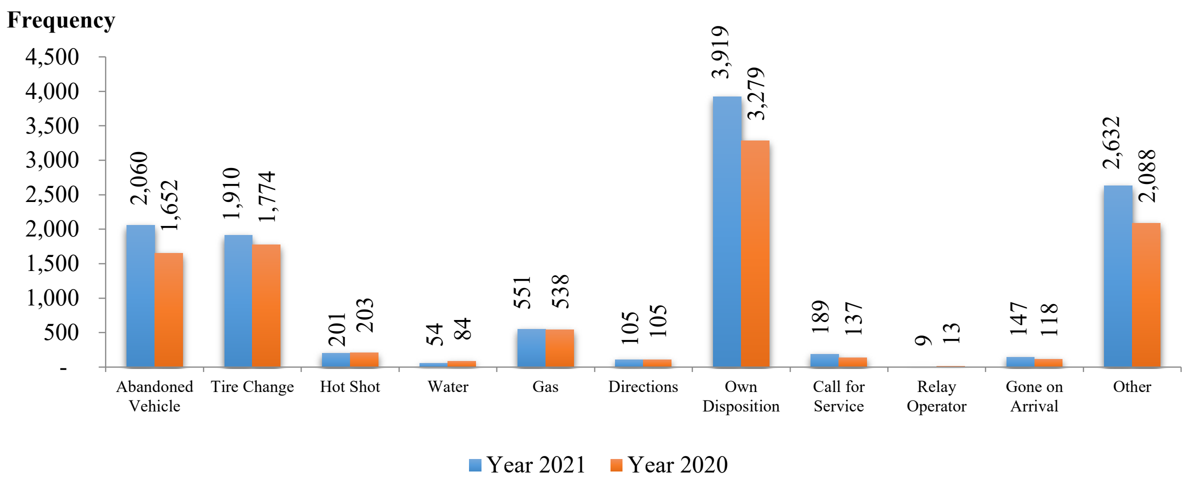


Figure 7.2 Classification of Driver Assistance Requests by Nature for TOC 3

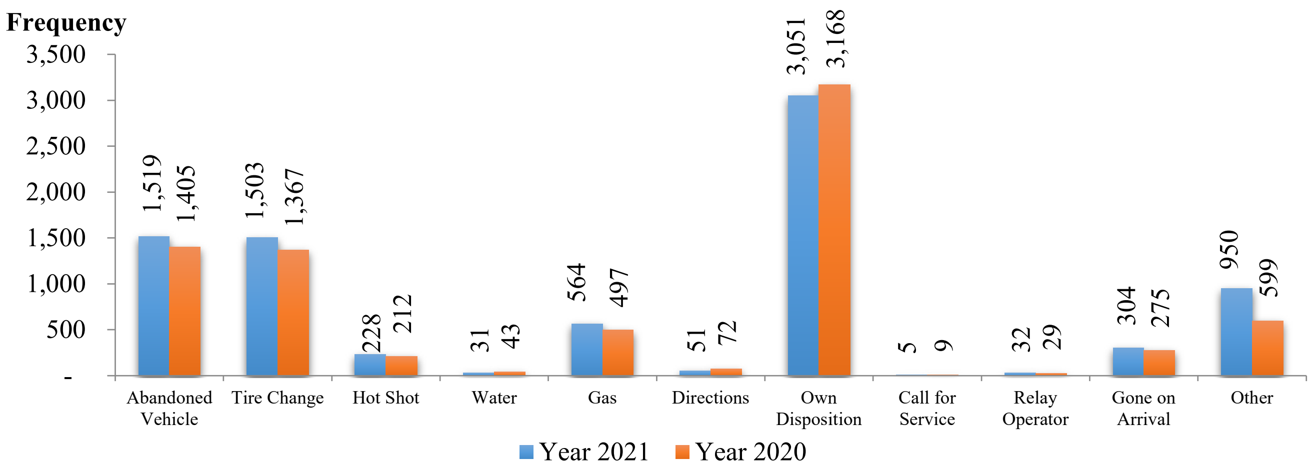


Figure 7.3 Classification of Driver Assistance Requests by Nature for TOC 4

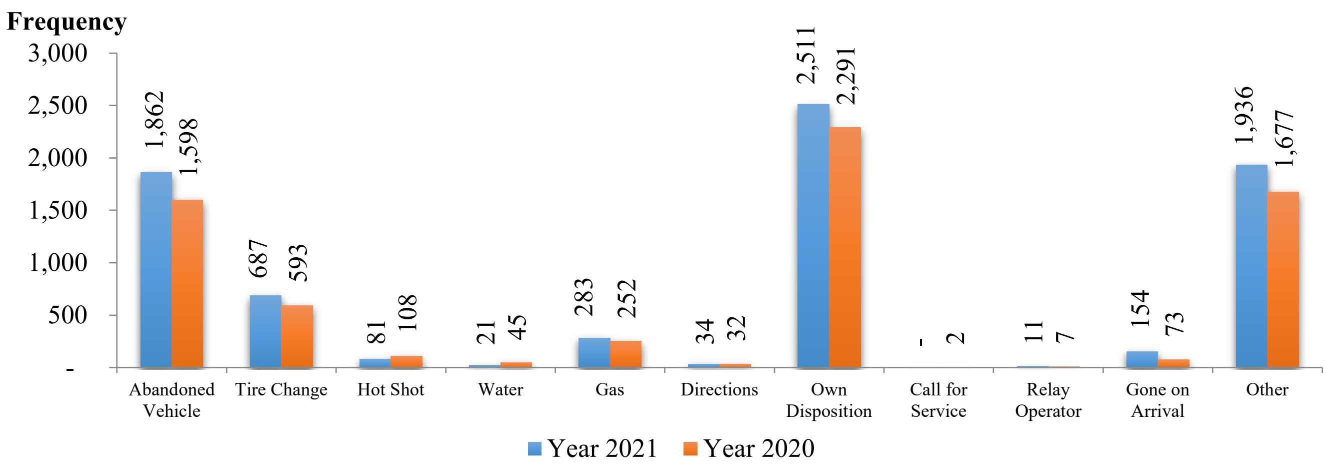


Figure 7.4 Classification of Driver Assistance Requests by Nature for TOC 7

These types of driver assistance in 2021 include flat tires, shortages of gas, or mechanical problems. Note that one requestes may be classified into mutiple categories due to the actual assistance provided. Out of the 38,447 assistance requests, 10,394 assists were related to "out of gas" or "tire changes", more than the number in 2020 (9,609 cases).

7.2 Potential Reduction in Secondary Incidents

Major accidents are known to induce a number of relatively minor secondary incidents. These may occur as a result of dramatic changes in traffic conditions, such as rapidly spreading queue lengths or substantial drops in traffic speed. Some incidents are caused by rubbernecking effects. Hence, the efficient removal of incident blockage is also beneficial in reducing potential secondary incidents.

Based on the experience gained from previous studies, 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 7.5 shows the distribution of incidents classified as secondary incidents by our definition, using the accident database of the MSP for the year 2021. Notably, 1,128 secondary incidents occurred in 2021. A linear correlation is assumed between the number of secondary incidents and incident duration; the reduction in secondary incidents due to CHART's operations is estimated as follows:

- Number of reported secondary incidents: 1,128
- Estimated number of secondary incidents without CHART, which reduced incident duration by 28.04 percent, calculated as: 1,128/(1-0.2804) = 1,567 incidents
- The number of incidents potentially reduced due to CHART/MDOT SHA operations: 1,567-1,128 = 439

Note that the 439 secondary incidents might have further prolonged the primary incident duration, increasing congestion, fuel consumption, and travel times. These associated benefits are not computed in this report due to data limitations but will be investigated in future studies.

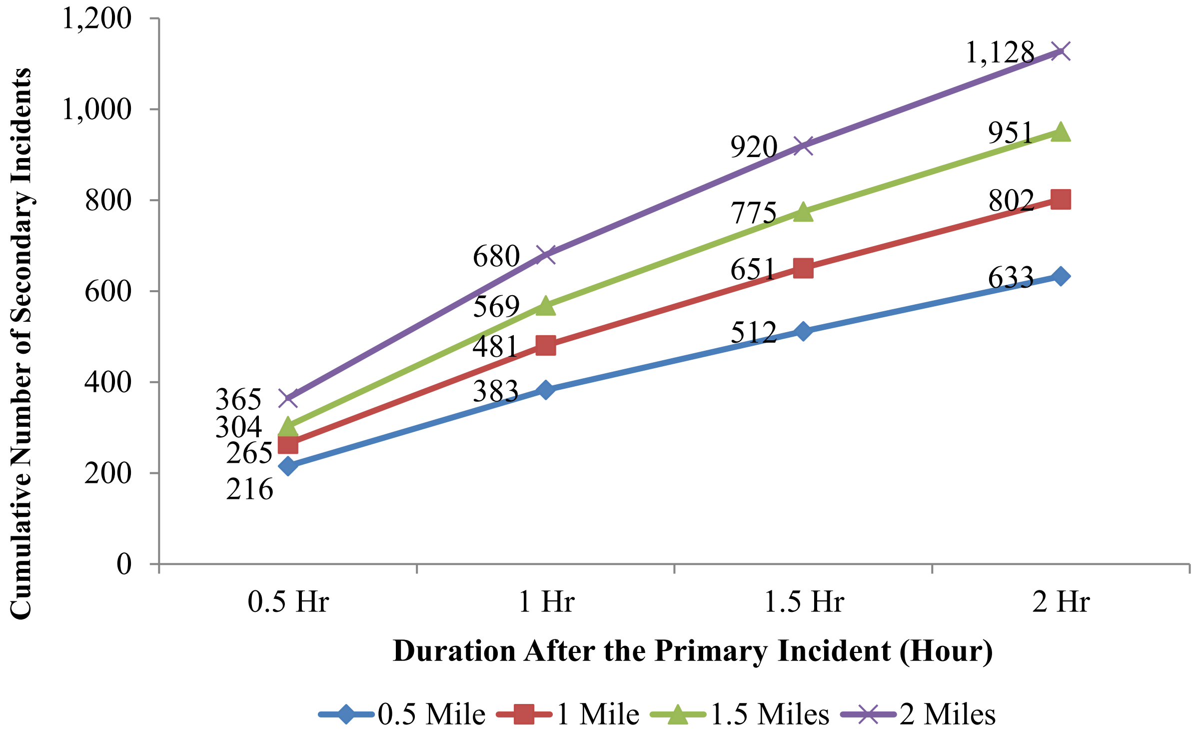


Figure 7.5 Distributions of Reported Secondary Incidents

Chapter 7
Benefits From CHART's Incident Management

7.3 Estimated Benefits due to Efficient Removal of Stationary Vehicles

It is noticeable that drivers are often forced to perform undesirable lane-changing maneuvers because of lane blockages around incident sites. Considering that improper lane changes is a prime contributor to traffic accidents, a prolonged obstruction removal certainly increases the risk of collision. Thus, CHART's prompt removal of stationary vehicles in travel lanes may directly alleviate potential lane-changing-related accidents around incident sites.

The estimated results with respect to reduction in potential incidents for selected freeways are reported in Table 7.1. Note that this estimation was made using peak period data. Off-peak data were omitted because they are known to have negligible correlations with the lane-changing maneuvers and accidents. A detailed description of the estimation methodology can be found in the previous CHART performance evaluation reports (chartinput.umd.edu).

Table 7.1 Reduction in Potential Incidents due to CHART Operations

Road Name		I-495/95	I-95	I-270	I-695	I-70	I-83	I/MD-295	US-50	Total
Mileage		41	63	32	44	13	34	30	42	
No. Potential Incidents Reduced	2021	186	333	53	171	96	36	42	67	984
	2020	170	264	49	137	71	26	30	53	800
	2019	175	286	62	156	73	30	21	57	860
	2018	173	231	57	184	74	33	28	69	849
	2017	229	212	62	207	79	45	23	98	955

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

7.4 Direct Benefits to Highway Users

The estimated benefits obtained as a result of reduced delays and fuel consumption are summarized in Table 7.2, where the monetized benefit conversion from delay reduction was based on the unit rates from the U.S Census Bureau (2021) and the Energy Information Administration (2021). Figure 7.6 also shows the difference in benefits between 2020 and 2021.

The evaluation for 2021 has adopted delay reduction for passenger cars and trucks to convert the delays to fuel consumption. One can refer to note 4 under Table 7.2 for details.

The estimated reductions in vehicle emissions for HC, CO, and NO were based on the parameters provided by MDOT and the total delay reduction. Since CO_2 is recognized as a primary factor for global warming, this study also included the estimated CO_2 reduction, based on the information from the Energy Information Administration. Using the cost parameters shown in Table 7.2 (DeCorla-Souza, 1998), the above reduction in emissions resulted in a total savings of 45.41 million dollars. Thus, CHART operations in Year 2021 generated a total net benefit of 1,875.25 million dollars.

Chapter 7

Benefits From CHART's Incident Management

Table 7.2 Total Direct Benefits to Highway Users in 2021

Reduction due to CHART		Amount	Unit rate	In M Dollar
Delay (M veh-hr)	**Truck**	2.10 (1.49)	Driver *$23.30/hour (21.75)* [1]	48.83 (32.45)
			Cargo $45.40/hour	95.14 (67.74)
	Car	37.64 (22.03)	*$44.15/hour (42.80)* [2]	1,661.87 (942.71)
Fuel Consumption (M gallon)		7.65 [4] (4.70)	Gasoline *$3.09/gal (2.26)* [3]	24.01 (11.01)
			Diesel *$3.28/gal (2.56)* [3]	
Emission	**HC(ton)**	519.47 (307.44)	$6,700/ton	45.41 (26.91)
	CO(ton)	5,834.48 (3,453.07)	$6,360/ton	
	NO(ton)	248.79 (147.24)	$12,875/ton	
	CO_2 (metric ton)	70,198.61 (43,372.14)	$23/metric ton [5]	
Total		**$1,875.25 (1,080.83)**		

Note:

** The number in each parenthesis is the data in year 2020.*

** All values are rounded to the nearest hundredth in this table only for the presentation purpose, since the actual values need more spaces to be presented. For example, the benefit from truck drivers = 2,095,517.32 veh-hr * $23.30/hr = $ 48,825,553.54…*

Source:

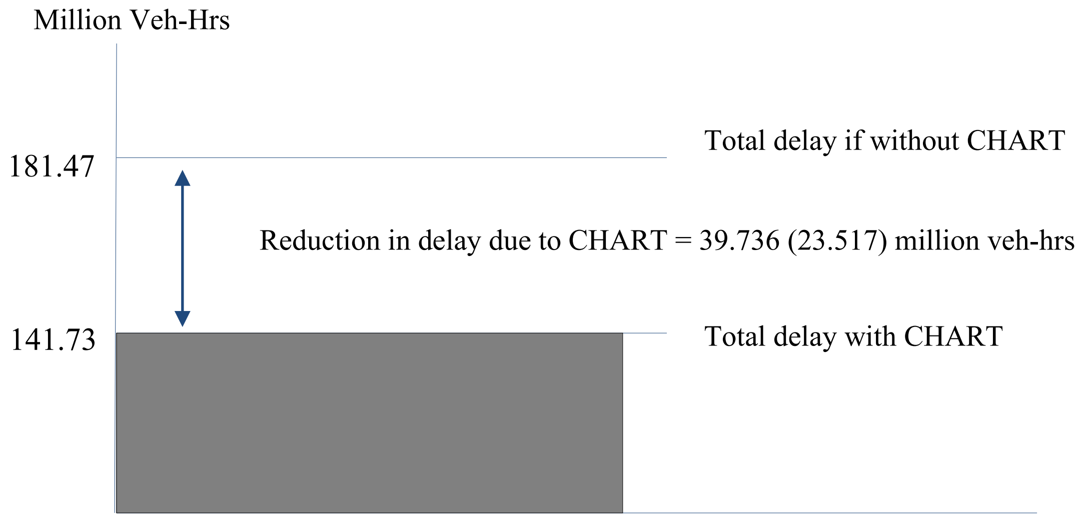
1. The truck driver's unit cost is based on the information from the Bureau of Labor Statistics in year 2021.

2. The car driver's unit cost is based on household income by the U.S. Census Bureau (2021).

3. The gasoline and diesel unit costs are from the Energy Information Administration in year 2021.

4. The fuel consumption was computed based on the rate of 0.156 gallons of gas per hour for passenger cars from the Ohio Air Quality Development Authority and the rate of 0.85 gallon per hour for trucks from the literature "Heavy-Duty Truck Idling Characteristics-Results from a Nationwide Truck Survey" by Lutsey et al. (2004) and the Environmental Protection Agency (EPA).

5. This value is computed based on the unit rates of 19.56 lbs CO_2/gallon of gasoline, 22.38 lbs CO_2/gallon of diesel from the Energy Information Administration and $23/metric ton of CO_2 from CBO (Congressional Budget Office)'s cost estimate for S. 2191, America's Climate Security Act of 2007.



*** The number in the parenthesis shows the data from year 2020**

Figure 7.6 Reduction in Delay due to CHART in Year 2021

The total benefits increased from 1,080.83 million dollars in 2020 to 1,875.25 million dollars in 2021. The main factors contributing to the total benefit are listed and tabulated as follows:

- The total number of incidents used for the benefit estimate increased by about 9.61 percent from year 2020 to year 2021 as shown in Table 7.3.
- The ratio, reflecting the difference between incident durations with CHART and those without CHART, decreased from 28.41 percent in 2020 to 28.04 percent in 2021 as shown in Table 7.4.
- Table 7.5 shows that the adjusted AADT in 2021 increased on all major roads compared to 2020.
- Table 7.6 shows that average truck percentage decreased in year 2021 over most major roads in Maryland, by 4.56 percent.

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Table 7.3 Total Number of Incidents Eligible for the Benefit Estimate from Year 2020 to Year 2021

	2020	2021	Δ('20 ~ '21)[2]
No. of Incidents	28,513	31,253	9.61%

Note: 1.The incidents causing main lanes blockage are included. The incidents causing only shoulder lanes blockage are excluded for the benefit analysis.
2. The percentage change in No. of Incidents (X) from Year 2020 to Year 2021 is calculated as follows:
$\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

Table 7.4 Average Incident Duration with and without CHART from Year 2020 to Year 2021[1]

	With CHART (mins) (A)	Without CHART (mins) (B)	Difference (mins) (B-A)	Ratio in Difference ((B-A)/B)
2020	27.06	37.80	10.74	28.41%
2021	27.99	38.89	10.90	28.04%
Δ('20 ~ '21)[2]	3.44%	2.88%	1.53%	-1.31%

Note: 1. The analysis is based on incidents that have main lanes blockage.
2. The percentage change in incident duration (X) from Year 2020 to Year 2021 is calculated as follows:
$\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

Table 7.5 The adjusted AADT (with peak hour factor) for Major Roads from Year 2020 to Year 2021

	Year	I-495	I-95	I-270	I-695	MD 295	US 50	US 1	I-83	I-70	Total
$\sum_{segments}$ AADT(vplph)*PHF	2020	10,502	6,827	6,127	9,316	3,600	2,082	4,115	2,293	2,843	47,706
	2021	11,912	7,981	6,987	10,586	4,087	2,342	4,746	2,434	3,162	54,237
Δ('20 ~ '21) (%)		13.43	16.90	14.04	13.63	13.53	12.49	15.33	6.15	11.22	13.69

Note: The percentage change in the adjusted AADT (X) from Year 2020 to Year 2021 is calculated as follows:
$\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

Table 7.6 Truck percentage for Major Roads from Year 2020 to Year 2021

	Year	I-495	I-95	I-270	I-695	MD 295	US 50	US 1	I-83	I-70	Average
Truck (%)	2020	9.08	15.62	6.96	8.32	3.03	9.82	4.85	10.54	10.73	8.77
	2021	7.76	11.98	5.41	7.57	2.72	11.30	4.84	13.25	10.47	8.37
Δ('20 ~ '21) (%)		-14.50	-23.31	-22.35	-9.01	-10.24	15.08	-0.23	25.68	-2.46	-4.63

Note: The percentage change in the truck percentage (X) from Year 2020 to Year 2021 is calculated as follows:
$\Delta X(\%)=(X_{2021}-X_{2020})/X_{2020}*100$

Since each key factor has a different degree of exponential impact on the resulting benefit change, Table 7.7 has further illustrated the results of sensitivity analysis with respect to each key contributor.

Table 7.7 Sensitivity Analysis of key factors contributing to the Benefits (Unit: M dollar)

Benefits of the Previous Year (2020)			**1,080.83**
Key Factor		**Δ('20 ~ '21)[1]**	**Estimated Benefits[2]**
Sensitivity Analysis	Adjusted AADT	↑ 13.69 %	1,548.85(↑43.30%)
	Number of incidents	↑ 9.61 %	1,151.53(↑6.54%)
	Incident duration percentage difference between w/ and w/o CHART	↓1.31 %	1,066.68(↓1.31%)
	Truck percentage	↓4.63 %	1,075.55(↓0.49%)
	Monetary unit of gas price	↑ 32.65 %	1,084.61(↑0.35%)
	Monetary unit of time value	↑ 5.14 %	1,112.88(↑2.97%)
Benefits of the Current Year (2021)			**1,875.25(↑73.50%)**

Note: 1. This field is showing the difference in percentage between 2020 and 2021.
2. The numbers in each parenthesis show the percentage of the benefit change from year 2020.

Note that the sensitivity results shown in Table 7.7 were obtained with the following steps:

- Identifying key factors contributing to the total CHART benefits, which are: traffic volume, the number of incidents resulting in lane blockage, incident duration with and without CHART involvements, truck percentage, value of time, and gas price;
- Computing the marginal impacts of the selected factor, using its 2021 value, but setting all other factors identical to those in 2020; and
- Following the same procedures to analyze the sensitivity of the total 2021 benefits with respect to each key factor

The increase in the average adjusted AADT by 13.69 percent in 2021 contributed to an increase of 43.30 percent in the total benefit. The number of lane-blockage incidents increased by 9.61 percent in 2021, resulting in the benefit increase of 6.54 percent. Note that the ratio with respect to the performance difference between incident durations with and without CHART involvement decreased by 1.31%, and thus directly resulted in a 1.31% reduction in the total benefit. An increase of 2.97 percent in the total benefit is due solely to the average raise of 5.14 percent in the MD driving populations' income (i.e., a proxy for time value).

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This chapter summarizes the benefits for major freeway corridors in 2021 due to CHART's incident response/operations. Table 7.8 shows the number of eligible main-lane-blockage incidents used for the benefit estimate, and the estimated delay reductions due to CHART for each corridor. The reductions in delay due to CHART's services on I-95, I-495/95, I-270, I-695, I-70, and I-83 are 7.87, 4.34, 1.40, 5.64, 2.40 and 0.84 million vehicle-hours, respectively, in 2021.

The total benefits produced from the reduction in delays, fuel consumption, and emissions for each major road in 2021 are summarized in Tables 7.9 (a) to 7.9 (f). The total benefits for I-95, I-495/95, I-270, I-695, I-70, and I-83 in 2021 are $381.26M, $207.70M, $65.63M, $267.64M, $116.06M, and $41.34M, respectively. Note that the benefits for those six major corridors account for 57.57% of the total CHART benefits of $1,875.25M.

Table 7.8 Number of Incidents Used for Benefit Estimate for the Six Major Corridors in 2021

Corridors	No. of Incidents*	Reduction in Delay due to CHART (M vehicle-hours)
I-95	5,203	7.87
I-495	3,273	4.34
I-270	969	1.40
I-695	3,486	5.64
I-70	1,601	2.40
I-83	725	0.84
Others	15,996	17.23

Note: Only incidents causing main lanes blockage are included in the benefit estimates, but not those incidents causing only shoulder lanes blockage.

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Table 7.9(a) Total Direct Benefits for I-95 in 2021

Reduction due to CHART		Amount	Unit rate	In M Dollar
Delay (M veh-hr)	Truck	0.78	Driver *$23.30/hour*[1]	18.09
			Cargo $45.40/hour	35.25
	Car	7.10	*$44.15/hour*[2]	313.28
Fuel Consumption (M gallon)		1.77[4]	Gasoline *$3.09/gal*[3]	5.59
			Diesel *$3.28/gal*[3]	
Emission	HC(ton)	102.91	$6,700/ton	9.06
	CO(ton)	1,155.86	$6,360/ton	
	NO(ton)	49.29	$12,875/ton	
	CO_2 (metric ton)	16,524.80	$23/metric ton[5]	
Total (M dollar)		$381.26		

Source:

1. The truck driver's unit cost is based on the information from the Bureau of Labor Statistics in year 2021.

2. The car driver's unit cost is based on the household income by the U.S. Census Bureau (2021).

3. The gasoline and diesel unit costs are from the Energy Information Administration in year 2021.

4. The fuel consumption was computed based on the rate of 0.156 gallons of gas per hour for passenger cars from the Ohio Air Quality Development Authority and the rate of 0.85 gallon per hour for trucks from the literature "Heavy-Duty Truck Idling Characteristics-Results from a Nationwide Truck Survey" by Lutsey et al. (2004) and the Environmental Protection Agency (EPA).

5. This value is computed based on the unit rates of 19.56 lbs CO_2/gallon of gasoline, 22.38 lbs CO_2/gallon of diesel from the Energy Information Administration, and $23/metric ton of CO_2 from CBO (Congressional Budget Office)'s cost estimate for S. 2191, America's Climate Security Act of 2007.

Table 7.9(b) Total Direct Benefits for I-495/I-95 in 2021

Reduction due to CHART		Amount	Unit rate	In M Dollar
Delay (M veh-hr)	Truck	0.33	Driver *$23.30/hour*[1]	7.78
			Cargo $45.40/hour	15.17
	Car	4.01	*$44.15/hour*[2]	176.91
Fuel Consumption (M gallon)		0.91	Gasoline *$3.09/gal*[3]	2.87
			Diesel *$3.28/gal*[3]	
Emission	HC(ton)	56.75	$6,700/ton	4.98
	CO(ton)	637.40	$6,360/ton	
	NO(ton)	27.18	$12,875/ton	
	CO_2 (metric ton)	8,430.79	$23/metric ton[5]	
Total (M dollar)		$207.70		

Table 7.9(c) Total Direct Benefits for I-270 in 2021

Reduction due to CHART		Amount	Unit rate	In M Dollar
Delay (M veh-hr)	Truck	0.06	Driver *$23.30/hour*[1]	1.37
			Cargo $45.40/hour	2.67
	Car	1.34	*$44.15/hour*[2]	59.18
Fuel Consumption (M gallon)		0.26	Gasoline *$3.09/gal*[3]	0.81
			Diesel *$3.28/gal*[3]	
Emission	HC(ton)	18.29	$6,700/ton	1.60
	CO(ton)	205.46	$6,360/ton	
	NO(ton)	8.76	$12,875/ton	
	CO_2 (metric ton)	2,364.00	$23/metric ton[5]	
Total (M dollar)		$65.63		

Table 7.9(d) Total Direct Benefits for I-695 in 2021

Reduction due to CHART		Amount	Unit rate	In M Dollar
Delay (M veh-hr)	Truck	0.35	Driver *$23.30/hour*[1]	8.07
			Cargo $45.40/hour	15.72
	Car	5.30	*$44.15/hour*[2]	233.87
Fuel Consumption (M gallon)		1.12	Gasoline *$3.09/gal*[3]	3.52
			Diesel *$3.28/gal*[3]	
Emission	HC(ton)	73.78	$6,700/ton	6.46
	CO(ton)	828.62	$6,360/ton	
	NO(ton)	35.33	$12,875/ton	
	CO_2 (metric ton)	10,322.43	$23/metric ton[5]	
Total (M dollar)		$267.64		

Table 7.9(e) Total Direct Benefits for I-70 in 2021

Reduction due to CHART		Amount	Unit rate	In M Dollar
Delay (M veh-hr)	Truck	0.23	Driver *$23.30/hour*[1]	5.24
			Cargo $45.40/hour	10.22
	Car	2.18	*$44.15/hour*[2]	96.16
Fuel Consumption (M gallon)		0.53	Gasoline *$3.09/gal*[3]	1.68
			Diesel *$3.28/gal*[3]	
Emission	HC(ton)	31.41	$6,700/ton	2.76
	CO(ton)	352.84	$6,360/ton	
	NO(ton)	15.05	$12,875/ton	
	CO_2 (metric ton)	4,957.83	$23/metric ton[5]	
Total (M dollar)		$116.06		

Table 7.9(f) Total Direct Benefits for I-83 in 2021

Reduction due to CHART		Amount	Unit rate	In M Dollar
Delay (M veh-hr)	Truck	0.10	Driver *$23.30/hour*[1]	2.31
			Cargo $45.40/hour	4.49
	Car	0.75	*$44.15/hour*[2]	32.93
Fuel Consumption (M gallon)		0.20	Gasoline *$3.09/gal*[3]	0.64
			Diesel *$3.28/gal*[3]	
Emission	HC(ton)	11.04	$6,700/ton	0.97
	CO(ton)	124.05	$6,360/ton	
	NO(ton)	5.29	$12,875/ton	
	CO_2 (metric ton)	1,887.02	$23/metric ton[5]	
Total (M dollar)		$41.34		

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In addition to the above benefit analysis, a reduction in emissions due to reduced travel time in the Baltimore and Washington regions has also been computed. The results are summarized in Tables 7.10(a) and 7.10(b), where the daily delay reductions for the Washington region in 2021 were 2,181 hours/day and 47,365 hours/day for trucks and cars, respectively, compared to the 1,836 hours/day for trucks and 30,441 hours/day for passenger cars in 2020. The delay reduction in the Baltimore region increased from 3,903, hours/day in 2020 to 5,878 hours/day in 2021 and from 54,271 hours/day in 2020 to 97,406 hours/day in 2021 for trucks and passenger cars, respectively. The overall reductions in emissions (i.e., by cars and trucks) for the entire region were $103,518/day and $174,636/day for the years 2020 and 2021, respectively.

Table 7.10(a) Delay and Emissions Reductions for Trucks Due to CHART/MSHA Operations for Washington and Baltimore Regions

Truck		Total by CHART		Washington Region		Baltimore Region	
		Year 2021	Year 2020	Year 2021	Year 2020	Year 2021	Year 2020
Annual Delay Reduction	hour	2,095,517	1,492,171	567,141	477,375	1,528,377	1,014,796
Daily Delay Reduction	hour	8,060	5,739	2,181	1,836	5,878	3,903
Emission Reduction							
HC reduction	ton/day	0.105	0.075	0.038	0.028	0.067	0.047
	$/day	705.94	502.68	256.86	190.50	449.08	312.18
CO reduction	ton/day	1.183	0.843	0.431	0.319	0.753	0.523
	$/day	7,526.50	5,359.45	2,738.52	2,031.05	4,787.97	3,328.40
NO reduction	ton/day	0.050	0.036	0.018	0.014	0.032	0.022
	$/day	649.69	462.63	236.39	175.32	413.30	287.31
CO_2 reduction	metric ton/ day	69.56	49.54	25.31	18.77	44.25	30.76
	$/day	1,599.97	1,139.31	582.15	431.76	1,017.82	707.55
Total	$/day	10,482.10	7,464.07	3,813.92	2,828.63	6,668.18	4,635.44

Table 7.10(b) Delay and Emissions Reductions for Cars Due to CHART/MSHA Operations for Washington and Baltimore Regions

Car		Total by CHART		Washington Region		Baltimore Region	
		Year 2021	Year 2020	Year 2021	Year 2020	Year 2021	Year 2020
Annual Delay Reduction	hour	37,640,498	22,025,139	12,314,833	7,914,609	25,325,665	14,110,530
Daily Delay Reduction	hour	144,771	84,712	47,365	30,441	97,406	54,271
Emission Reduction							
HC reduction	ton/day	1.893	1.107	0.689	0.420	1.204	0.688
	$/day	12,680.37	7,419.85	4,613.77	2,811.88	8,066.61	4,607.98
CO reduction	ton/day	21.257	12.438	7.734	4.714	13.523	7.725
	$/day	135,193.83	79,107.96	49,190.40	29,979.26	86,003.44	49,128.71
NO reduction	ton/day	0.906	0.530	0.330	0.201	0.577	0.329
	$/day	11,670.06	6,828.67	4,246.16	2,587.84	7,423.90	4,240.84
CO2 reduction	metric ton/ day	200.43	117.28	72.93	44.45	127.50	72.84
	$/day	4,609.90	2,697.46	1,677.32	1,022.25	2,932.59	1,675.21
Total	$/day	164,154.16	96,053.95	59,727.64	36,401.21	104,426.52	59,652.73

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

Chapter 8
Conclusions and Recommendations

8.1 Conclusions

Building on the previous research experience, this study has conducted a rigorous evaluation of CHART's performance in 2021 and its resulting benefits under the constraints of data availability and quality. Overall, CHART has made significant progress in recording more reliable incident reports, especially after implementation of the CHART-II Database.

However, much remains for CHART to do in terms of collecting more data and extending its operations to major local arterials if resources are available to do so. For example, data associated with the potential impacts of major incidents on local streets have not been collected by CHART. Without such information, one may substantially underestimate the benefits of CHART operations, as most incidents causing lane blockage on major commuting freeways are likely to spill their congestion back to neighboring local arterials if the speed of traffic queue formation is faster than the pace of progress on incident clearance. Similarly, a failure to respond to major accidents on local arterials, such as MD-355, may also significantly degrade traffic conditions on 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 its performance, CHART has maintained nearly the same level of efficiency in responding to incidents and driver assistance requests in recent years. The average response time in 2021 was 12.25 minutes. In view of the worsening congestion and the increasing number of incidents in the Washington-Baltimore region, it is commendable that CHART can maintain its performance efficiency with diminishing resources.

In brief, CHART operations by MDOT SHA in Year 2021 have yielded significant benefits by assisting drivers, and by reducing delay times and fuel consumption, as well as emissions. Other, indirect benefits could be estimated if appropriate data regarding traffic conditions before and after incidents were collected during each operation. Such benefits include impacts related to secondary incidents, potential impacts on neighboring roadways, and reductions in driver stress 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 networks covered by CHART.

8.2 Recommendations and Further Development

The main recommendations, based on the performance of CHART in 2021, are listed below:

- A strategy should be developed and updated to allocate CHART's resources between different response centers, based on their respective performance and efficiency so that they can effectively contend with the ever-increasing congestion and accompanying incidents both in urban and suburban areas.
- CHART's quality evaluation report should be made available to the operators to facilitate their continuous improvement of response operations.
- CHART should coordinate with county traffic agencies to extend its operations to major local routes and to include the data collection, as well the performance benefit, in the annual CHART review.
- Training sessions should be implemented to educate/re-educate operators on the importance of high-quality data and discuss how to effectively record critical performance-related information.
- The data structure used in the CHART-II system for recording incident locations should be improved to eliminate the current laborious, complex procedures.
- The database structure should be documented and re-investigated on a regular basis to improve the efficiency and quality of collected data.
- Possible explanations for extremely short or long response and/or clearance times should be documented so that the results of performance analysis can be more reliable.
- Police accident data should be efficiently integrated into the CHART incident response database in order to have a complete representation of statewide incident records.
- The benefits of reduced potential secondary incidents on delay and fuel consumption should be incorporated into the CHART benefit evaluation.

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36. Federal Highway Administration, HERS-ST v20: Highway Economic Requirements System - State Version Technical Report. Federal Highway Administration, FHWA¬IF-02-060, 2002.
37. Mackie, P.J. et al, Value of Travel Time Savings in the UK - Summary Report. Institute for Transport Studies, University of Leeds, for the UK Department for Transport, 2003.

APPENDIX A - Additional Analyses

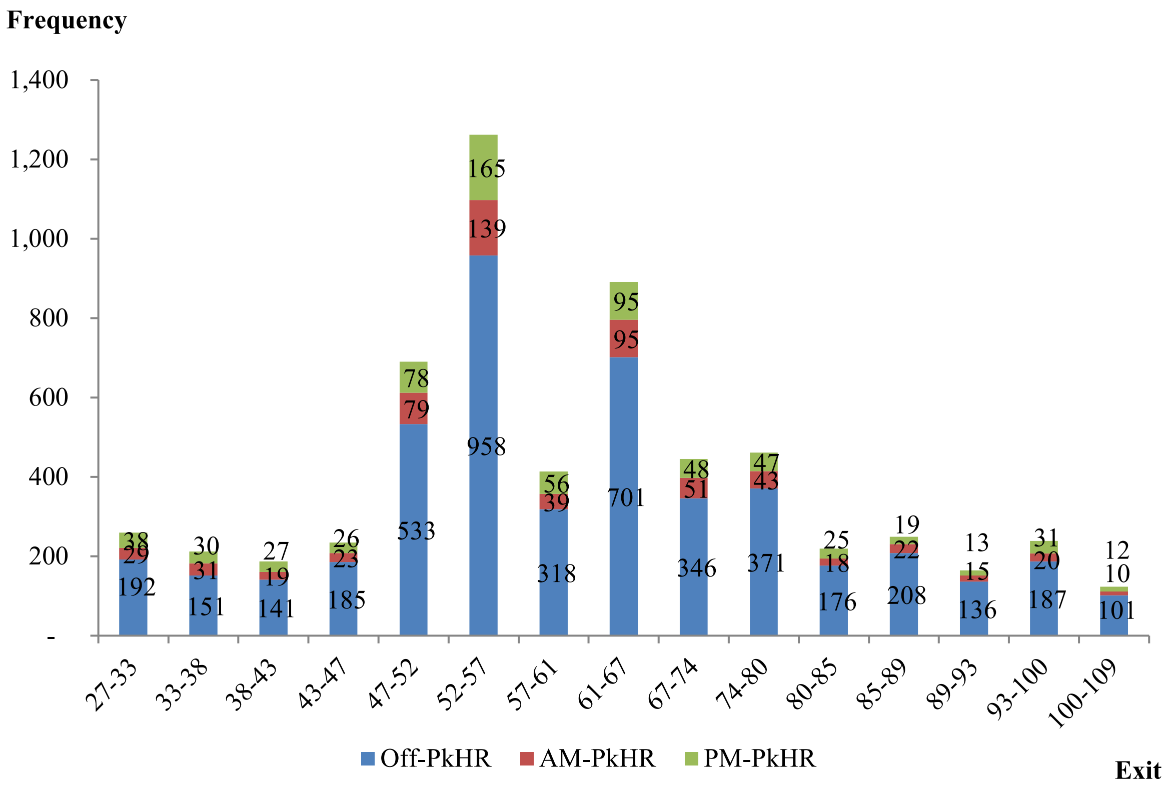

Figure A.1 Distributions of Incidents by Time of Day on I-95 in Year 2021

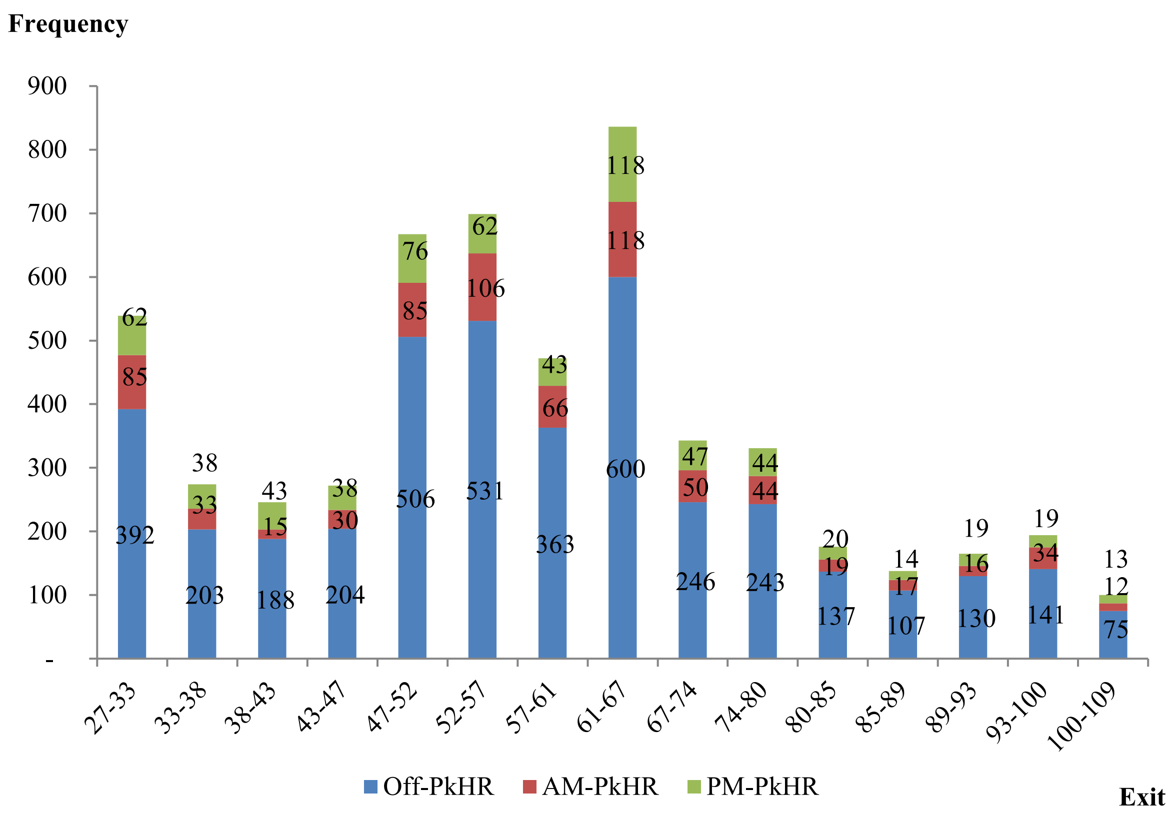

Figure A.2 Distributions of Disabled Vehicles by Time of Day on I-95 in Year 2021

APPENDIX A - Additional Analyses

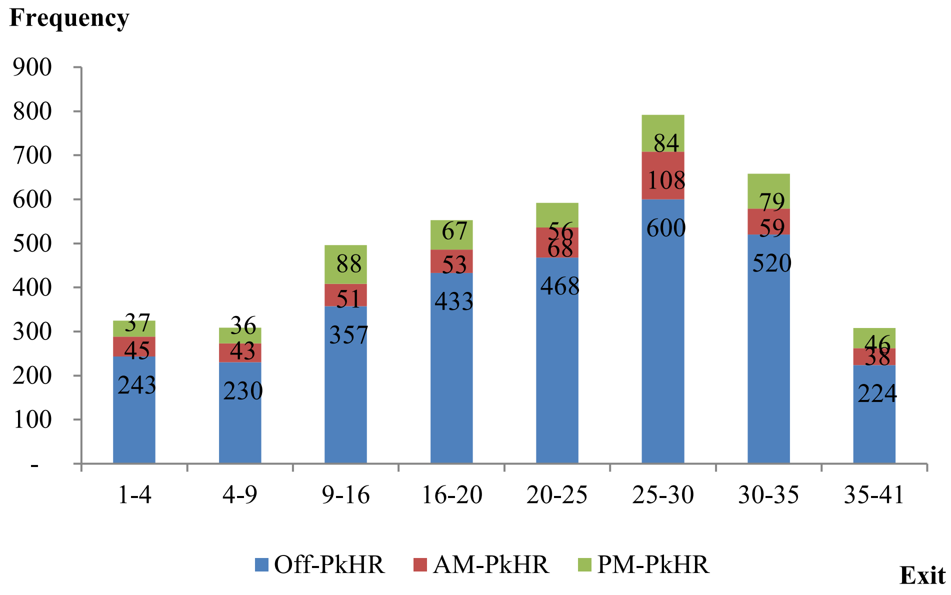

Figure A.3 Distributions of Incidents by Time of Day on I-495 in Year 2021

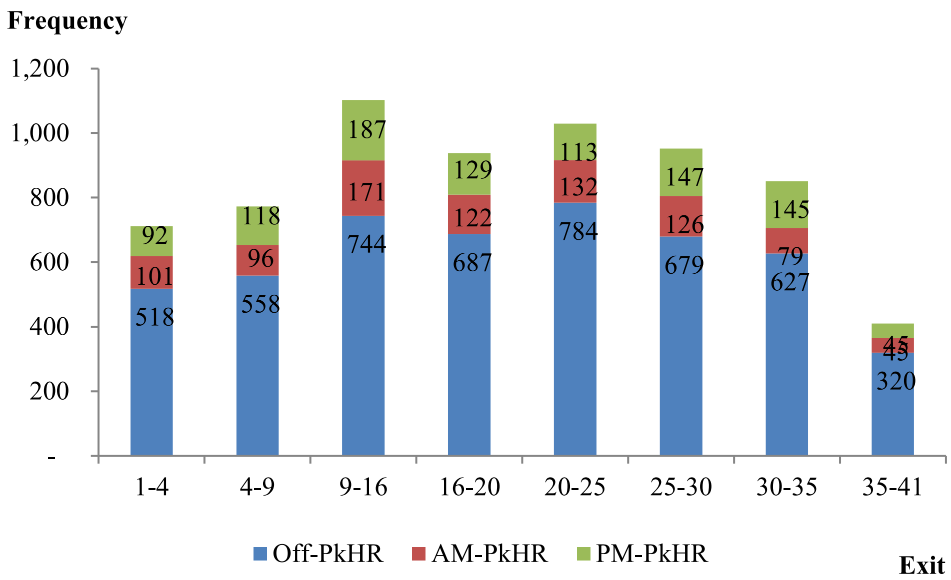

Figure A.4 Distributions of Disabled Vehicles by Time of Day on I-495 in Year 2021

APPENDIX A - Additional Analyses

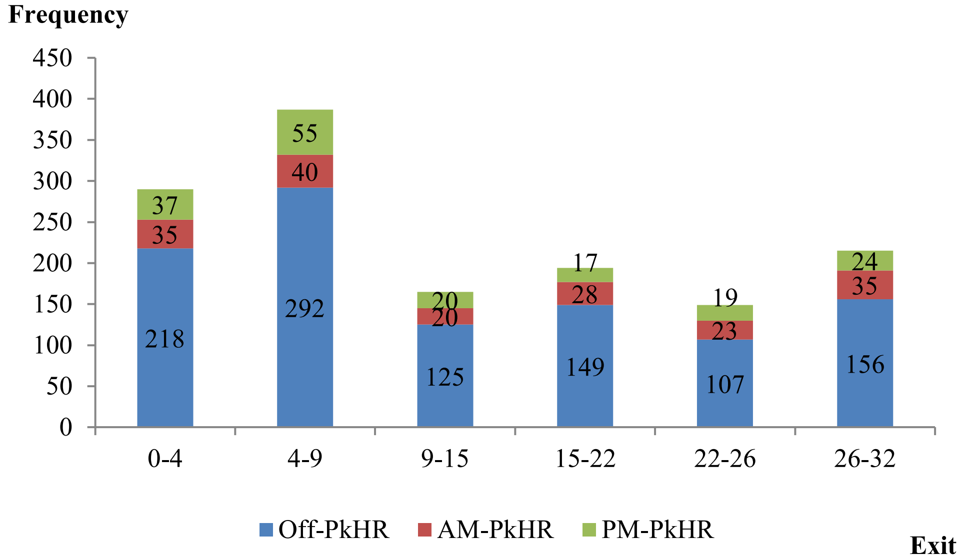

Figure A.5 Distributions of Incidents by Time of Day on I-270 in Year 2021

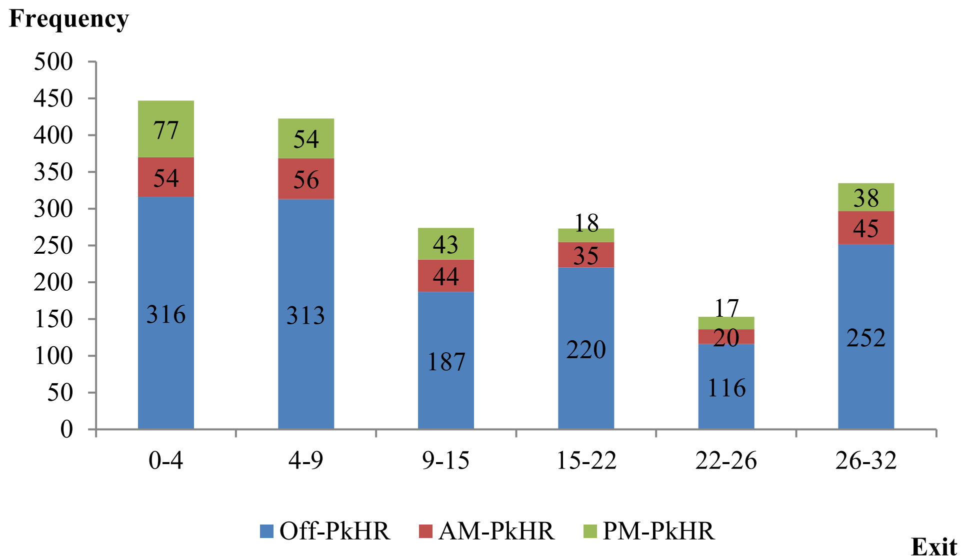

Figure A.6 Distributions of Disabled Vehicles by Time of Day on I-270 in Year 2021

APPENDIX A - Additional Analyses

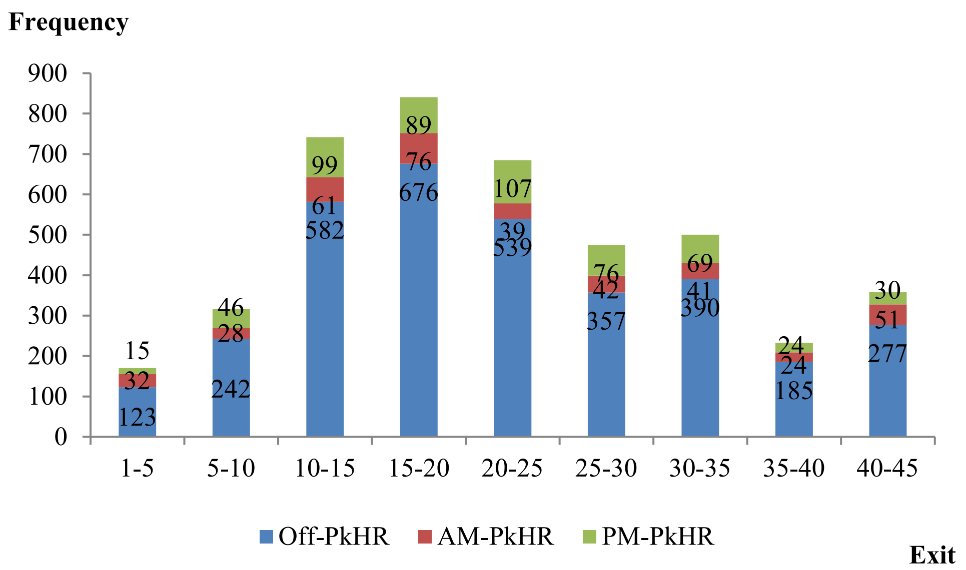

Figure A.7 Distributions of Incidents by Time of Day on I-695 in Year 2021

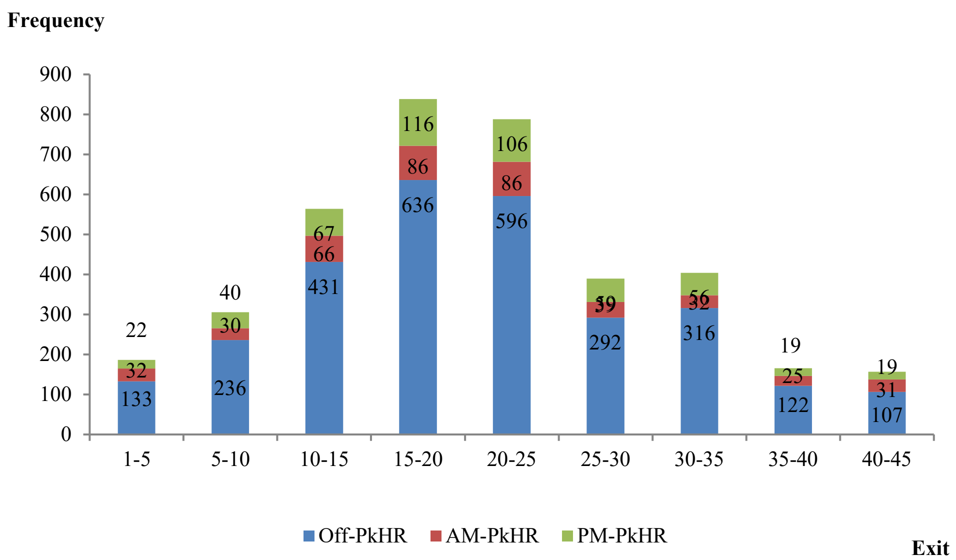

Figure A.8 Distributions of Disabled Vehicles by Time of Day on I-695 in Year 2021

APPENDIX A - Additional Analyses

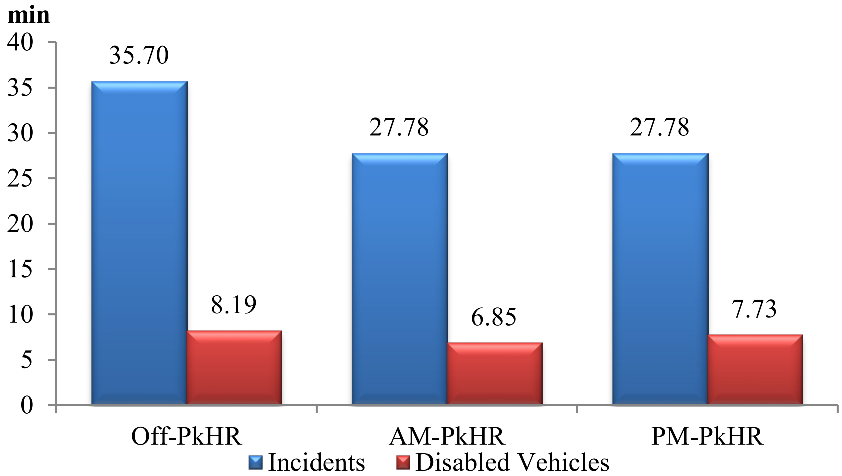

Figure A.9 Distributions of Clearance Time by Time of Day in Year 2021

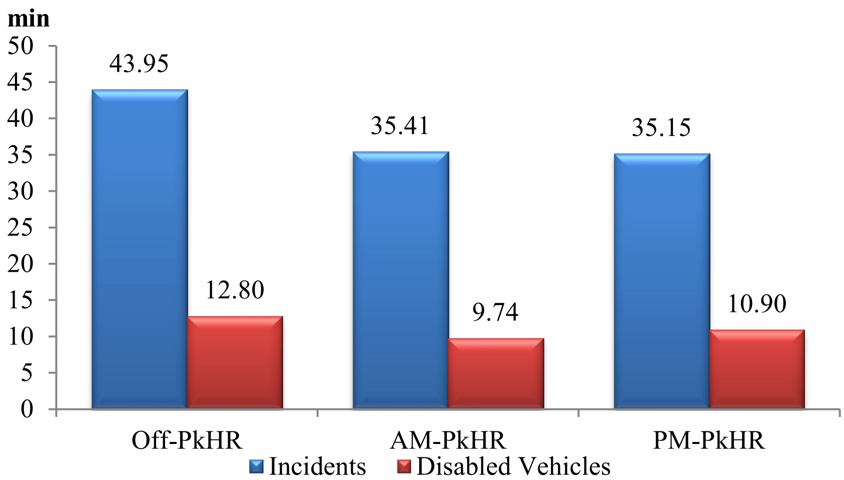

Figure A.10 Distributions of Incident Duration by Time of Day in Year 2021

APPENDIX A - Additional Analyses

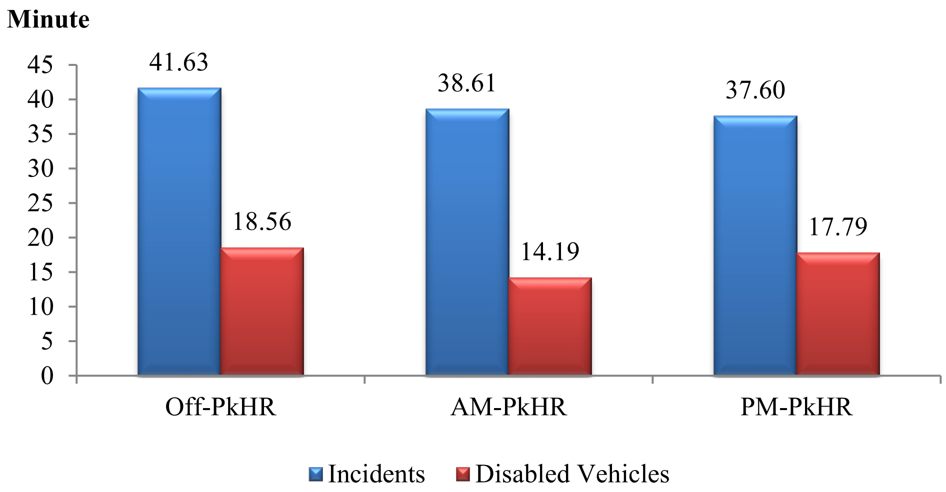

Figure A.11 Distributions of Incident Duration by Time of Day on I-95 in Year 2021

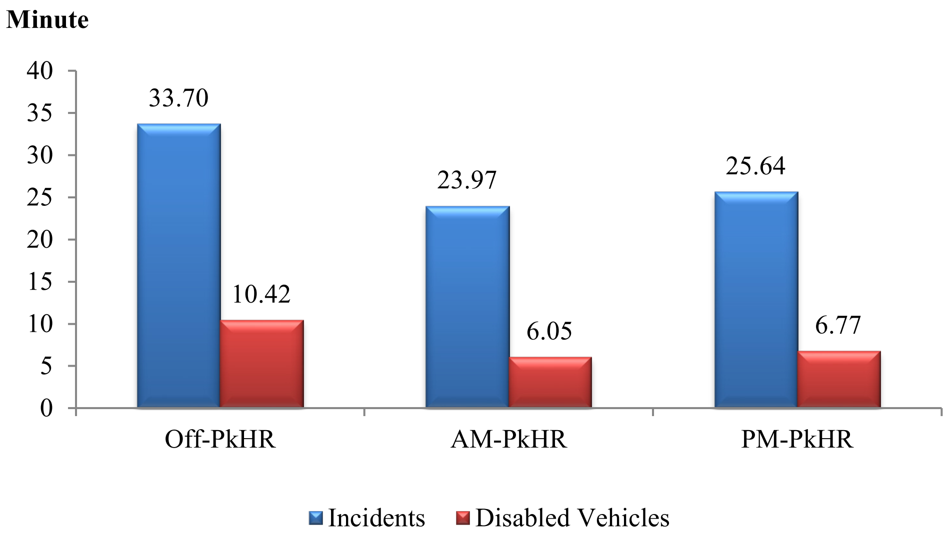

Figure A.12 Distributions of Incident Duration by Time of Day on I-495 in Year 2021

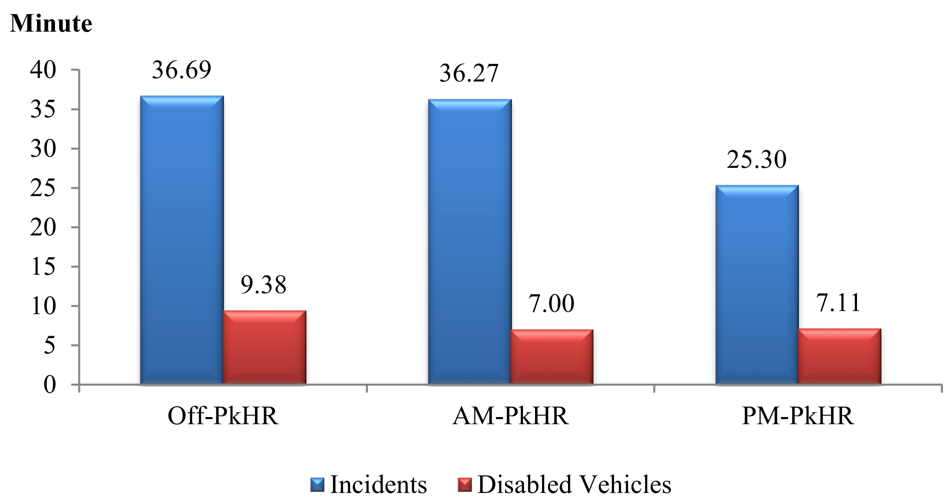

Figure A.13 Distributions of Incident Duration by Time of Day on I-270 in Year 2021

APPENDIX A - Additional Analyses

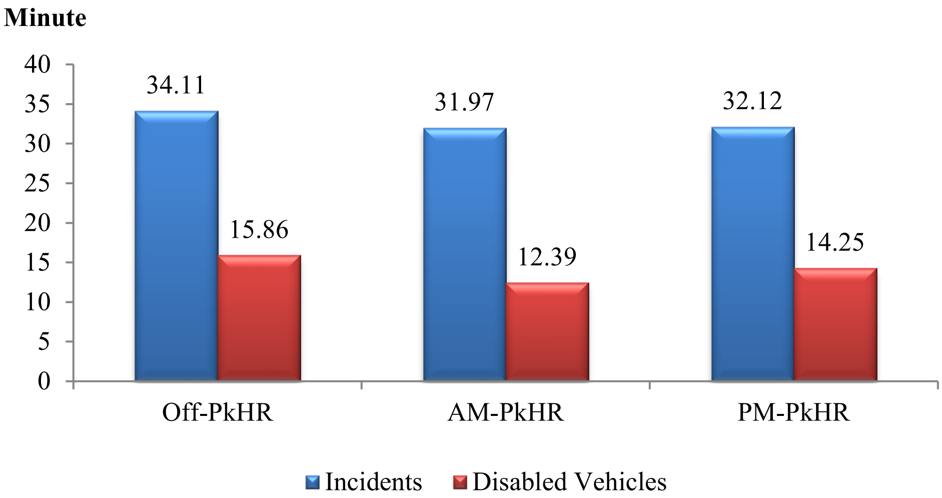

Figure A.14 Distributions of Incident Duration by Time of Day on I-695 in Year 2021

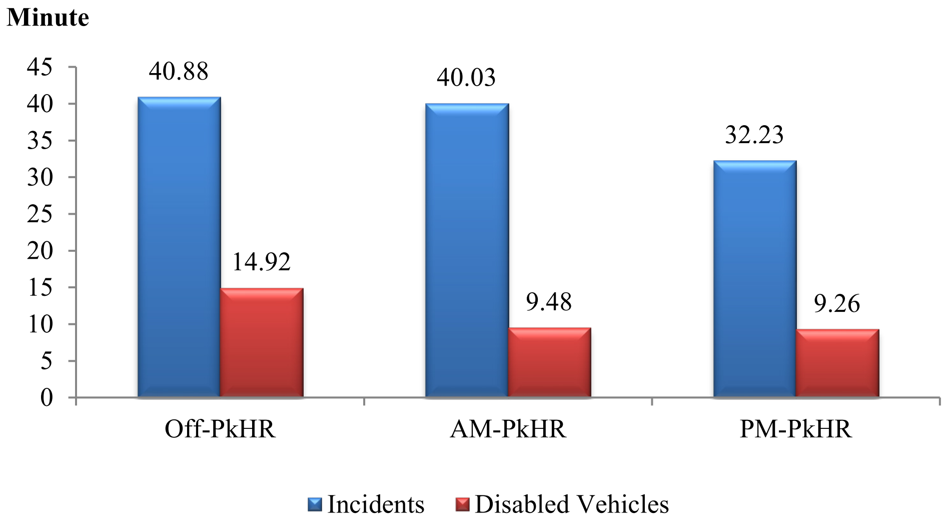

Figure A.15 Distributions of Incident Duration by Time of Day on I/MD-295 in Year 2021

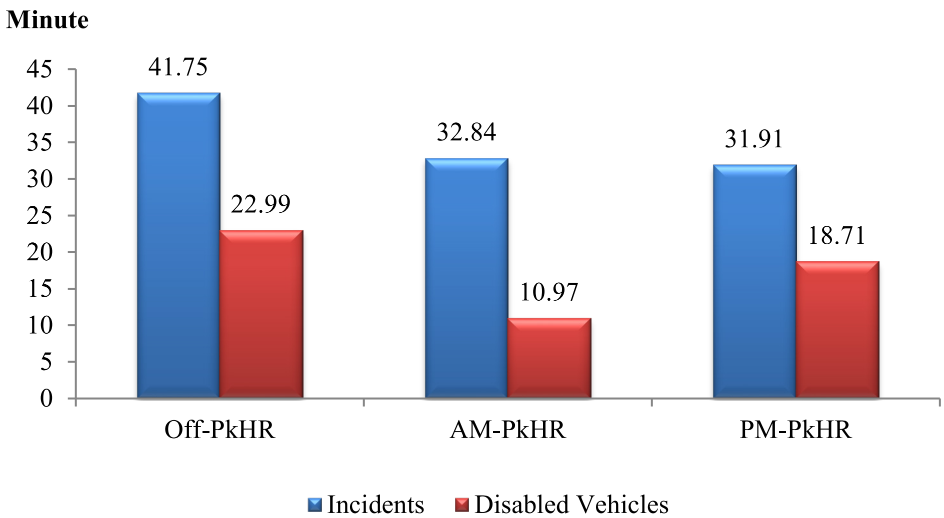

Figure A.16 Distributions of Incident Duration by Time of Day on I-83 in Year 2021

APPENDIX B - Benefit Estimation Procedure and Sensitivity Analysis

❖ The procedure to estimate the total benefit induced by the CHART performance

Step 1: Obtain info. regarding lane blockages, durations, locations, and response units for incidents from CHART-II DB

↓

Step 2: Collect additional data - AATD, peak hour factor(PHF), and % of truck for major roads in MD (I-495, I-95, I-270, I-695, I/MD 295, US 50, US 1, I-70, and I-83)

↓

Step 3: Compute the total delay by segment (*TDseg*) for each major road based on traffic volume, lane blockage ratio, average incident duration, and number of incidents

↓

Step 4: Estimate the total delay (*TD*) for all roads in MD based on the number of incidents detected during the target year

↓

Step 5: Estimate the total delay reduction (*ΔTD*) by the CHART performance based on the estimated CHART efficiency

↓

Step 6: Convert the total delay reduction (*ΔTD*) by the CHART performance into fuel consumption reduction (*Δfuel*) and emission reduction (*Δemission*) using conversion factors (α) (e.g., *Δfuel* = *ΔTD* x α)

↓

Step 7: Convert the total delay reduction, fuel consumption reduction, emission reduction into monetary values

APPENDIX C - Sources of Images Used in This Report

P18: From Maryland State Highway Administration (SHA)

P20, P78:
https://www.wikiwand.com/en/Snowplow
http://ops.fhwa.dot.gov/publications/fhwahop10014/s3.htm
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P25:
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P104:
http://apps.roads.maryland.gov/webprojectlifecycle/ProjectPhotos.aspx?projectno=AW5181115
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