Integration of a Discrete Choice Model and a Rule-Based System for Estimation of Incident Duration: a Case Study in Maryland

Pei-Wei Lin, Nan Zou, and Gang-Len Chang

Phone: (301) 405-6550
Fax: (301) 405-2585
1173 G. Martin Hall, Dept. of CEE,
University of Maryland at College Park,
20740, MD, USA
pwlin@wam.umd.edu

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ABSTRACT: This paper presents a system that integrates the discrete choice model with a rule-based supplemental module for estimating the duration of a detected incident. The entire system is developed with the archived incident information in Year 2001 from Maryland State Highway Administration, and tested with the Year 2002 incident data. The primary function of the embedded discrete model is to estimate those incidents having durations less than 60 minutes. For severe incidents that may last more than one hour, the system will employ a rule-based supplemental module constructed with information from previous incident management to perform the estimation. With such a system, the control center operators can estimate the potential impact of a detected incident, and select proper real-time incident management strategies, such as detour operations or ramp closure.

INTRODUCTION

Efficient response to a detected incident so as to minimize the impact of non-recurrent congestion has long been recognized by highway traffic agencies, and a variety of coordinated traffic management programs have also been implemented over the past decades, especially since the emerge of Intelligence Transportation System (ITS). One of the essential aspects which has yet to be better addressed in the incident management is to have a system that can reliably project the incident impacts on the traffic network within a time period sufficiently short for real-time operations, such as display of variable message signs (VMS) at proper locations, implementation of detour plans at critical ramps, and report of traffic conditions through highway advisory radios. With such information, traffic control operators can employ available management strategies to prevent the formation of traffic queue, or to mitigate the congestion level cause by incidents.

In fact, most congestion management strategies cannot function as effectively as expected without an approximate incident duration. Estimation of the required clearance duration for a detected incident, however, is a quite challenge task as it varies with a variety of factors, including the nature of incidents, location, number of blocked lanes, severity level of personal injuries, any need of special equipments (1-7). This is one of the primary reasons for having only very limited studies on this regard.

Available approaches in the existing literature for such a subject can be categorized into five groups, including Probabilistic Distribution Approach (1, 2), Linear Regression (3, 4), Conditional Probabilities (5, 6), Time Sequential Models (7), and Decision Tree Model (2). Most of those approaches are probabilistic in nature, and have made significant contribution towards a better understanding between required incident duration and associated critical factors. Much, however, remains to be improved to ensure the successful implementation of an incident duration estimation model. Grounded on the valuable information of existing literature, this study intends to pursue a different avenue with actual data from MDSHA (Maryland State Highway Administration). The proposed method has integrated a discrete choice model with a rule-based supplemental module. The former component is proposed in response to the following facts: 1) most traffic center operators would prefer the duration of a detected incident to be estimated in a range of time interval (e.g., 30-40 minutes), rather than in a precise time frame (e.g. 34, minutes); and 2) A large number of critical factors contributing the resulting incident duration are either discrete in nature or represented with binary indicators.

The supplemental module is designed to capture those severe incidents, which generally belong to a particular category (e.g., fatalities) with their durations determined mainly by one or two critical factors. Inclusion of those severe incident samples in development of the first component would significantly degrade the prediction quality of the resulting model. Hence, as shown in Figure 1, this study intends to integrate an advanced statistical model with available operational experience presented in the format of rules so as to take the full strengths of both methods in contending with the difficult task of estimating incident duration.

This paper is organized as follows: an exploratory analysis of critical variables associated with the incident duration is presented in the next section. This is followed by the construction of a discrete choice model and a rule-based supplemental module in Section 3 and Section 4, respectively. Conclusions and further research needs are reported in the last section.

EXPLORATORY ANALYSIS

The data used for model development is from the Maryland CHART (Coordinated Highway Action Response Team) II Database. Starting from February 2001, CHART has adopted a statewide database system to store the information for both traffic conditions and responsive activities. The total numbers of the data in Year 2001 and Year 2002 are 23,979 and 32,814, respectively. Only the data of Incidents is used in this study. The total numbers of incident data in Year 2001 and Year 2002 are 8,743 and 13,752, respectively.

Since each year contains a sufficient number of data, this study has adopted only the Year 2001 data for model development. The Year 2002 data is used for assessing the developed model's potential for real-world applications.

As reported in the literature (1-7), the following variables may have significant impacts on the required operational duration of a reported incident.

- Incident or accident type
- Number of lanes blocked
- Incident time
- Truck involved
- Number of vehicles involved

- Response time (e.g. travel time to the incident site)
- Weather condition and visibility
- The use of a heavy wrecker

In contrast, the CHART II Database consists of the following information:

- Time Stamps: received time, confirmed time, dispatched time, arrival time, cleared time, and event-closed time
- County name
- Detection Source
- Incident nature
- Lane blockage information
- Incident or disabled vehicle location, including road name, location, and direction
- Type of vehicle involved
- Number of vehicles involved

Based on those reported in the literature and the information in the CHART II Database, we have selected the following critical incident related variables for model development.

Incident Times

Figure 2 presents the relation between the response time and the incident duration recorded in the CHART II Database, which seems to exhibit a positive correlation. Figure 3 shows the relation between incident starting time and the incident duration, reflecting that the average duration for those incidents incurred during the night time (i.e. from 0:00 to 6:00 and from 21:00 to 23:59) is longer than those during other time periods.

Incident Nature

The incident nature includes: vehicles fire, debris in the roadway, collision/personal injury, collision/property damage, collision/fatality, and disabled vehicles on the road. Figure 4 shows the relation between incident nature and the incident duration.

Among all available data, incident nature is one of the most important variables for estimating the required incident duration. For example, as shown in Figure 4, highway segments experiencing fatalities generally need a significantly longer duration than others for clearance and recovery.

Lane Blockage

Figure 5 shows the distribution of the Incidents and Disabled Vehicles by lane blockage and road for the Washington Region. Note that “shoulder lane blockage” is defined as incidents that result in only shoulder lane blockage.

Figure 6 shows the positive correlation between the number of blocked lanes and the resulting incident duration.

Spatial Distribution of Incidents

CHART II Database also offers the information for analyzing the spatial distribution of incidents along each primary highway system (see Figure 7).

Figure 8 shows the distribution of average incident duration on different highway systems. The discrepancy in incident duration is due in part to the difference in congestion level and the distribution of MDSHA’s patrol units.

Including those critical variables presented above, all incident-related factors used for model development are shown in Table 1.

THE DISCRETE CHOICE MODEL

Note that in developing the discrete choice model, all sample incident durations have been divided into a number of intervals, each having an increment of five minutes. This is proposed in response to the need of control center operators. For instance, it will be sufficient for operators to know if the incident duration may lie within, for example, 30 to 35 minutes, rather than 38.5 minutes. Since all samples incident durations for model estimation are classified into discrete intervals at an ascending order, the Ordered Probit Model offers a uniquely effective way for model calibration.

The Ordered Probit Model is grounded on the following latent regression:

$$y^* = \beta' x + \varepsilon$$

where y^* is unobserved. What we do observe is:

$$\begin{aligned} y &= 1 \text{ if } \quad y^* <= 0 \\ &= 2 \text{ if } 0 < y^* <= \mu_1 \\ &= 3 \text{ if } \mu_1 < y^* <= \mu_2 \\ &\dots \\ &= N \text{ if } \mu_{N-2} < y^* \end{aligned}$$

where μ_i are unknown parameters to be estimated with β

$$\Pr ob(y = 1) = cnorm(0 - \beta' x) - 0$$

$$\Pr ob(y = 2) = cnorm(\mu_1 - \beta' x) - cnorm(0 - \beta' x)$$

$$\dots$$

$$Prob(y = N) = 1 - cnorm(\mu_{N-2} - \beta' x)$$

One can construct the log-likelihood function and compute its derivatives with standard methods. The interval with the highest probability is selected as the most likely interval for the incident duration. A detailed description of the Ordered Probit Model is available elsewhere (9).

To be consistent with actual practices and convenience for model estimation, the study has divided all incident duration data into 24 categories at an increment of 5 minutes. For instance, Category 0 contains those sample cases having duration of 0-5 minutes, and Category 1 includes those between 5 to 10 minutes. With respect to those severe incidents lasting more than 2 hours, estimation of their durations is neither quite meaningful nor possible as the resulting clearance time may vary with a variety of non-technical factors such as institutional barriers, required special equipments. Therefore, they are all grouped into the last category (i.e. Category 24). In addition to the variables mentioned above, the following interaction terms have also been used in the model development:

- X1 – (SHLDR + LB) / LN
- Y1 – I95N * AMPEAK
- Y2 – I95S * AMPEAK
- Y3 – I495IL * AMPEAK
- Y4 – I495OL * AMPEAK
- Y5 – I270N * AMPEAK
- Y6 – I270S * AMPEAK
- Y7 – I695IL * AMPEAK
- Y8 – I695OL * AMPEAK
- Z1 – I95N * PMPEAK
- Z2 – I95S * PMPEAK
- Z3 – I495IL * PMPEAK
- Z4 – I495OL * PMPEAK
- Z5 – I270N * PMPEAK
- Z6 – I270S * PMPEAK
- Z7 – I695IL * PMPEAK
- Z8 – I695OL * PMPEAK

The variable X1 is the ratio between the number of lane blockage (including shoulder lane blockage) and total number of travel lanes. Those Yi and Zi are the interaction variables for indicating those primary highways under different peak periods. Because both traffic conditions and incident duration in those commuting corridors vary significantly with the direction of traffic flows and times of a day. The initial Ordered Probit Model estimated with the Year 2001 data is shown in Table 2. The number of data points in Year 2001 with complete information is 770 for model estimation.

With the standard procedures for variable selection, we have finalized the incident duration model and presented the results in Table 3. The implications of estimated results by category are discussed briefly below.

Traffic Condition Information

The negative coefficient of the shoulder blockage indicator (SHLDR) indicates that the required duration for an incident will be shorter if the shoulder roadway is not blocked. The coefficient for the ratio between the number of blocked lanes (including shoulder lane blockage) and the total number of travel lanes (X1), as expected, is positive.

Operations Information

The negative coefficient of the MDSHA patrol indicator (CHART) shows that the incident duration generally decreases with the involvement of the MDSHA incident response unit, which is consistent with the CHART evaluation results (10). The response time (RESTIME) is the time period between receiving the report of a incident and the arrival of response units on the scene, which may vary with the distance between the operation center to the incident scene, traffic conditions, and the required equipments, etc. This result shows that a longer response time, as expected, will result in a longer incident duration.

Time Information

In this category, only weekend indicator (WEEKEND) is significant with a positive coefficient due to fewer operation patrols from CHART during the weekend. Both peak hour variables (AMPEAK and PMPEAK) are not significant, except those interaction terms capturing roadway conditions under different peak periods.

Incident Nature Information

Both truck (TRUCK) and tractor-trailer (TRACTORTRAILER) involved indicators are positively significant. Those incidents involving trucks or tractor-trailers are generally more severe, and require longer clearance time. In addition, those with the nature of vehicle fire, property damage, fatality, and personal injuries are all required longer duration as evidenced in their positive coefficients.

Road Information

The road indicators listed in this study are those primary and congested commuting corridors. In the final model, those indicators for I-495 inner loop (I495IL), I-495 outer loop (I495OL), I-270 northbound (I270N), and the interaction term for I-695 inner loop and the evening peak period (Z7) all exhibit significantly negative coefficients. Such results indicate that incidents on those major highways generally take a shorter duration than the same type of incidents on other highways, as MDSHA has placed more highway patrol units on these main commuting highways.

To assess the potential of using the estimated model for prediction, the sample incident duration data for convenience of presentation is separated into four groups: 0~30 minutes, 30~60 minutes, 0~60 minutes, and over 60 minutes. Table 4 shows the estimation result with the Year 2001 data.

As shown in Table 4, using the difference of 10 minutes as an acceptable range for management and impact assessment, the estimated model can achieve the correct estimation of 93.97%, 61.96%, and 36.96%, respectively, for incidents with duration of 0~30 minutes, 30~60 minutes, and larger than 60 minutes. It suggests that the discrete model proposed in this study offers reasonably reliable estimate for those incidents with duration less than 60 minutes (about 84.65%). For those severe incidents taking more than one hour, estimation of their duration is neither quite meaningful nor possible as the resulting clearance time may vary with a variety of non-technical factors such as institutional barriers, required special equipments.

Note that for those cases with incident duration between 30 to 60 minutes, the percentage of the underestimated cases is about 28.26%. From the operation point of view, the predicted traffic impact will also be underestimated if the incident duration is underestimated. Thus, those cases with incident duration between 30 to 60 minutes need to be adjusted systematically with a constant, based on information in the knowledge base so as to decrease the percentage of underestimated cases. Table 5 shows estimation results compared with the actual year 2002 data after placing different adjustment factors to those incidents lie between 30-60 minutes.

As shown in Table 5, the estimation result after adjust +3 interval (15 minutes) has the higher percentage of correct estimation and less percentage of under estimation. Table 7 shows the estimation results with the Year 2002 incident data after adding adjustment terms for those incidents with duration between 30 to 60 minutes. The number of available data points for comparison is 905.

As shown in Table 6, with a 10-minute acceptable interval, the developed model can estimate incidents of 0~30 minutes and 30~60 minutes at the accuracy level of 89.22% and 67.76%, respectively. The percentage of underestimated cases has decreased to 13.47%. Overall, the accuracy for those cases with incident duration less than 60 minutes is 82.25%.

From the results in Tables 4 and 6, it seems clear that the proposed discrete model is sufficiently reliable for those incidents with duration less than one hour, as the response procedures are more likely to be standardized. However, for those severe incidents with duration falling in the category of more than one hour, it is difficult to estimate their durations within a reliable range. Some of those severe incidents belong to particular categories, however, can be approximated to some degree with general rules developed from previous operational data.

THE RULE-BASED SUPPLEMENTAL MODULE

As the ordered probit model cannot fully capture all factors and their complex interactions that may affect the resulting incident duration, this study has developed a rule-based supplemental module for estimating the duration of some particular types of severe incidents.

The rule-based supplemental module is constructed based on the same Year 2001 and Year 2002 data from the CHART II database but with more samples as the rule-based module does not require all information needed in the discrete model. A total of 1,104 sample incidents have been used in identifying rules for developing this supplemental module. The constructing procedures for the rule-based supplemental module is summarized in steps below:

Step 1: Classifying all sample incident durations based on the following information:

- Incident nature
- Peak hour indicator
- Number of vehicles involved
- Truck indicator
- Tractor-trailer indicator
- Weekday indicator
- Number of lanes closed
- Response time

Step 2: Grouping incidents based on the above similarity classifications and set the rules.

Step 3: Compute applicable range for each rule to estimate the incident duration based on available cases in each group.

Based on the above procedures, for example, the Incident Nature is set as the first layer for the rule-based decision tree, and Peak-Hour Indicator is adopted as the second layer in the decision tree. Other variables are also used in constructing the rule-based module, but are not used for all rules. Table 7 shows the developed rules and their performance. Those rules are constructed for incidents with the nature of Disabled on Road, Collision/Fatality and Collision/Property Damage only.

Note that although the rule-based approach seems to offer a reasonable approximate for above identified types of severe incidents, some other severe incident scenarios, natures of Vehicle Fire or Debris on Roadways, remain varying in a wide range, and are difficult to capture their patterns based on the currently available data. Also, no rule can be established for incidents with nature of Collision that results in "Personal Injury" yet. Table 8 shows the set of scenarios that await more data available in the next few years for possible development of some effective rules.

SUMMARY AND CONCLUSIONS

This paper has presented a system for estimating the duration of a detected incident. The study has first developed a discrete choice model with the Year 2001 incident data from MDSHA for estimating the incident duration, and the Year 2002 incident data for model performance test. The preliminary evaluation results seem to indicate that the discrete model is sufficiently reliable for estimating those incidents having duration less than 60 minutes. For severe incidents that may last more than one hour, the study has further proposed a rule-based supplemental module to approximate their durations.

It is fully recognized that much remains to be improved in developing a robust prediction model for incident duration, which is complex and uncertain in nature. However, this study, as the first step, seems to achieve a reasonable progress and offers the potential for real-world applications as more than 83.1% of incidents in Maryland highway networks are shorter than one hour. Our on-going work is to collect more quality data and employ an integrated neural network/rule-based model to estimate these categories of incidents that cannot be tackled at the current stage.

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Table 1. Variables Used in the Model Development

Category	Variable	Notation	Range
Traffic Condition Information	1. Shoulder blockage indicator	SHLDR	0, 1
	2. Number of lane blockage	LB	1, 2, 3, 4
	3. Number of lanes	LN	1, 2, 3, 4
Operation Information	4. MDSHA patrol participant indicator	CHART	0, 1
	5. The response time	RESTIME	> 0
Time Information	6. Weekend indicator	WEEKEND	0, 1
	7. Morning peak-hour indicator (6:00am~9:00am)	AMPEAK	0, 1
	8. Evening peak-hour indicator (4:00pm~7:00pm)	PMPEAK	0, 1
Incident Property Information	9. Number of vehicles involved	VEHNUM	> 0
	10. Truck involved indicator	TRUCK	0, 1
	11. Tractor-trailer involved indicator	TRACTORTRAILER	0, 1
	12. Vehicle fire indicator	VEHFIRE	0, 1
	13. Collision–property damage indicator	CPD	0, 1
	14. Collision–fatality indicator	CF	0, 1
	15. Collision–personal injury indicator	CPI	0, 1
Roadway Information	16. I-95 northbound indicator	I95N	0, 1
	17. I-95 southbound indicator	I95S	0, 1
	18. I-495 inner loop indicator	I495IL	0, 1
	19. I-495 outer loop indicator	I495OL	0, 1
	20. I-270 northbound indicator	I270N	0, 1
	21. I-270 southbound indicator	I270S	0, 1
	22. I-695 inner loop indicator	I695IL	0, 1
	23. I-695 outer loop indicator	I695OL	0, 1

Table 2. The Initial Ordered Probit Model Estimated with the Year 2001 Data

Data Points	770 (from CHART II Database in year 2001)		
Parameter	Estimate	t-statistic	P-value
C	**1.69600**	**4.18853**	[.000]
SHLDR	**-.256916**	**-1.77127**	[.077]
LB	-.032577	-.268495	[.788]
LN	.070111	.748545	[.454]
X1	**.709126**	**1.71953**	[.086]
CHART	**-1.01701**	**-4.22810**	[.000]
RESTIME	**.059333**	**21.1407**	[.000]
WEEKEND	**.344751**	**1.68435**	[.092]
AMPEAK	-.034086	-.183805	[.854]
PMPEAK	-.153726	-.786781	[.431]
VEHNUM	-.017955	-.435492	[.663]
PICKUPVAN	.104810	1.08078	[.280]
TRUCK	**.436106**	**3.82967**	[.000]
TRACTORTRAILERS	**.280141**	**2.26792**	[.023]
DEBRIS	-.409461	-.999010	[.318]
VEHFIRE	**.459718**	**2.06240**	[.039]
CPD	**.279037**	**2.40952**	[.016]
CF	**2.14521**	**5.02067**	[.000]
CPI	**.813981**	**6.31518**	[.000]
I95N	.306017	.935970	[.349]
I95S	**.439708**	**1.53045**	[.126]
I495IL	**-.501027**	**-2.89683**	[.004]
I495OL	**-.370249**	**-2.09346**	[.036]
I270N	**-.691557**	**-1.45203**	[.146]
I270S	.283559	.390291	[.696]
I695IL	**.495027**	**1.92128**	[.055]
I695OL	.053265	.216450	[.829]
Y1	.331240	.545620	[.585]
Y2	**-.923622**	**-1.76800**	[.077]
Y3	.620578E-02	.022411	[.982]
Y4	-.051456	-.194561	[.846]
Y5	-.260716	-.339165	[.734]
Y6	-.456714	-.577245	[.564]
Y7	-.479147	-1.29044	[.197]
Y8	-.028204	-.078782	[.937]
Z1	-.361687	-.662093	[.508]
Z2	-.522649	-.874901	[.382]
Z3	.224969	.879240	[.379]
Z4	.017880	.066888	[.947]
Z5	.571017	1.00177	[.316]
Z6	-.126043	-.147841	[.882]
Z7	-1.66375	-1.96619	[.049]
Z8	.982291	1.27795	[.201]

Table 3. The Final Ordered Probit Model Estimated with the Year 2001 Data

Data Points	770 (from CHART II Database in year 2001)		
Parameter	Estimate	t-statistic	P-value
C	1.87822	7.3866	[.000]
SHLDR	- .19712	- 2.1364	[.033]
X1	.56403	4.2109	[.000]
CHART	- .98747	- 4.2639	[.000]
RESTIME	.05870	21.3168	[.000]
WEEKEND	.49032	2.6455	[.008]
TRUCK	.40631	3.6691	[.000]
TRACTORTRAILERS	.28265	2.3754	[.018]
VEHFIRE	.54871	2.5072	[.012]
CPD	.26205	2.5165	[.012]
CF	1.97082	4.7246	[.000]
CPI	.82413	7.2073	[.000]
I495IL	- .44350	- 4.5176	[.000]
I495OL	- .39520	- 3.9596	[.000]
I270N	- .44709	- 1.9410	[.052]
Z7	-1.38157	- 1.7318	[.083]

Table 4. The Estimation Result of the Year 2001 Data

Estimated Error	±5 min			±10 min		
Incident Duration	Correct Estimation	Under Estimation	Over Estimation	Correct Estimation	Under Estimation	Over Estimation
0 ~ 30 min	73.21%	5.58%	21.21%	93.97%	0.67%	5.36%
30 ~ 60 min	44.57%	40.76%	14.67%	61.96%	28.26%	9.78%
0 ~ 60 min	64.87%	15.82%	19.30%	84.65%	8.70%	6.65%
Over 60 min	34.06%	–	–	36.96%	–	–

Table 5. The Estimation Results compared with the Year 2002 Data

Estimated Error	±5 min			±10 min		
Adjust Interval	Correct Estimation	Under Estimation	Over Estimation	Correct Estimation	Under Estimation	Over Estimation
+0	28.57%	63.67%	7.76%	44.08%	50.61%	5.31%
+1	35.51%	51.84%	12.65%	52.65%	39.59%	7.76%
+2	41.63%	39.59%	18.78%	64.49%	22.86%	12.65%
+3	**43.67%**	**22.86%**	**33.47%**	**67.76%**	**13.47%**	**18.78%**
+4	39.18%	13.47%	47.35%	60.82%	5.71%	33.47%
+5	33.88%	5.71%	60.41%	49.80%	2.86%	47.35%

Table 6. The Prediction Results Compared to the Actual Incident Duration in Year 2002

Estimated Error	±5 min			±10 min		
Incident Duration	Correct Estimation	Under Estimation	Over Estimation	Correct Estimation	Under Estimation	Over Estimation
0 ~ 30 min	70.39%	6.27%	23.33%	89.22%	1.57%	9.22%
30 ~ 60 min	43.67%	22.86%	33.47%	67.76%	13.47%	18.78%
0 ~ 60 min	61.72%	11.66%	26.62%	82.25%	5.43%	12.32%

Table 7. Available Rules and Their Performances

No.	Rule	Correct Est.	Total cases
1	IF Nature = Disabled on Road AND Response Time > 60 minutes THEN 60 minutes < Incident Duration < 90 minutes	85.7%	7
2	IF Nature = Disabled on Road AND Response Time < 60 minutes THEN Incident Duration < 60 minutes	98.1%	641
3	IF Nature = Collision, Fatality AND in Peak Hours AND (Truck Involved OR Tractor Trailers Involved OR Pick/Van Involved) THEN Incident Duration > 3 hours	100%	8
4	IF Nature = Collision, Fatality AND Not in Peak Hours AND in Weekdays AND 1 vehicle involved Then Incident Duration > 140 minutes	100%	6
5	IF Nature = Collision, Fatality AND Not in Peak Hours AND in Weekdays AND 2 vehicles involved Then Incident Duration > 145 minutes	70%	10
6	IF Nature = Collision, Fatality AND Not in Peak Hours AND in Weekdays AND 3 or more vehicle involved Then Incident Duration > 3 hours	100%	6
7	IF Nature = Collision, Fatality AND Not in Peak Hours AND Not in Weekdays AND 2 or more vehicles involved Then Incident Duration > 160 minutes	90%	10
8	IF Nature = Collision, Property Damage AND in Peak Hours AND 1 vehicle involved AND Truck Involved AND 2 or less lanes closed THEN 60 minutes < Incident Duration < 100 minutes	100%	3
9	IF Nature = Collision, Property Damage AND in Peak Hours AND 2 or more vehicles Involved Response Time > 60 minutes THEN 90 minutes < Incident Duration < 120 minutes	83.3%	6
10	IF Nature = Collision, Property Damage AND Not in Peak Hours AND Response Time > 60 minutes AND Tractor Trailer Involved THEN Incident Duration > 160 minutes	75%	12
11	IF Nature = Collision, Property Damage AND Not in Peak Hours AND Response Time > 60 minutes AND No Tractor Trailer Involved THEN 70 minutes < Incident Duration < 120 minutes	100%	6

Table 8. Scenarios that cannot be Observed by Rules

No.	Scenario	Total cases
1	Nature = Collision, Fatality AND in Peak Hours AND Not Truck Involved AND Not Tractor Trailers Involved AND Not Pick/Van Involved	8
2	Nature = Collision, Fatality AND Not in Peak Hours AND Not in Weekdays AND 1 vehicle involved	6
3	Nature = Collision, Property Damage AND in Peak Hours AND 1 vehicle involved AND Truck Involved AND 3 or more lanes closed	1
4	Nature = Collision, Property Damage AND in Peak Hours AND 1 vehicle Involved AND No Truck Involved AND (8 out of 56 cases with duration more than 60 minutes)	56
5	Nature = Collision, Property Damage AND in Peak Hours AND 2 or more vehicles Involved AND Response Time > 60 minutes (15 out of 317 cases with duration more than 60 minutes)	317
6	Nature = Collision, Property Damage AND Not in Peak Hours AND Response Time < 60 minutes AND (47 out of 414 cases with duration more than 60 minutes)	414
7	Nature = Vehicle Fire	20
8	Nature = Collision, Personal Injury	224
9	Nature = Debris on Roadway	26

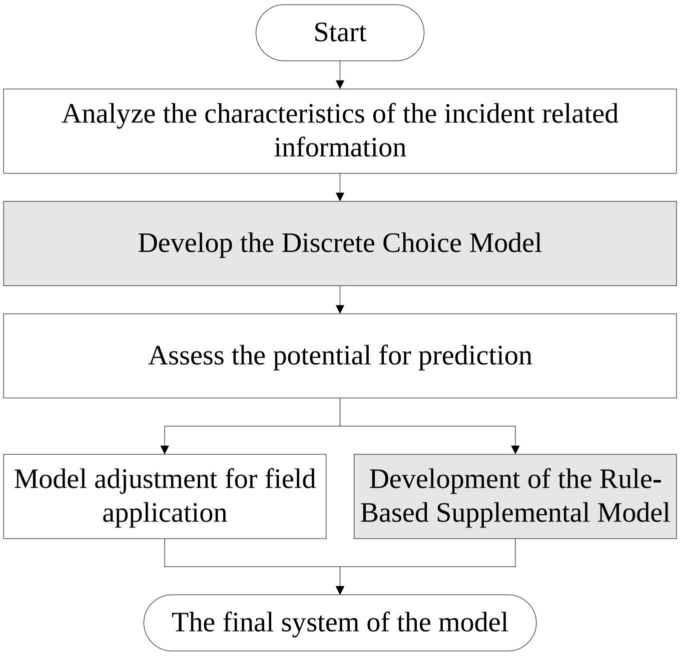


Figure 1. The Flow Chart of the Entire System

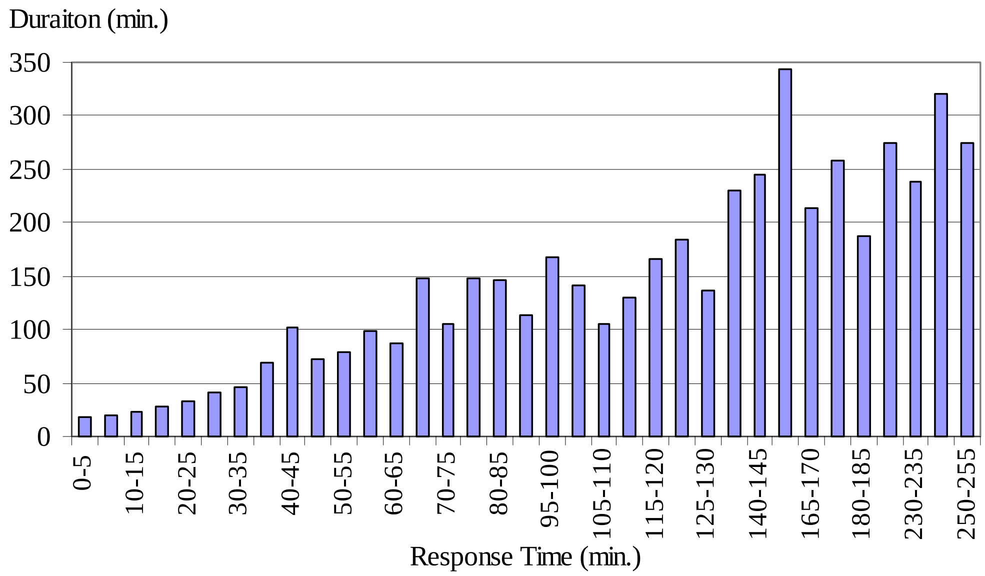


Figure 2. The Average Incident Duration for Different Response Time periods

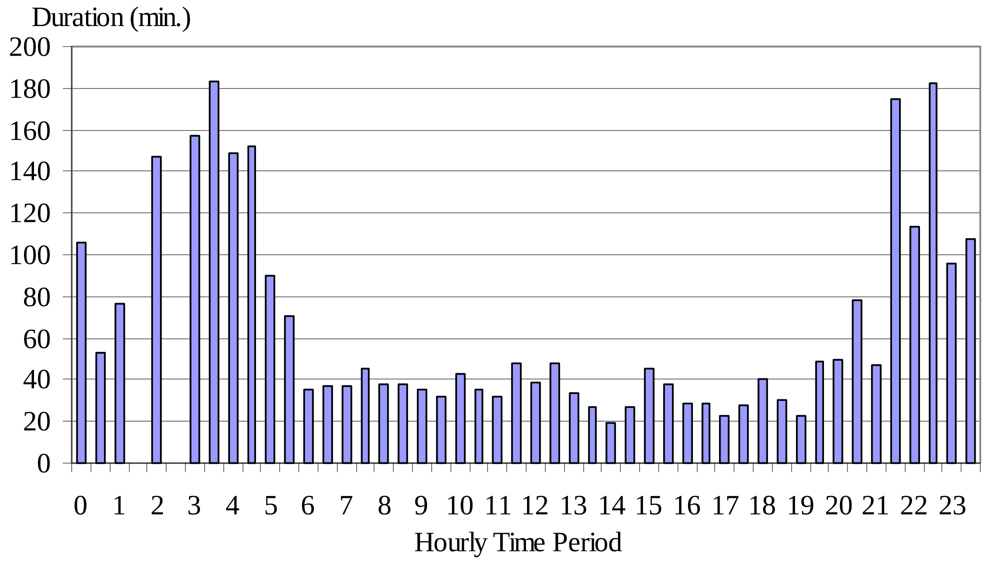


Figure 3. The Average Incident Duration for Different Starting Time Periods

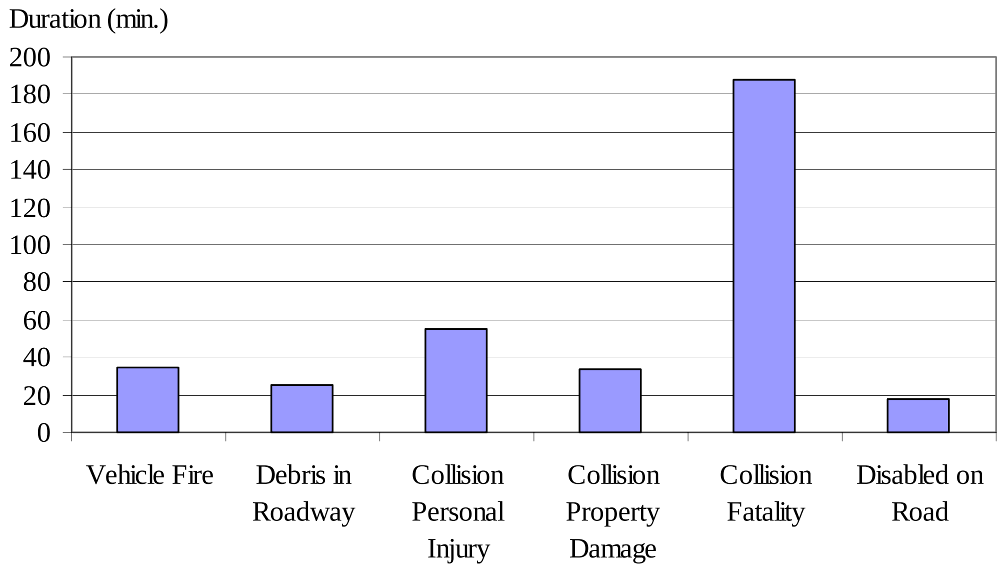
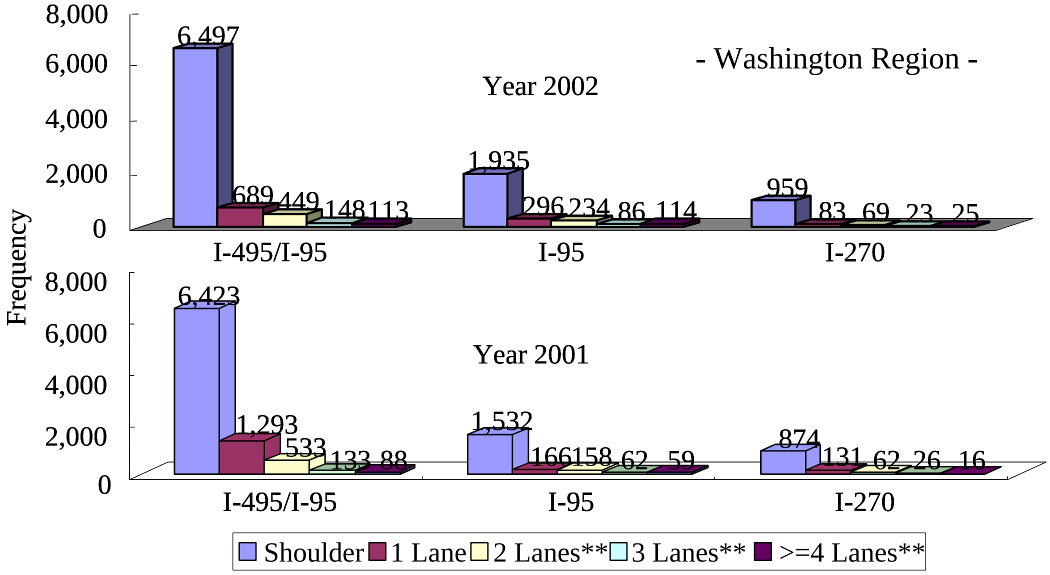


Figure 4. The Average Incident Duration for Different Incident Natures



Note: ** also includes shoulder lane blockages

Figure 5. The Distribution of Incidents and Disabled Vehicles by Lane Blockage and Road for the Washington Region

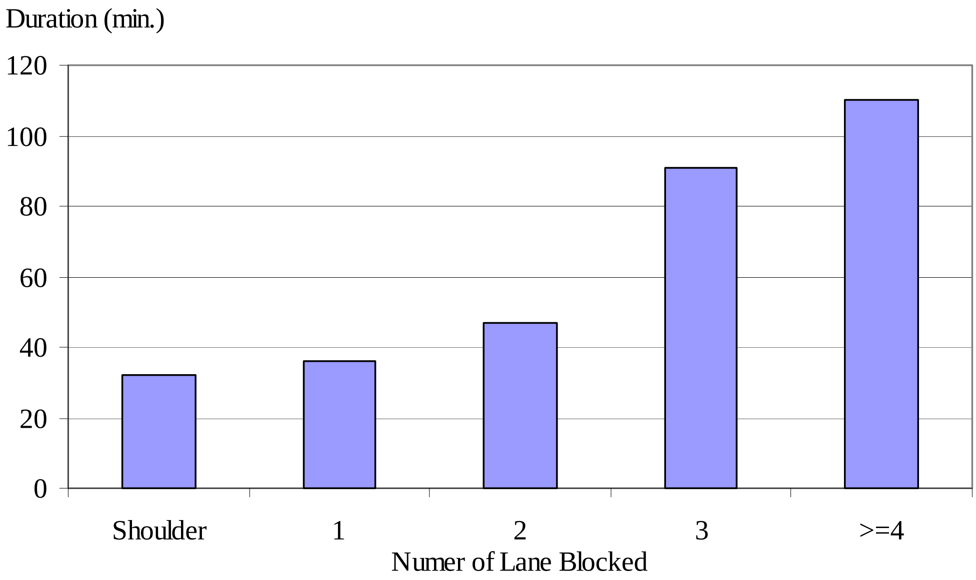


Figure 6. The Average Incident Duration for Different Numbers of Lane Blockage

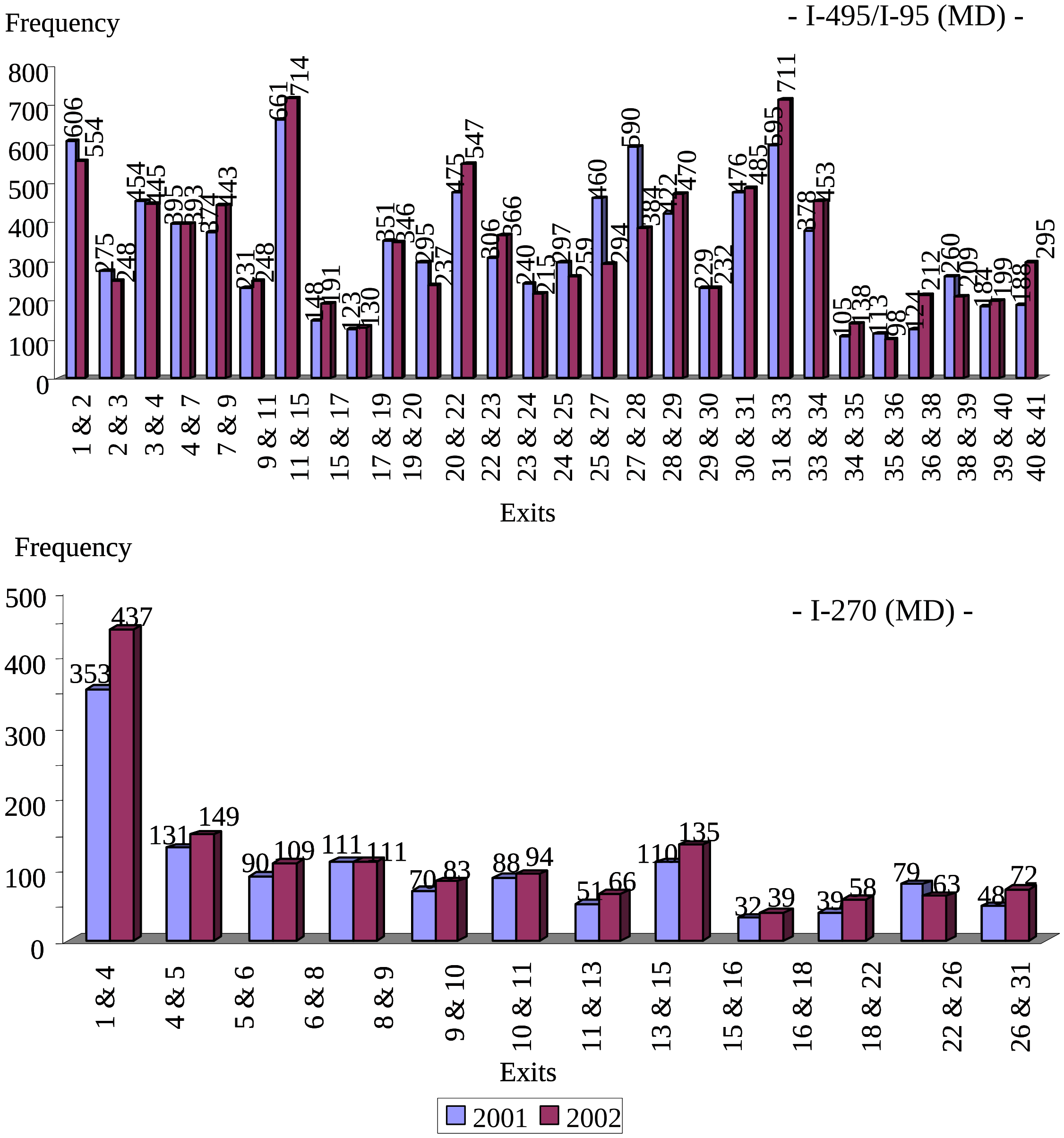


Figure 7. The Distributions of Incidents and Disabled Vehicles by Location

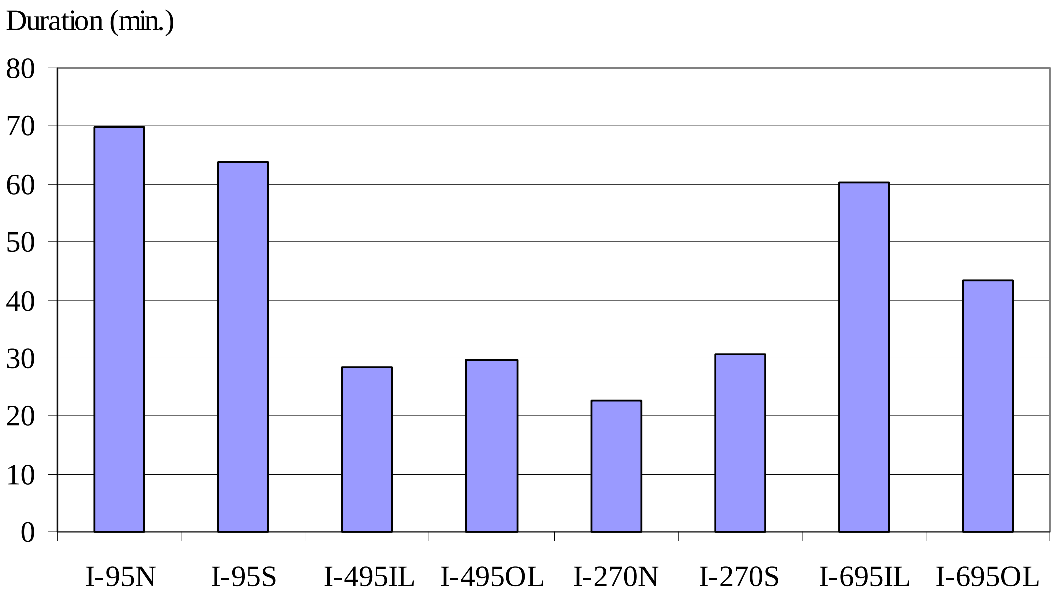


Figure 8. The Average Incident Duration for Different Roads by Direction