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MARYLAND DEPARTMENT OF TRANSPORTATION
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RESEARCH REPORT

DEVELOPMENT OF A TRAFFIC MANAGEMENT DECISION SUPPORT TOOL (DST) FOR FREEWAY INCIDENT TRAFFIC MANAGEMENT PLAN DEVELOPMENT

Phase-2: An enhanced DST-2, including I-95, I-495, I-695, I-70, US 29

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FINAL REPORT

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16. Abstract

Ground in the development experience of the piloting the **I**ncident **D**uration **P**rediction **M**odule (IDPM) for I-95 and its application results, this study further developed IDPMs for I-495, I-695, I-70, and US 29, each with distinguishing traffic patterns and roadway features. Considering the uniquely critical role assumed by I-495 and I-695, respectively, in the Washington and Baltimore regions and their large incident records, the design and construction of these two IDPMs mostly follow the same methodology as with IDPM-I-95. To circumvent the demanding expertise and efforts needed for data quality control and calibration of an IDPM's prediction rules from many incident records, this study has developed an innovative **T**ransferability **A**ssessment **M**ethod (TAM) that allows construction of a new system to take advantage of existing IDPMs' embedded knowledge. The developed TAM has been adopted for constructing the IDPMs for I-70 and US 29, based on the prediction rules in IDPMs for I-95, I-695, and I-495.

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Chapter 1. Introduction of the Project

1.1 Research background

It is well recognized that traffic incidents can result in a roadway's capacity reduction and reliability degradation and can lead to significant delays for commuters. Over the past several decades, many U.S. highway agencies have established a Traffic Incident Management (TIM) system to help mitigate such impacts and restore normal traffic conditions. A TIM system typically consists of a coordinated multi-disciplinary process to detect, respond to, and clear traffic incidents. It is expected that such a system can effectively reduce the clearance duration of detected incidents, and in turn, reduce impacts on traffic and safety.

To do so, a TIM system first needs a reliable and robust model to predict the required duration for incident clearance operations and to assess its time-varying traffic queues and resulting delays, because such information is essential for determining the proper control strategies and the responsive traffic management tasks.

Figure 1-1 shows three key models and their interrelations for use in supporting the TIM system's operations. The first is an incident duration prediction model, designed to estimate the duration of a detected incident using available information such as incident type, the number of blocked lanes, the number of involved vehicles and response units, pavement conditions, time, and location. The second model is for estimating the reduced capacity of the roadway due to the incident and its clearance operations, based on both the incident-related and the traffic-related information, including traffic speed, volume, and merging ratio. The last model functions to predict the resulting time-varying traffic impacts, based on the estimates provided by the incident duration and the capacity-reduction models. With the above models, a TIM support system can provide the temporal and spatial impacts of a detected incident to both en-route motorists and traffic control centers, allowing their operators/responders to select proper operational strategies (e.g., ramp closure, detour operations) and execute essential tasks in proper sequence.

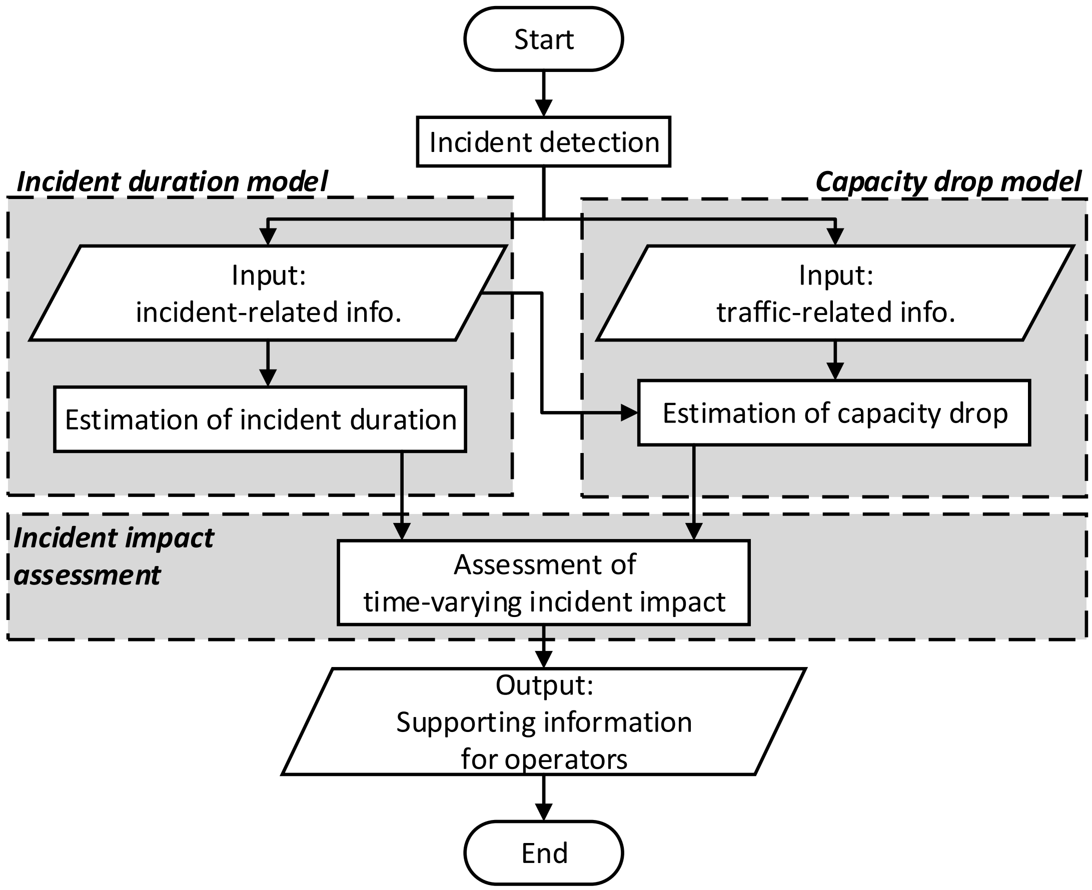

Figure 1-1: Graphical illustration of key modules in a traffic incident management system

As part of the TIM system development efforts, Maryland Department of Transportation State Highway Administration (MDOT SHA) has worked with the research team at Phase-I of this study to produce a prototype **D**ecision **S**upport **T**ool (DST-1) software, using the hybrid modeling logic shown in Figure 1-2, for estimating the duration of various incidents on I95. While the performance of the DST-1 will continue to be enhanced with available quality data, this exploration—the first of its kind in the country—has shown potential as an effective component of a real-time incident response and management system, as shown in Figure 1-1. The extensive knowledge and invaluable lessons accumulated from developing the DST-1, especially in contending with various complex data nature and missing variables, have provided a solid basis for enhancing the existing DST-1 and expanding its coverage to primary connected highways such as I-495, I-695, I-70, and US 29.

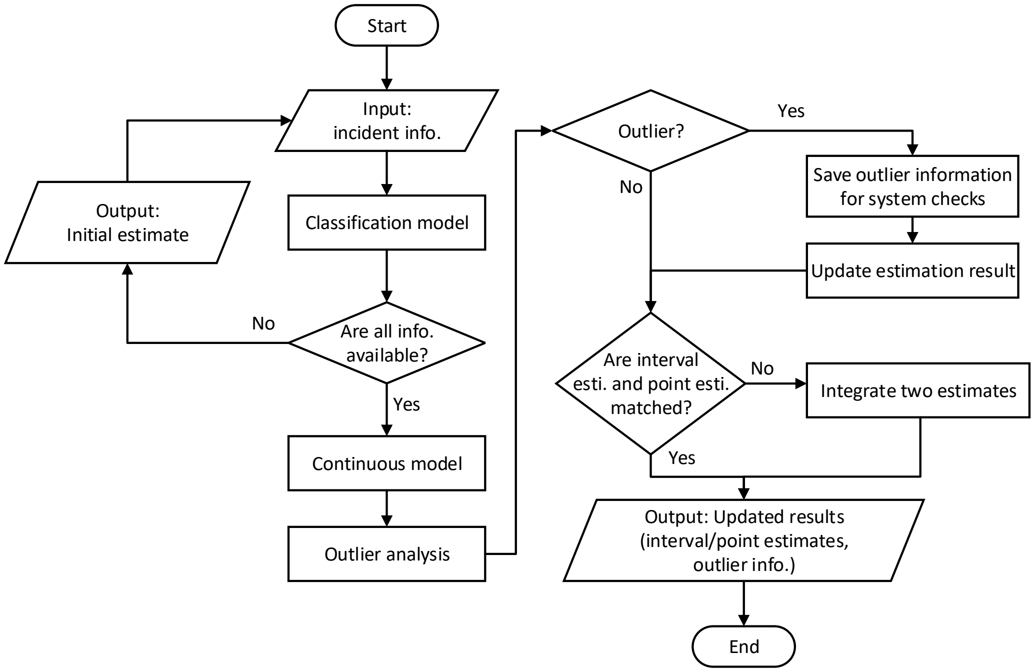

Figure 1-2: Flowchart for developing a knowledge-based incident duration prediction model

1.2 Research objective

The primary objective of this project is to continue the development of a Decision Support Tool (DST) for MDOT-SHA's incident traffic management system, including:

- enhance and refine the I-95 **I**ncident **D**uration **P**rediction **M**odel (IDPM
- -I-95), named DST-1;
- extend IDPM-I-95 in DST-1 to IDPM-I-495, IDPM-I-695, IDPM-I-70, and IDPM-US 29, named DST-2, in Maryland;
- develop a knowledge-based transferability assessment methodology that can serve as the tool for transferring well-established prediction rules in existing DSTs to other highways that do not have sufficient incident records for calibrating their own incident prediction modules; and
- design a user-friendly software to facilitate the application of DST-2 and evaluate its effectiveness with field data.

1.3 Report organization

Based on the research objectives, this project has yielded the following three types of products: (1) a stand-alone software for field operators to work on day-to-day incident management; (2) a set of empirical rules as well as their decision structures associated with each of the selected highways, included in DST-2 for exercising the prediction of a detected incident's duration; and (3) the methodology of transferability assessment to facilitate the expansion of existing DSTs' coverage to other roadway segments, especially for those lacking sufficient incident records for model development. All key research results associated with the three products are presented in this report and are organized as follows:

Chapter 2 reports on the developed software's key features, including its interface design, presentation of predicted outputs, and its underlying decision structure. Some sample applications to illustrate the evaluation and reliability of the developed software, DST-2, are also included in this chapter.

Chapter 3 presents the knowledge-based methodology used in this research to calibrate various prediction rules from incident records and construct their interrelations into an efficient decision structure for DST-2. This decision structure allows the developed system to conveniently update with the most recently available data and incorporate experienced operators' knowledge in maximizing the prediction accuracy.

Chapter 4 illustrates the development process and resulting prediction structure for the DST-2 system's IDPM-I-495 and IDPM-I-695 with the methodology detailed in Chapter 3. Since both freeways have sufficient incident records for model calibration and search of prediction rules, the discussion in this chapter centers on the methodology enhancement from DST-1 (i.e., only IDPM-I-95) with respect to efficient search and classification of prediction rules from massive available incident records between 2016-2018. The results of performance evaluation for IDPM-I-495 and IDPM-I-695 with respect to lane-blockage incidents in 2019 are also included in this chapter.

Chapter 5 highlights the transferability assessment methodology that allows the development of DST-2 system's IDPM-I-70 module to take advantage of well-established prediction rules embedded in the I-495 and I-695 modules. Illustration of the benefits from adopting such an innovative methodology with respect to substantial reduction in modeling efforts and sample data requirements constitutes the core this chapter. Also included in this chapter are the results of the performance evaluation of the IDPM-I-70 with 2019 incident data and the evidence of its prediction accuracy compared to DST-2 system's other modules developed with the knowledge-based association method from extensive incident records.

Chapter 6 first analyzes the challenges encountered in developing IDPM-US 29 in Maryland, a highway segment with insufficient incident records to either construct its own location-specific prediction model or to perform direct assessment of transferring those prediction rules from other developed modules. This is followed by a detailed presentation of a refined transferability assessment methodology, customized for construction of the incident prediction rules for those highways (such as US 29) with only limited incident records. Illustration of the development process for the US 29 module with its customized methodology, and the resulting performance with its 2019 incident records, are also reported in this chapter.

Chapter 7 primarily summarizes the research findings from this project and valuable lessons learned from developing reliable and trackable models for use in practice from incident records containing mostly qualitative and interdependent factors. The challenges and benefits in developing a generalized IDPM for all highways included in MDOT SHA’s incident response operations will also be discussed along with such a system’s potential contributions to managing non-recurrent congestion in this concluding chapter.

Chapter 2. System Structure and Interface for DST-2

2.1 System features and structure

To facilitate incident response teams' daily applications, this study has further integrated all developed **I**ncident **D**uration **P**rediction **M**odels (IDPM) into a stand-alone, user-friendly software named **D**ecision **S**upport **T**ool-**2** (DST-2). This level-2 DST, extended from DST-1 for the I-95 segment in Maryland, comprises those IDPMs developed for I-495, I-695, I-70, and US 29. It is expected that the level-3 DST, named DST-3 will include all highway networks covered by MDOT SHA's CHART incident response operations. This chapter will provide a concise introduction of the developed DST-2, including its key system features, design structure, flowchart of the prediction algorithms, and the customized interface to facilitate its applications.

System features

DST-2 is expected to be used in a real-time environment to provide timely estimation of a detected incident's required clearance duration, as either a stand-alone application or integration with other traffic management systems. Such information can then be further analyzed to yield the projected traffic queue distance during the incident clearance period and assess the need to implement any traffic management strategies. Designed to assisting incident response operators in their effort to minimize an incident's impacts on congestion, DST-2 offers the following essential features:

- minimal data requirements for executing the prediction;

- sufficient robustness to accommodate the deficiencies in quality and precision of input data available during the incident response and clearance operations;

- flexibility to incorporate experienced engineers' knowledge as supplemental information to minimize the impacts of missing data on the system's prediction accuracy;

- computational efficiency for use in real-time operations and for updating the estimation results in a timely manner in response to the evolving nature of incident response operations and uncertainly of traffic flow dynamics; and

- modularized structure for effective and seamless integration with other related incident management systems, such as traffic queue length and detour rate predictions.

In addition, the DST-2's prediction mechanism, constituted with the knowledge-based rule sets, is designed with maximum transparency so that it can be updated conveniently when more off-line incident records become available. Moreover, the set of knowledge-based rules, employed by DST-2 to estimate the duration for different types of incidents on different highway segments, are likely transferable to other roadway networks with similar traffic characteristics and response operations. Such a transferable feature is especially beneficial for traffic agencies in the design of similar IDPMs for highway segments with insufficient incident records for statistically meaningful model calibration and development.

System structure

Figure 2-1 shows the main structure of the developed DST-2, consisting of the input module from the interface and the output of the estimated incident duration from the core computing model. Prior to integration with other online database or geographical information systems, the program's main required information at the level-2 stage will be mainly provided by the incident response operators, which include three categories of data: (1) geographical features of the incident scene; (2) operational characteristics associated with the response team responsible for clearance of the detected incident; and (3) reported incident nature and lane-blockage conditions. Note that most data in the first two categories can be automatically fed into DST-2 after it has been extended to interact online with other GPS and GIS modules in a responsible traffic agency's primary incident response and traffic management systems.

As for the main prediction model, it is designed with a compartmentalized structure to allow its five embedded models (i.e., IDPM-I-95, IDPM-I-495, IDPM-I-695, IDPM-I-70, and IDPM-US 29) to function independently. It is expected that one more generalized module, IDPM-G, will be developed in the next phase of DST-3 for all other highways responsible by the CHART's incident response teams. Specifically, the IDPMs of highways embedded in DST-1, DST-2, and DST-3, respectively, are as follows:

- DST-1: IDPM-I-95
- DST-2: IDPM-I-95, IDPM-I-495, IDPM-I-695, IDPM-I-70, and IDPM-US 29
- DST-3: IDPM for all highways responsible by the CHART's incident response teams

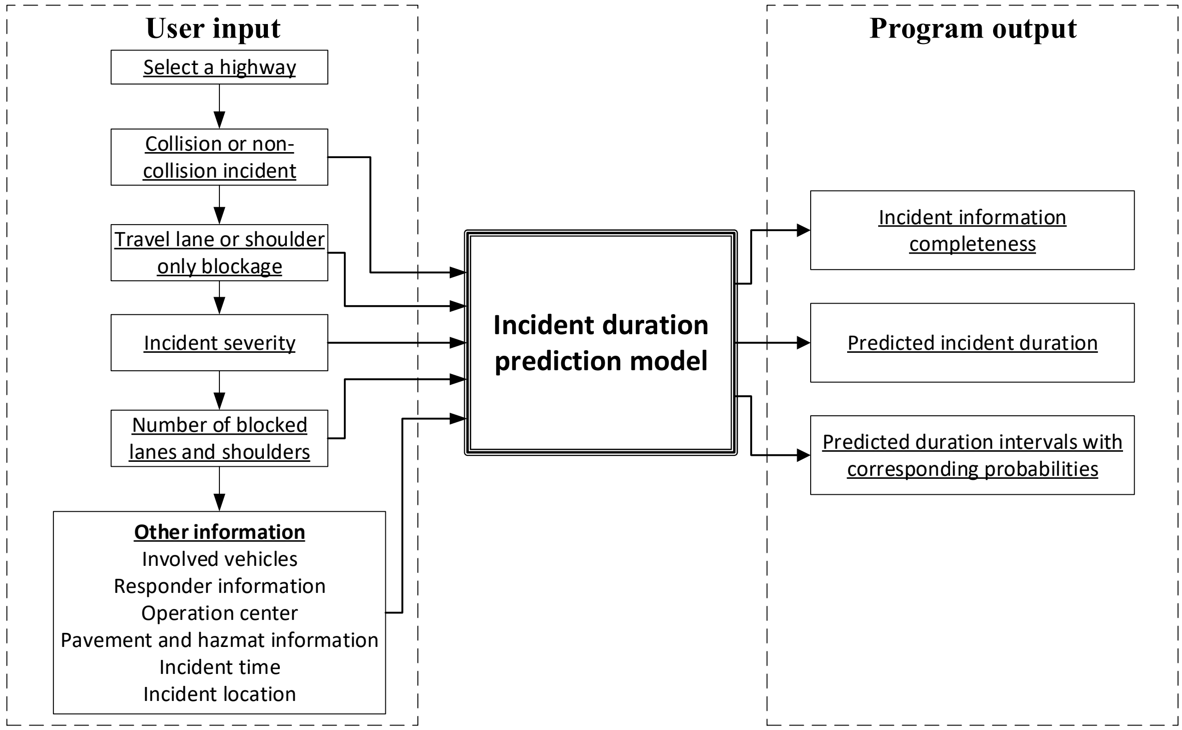

Figure 2-1: Overall structure of the developed DST-2 for predicting incident duration

Figure 2-2 illustrates the core logic embedded in each prediction module, where the prediction model will first designate one of its existing modules based on the detected incident's location to proceed the classification and prediction tasks. The assigned module will then execute its classification algorithm to identify the nature of incidents (e.g., collisions or not), incurred lane-blockage conditions, and the resulting severity level. As shown in the parallel structure of Figure 2-2, each detected incident, based on real-time information reported by the incident response team, will be classified into one of the following types:

- CF: for incidents resulting in fatalities;
- SI: for non-collision incidents causing only shoulder-lane blockage;
- CPD-1: for incidents due to collision and resulting in one-lane blockage;
- CPD-2: for incidents due to collision and resulting in two-lane blockage;
- CPD-3: for incidents due to collision and resulting in 3-or-more-lane blockage;
- CPI-1: for incidents due to collision and resulting in both one-lane blockage and personal injuries;

- CPI-2: for incidents due to collision and resulting in both two-lane blockage and personal injuries; and

- CPI-3: for incidents due to collision and resulting in both 3-or-more-lane blockage and personal injuries.

After classifying a detected incident as one of the pre-categorized types, the designated module will then employ its embedded set of prediction rules with a sequential "IF-THEN" process to identify incidents in the historical records that can best match the detected incident's characteristics and related response patterns. The final estimate of the detected incident's duration is computed with the probabilistic method from the average duration of incidents identified in the historical records that share similar characteristics, reported in real-time to the response center.

Note that considering the available input data's precision level in real-time response operations and inevitable uncertainties (e.g., arrival time of ambulance) affecting the required clearance time, the DST-2 will produce a resulting estimate of incident duration with four likely intervals: less than 30 minutes, between 30-60 minutes, 60-120 minutes, and over 120 minutes. Certainly, depending on the purported application of the estimated incident duration (e.g., adaptive off-ramp control for detour operations) and available data quality, one can fine-tune key prediction rules in DST-2 to transform its output in a short time interval, such as 30 minutes.

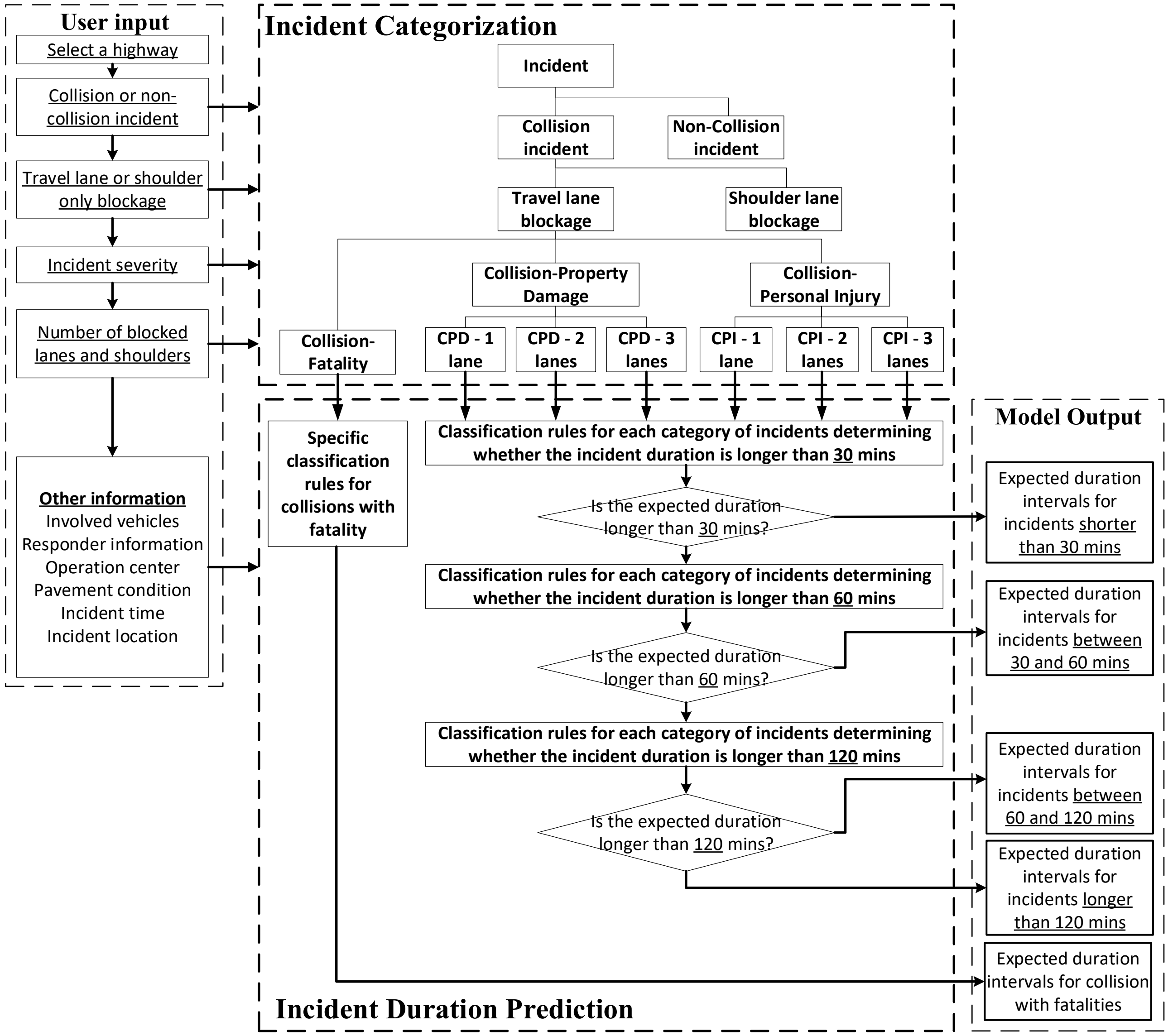

Figure 2-2: Operational flowchart of the incident duration prediction process

2.2 System interface and output modules

The interface

The interface for DST-2 is designed with the following principles in mind:

- sufficiently friendly for potential users to master the software’s functions without going through any training workshop;

- design the input sequence of required factors for DST-2 to execute the prediction based on the relative weight of each factor’s impact on the resulting incident clearance duration; and

- dynamically interact with field incident response teams to constantly update the prediction results based on the key input data increasingly available in real-time operations.

Figure 2-3 shows the cover page of and DST-2 and the required first step to select the target highway where an incident has been detected form available sources. As noted previously, the software currently comprises IDPMs for I-95, I-495, I-695, I-70, and US 29, each having a customized set of prediction rules for predicting the duration of incidents occurring within its own geographical boundaries.

Figure 2-4 indicates the two most important factors for DST-2 to perform the estimation of a detected incident’s duration: resulting in collisions or not and causing travel lane blockage or not. This is because most non-collision incidents can be cleared quickly and solely by the arrival of the first response unit, and those not blocking any travel lanes typically can be towed to the shoulder and receive all necessary care within 30 minutes. In contrast, for incidents due to collisions and resulting in lane blockage, their required clearance times may differ with various factors inputted in the later sequence of the interface.

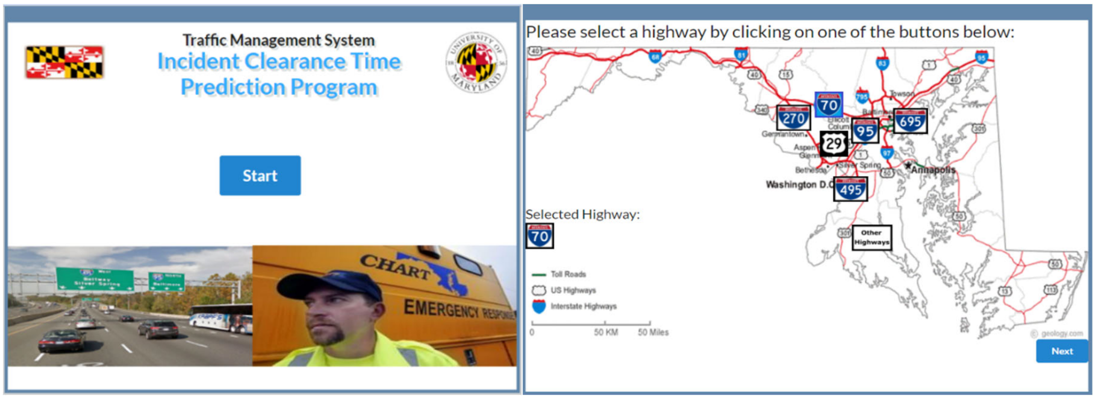

Figure 2-3: Cover page of the DST-2 software and the interface for identifying incident location (includes IDPM-I-95, IDPM-I-495, IDPM-I-695, IDPM-I-70, and IDPM-US 29)

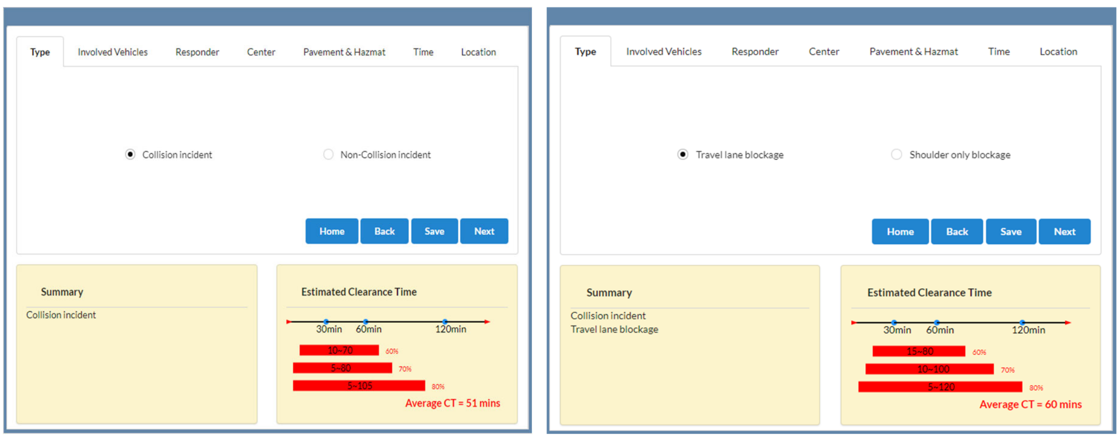

Figure 2-4: The interface pages for DST-2 to identify if the detected incident results in collision and travel lane blockage

If the target incident is reported to cause collisions and lane blockage, then the next most critical information is the number of blocked lanes and the incident nature, such as fatality, personal injuries, or property damage. For instance, it typically will take more than 60 minutes for the response team to clear an incident resulting in fatalities. Figure 2-5 illustrates the interface features designed to receive such information and its initial estimate of incident duration.

Note that DST-2 can provide the initial estimate of the detected incident's required clearance based on the information available up to this stage. An updated estimate will be provided by the system when more data are available at the later stage of response operations.

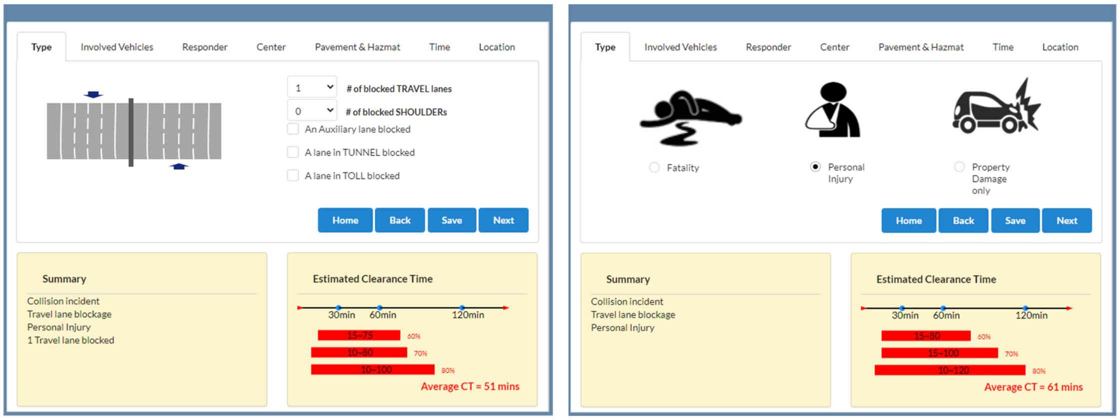

Figure 2-5: Interface for receiving the information of incident nature and the resulting number of blocked lanes

As is well-recognized and revealed in the CHART-II database, an incident's clearance time varies distinctly with the number and the type of vehicles involved. In general, any incident involving large trucks will demand an excessively long time to clear mainly because it requires a special tow arrangement. The interface shown in Figure 2-6 is designed to picture the incident scene for DST-2 to better assess the severity of the target incident, which includes all different types of vehicles and non-driving individuals involving in the incidents.

In addition, since the available resources to best respond to the incident with the reported nature and severity has played a critical role in reducing the clearance duration, DST-2 is also designed to take advantage of such information via its interface, if available, to refine its initially estimated clearance time. The most critical resource information to the system, as shown in Figure 2-6, includes the number of emergency response units from different agencies (e.g., fire trucks, ambulance), and the type of the response unit first arriving at the incident scene.

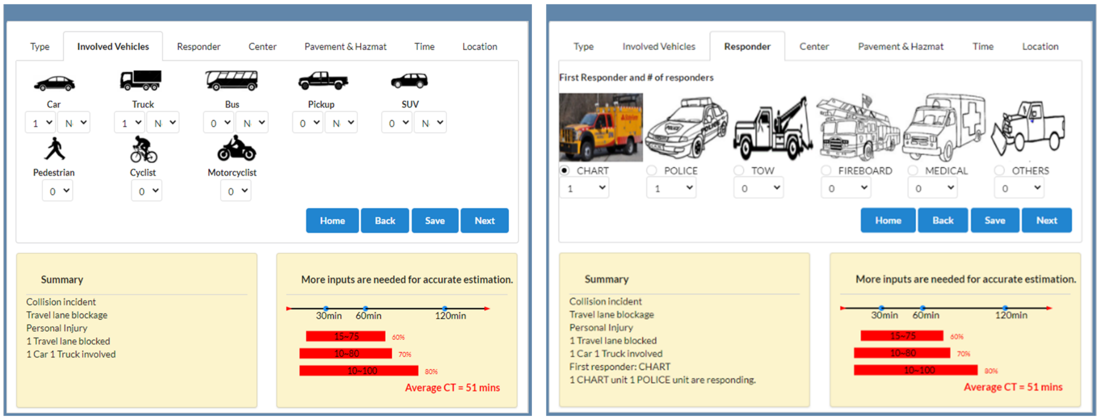

Figure 2-6: Interface to input the number and type of vehicles involved in the incident and the response units from different agencies

Given the above data, the next level of information that may affect the resulting incident clearance time includes the pavement conditions (e.g., wet, snowy) and the operational center responsible for clearing the reported incident and resulting traffic management. The former is to reflect the impacts of weather and environmental conditions on the clearance operations and the latter allows the system to revise the estimated incident duration, considering the available resources and constraints associated within each CHART's operational center. Figure 2-7 illustrates the interface designed to secure such information for DST-2 to further fine-tune the estimated clearance time.

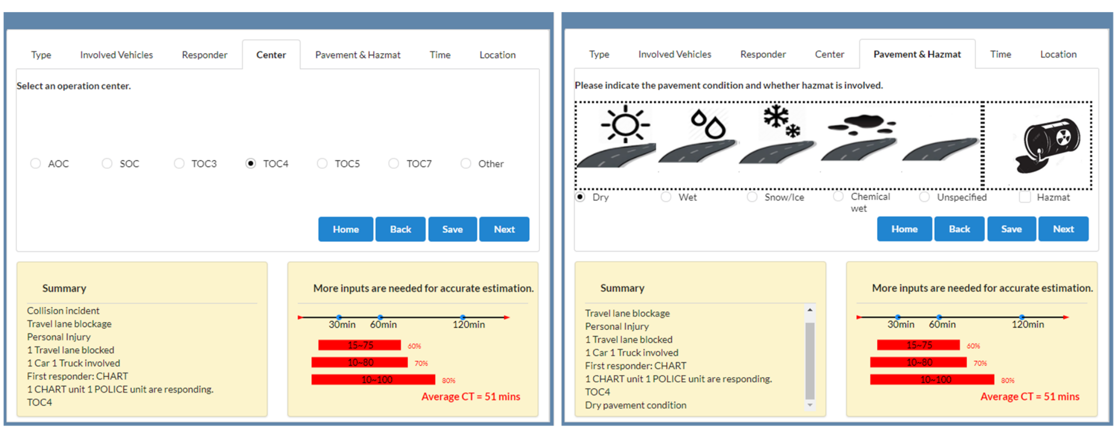

Figure 2-7: Interface designed for receiving information from the operational center responsible for clearing the detected incident and reporting the pavement conditions

The last set of factors that may impact the final estimation of the detected incident's clearance time are: (1) the incident's detected date and time; and (2) the nearest highway exit and direction to reach the incident scene. This is because incident clearance efficiency has been recorded to vary significantly with the roadway's traffic volume and congestion level, which are time-dependent in nature and fluctuate substantially between different days of a week, and between the peak and off-peak periods.

Information on the nearest exit from the incident scene is for DST-2 to assess the accessibility of the incident location to various response units that in turn affects the overall response efficiency and the resulting clearance time. Figure 2-8 and Figure 2-9 show the interface designs for the system to receive the last set of vital information.

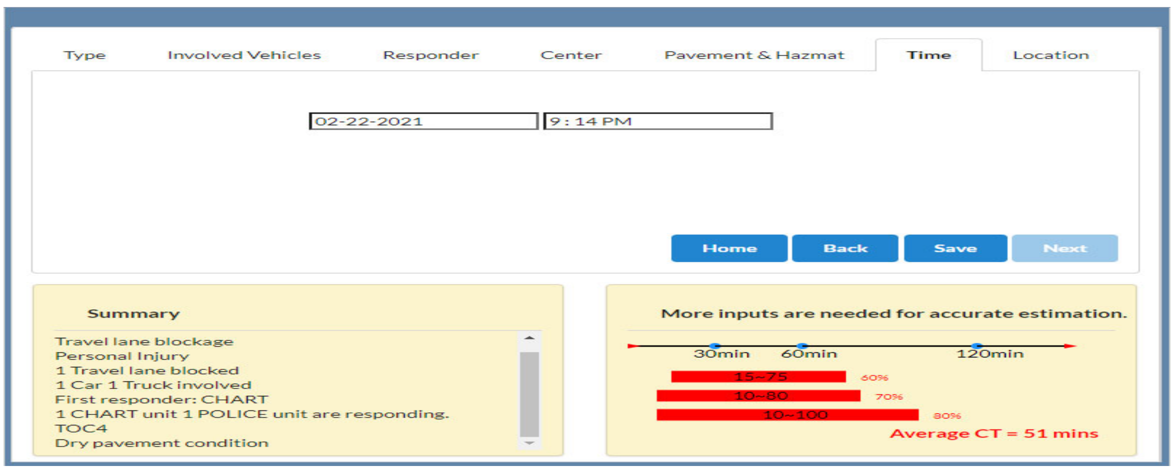

Figure 2-8: Interface for inputting the incident's onset time and date

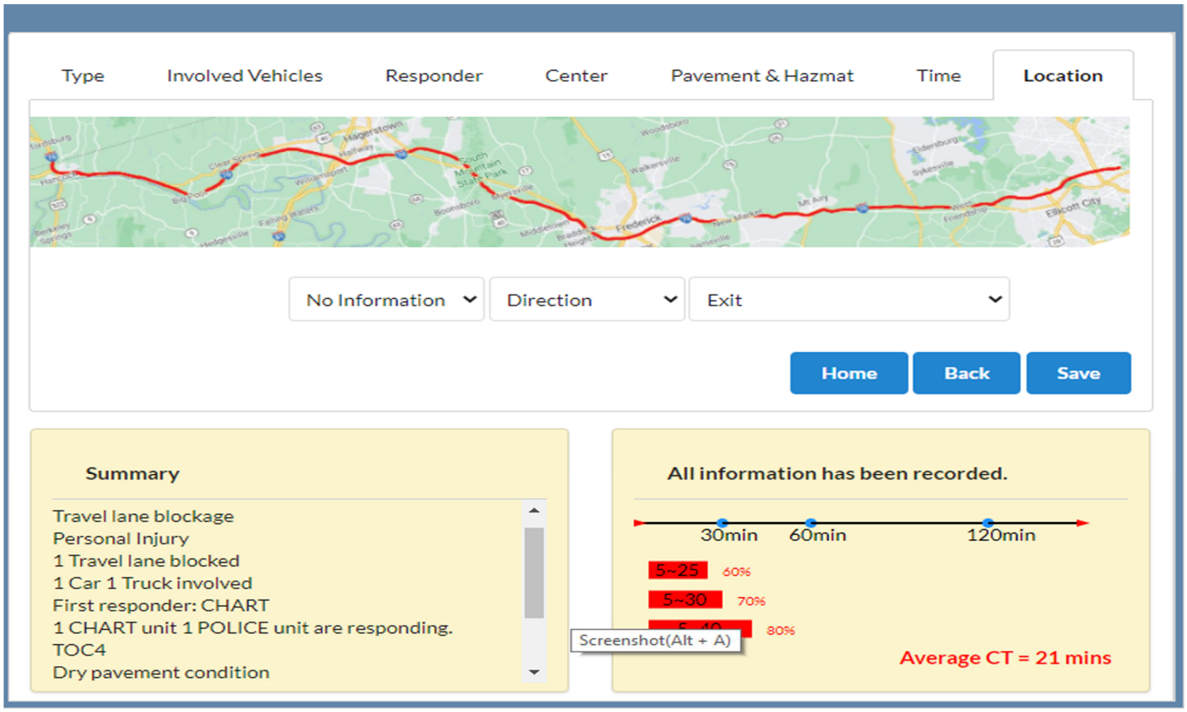

Figure 2-9: Interface to input the precise incident location based on the nearest roadway exit

System output

With all essential information, DST-2 will generate the final estimate of the projected incident clearance duration. In view of the precision of most data acquired during the real-time emergency response process and the dynamic relation between the clearance and its key contributors, the estimated results are characterized with three confidence intervals of 60%, 70 %, and 80%, indicating the probability associated with the likely variation range of the final clearance time for the target incident.

For instance, the example in Figure 2-9 shows that the projected incident clearance time is mostly likely around 21 minutes, but it has a 60%, 70%, and 80% probability to vary between the intervals of 5-25 minutes, 5-30 minutes, and 5-40 minutes, respectively. To facilitate experienced traffic engineers' assessment of the estimated results and provide necessary modification, the system's output also includes a summary of key information associated with both the incidents and the operations of the response team.

2.3 Summary

This chapter has provided a concise illustration of the developed DST-2 software, including its key system features, customized input process, and interval-based output to reflect the uncertainties associated with field clearance operations. DST-2 at this development level has been designed to integrate all five existing incident duration prediction models (i.e., IDPM-I-95, IDPM-I-495, IDPM-I-695, IDPM-I-70, and IDPM-US 29) into a user-friendly, interactive program for use in real-time estimation of a detected incident's clearance time. With a convenient parallelized structure for the DST-2's core set of prediction rules, one can easily add additional IDPMs for different highways into the system under the same interface design.

To cope with insufficient incident records on some highways for model calibration and for minimizing the demanding efforts that involve structuring effective rules from a mass dataset, the study has adopted an innovative transferability analysis method that allows a new target IDPM to directly transfer some of those effective prediction rules used by the existing IDPMs (e.g., IDPM-I-95) to its prediction base. By doing so, one can then focus on calibrating only some location-specific prediction rules to reflect the unique impacts of some factors on the target highway's clearance operations. This innovative method has been applied in developing the IDPMs for I-695, I-70, and US 29. A detailed description of its core methodology and resulting performance will be presented in later chapters.

Chapter 3: The Core Methodology for a Rule-Based Incident Duration Model

3.1 Introduction

As stated in previous chapters, the focus of this study is to develop **I**ncident **D**uration **P**rediction **M**odels (IDPM) for I-495, I-695, I-70, and US 29, based on the same rule-based modeling structure in the IDPM-I-95 developed by Won et al. (2018). Their development process with the Association Rule Mining method and customized estimation statistics, as shown in Figure 3-1, consists of the following four stages: 1) pre-processing of incident records; 2) categorization of incident records by key association factors; 3) search and construction of classification rules; and 4) model evaluation. A brief description of key tasks conducted at each stage is presented in sequence in the following sections.

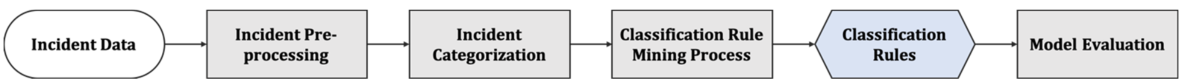

Figure 3-1: Development process for the incident clearance duration model for I-95

Incident Data Pre-processing

The primary focus at this stage is to remove those incident records plagued by obvious input errors or missing key factors so that one need not develop prediction rules to accommodate those sample data recorded improperly. In developing the IDPM-I-95, Won et al. (2018) used the incident records from 2012–2017 in the CHART II Database for model construction and refinement. The data from the first four years (i.e., 2012–2015) were used as the training dataset for model calibration, while the data from 2016–2017 were adopted for validation and performance evaluation. To remove some data errors inputted by system operators, often occurred during the real-time incident response and management process, Won et al. (2018), after consultation with experienced field operators, took the following steps to perform the data pre-processing:

- **Step-1**: If the difference between the recorded “event-cleared time” and the “all-blocked-lane-reopened time” (including shoulders) associated with each detected incident exceeds 5 minutes, then the all-blocked-lane-reopened time was taken as the actual “event-cleared time” for computing the incident clearance duration.

- **Step-2**: Any incident record involving collisions but with less than 5 minutes of clearance time was not included in the dataset for model development in view of the potential recording errors by the system operators.

- **Step-3:** The data records for incidents that did not cause any lane closure but with clearance duration exceeding 2 hours were viewed as anomalies and excluded from the final dataset for model development.

- **Step-4:** Those incidents resulting in travel lane blockage and taking more than 10 hours for clearance operations were viewed as special high hazardous incidents and placed in a different category for the incident response team to perform in-depth review and analysis.

Upon removing of those obvious defect data records, one can then proceed with the categorization of all available incident records based their key associated factors.

Incident Categorization

Given the pre-processed incident dataset, Won et al. (2018) suggested that the incident data be first classified into several subsets based on the incident types and the number of blocked lanes. As illustrated in Figure 3-2, the incident data is first classified into two categories: travel-lane blockage and shoulder-lane blockage. Those causing travel-lane blockage are further divided into three subsets: Collision with Fatality (CF), Collision with Personal Injury (CPI), and Collision with Property Damage (CPD).

Incident records in the subsets of CPI and CPD are further separated into six subsets depending on the number of blocked lanes (e.g., CPI1 is the subset that contains the incidents with collisions with personal injury and one-travel-lane blockage). Notably, due to the small sample size and unique clearance duration pattern, those incident records in CF are not further separated. The incident dataset resulting in only shoulder blockage are not further decomposed either since the clearance times for all such incidents distribute consistently within a relatively stable and short interval. With respect to each pre-classified subset of incident data, one can then compute its mean clearance duration and the range of variation at the confidence levels of 60%, 70%, and 80%.

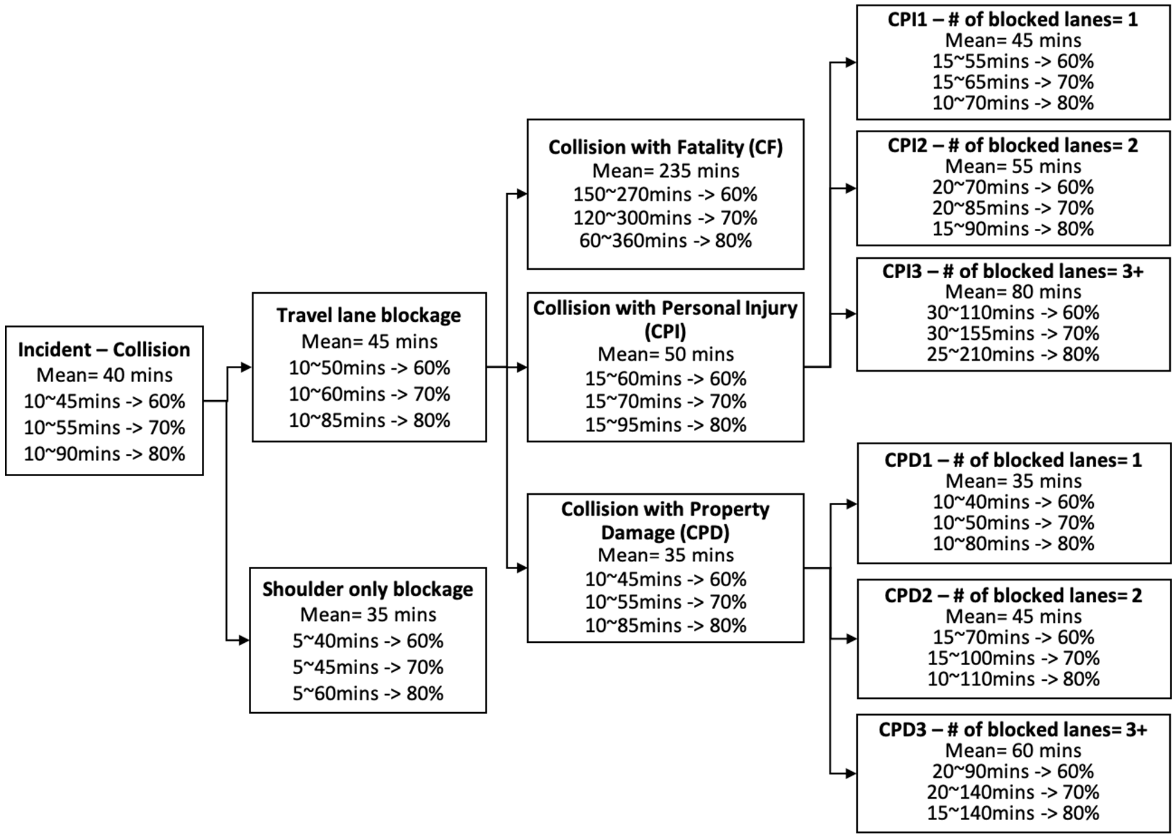

Figure 3-2: Initial incident categorization and estimated clearance durations for I-95

3.2 The mining process for identifying classification rule

After categorization of the incident data, Won et al. (2018) proposed to utilize the Association Rule Mining method with respect to each of the last seven subsets (i.e., CPI1, CPI2, CPI3+, CPD1, CPD2, CPD3+, and CF) to identify the set of classification rules with a sequence of IF-THEN patterns for estimating the incident clearance duration. With such a rule-based structure for model construction, potential users can better comprehend the relationships between the estimated incident duration and its contributing factors under different constraints and assess the applicability of the estimated results for incident impact assessment and traffic management. The procedures for identifying such IF-THEN prediction rules for those final seven subsets of incidents are described below.

Collision with Personal Injury (CPI) and Collision with Property Damage (CPD)

As stated in the work by Won et al. (2018), the incident data in those six subsets of CPI and CPD would be first classified into two classes of "< 30 minutes" and "≥ 30 minutes" by using the Association Rule Mining method. Then, the incident data classified in the class of

"≥ 30 minutes" is further divided into two groups of "< 60 minutes" and "≥ 60 minutes" for searching other classification rules. With the same logic, one can then further decompose the incident data group of "≥ 60 minutes" into two clusters of "< 120 minutes" and "≥ 120 minutes." Finally, based on the distributions of the incident clearance duration, three intervals of expected clearance duration under the confidence levels of 60%, 70%, and 80% can be produced from the sequential classification process.

Figure 3-3 shows the logic flows of the searching process for identifying those classification rules with the Association Rule Mining method. A concise step-by-step description of the entire development process is briefly described below:

- **Step-1**: Search for classification rules to classify the data set into pre-specified groups (e.g., "<30 minutes" and "≥30 minutes") by using the Association Rule Mining method.

- **Step-2**: Select a rule with the confidence level higher than 75% and the highest support level (i.e., coverage of the incident records).

- **Step-3**: Filter out the data associated with the selected rule from the development dataset and then proceed further classification rules mining with the remaining data.

- **Step-4**: Stop the classification rules mining steps if no further rule can be constructed to classify the remaining data; otherwise, go to Step-1 and repeat the same procedures.

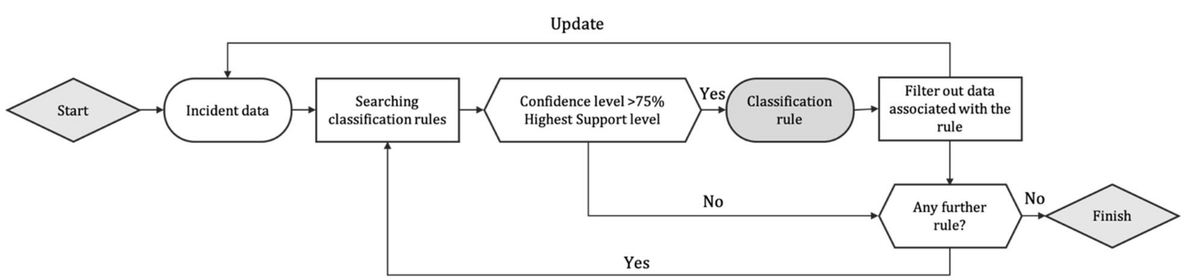

Figure 3-3: Flowchart of the classification rules mining process

Collision with Fatality (CF)

Notably, due to the small sample size of incidents resulting in both collision and fatality, a different searching process should be adopted for identifying classification rules for predicting their needed clearance durations. Further analysis of the data for such incidents also reveals that the lower bound of clearance duration needed for such CF incidents in the I-95 dataset for model development is 120 minutes. Hence, in the study by Won et al. (2018) all CF cases were first divided into two groups, based on the computed median of their incident clearance durations. Then, one can further identify some "IF-THEN" rules that can classify all such CF incidents into two distinct groups with the Association Rule Mining method. The finally adopted classification rules shall have properties consistent with the specified confidence level and the required support level with respect to the CF incidents in the model development dataset.

3.3 Model evaluation

As presented previously, the incident duration prediction model—IDPM-I-95, by Won et al. (2018)—used the incident data from 2012–2015 for model training, calibration, and development, and the records from 2016–2017 for model validation and evaluation. Appendix A shows all the classification rules identified from the training dataset.

Taking the category of CPD3 as an example, Figure 3-4 presents the application process of those developed rules, showing the set of sequential IF-THEN rules embedded in the model for estimating the clearance duration of a detected incident.

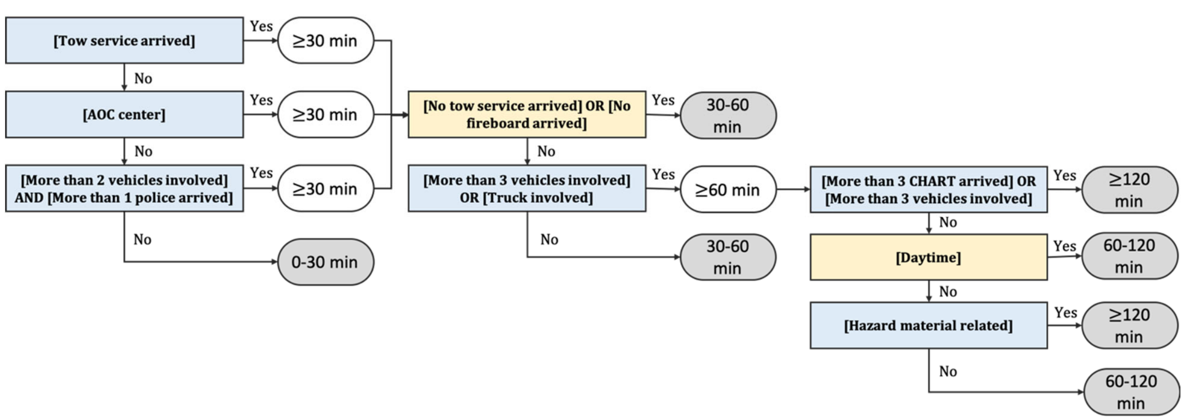

Figure 3-4: Illustration of model applications with the classification rules for CPD3

Table 3-1 summarizes the classification and prediction rules for CPD3 embedded in IDPM-I-95.

Table 3-1: Calibrated prediction rules for CPD3 for incidents on I-95

	Classification Rules Description – CPD3		Case
IF	[Tow service arrived]	THEN	≥30
IF	[AOC center]	THEN	≥30
IF	[More than 2 vehicles involved] AND [More than 1 police arrived]	THEN	≥30
	ELSE THEN		<30
IF	[No tow service] OR [No fireboard arrived]	THEN	<60
IF	[More than 3 vehicles involved] OR [Truck involved]	THEN	≥60
	ELSE THEN		<60
IF	[More than 3 CHART arrived] OR [More than 8 Response units arrived]	THEN	≥120
IF	[Daytime]	THEN	<120
IF	[Hazard materials related]	THEN	≥120
	ELSE THEN		<120

Table 3-2 and

Table **3-3** show the performance results of the developed IDPM-I-95 in each pre-specified incident clearance interval, where they summarize the performance with the training and the testing datasets, respectively, in each category of incidents. Also included in the summarized results are the distributions of estimation errors by category, classified by either over- or underestimates of the clearance times for the target incidents. As reflected from the summarize statistics, the developed IDPM-I-95 can achieve the accuracy level of approximately 77% for the training dataset and 78% for the testing dataset, both sufficient for use in field operations. Notably, severe incidents with clearance times exceeding one hour, due to involvement of different response vehicles or equipment, are more difficult to predict to the desirable level of accuracy.

To remove the impacts of data outliers on the construction of classification and prediction rules, this study has further adopted the method of outlier detection by Liu et al. (2020) to clean the entire dataset from 2012-2017 and resulted in the removal of 25 out of the 2286 incident records that contain multiple inconsistent data.

Table 3-4 further summarizes the prediction accuracy of IDPM-I-95 with the entire dataset by incident nature and lane-blockage condition after excluding faulty data. Except for CPD 1 at 74%, the prediction accuracies for all other types are all distributed within the range of 77 – 85%.

Table 3-2: Evaluation results of the IDPM-I-95 (training dataset)

2012-2015 I-95		Actual CT (minutes) < 30	30 ~ 60	60 ~ 120	≥ 120	Overall
Over estimated	> 120	0	0	0	0	0
	60~120	0	0	0	0	0
	30~60	0	0	1	0	1
	10~30	0	2	0	0	2
	0~10	29	0	1	0	30
Within boundaries		**719**	**549**	**122**	**46**	**1436**
Under estimated	-10~0	0	76	**59**	**2**	137
	-30~-10	0	46	**86**	**3**	135
	-60~-30	0	0	**60**	**5**	65
	-120~-60	0	0	**13**	**32**	45
	< -120	0	0	**0**	**9**	9
Total # of cases		748	673	342	97	1860
TP rate and Accuracy		96.12%	81.58%	35.67%	47.42%	77.20%

Table 3-3: Evaluation results of the IDPM-I-95 (testing dataset)

2017 I-95		Actual CT (minutes) < 30	30 ~ 60	60 ~ 120	≥ 120	Overall
Over estimated	> 120	0	0	0	0	0
	60~120	0	0	0	0	0
	30~60	0	0	0	0	0
	10~30	0	1	0	0	1
	0~10	5	2	1	0	8
Within boundaries		**161**	**129**	**27**	**15**	**332**
Under estimated	-10~0	0	11	19	2	32
	-30~-10	0	12	17	0	29
	-60~-30	0	0	13	3	16
	-120~-60	0	0	3	4	7
	< -120	0	0	0	1	1
Total # of cases		166	155	80	25	426
TP rate and Accuracy		96.99%	83.23%	33.75%	60.00%	77.93%

Table 3-4: Summary of accuracy statistics by incident types and blocked lanes

Highway	Collisions with Travel Lane Blockage CPI 1	CPI 2	CPI 3+	CPD 1	CPD 2	CPD 3+	Total
I-95 (2012-2017)	77.2% (446/578)	84.6% (203/240)	78.8% (82/104)	74.3% (795/1070)	80.5% (177/220)	83.7% (41/49)	77.1% (1744/2261)

3.4 Summary

The IDPM-I-95 developed with the methodology proposed by Won et al. (2018) has been published and used by field operators as a piloting system in their daily responses to traffic incidents. While much can be improved when more quality data become available, the development methodology for the IDPM-I-95 can certainly serve as the baseline methodology for developing the IDPM for other highways operated by the same response agency.

However, it should be mentioned that the effectiveness of such a model is dependent on the availability of sufficient quality data over different types of incidents, which may not be available for some highway segments experiencing less frequency of incidents. As such, the interrelations between the resulting clearance duration of a detected incident and all contributing factors may not be adequately reflected in the available incident records, and the sample size may be insufficient for calibrating statistically valid rules for prediction. Moreover, searching and identifying reliable rules from the large dataset for incident classification and duration prediction demands a tremendous effort on the part of developers with sufficient expertise in field incident responses and operations.

One potentially effective alternative to get around those issues is to take advantage of the knowledge and rules embedded in the IDPM-I-95. With a well-designed process for transferability analysis, one can assess the effectiveness of those prediction rules embedded in the IDPM-I-95 with respect to the target highway's incident records and select those achieving the expected level of performance to transfer directly to the new IDPM. By doing so, one can devote most effectors and resources to developing sophisticated customized rules or models for the remaining incident records that cannot be captured with existing prediction rules due to local-specific incident characteristics or response constraints.

The next chapter will present the transferability process developed for constructing a new IDPM with available prediction rules from the existing IDPM-I-95. Applications of the developed transferability process on I-495, I-695, I-70, and US 29, along with the resulting performance evaluation, will be reported in the ensuing chapters.

Chapter 4: Developing Incident Duration Prediction Models for I-495 and I-695 with the Transferability Analysis Method

4.1 Background

This chapter presents the methodology of using the **K**nowledge **T**ransferability **A**nalysis (KTA) to develop incident duration prediction models (IDPM) for I-495 and I-695 in Maryland with the set of prediction rules embedded in the IDPM-I-95. Note that the KTA methodology was first applied to I-495, and then to I-695. As such, only the knowledge and prediction rules embedded in IDPM-I-95 have gone through the KTA for developing the IDPM-I-495. Since each IDPM for a target highway may contain some supplemental prediction rules in addition to those from the KTA process, the later developed IDPM-I-695 has the advantage of transferring potentially applicable prediction rules from both IDPM-I-95 and IDPM-I-495.

As illustrated in Figure 4-1, the entire KTA methodology used for constructing IDPMs for I-495 and I-695 consists of five stages: 1) incident data pre-processing; 2) incident categorization; 3) assessment and transferring of available classification rules; 4) mining and construction of supplemental rules; and 5) model evaluation.

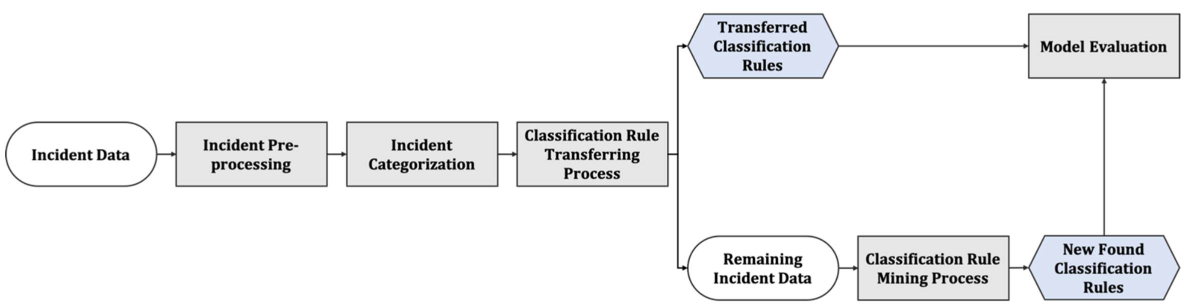

Figure 4-1: Model development process with the Knowledge Transferability Analysis methodology

The analysis tasks conducted at each stage to finalize the model development are detailed in the following sections.

4.2 Pre-processing and categorization of incident records

As with the methodology for constructing the IDPM-I-95, incident records involving collisions from 2015–2018 in the CHART II Database are used to develop the IDPM-I-495, where the first dataset from the first three years (2015–2017) and the second dataset from year 2018 serve for model development and evaluation. Likewise, the incident records of I-

695 from 2016–2018 are designated for model calibration, while the incident records in 2019 are designated for performance evaluation. Those key steps used at the first stage of pre-processing and identifying obvious data errors or anomalies are identical to those employed in developing the IDPM-I-95 proposed by Won et al. (2018).

Note that the initial incident categorization procedures for I-495 and I-695 are identical to those adopted for developing the IDPM-I-95, based mainly on the incident types and status of lane blockage. Also, the mean incident clearance duration and its estimated ranges of variation with the confidence levels of approximately 60%, 70%, and 80% are computed for each categorized subset for the incident data of I-495 and I-695, as illustrated in Figure 4-2 and Figure 4-3.

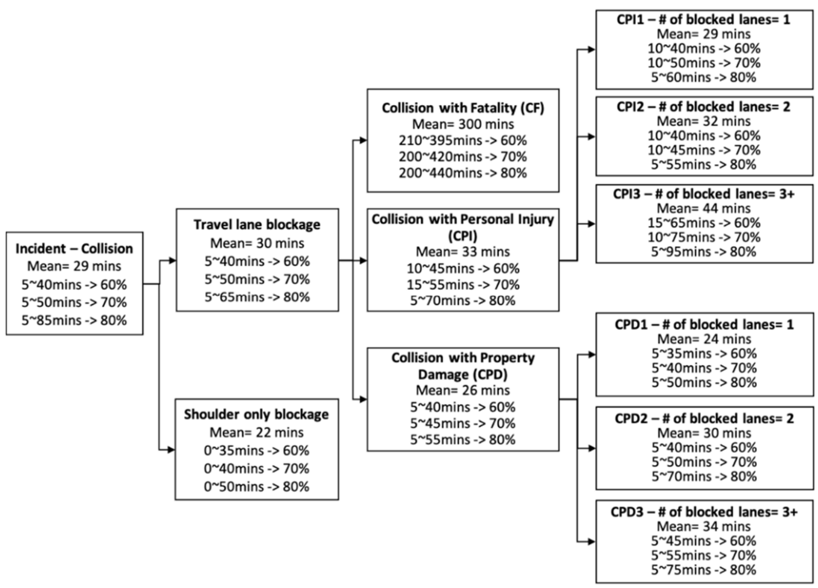

Figure 4-2: Initial incident categorization and estimated clearance duration for I-495

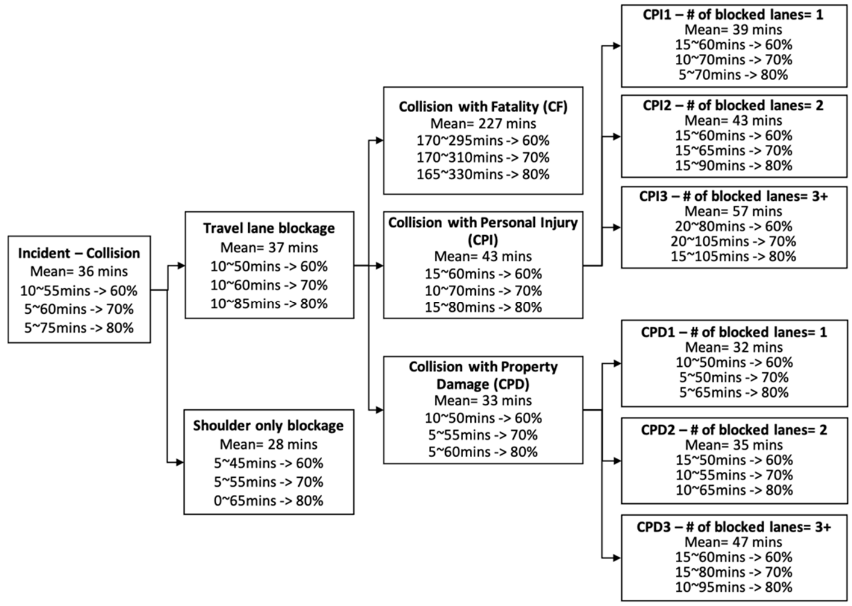

Figure 4-3: Initial incident categorization and estimated clearance duration for I-695

4.3 Prediction rules classification and transferring process

As stated previously, the purpose of applying the KTA process for developing IDPMs for different highways (e.g., I-495 and I-695) managed by the same incident response agency, is to take advantage of their common characteristics (e.g., response strategies, available respondents, tow trucks) associated with the incident clearance operations, specifically reflected in relationships between the resulting incident duration and all key contributing factors. A typical KTA process for new model development consists of the following two major steps: 1) Rule Box generation and updating, and 2) transferability analysis and effectiveness assessment.

Rule Box Generation and Updating

To best use the "knowledge" (i.e., well-structured trees of prediction rules) from previously developed models, one of the most critical tasks is to sort available classification rules and generate a Rule Box for transferability analysis and evaluation. The same type of incidents under slightly different traffic environments and response strategies may be subjected to different prediction rules to yield the best estimate of their resulting clearance times.

As reported by Won et al. (2018), all incident records in CPI and CPD are divided into the following four groups based on their incident durations: 1) between 0 to 30 minutes, 2) between 30 to 60 minutes, 3) between 60 to120 minutes, and 4) exceeding 120 minutes. With such information, one can then classify the prediction rules in the previously developed models based on their designated functions. For instance, those candidate classification rules for CPI and CPD, as illustrated in Figure 4-4, can be partitioned into three groups: 1) rules for determining whether clearance duration would be shorter or longer than 30 minutes, 2) rules for determining whether clearance duration would be shorter or longer than 60 minutes, and 3) rules for determining whether clearance duration would be shorter or longer than 120 minutes.

Note that the number of classification rules for prediction to be included in the Rule Box will naturally increase with the available new IDPMs after they have demonstrated their effectiveness in field operations. Hence, the Rule Box for developing the IDPM-I-695 consists of the classification rules from both I-95 and I-495.

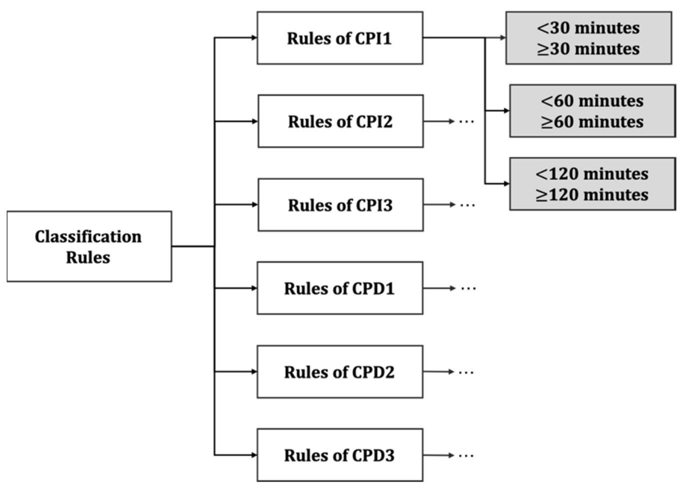

Figure 4-4: Rules categorization in the Rule Box

4.4 Transferability analysis

After categorizing all candidate classification rules into the Rule Box's database structure, the next step is to evaluate the transferability of such rules with an efficient and effective assessment process. As with most studies for transferability analysis, this study adopts the following two measures of effectiveness (MOEs) for assessing each candidate rule's performance with respect to the incident records from the target roadway: 1) the *confidence level* that demonstrates the accuracy of a candidate rule and 2) the *support level* that shows the percentage of incident records for which an identified classification rule is applicable to provide their clearance time estimates.

Conceivably, those classification rules yielding a sufficiently high *confidence level* and having a reasonable *support level* will be deemed transferable. As illustrated in Figure 4-5, the entire process for transferability analysis and evaluation with respect to all candidate classification rules in the Rule Box can be illustrated with the following steps:

- **Step-1**: Determine the minimum *confidence level* ($X\%$) and the lower bound ($S_L\%$) as well as the upper bound ($S_U\%$) of the *support level* based on the information in the Rule Box and the available incident records from the target highway;

- **Step-2**: Utilize the incident data of the target highway in each subset of CPI and CPD to verify the transferability of each classification rule for the target incident group;

- **Step-3**: Transfer the classification rule to the new model if it can achieve the *confidence level* and the *support level* specified at Step-1

- **Step-4**: Filter out the incident records successfully classified by the classification rule transferred from the Rule Box and the target incident dataset, and proceed with the same transferability analysis process with the remaining incident records;

- **Step-5**: Stop the transferring process if no more classification rule can be transferred; otherwise, go to Step-2.

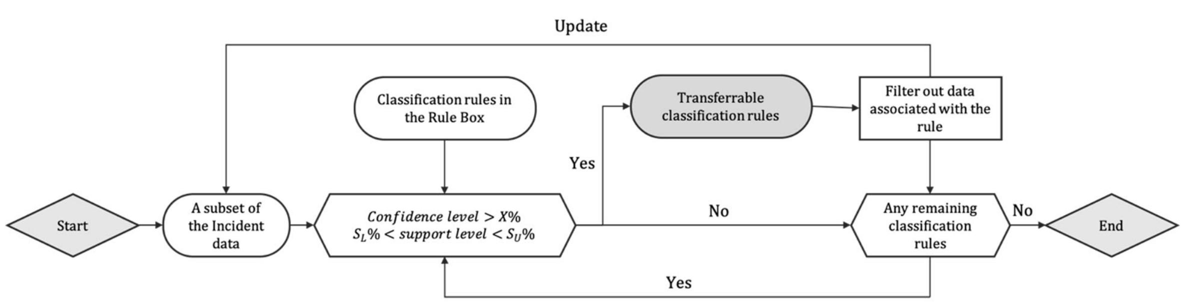

Figure 4-5: Flowchart of the transferability test in the classification rules transferring process

Note that due to the difference in available data for each subset of incident groups, different criteria should be adopted for setting the minimum *confidence level* and the reasonable *support level* to ensure the effectiveness of those candidate rules when transferred to the new IDPM. The guidelines for doing so are summarized below:

♦ *Confidence level:*

1) The minimum *confidence level* for classification rules in each group in the Rule Box acceptable for transfer can be determined by the performance of such rules in their original IDPMs. For example, if those prediction rules collected and classified in the Rule Box show that they can achieve an accuracy level of 67% in their original models, then one can take the same percentage as the minimum confidence level for those rules in the Rule Box for transferability assessment.

2) For prediction rules with the initially specified minimum *confidence level* that can correctly estimate the clearance times only for some incident records in the same category, one shall raise such a criterion and search for more effective rules. For example, if a candidate prediction rule can correctly predict only 40 out of 60 incidents with its specified confidence level of 67%, then one ought to raise the minimum confidence level and proceed the search for other more effective rules. Otherwise, there are up to 20 incident records that will likely be misclassified by this firstly selected candidate rule. In contrast, if only a small number of incident records in the same incident group cannot be correctly estimated by a candidate rule (e.g., two out of three incidents are correctly classified and the *confidence level* is also 67%), such a refinement process of raising the confidence level may not be needed.

♦ *Support level:*

1) One needs to initially set the upper and lower bounds with respect to the *support level for selecting candidate rules for transferability assessment*, based on the available sample size in the target incident group. Such a support level can be dynamically adjusted with its performance when the increasing number of incident records are included in the process of transferability analysis.

2) If a candidate rule for transferability assessment, constituted by a large number of incident-contributing factors, is applicable for less than the prespecified percentage of incident records in the target subset (e.g., 70%), one shall reset the upper bound for the support level to filter out such a rule, and proceed the search of other rules with better performance. This is due to the fact that such a rule to achieve its current support level (i.e., the percentage of incident records that can be characterized with all "IF" conditions constituted the candidate rule) has already included most factors associated with the clearance duration of incidents in the

target subset. This renders incidents not covered by this rule difficult to be characterized by other candidate rules constituted by the small number of remaining factors. As such, instead of having one dominate rule—containing many key factors—to provide the clearance time estimate for one target type of incident (e.g., CPI-2), it would be more effective to have multiple sets of rules, constituted by both common and different factors, to further distinguish the target type of incidents into multiple subclasses, and adopt different sets of candidate rules to collectively cover all incidents classified in the same category.

3) If multiple rules can cover a small number of incidents (e.g., one or two incident records), then one shall raise the lower bound of the *support level* to prevent such candidate rules from transfer to the new system, and proceed the search to identify other rules that can cover more incidents with more common characteristics and response patterns.

Overall, the transferability analysis process will enable potential users to effectively utilize the knowledge and prediction rules collected in the Rule Box to minimize their efforts in developing the IDPM for different highways sharing similar traffic patterns and emergency response operations. It also offers flexibility for users to dynamically adjust the rule-filtering and evaluation criteria (i.e., the *confidence level* and the *support level)* in the transferability analysis process so that all transferred rules can best fit both the common and unique characteristics associated with each set of incident data from the target highway.

Classification Rule Mining Process

Conceivably, after the rule transferring process, it is likely that some incidents on the target highway may not be fully captured with those transferred rules, due to some unique locally related factors. Hence, one shall use the method by Won et al. (2018) reported in Chapter 2 to construct supplemental rules to characterize and capture those incidents with clearance durations significantly affected by local-unique factors. Such supplemental rules can also be adopted to enhance the knowledge base in the Rule Box.

Note that the CF cases of I-495 and I-695 are completely modeled by the classification rule mining process due to the very small sample size and the high variation of their resulting incident durations.

4.5 Model evaluation

After using the data from 2015–2017 for developing the IDPM-I-495, the developed model's performance has been evaluated with the data from 2018. Likewise, the incident records of I-695 from 2016–2018 is used for model development, while the dataset from 2019 serves for model evaluation.

Table 4-1 and Table 4-2 show the list of prediction rules for CPI-1 for IDPM-I-495 and IDPM-I-695, respectively. A complete list of all such rules for these two new systems, including those transferred and customized, can be found in the appendices.

Table 4-1: Classification rules for CPI-1 in IDPM-I-495

	Classification Rules Description – CPI-1		**Case**
IF	[Tow service arrived] AND [More than 4 response units arrived]	THEN	≥30
IF	[Shoulder lane blocked] AND [More than 4 response units arrived]	THEN	≥30
IF	[Car overturned] AND ([Weekend] OR [Tow service arrived])	THEN	≥30
IF	[More than 5 vehicles involved] AND [Peak hour]	THEN	≥30
IF	([AM] OR [Fireboard first arrived]) AND [More than 1 police arrived]	THEN	≥30
IF	[Fall] AND [Fireboard first arrived]	THEN	≥30
IF	[Truck involved] AND [Van involved]	THEN	≥30
	ELSE THEN		<30
IF	[Auxiliary lane blocked] AND ([More than 4 response units arrived] OR [More than 1 CHART arrived])	THEN	≥60
IF	[Hazard Material] OR [More than 1 tow service arrived] OR [Bus involved]	THEN	≥60
IF	([More than 2 police arrived] OR [Weekend] OR [Wet Pavement]) AND [Pickup involved]	THEN	≥60
IF	[Truck involved] AND [Tow service arrived]	THEN	≥60
	ELSE THEN		<60
IF	[More than 1 vehicle involved] AND [More than 6 response units arrived]	THEN	≥120
	ELSE THEN		<120

Table 4-2: Classification rules for CPI-1 in IDPM-I-695

	Classification Rules Description – CPI1		Case
IF	*[Tow service arrived]*	THEN	≥30
IF	*[Fireboard first arrived]*	THEN	<30
IF	[TOC4 Center] AND [No truck involved]	THEN	<30
IF	[More than 1 CHART arrived] AND [Police first arrived]	THEN	≥30
IF	[More than 1 truck involved] AND [More than 3 response units arrived]	THEN	≥30
IF	[Pickup involved] AND ([More than 2 response units arrive] OR [Police arrived])	THEN	≥30
	ELSE THEN		<30
IF	*([Night] AND [More than 6 response units]) OR [More than 4 vehicles involved]*	THEN	≥60
IF	[Snow-iced pavement condition] OR [More than 1 truck involved] OR [More than 7 response units arrived] OR [AOC center]	THEN	≥60
IF	[Pickup involved AND ([Auxiliary lane blocked] OR [Winter])	THEN	≥60
IF	[Weekend] AND [Vehicle overturned]	THEN	≥60
IF	[More than 1 police arrived] AND [More than 1 fireboard arrived]	THEN	≥60
	ELSE THEN		<60
IF	[Truck involved] AND [More than 5 response units arrived]	THEN	≥120
IF	[Lane blocked in toll lane] OR [More than 1 shoulder lane blocked]	THEN	≥120
	ELSE THEN		<120

******Italic classification rules* **are transferred from the Rule Box**

Table 4-3 to Table 4-6 show the performances of these two models with the training and evaluation datasets, while Table 4-7 presents the overall prediction accuracy (after removing some faulty data with the customized detection method) of these two systems in comparison with IDPM-I-95 by lane-blockage status and incident nature with all datasets. It is noticeable that IDPM-I-495 can yield the overall estimation accuracy of 80% for all types of incidents except for CPI-3+. The same is true of the performance of IDPM-I-695, which has achieved average performance of 85% for all incidents, with exception of 78% for CPI 3+.

Table 4-3: Performance of IDPM-I-495 (calibration dataset) by resulting clearance time

2016-2018 I-495		Actual CT (minutes)				Overall
		< 30	30 ~ 60	60 ~ 120	≥ 120	
Over estimated	> 120	0	0	0	0	0
	60~120	0	0	0	0	0
	30~60	3	0	0	0	3
	10~30	8	5	3	0	16
	0~10	65	4	0	0	69
Within boundaries		1129	266	74	38	1507
Under estimated	-10~0	0	65	12	0	77
	-30~-10	0	29	18	0	47
	-60~-30	0	0	24	0	24
	-120~-60	0	0	3	3	6
	< -120	0	0	0	4	4
Total # of cases		1205	369	134	45	1753
TP rate and Accuracy		93.69%	72.09%	55.22%	84.44%	85.97%

Table 4-4: Performance of IDPM-I-495 (test dataset) by resulting clearance time

2019 I-495		Actual CT (minutes)				Overall
		< 30	30 ~ 60	60 ~ 120	≥ 120	
Over estimated	> 120	0	0	0	0	0
	60~120	0	1	0	0	1
	30~60	1	0	0	0	1
	10~30	3	0	0	0	3
	0~10	12	0	0	0	12
Within boundaries		321	74	10	9	414
Under estimated	-10~0	0	18	11	1	30
	-30~-10	0	9	10	0	19
	-60~-30	0	0	17	1	18
	-120~-60	0	0	2	3	5
	< -120	0	0	0	1	1
Total # of cases		337	102	50	15	504
TP rate and Accuracy		95.25%	72.55%	20.00%	60.00%	82.14%

Table 4-5: Performance of IDPM-I-695 (calibration dataset) by resulting clearance time

2016-2018 I-695		Actual CT (minutes)				Overall
		< 30	30 ~ 60	60 ~ 120	≥ 120	
Over estimated	> 120	0	0	0	0	0
	60~120	0	0	0	0	0
	30~60	0	0	0	0	0
	10~30	5	4	1	0	10
	0~10	66	8	0	0	74
Within boundaries		682	441	112	34	1269
Under estimated	-10~0	0	27	18	2	47
	-30~-10	0	11	34	0	45
	-60~-30	0	0	7	2	9
	-120~-60	0	0	0	5	5
	< -120	0	0	0	2	2
Total # of cases		753	491	172	45	1461
TP rate and Accuracy		90.57%	89.82%	65.12%	75.56%	86.86%

Table 4-6: Performance of IDPM-I-695 (test dataset) by resulting clearance time

2019 I-695		Actual CT (minutes) < 30	30 ~ 60	60 ~ 120	≥ 120	Overall
Over estimated	> 120	0	0	0	0	0
	60~120	2	3	0	0	5
	30~60	2	0	2	0	4
	10~30	1	0	0	0	1
	0~10	15	1	1	0	17
Within boundaries		214	120	17	1	352
Under estimated	-10~0	0	14	5	0	19
	-30~-10	0	2	9	0	11
	-60~-30	0	0	6	1	7
	-120~-60	0	0	2	4	6
	< -120	0	0	0	3	3
Total # of cases		234	140	42	9	425
TP rate and Accuracy		91.45%	85.71%	40.48%	11.11%	82.82%

Table 4-7: Accuracy comparison by incident types and # of blocked travel lanes

Highway	Collision with Travel Lane Blockage CPI 1	CPI 2	CPI 3+	CPD 1	CPD 2	CPD 3+	Total
I-95 (2012-2017)	77.2% (446/578)	84.6% (203/240)	78.8% (82/104)	74.3% (795/1070)	80.5% (177/220)	83.7% (41/49)	77.1% (1744/2261)
I-495 (2015-2018)	78.7% (392/498)	78.7% (295/375)	61.7% (113/183)	79.8% (631/791)	81.6% (301/369)	79.2% (95/120)	80.0% (2018/2523)
I-695 (2016-2019)	85.6% (297/347)	82.4% (150/182)	78.7% (59/75)	87.0% (842/968)	87.6% (219/250)	82.7% (43/52)	85.9% (1610/1874)

4.6 Summary

This chapter has summarized the model development process and transferability method for IDPM-I-495 and IDPM-I-695. Based on the performance statistics shown in those tables, it is noticeable that both IDPMs for I-495 and I-695 can yield sufficiently reliable results of around 80% accuracy for use in design of incident traffic management. It remains quite difficult to estimate the clearance durations of incidents within the category of 60-120 minutes at the desired level of accuracy due to both relatively small samples and their inclusion of incidents with quite different scenarios and lane-blockage states (e.g., CPI-1 and CPD-3).

Also note that only a small number of the classification rules, as shown in Appendix B and Appendix C, are transferred from the Rule Box containing only rules from I-95 (i.e., 18.8% for I-495 and 13.6% for I-695). This clearly reflects the distinct discrepancies of incident patterns and response operations between these three major highways of different functions. Specifically, I-95 is a commuting corridor with some segments operated as a toll road, whereas I-495 and I-695 are both ring highways but half of the former is managed by Virginia Department of Transportation.

All prediction rules developed for these three highways of unique traffic patterns and response characteristics, can collectively serve as the Rule Box's most valuable resource for transferability analysis, as incident records on many other highways in the same region may share the same relationships between their clearance duration and key contributing factors. Hence, those predictions rules, collected from IDPMs for I-495, I-695, and I-95 for use in the Rule Box for transferability analysis, are likely to have a wide range of applications for developing the same IDPM for other highways.

Chapter 5: Development of Incident Duration Model for I-70

5.1 Background

Since CHART's operational centers adopt the same incident response process, it is conceivable that one may develop the incident duration prediction model (IDPM) for I-70 with those well calibrated rules (i.e., collected in the Rule Box) embedded in existing IDPMs (e.g., I-95, I-695, and I-495). However, the complex interrelations between those prediction rules—such as those mutually exclusive or supplementary in nature—may render the effectiveness of IDPM-I-70 dependent on not only which rules to adopt, but also their sequence of execution in the decision structure. Hence, the challenges for best use available knowledge in the existing IDPMs shall include (1) assessing the transferability of each candidate rule; (2) identifying the interrelations among all prediction rules qualified for transfer; and (3) constructing the decision structure to assign the proper execution sequence for each transferred rule to maximize the resulting prediction accuracy. This chapter is thus focused on presenting the methodology developed for both transferability analysis and construction of the decision structure for those rules transferred from existing systems.

As with the IDPMs for I-495 and I-695, the development process for I-70 (see Figure 5-1) consists of the following five stages: 1) incident data pre-processing; 2) incident categorization; 3) rule assessing, transferring, and clustering process; 4) mining process for new classification rules; and 5) model evaluation. A brief discussion of key activities conducted at each stage is presented in the ensuing sections.

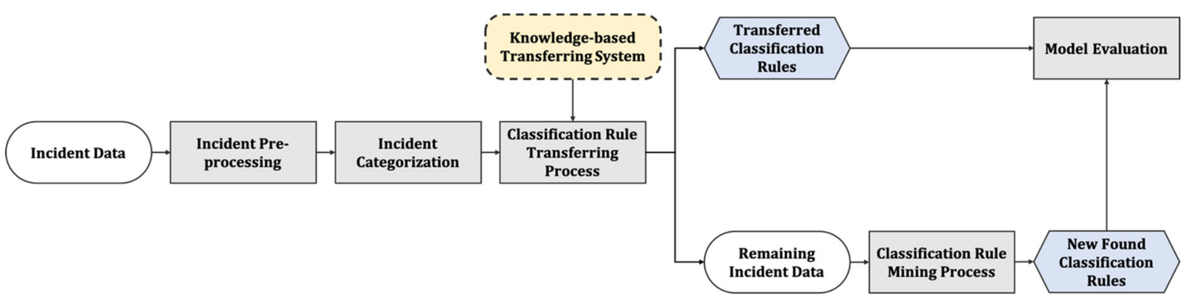

Figure 5-1: Flowchart for development of the incident clearance duration model for I-70

5.2 Incident data pre-processing and categorization

As with previous development tasks, incident records from 2016–2018 in CHART II Database are used for calibrating the IDPM-I-70, and the dataset for 2019 is reserved for the model evaluation. The target IDPM-I-70 includes only those incidents that occurred in Maryland and resulted in collisions. To remove some data recording errors made by system operators during the real-time incident response process, the same pre-processing procedures used in developing the IDPMs for I-695 and I-495 are applied at this stage to ensure the quality of the dataset for transferability analysis and new rule search.

Using the same categorization methodology as with previously developed IDPMs, but without CPI-3 and CPD-3 due to insufficient incident records in these two categories, both CPI-2 and CPD-2 in the IDPM-I-70 are redefined as those resulting in injuries and property damage, respectively, and causing two or more lane blockage. The results of initial categorization are shown in Figure 5-2, including the mean for each categorized group and the range of its variation at the confidence intervals of 60%, 70%, and 80%.

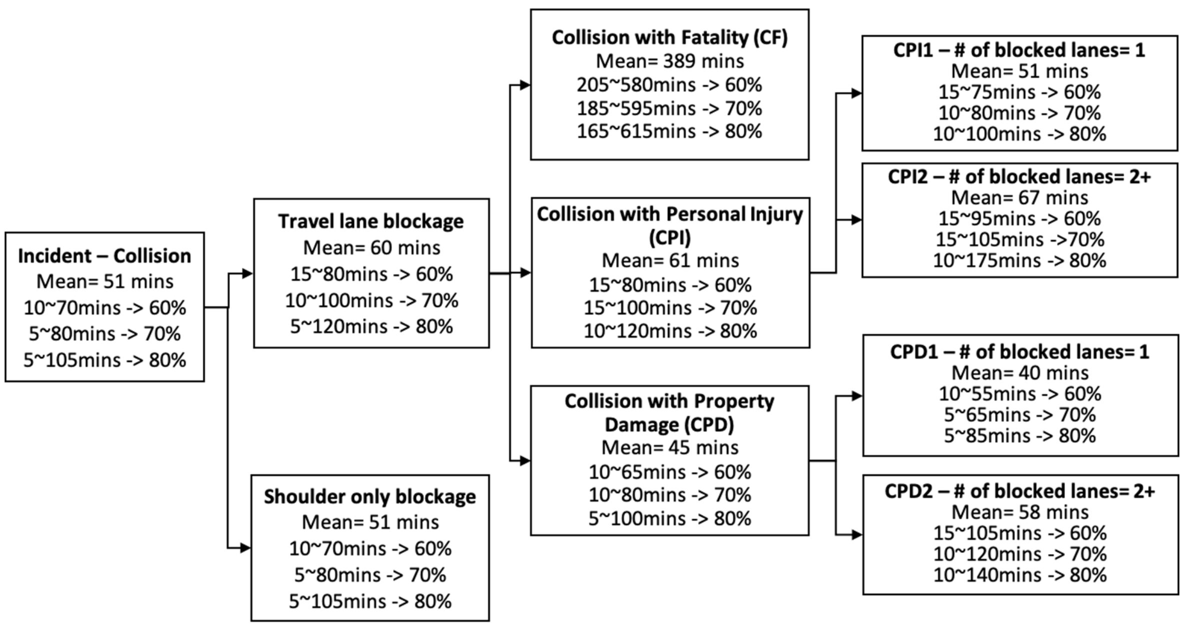

Figure 5-2: Initial incident categorization and estimated clearance duration for I-70

5.3 Evaluation and transfer of available prediction rules

As stated previously, the sequence of transferability analysis, due to complex interrelations between a large body of candidate rules (i.e., from I-95, I-695, and I-495), may directly affect the decision structure for the new model (i.e., IDPM-I-70) and its resulting effectiveness. Hence, it is imperative that an effective process be developed to identify the priority of available rules for transferability analysis, and then transfer the more important ones, if meeting the evaluation criteria, to construct the higher layers of the new model's decision structure. By doing so, one has the best likelihood to achieve the expected accuracy with the minimum number of transferred rules.

Figure 5-3 illustrates the following four stages constituting the entire process of the **t**ransferability **a**ssessment **m**ethod (TAM) for analysis of the rule transferring priority and effectiveness assessment: 1) Rule Box generation and updating; 2) analysis of the incident pattern; 3) assigning priority grades for candidate rules in the Rule Box; and 4) performing the transferability test.

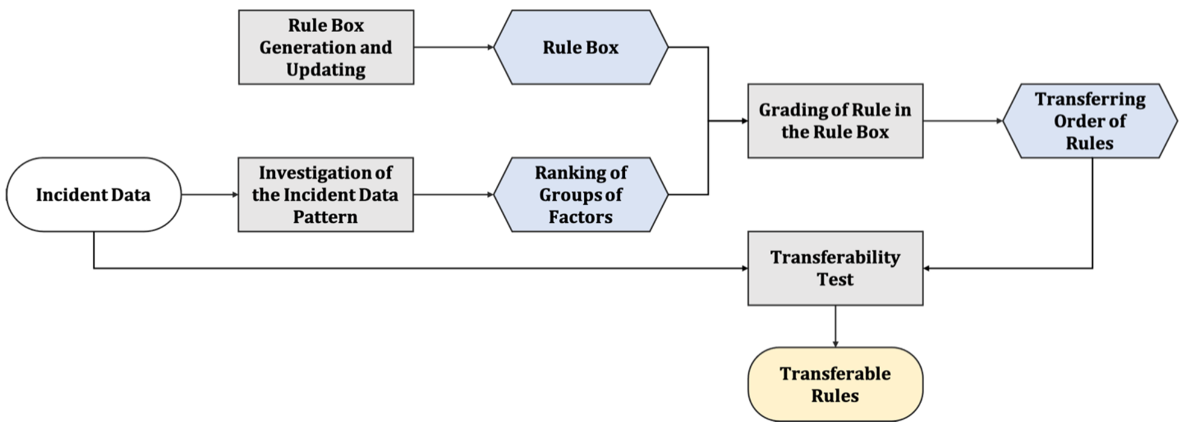

Figure 5-3: The process for ranking and selection of candidate rules for transferability analysis for I-70

The key activities to be conducted at each stage are briefly described below.

Rule Box Generation and Update

Table 5-1 shows the list of available rules and their accuracy levels in the Rule Box, collected from the IDPMs for I-95, I-695, and I-495, for predicting the incident duration for each group of incidents. For instance, 20 candidate rules with the average accuracy of 77.9% are available for IDPM-I-70 for predicting its CPI-1 incidents. Only 9 candidate rules with the accuracy of 81.3 % can be transferred to IDPM-I-70 for estimating if the clearance duration of its CPD-2 incidents will exceed 60 minutes.

Notably, based on the results of initial categorization with respect to I-70's incident records, those resulting in CPI-3 and CPD-3 are included in the CPI-2 and CPD-2, respectively, due to their small sample records. Thus, only those classification rules for CPI-1, CPI-2, CPD-1, and CPD-2 incidents in the Rule Box are selected for priority ranking and transferability analysis.

Table 5-1: Summary of available rules and their effectiveness by incident category

Subset	Estimated CT Range	# of rules	Accuracy (Range)	Accuracy (Mean)
CPI1	$\geq 30 \; or < 30$	20	67 – 100%	77.9%
	$\geq 60 \; or < 60$	13	68 – 100%	81.5%
	$\geq 120 \; or < 120$	5	60 – 100%	87.6%
CPI2	$\geq 30 \; or < 30$	12	62 – 100%	80.5%
	$\geq 60 \; or < 60$	10	64 – 100%	81.3%
	$\geq 120 \; or < 120$	3	63 – 100%	87.7%
CPI3	$\geq 30 \; or < 30$	10	71 – 100%	89.6%
	$\geq 60 \; or < 60$	10	67 – 100%	82.5%
	$\geq 120 \; or < 120$	8	67 – 100%	87.8%
CPD1	$\geq 30 \; or < 30$	20	67 – 100%	77.9%
	$\geq 60 \; or < 60$	11	68 – 100%	81.5%
	$\geq 120 \; or < 120$	4	60 – 100%	87.6%
CPD2	$\geq 30 \; or < 30$	10	62 – 100%	80.5%
	$\geq 60 \; or < 60$	9	64 – 100%	81.3%
	$\geq 120 \; or < 120$	5	63 – 100%	87.7%
CPD3	$\geq 30 \; or < 30$	6	71 – 100%	89.6%
	$\geq 60 \; or < 60$	6	67 – 100%	82.5%
	$\geq 120 \; or < 120$	4	67 – 100%	87.8%

Computing the priority for transferability analysis

As stated previously, since the rule transferring sequence concurrently determines not only which rules to transfer but also their execution structure (i.e., rule application sequence), it is essential to develop a methodology for ranking candidate rules when assessing their transferability. The core of such a methodology shall depend on those key factors adopted by each candidate rule and their collective impacts on the target type of incidents' clearance times, revealed in the dataset for new model development. To do so, all key factors contributing to the required incident duration are initially classified into the following seven groups: 1) Group-1 for indicators associated with the number of different responders arriving at the incident scene; 2) Group-2 for indicators associated with the type of responders first arriving at the incident scene; 3) Group-3 for indicators associated with the number and the type of vehicles involving in incidents and their damage levels; 4) Group-4 for all indicators used to describe the pavement conditions; 5) Group-5 for all indicators adopted to denote the lane-blockage conditions; 6) Group-6 for indicators reflecting different incident response centers; and 7) Group-7 for all temporal-related indicators associated with an incident. The list of factors included in each group is shown in

Table **5-2**.

Table 5-2: The list of incident duration's key contributing factors classified by group

Group	Item
Group-1: the number of different responders arriving at the incident scene;	# of total response units # of arrived CHART # of arrived police # of arrived fireboard # of arrived medical service # of arrived tow service
Group-2: type of the first-arriving responders	Police first arrived Medical service first arrived Tow service first arrived CHART first arrived Fireboard first arrived
Group-3: the number and the type of vehicles involving in incidents and their damage levels	Damage conditions (overturned, lost-load, jack-knife) # of total involved vehicles # of involved passenger cars # of involved trucks # of involved motorcycles
Group-4: indicators for the pavement conditions	Wet, dry, snow-ice, chemical wet, hazard material related
Group-5: indicators to denote the lane-blockage conditions	# of blocked lanes # of blocked shoulder lanes # of blocked travel lanes # of blocked auxiliary lanes Travel lane blocked in tunnel Travel lane blocked in toll
Group-6 : indicators reflecting different incident response centers	AOC, TOC3, TOC4, TOC5, SOC # of blocked lanes
Group-7: temporal-related indicators associated with an incident	AM peak, PM peak, daytime, night weekday, weekend holiday, non-holiday Spring, Summer, Fall, Winter

Then, the next step is to apply the permutation-based variable-importance measure (Biecek, and Burzykowski, 2020) to rank the impacts of those groups of factors on the final clearance duration of those incidents in the I-70 dataset. A concise description of the core algorithm for such a ranking process is presented below:

Consider a set of n *incident records for* p *contributing factors and the incident clearance duration* Y*. Then, let* X *denote the matrix of* p *columns and* n *rows, and the column vector of* $\underline{y}$ *shows the observed values of* Y*. As such,* $\underline{\hat{y}} = \left(f\left(\underline{x}_1\right), \ldots, f\left(\underline{x}_n\right)\right)'$ *denote the corresponding vector of predictions from the random forest for* $\underline{y}$ *for model* $f()$*, and* $\mathcal{L}(\underline{\hat{y}}, \underline{X}, \underline{y})$ *be a loss function that quantifies goodness-of-fit of model* $f()$*. With all above defined key terms, one can summarize the core of the algorithm as follows:*

1. *Compute* $L^0 = \mathcal{L}(\underline{\hat{y}}, \underline{X}, \underline{y})$ *i.e., the value of the loss function for the original data. Then, for each contributing factor* X^j *included in the model, and repeat steps 2-5.*

2. *Create matrix* $\underline{X}^{*j}$ *by permuting the* j*-th column of* $\underline{X}$*, i.e., by permuting the vector of observed values of* X^j*.*

3. *Compute the model predictions* $\underline{\hat{y}}^{*j}$ *based on the modified data* $\underline{X}^{*j}$*.*

4. *Compute the value of the loss function for the modified data:* $L^{*j} = \mathcal{L}(\underline{\hat{y}}^{*j}, \underline{X}^{*j}, \underline{y}^{*j})$

5. *Quantify the importance of* X^j *by calculating* $vip^j_{Ratio} = L^{*j}/L^0$

The computation results with respect to all key factors contributing to incident duration are shown in Figure 5-4, where the one reflecting the number of responders exhibits the highest rank.

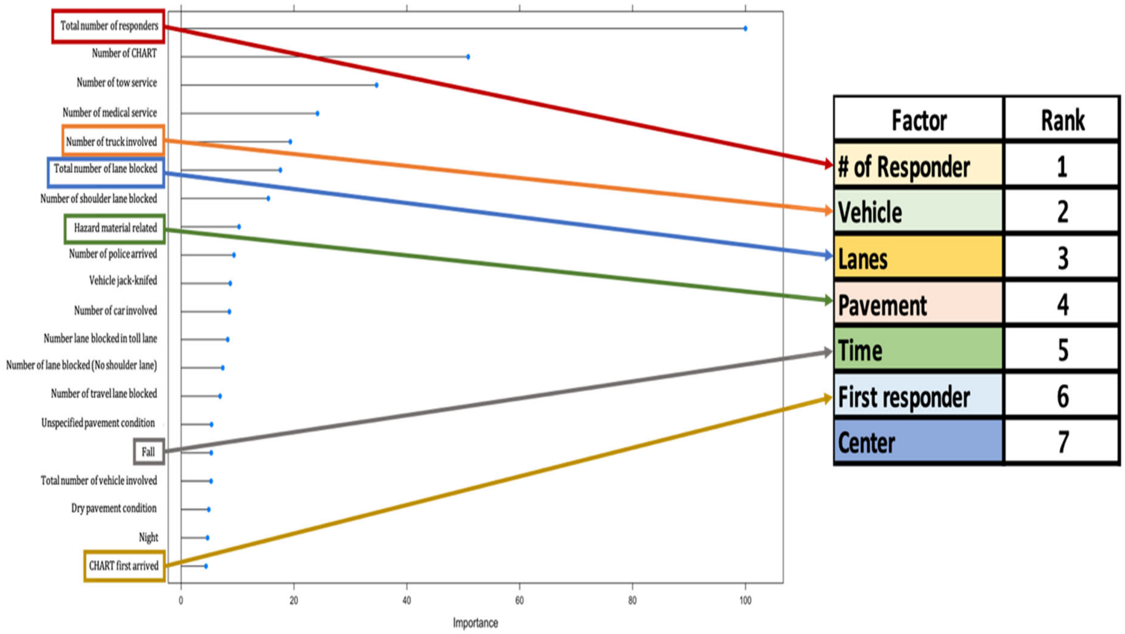

Figure 5-4: Ranking the impacts of those seven groups of factors on the incident clearance time, based on each group's highest-rank factor

After computing the importance of each factor, one can then rank the seven classified groups based the highest-importance factor in each group. For instance, "total number of responders" is identified to be the most important factor, thus the group (i.e., Group 1) having this factor would be assigned with the highest rank of 1. Then, by excluding all other factors in Group 1 from the list of comparison, the one with the highest importance in the remaining list belongs to *"number of trucks involved."* Hence, Group-3, containing this factor, shall be assigned with the rank of two. The same procedures can be iteratively executed to identify the proper rank of each of the remaining groups.

The rankings for the records will be on a descending order where the group ranked at the top of the list, as shown in Figure 5-4, indicating that it contains the set of contributing factors with the most impacts on a detected incident's resulting clearance duration. As such, those candidate rules, based on the factors from a high-rank group, will thus be given a high priority in the sequence of transferability analysis, and play more important roles in the target model's decision structure.

However, it is noticeable that the Rule Box, due to the contributions from several well-developed IDPMs, may contain multiple prediction rules constituted by the same group of factors but for either the same or different types of incidents. Thus, the following process has been proposed in this study to set the priority for transferability analysis for such rues sharing the same group of factors.

Step-1: Characterize all candidate rules

For convenience of assessing the transferring priority, all candidate rules based on their logic structure and target incident types are characterized into the following types and assigned with a specified weight:

Type A*: Rules with a simple IF-THEN statement for estimating the lower bound of an incident's clearance duration, such as "IF more than 8 response units arrived, THEN the duration > 120 minutes."*

Type B: *Rules with a simple IF-THEN statement for estimating the upper bound of an incident's clearance duration, such as "IF no tow services are needed, THEN the duration < 30 minutes."*

Type C: Rules constituted with a nest of *IF-THEN statements and the relation of "AND" such as "IF on [holiday] AND [truck involved], THEN the duration >60 minutes."*

Type D: Rules constituted with a nest of *IF-THEN statements and the relation of "OR" such as "IF on [weekend] OR [police first arrived], THEN the duration >30 minutes."*

Step-2: Assign an assessment score to each candidate rule as follows:

Type-A rules*: Assign a score for each of such rules, based on the rank of the group associated with the factor constituting the rule*. For instance, the rule, *"IF more than 8 response units arrived, THEN the duration > 120 minutes" will be assigned with the score of "**1**," because the condition variable of "8 response unit" belongs to Group-1 factors.*

Type-B rules*: Assign a score for each of such rules used to set the lower bound of an incident's duration, based on the rank of the group associated with the factor constituting the rule and a status score of* ***"200,"*** *to ensure that all such rules will be assessed and transferred after all other types of rules*. For instance, the rule, *"IF no tow services are needed, THEN the duration < 30 minutes" for setting the lower bound of a detected incident's duration will be assigned with the assessment score of 201, because its condition variable of "no tow service," belongs to Group-1 factors.*

Type-C rules*: Assign a score for each of such rules based on the sum of scores computed from the rank of the group associated with the factor constituting each IF-THEN statement in the entire set of rules connected with "AND."* For instance, the rule of *"IF on [holiday] AND [truck involved], THEN the duration >60 minutes" will be assigned with the assessment score of "7," because its two condition variables, [holiday] and [truck involved], belong to factors in Group 5 and Group 2, respectively.*

Type-D rules*: assign a score for each of such rules, based on the sum of its assigned priority status score of* ***"100"*** *and the lowest score, computed from all IF-THEN statements in the same set connected with "OR,"* based on *the rank of the group associated with each of their conditional variables.* As such, the rule of *"IF on [weekend] OR [police first arrived], THEN the duration >30 minutes" will be assigned with the assessment score of "105", because its two condition variables, [weekend] OR [police first arrived], belong to Groups 5 and 6, respectively. The final assessment score for this rule shall be the sum of* ***"100" plus "5."***

Given the computed score assigned for each set of prediction rule, one can then proceed the transferability analysis with a score-based descending order for all candidate rules to ensure that a more important set of rules, if they meet the specified criteria, can be assigned to assume more important roles in the target model's decision structure. The criteria for assessing the transferability of each candidate rule are identical to those used in developing the IDPMs for I-495 and I-695, mainly based on the resulting *confidence level* and *support level* with respect to the target application.

Mining Process for new classification rules

Note that a total of **36** prediction rules and their execution relationship with the above knowledge-based transferring process have been accepted for use in the IDPM-I-70. Similar to what has been done for the IDPMs for I-495 and I-695, the mining process has been exercised on the remaining small set of data and produced **11** local-unique prediction rules for those types of incident response operations that cannot be covered with those 36 transferred rules.

Table 5-3 shows the set of rules for predicting the required clearance duration for a detected person-injury incident on I-70; the complete set of prediction rules for IDPM-I-70 and their decision structures are available in Appendix C.

Table 5-3: Prediction rules for incidents with Collision and Personal Injury (CPI-1) on I-70

	Classification Rules Description – CPI-1		Case
IF	*[Tow service arrived]*	THEN	≥30
IF	*[More than 3 vehicles involved]*	THEN	≥30
IF	*[More than 1 CHART arrived] AND [Police first arrived]*	THEN	≥30
IF	*[Peak hour] AND [More than 2 vehicles involved]*	THEN	≥30
IF	*[Car overturned] AND ([Weekend] OR [Tow service arrived])*	THEN	≥30
IF	*[Fireboard first arrived]*	THEN	<30
	ELSE THEN		<30
IF	[More than 4 vehicles involved]	THEN	≥60
IF	[More than 1 police arrived] AND [CHART first arrived]	THEN	≥60
IF	*[Snow-ice pavement] OR [More than 1 truck involved] OR [More than 7 respond units arrived] OR [AOC center]*	THEN	≥60
IF	[Tow service arrived] AND [Vehicle overturned] AND [Wet pavement]	THEN	≥60
IF	*[No tow service arrived] AND [No truck involved]*	THEN	<60
	ELSE THEN		<60
IF	*[Less than 4 response units arrived] OR [No truck involved]*	THEN	<120
IF	[More than 8 response units arrived]	THEN	≥120
	ELSE THEN		<120

5.4 Performance evaluation

The performance evaluation results of the IDPM-I-70 with both transferred and customized local rules are shown in Table 5-4 and

Table 5-5, where the former is with the training dataset of incident records from 2016-2018, and the latter is the dataset of the 2019 incident records for model test. Noticeably, the IDPM-I-70 developed mainly with transferred rules (i.e., 36 out of 54 rules) can achieve the accuracy level of 87% with the training dataset and about the same level with respect to the test dataset. Most importantly, the overall accuracy of the IDPM-I-70, by taking advantage of knowledge and rules from previously developed models, can yield the comparable level of performance but at the must less effort.

Table 5-4: Evaluation results of IDPM-I-70 (training dataset)

2016-2018 I-70 ALL		Actual CT (minutes) < 30	30 ~ 60	60 ~ 120	≥ 120	Overall
Over estimated	> 120	0	0	0	0	0
	60~120	0	0	0	0	0
	30~60	0	0	0	0	0
	10~30	1	2	2	0	5
	0~10	9	0	1	0	10
Within boundaries		76	71	23	23	193
Under estimated	-10~0	0	4	3	0	7
	-30~-10	0	0	5	0	5
	-60~-30	0	0	0	1	1
	-120~-60	0	0	0	1	1
	< -120	0	0	0	0	0
Total # of cases		86	77	34	25	222
TP rate and Accuracy		88.37%	92.21%	67.65%	92.00%	86.94%

Table 5-5: Evaluation results IDPM-I-70 (test dataset)

2019 I-70 ALL		Actual CT (minutes) < 30	30 ~ 60	60 ~ 120	≥ 120	Overall
Over estimated	> 120	0	0	0	0	0
	60~120	0	0	0	0	0
	30~60	0	0	1	0	1
	10~30	1	0	0	0	1
	0~10	2	0	0	0	2
Within boundaries		22	21	3	3	49
Under estimated	-10~0	0	2	0	0	2
	-30~-10	0	0	2	0	2
	-60~-30	0	0	2	0	2
	-120~-60	0	0	0	0	0
	< -120	0	0	0	1	1
Total # of cases		25	23	8	4	60
TP rate and Accuracy		88.00%	91.30%	37.50%	75.00%	81.67%

In summary, as shown in Appendix D, most prediction rules (i.e., 66%) embedded in the developed IDPM-I-70 are transferred from the Rule Box (i.e., 36/54, 66%), demonstrating the potential of the proposed knowledge-based transferring process. Table 5-6 summarizes the comparison of its performance evaluation results with the IDPMs for I-95, I-695, I-495, and I-70, further confirming its effectiveness achieved with much less sample incident records and substantially reduced development effort.

Table 5-6: Summary of the model evaluations for I-95, I-495, I-695, and I-70

Accuracy		
Highway	**Training Dataset**	**Testing Dataset**
I-95	79.8% (1549/1958)*	74.3% (465/626)
I-495	86.3% (1756/2034)	82.1% (414/504)
I-695	86.9% (1269/1461)	82.3% (352/425)
I-70	86.9% (193/222)	81.7% (49/60)

*The number of sample incidents

Chapter 6: Incident Clearance Duration Prediction Model for US 29

6.1 Introduction

In principle, one can follow the same development process, reported in Chapter 5 for IDPM-I-70, for IDPM-US 29, which consists of 1) incident data pre-processing, 2) incident categorization, 3) rule transferability analysis, 4) data mining process for new local rules, and 5) model evaluation. However, the small size of incident records from US 29 (i.e., 101 lane-blockage incidents between 2016-2019) offers statistically insufficient data for ranking the relative weight of each contributing factor on the resulting incident duration, the essential information for ranking and selecting candidate rules in the Rule Box. As such, a customized method for analysis of rule transferring priority has been developed in design of IDPM-US 29 to accommodate the sample size limitation.

The construction of IDPM-US 29, nonetheless, has the advantage of having more potentially transferable rules from early developed IDMs (e.g., I-95, I-495, I-695, and I-70) to reduce the system development efforts. A large body of such prediction rules for selection and adoption will certainly contribute to the effectiveness of IDPM-US 29, despite far fewer incident records than other highways for model calibration and rule development.

The remaining sections of this chapter will follow the process illustrated in Figure 6-1 to detail the development of the IDPM-US 29, including key activities at each stage, the results of performance evaluation, and comparison with other existing IDPMs.

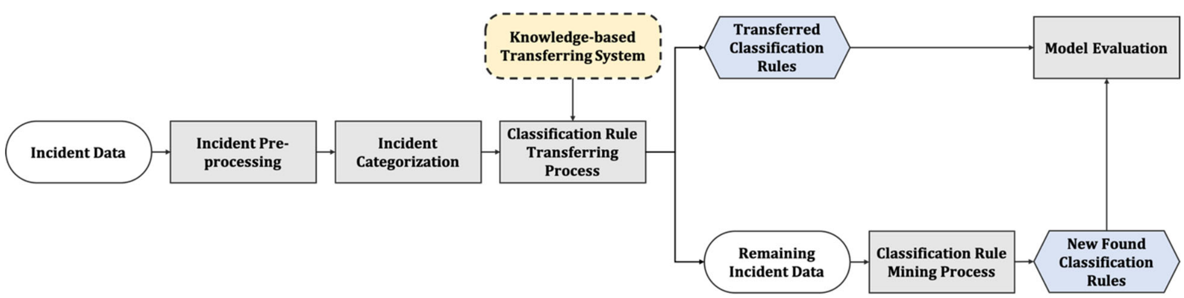

Figure 6-1: Development flowchart for the incident duration model for US 29

6.2 Incident data pre-processing and categorization

As with previously developed IDPMs, the incident records from 2016 to 2018 constitute the training dataset for training and calibration, and the data from 2019 serve to assess the system's performance. Note that only the segment of US-29 within Maryland and those incidents resulting in collision are included in the model. The same procedures used in developing other IDPMs have also been adopted in pre-processing of incident records from US 29 for better data quality control.

Due to the very small number of incident records in CPI-3 and CPD-3, the initial incident categorization for US 29 has merged the subsets CPI-3 and CPD-3, respectively, into CPI-2 and CPD-2. Figure 6-2 shows the average clearance time for each category of incidents and the range of variation at the confidence intervals of 60%, 70%, and 80%.

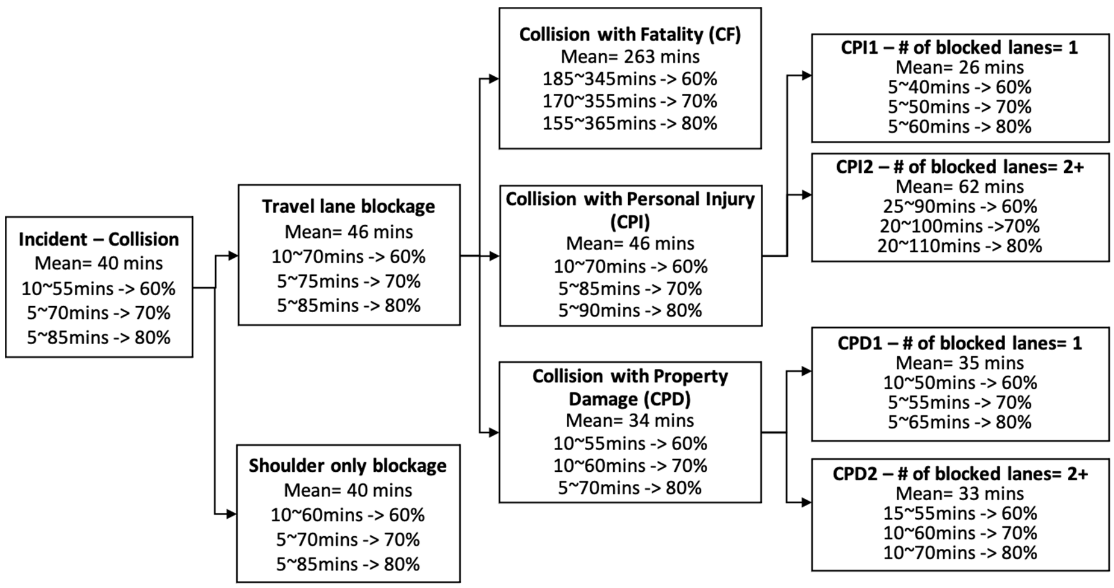

Figure 6-2: Results of initial incident categorization and estimated clearance duration for US 29

6.3 Classification rule transferring process

As reported in previous chapters, the sequence of transferring candidate rules to a new system is critical to the construction of its decision structure and the resulting effectiveness. The incident records from US 29 due to its small sample size, however, cannot reliably reflect the relative weights of their contributing factors' impacts on the resulting incident duration. As such, a four-stage process (shown in Figure 6-3) of the **t**ransferability **a**ssessment **m**ethod-**2** (TAM-2), specially designed for rule assessment and transferability analysis for IDPM-US 29 under the sample size limitation, is presented hereafter.

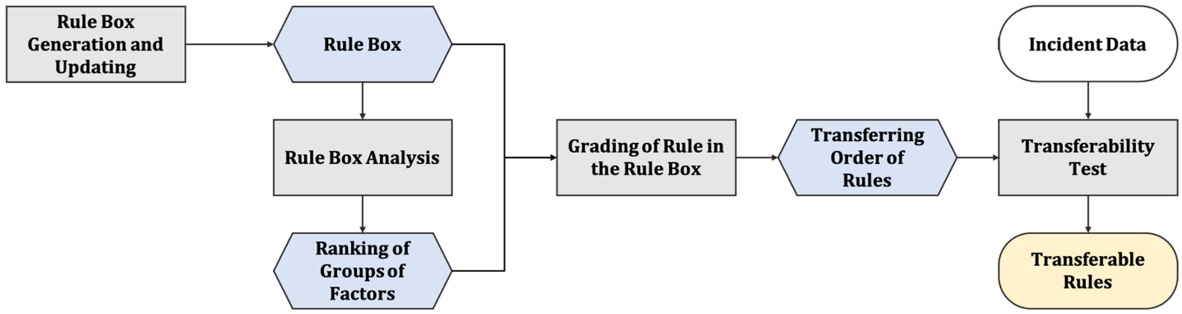

Figure 6-3: The rule transferring process for the IDPM-US-29

Note that the Rule Box for IDPM-US 29 development can take advantage of all effective prediction rules embedded in existing IDPMs for I-95, I-495, I-695, and I-70. Due to a lack of sufficient incident records resulting in CPI-3 and CPD-3, only those rules for predicting the duration of CPI-1, CPI-2, CPD-1, and CPD-2 will be subjected to the analysis of effectiveness and priority for transfer.

To circumvent the constraints posed by limited sample data, the development task starts with characterizing all major factors contributing to incident duration into seven groups; they are then evaluated by how often each group of factors have been adopted in existing candidate rules and the resulting effectiveness. The criteria for assessing each of such groups' roles among all candidate rules in the Rule Box are defined as follows:

- *Frequency*: the number of classification rules in the Rule box that contains one or more factors from each group. For instance, Table 6-1 indicates that the group of factors, named "*the number of responders,*" will be assigned with a frequency of 134, because there are 134 prediction rules in the Rule Box which contain one or more factors from this group.

- C*overage*: the total number of incident records in the integrated dataset (i.e., all records from I-495, I-685, I-70, I-95) that have been predicted by a particular set of rules containing one or more factors in each of those seven pre-classified groups. For instance, the set of 134 rules that contain either one or more factors from the group of "*the number of responders*" has been used to predict the duration for 2,979 incidents (see Table 6-1). As such, the group of "*the number of responders*" will be characterized as having the coverage of 2,979 cases.

- A*ccuracy:* the total number of correctly predicted incidents out of the total "coverage" by the set of rules (i.e., *frequency*) associated with each group of factors. For instance, the group of "*the number of responders*" will be assessed with the "accuracy" level of 83.42% based on their prediction accuracy with respect to their application to 2,797 incidents.

- *Proportion of composite rules*: the number of rules constituted with the command of "AND" out of the total rules (*defined as frequency*) associated with each of those seven pre-classified groups of factors.

Table 6-1 shows the summary of statistics associated with each of the groups based on the above four measurements. The resulting rank of importance associated with each group with respect to its role in developing existing prediction rules is computed with the method of Data Envelopment Analysis (DEA) (Charnes et al., 1978), based on the measurements.

The primary steps for applying the DEA method along with the computed results are summarized below:

Step 1: Characterize the relationship between each group of factors and available rules with the selected measurements (see Table 6-1).

Table 6-1: Summary of measurement statistics for all groups of factors

	# of Responders	***First Responder***	***Vehicle***	***Pavement***	***Lane***	***Center***	***Time***
Frequency (# of rules)	134	15	129	41	31	16	54
Coverage (# of cases)	2979	247	1478	1220	343	596	684
Accuracy (mean)	83.42%	75.33%	84.62%	89.24%	87.87%	81.75%	82.06%
Proportion of composite rules	0.59	0.80	0.64	0.39	0.68	0.69	0.81

Step 2: Standardize all measurements in Table 6-1 as shown in Table 6-2.

Table 6-2: Normalized the measures for each group of factors

	# of Responders	***First Responder***	***Vehicle***	***Pavement***	***Lane***	***Center***	***Time***
Frequency (# of rules)	0.6647	0.0744	0.6399	0.2034	0.1538	0.0794	0.2679
Coverage (# of cases)	0.8093	0.0671	0.4015	0.3314	0.0932	0.1619	0.1858
Accuracy (mean)	0.3772	0.3407	0.3827	0.4036	0.3974	0.3697	0.3711
Proportion* of composite rules	0.3327	0.4515	0.3588	0.2202	0.3823	0.3880	0.4599

*non-beneficial measure

Step 3: Characterize each selected measurement as "positive" or "negative" in nature with respect to its contribution to the accuracy and applicability of associated prediction rules in the Rule Box. For instance, the group of factors exhibiting a high value for the measurement of "proportion of composite rules" implies that its will be less effective for developing simple and definitive prediction rules for estimating incident duration. As such, it is viewed as less favorable in the ranking of transferring priority and characterized as a "non-beneficial" measurement in the following step. In contrast, the other three measures are positively correlated with the adoption of each group of factors among the existing rules and are classified as "beneficial."

Step 4: Formulate the analysis for each group with a fractional linear programming as follows:

$$\begin{aligned} &Maximize && E_k = \textstyle\sum_{r=1}^{s} u_i y_{rk} \\ &Subject\ to && \textstyle\sum_{r=1}^{s} u_r y_{rk} - \sum_{i=1}^{m} v_i x_{ik} \le 0 \\ & && \textstyle\sum_{r=1}^{s} v_i x_{ik} = 1 \\ & && u_r \ge 0,\ r = 1, \dots, s \\ & && v_i \ge 0,\ i = 1, \dots, m \end{aligned}$$

where:

$$E_k = Effectiveness\ of\ group\ k$$
$$u_r = r^{th}\ beneficial\ MOE$$
$$v_i = i^{th}\ nonbeneficial\ MOE$$
$$y_{rk} = r^{th}\ value\ of\ beneficial\ MOE\ of\ group\ k$$
$$x_{ik} = i^{th}\ value\ of\ nonbeneficial\ MOE\ of\ group\ k$$

For example, for the group of "# of responders," the results of this step can be shown as follows:

$$\begin{array}{ll} Maximize & E_{\#\ of\ responders} = 0.6647u_1 + 0.3772u_2 + 0.8093u_3 \\ Subject\ to & 0.6647u_1 + 0.3772u_2 + 0.8093u_3 - 0.3327v_1 \leq 0 \\ & 0.0744u_1 + 0.3407u_2 + 0.0671u_3 - 0.4515v_1 \leq 0 \\ & 0.6399u_1 + 0.3827u_2 + 0.4515u_3 - 0.3588v_1 \leq 0 \\ & 0.2034u_1 + 0.4036u_2 + 0.3314u_3 - 0.2202v_1 \leq 0 \\ & 0.1538u_1 + 0.3974u_2 + 0.0932u_3 - 0.3823v_1 \leq 0 \\ & 0.0794u_1 + 0.3697u_2 + 0.1619u_3 - 0.3880v_1 \leq 0 \\ & 0.2679u_1 + 0.3711u_2 + 0.1858u_3 - 0.4599v_1 \leq 0 \\ & 0.3327v_1 = 1 \end{array}$$

Step 5: Solve the effectiveness for $E_{\#\ of\ responders}$ and then repeat *Step 4* for other groups.

Step 6: remove the measure that has the same value for multiple groups and redo the same computation if some groups have identical E-value.

Step 7: assign the rank of transferring priority associated with the group based on its E-value, where Rank 1 will have the highest priority for transferability assessment.

The resulting effectiveness value (E-value) associated with each group is shown in Table 6-3, where those prediction rules developed with the group of factors with the highest E-value will be given the highest weight in the transferability analysis.

Table 6-3: The efficiency and the resulting rank of each group

	# of Responders	***First Responder***	***Vehicle***	***Pavement***	***Lane***	***Center***	***Time***
$\boldsymbol{E-val}$	1.000*	0.412	0.915	1.000*	0.567	0.520	0.487
$\boldsymbol{Rank}$	1	7	3	2	4	5	6

*either one can be assigned to the first rank.

Based on the rank for each group of factors, one can follow the same procedures as with IDPM-I-70 to set the assessing and transferring sequence for all candidate rules in the Rule Box for IDPM-US 29. The final transferability decision with respect to each candidate rule will be based mainly on each set of rules' *confidence level* and *support level*, as used in other IDPMs. With this ranking and evaluation process, a total of 16 prediction rules in the Rule Box has been accepted for use in the IDPM-US 29.

As with the IDPM development for other highways, some local-specific rules are needed to reflect the uniquely critical impacts of some factors associated with the incident response for US 29 and the resulting clearance duration. Hence, the same rule-searching process has been adopted to identify an additional 18 rules to cover the remaining incident records that cannot be predicted to the acceptable level of confidence with those transferred rules. For instance, all prediction rules for incidents in the category of CF on US 29 are constructed from the dataset rather than transferred from other systems, because its sample size is insufficient for use in the transferability analysis. Table 6-4 presents all such predictions rules constructed for incidents in the CPD category.

Table 6-4: List of prediction rules for incidents with Collision with Damage Property (CPD)

	Classification Rules Description – CPD-1		**Case**
IF	[More than 2 vehicles involved] AND [More than 3 response units arrived]	THEN	≥30
IF	*[Truck involved] AND [More than 1 police arrived]*	THEN	≥30
IF	*[Chemical wet pavement] AND [Police arrived]*	THEN	≥30
IF	([Winter] AND [Tow service arrived]) OR ([TOC3 center] AND [Auxiliary lane blocked])	THEN	≥30
	ELSE THEN		<30
IF	*[More than 7 response units arrived] OR [Chemical wet pavement]*	THEN	≥60
IF	*([More than 2 vehicle involved] AND [More than 1 tow service arrived]) OR [TOC3 center]*	THEN	≥60
	ELSE THEN		<60
IF	*[Truck involved] OR [More than 5 response units arrived] OR [Chemical wet pavement]*	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD-2		Case
IF	*[Tow service arrived] AND [Fireboard arrived]*	THEN	≥30
IF	*[Snow-ice pavement] OR [Chemical wet pavement] OR [Truck jacknifed] OR [More than 6 response units arrived]*	THEN	≥30
IF	([Fireboard arrived] OR [More than 3 travel lanes blocked]) AND [Police first arrived]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 1 tow service arrived]*	THEN	≥60
IF	*[Truck involved] AND [More than 5 response units arrived]*	THEN	≥60
IF	[More than 4-lanes blocked] OR [Snow-ice pavement] OR [Wet pavement]	THEN	≥60
	ELSE THEN		<60
IF	([More than 5-lanes blocked] AND [Snow-ice pavement]) OR [Chemical wet pavement]	THEN	≥120
	ELSE THEN		<120

6.4 Model evaluation

The IDPM-US 29, developed with data from 2016-2018, is further evaluated with incident records from 2019. All its embedded rules, including those transferred from other systems and calibrated from local data, are shown in Appendix E. With respect to its performance, as shown in Table 6-5 and

Table **6-6**, the system with mostly transferred rules can achieve the accuracy of 93% for those in the calibration data set, and an accuracy of 77% with the 2019 data for evaluation. Considering the fact of only a few incident records per year, especially in 2019, it is likely that the resulting prediction accuracy will increase with available incident records.

Table 6-5: Evaluation results of IDPM-US 29 (2016-2018 dataset)

2016-2018 US 29 ALL		Actual CT (minutes)				Overall
		< 30	30 ~ 60	60 ~ 120	≥ 120	
Over estimated	> 120	0	0	0	0	0
	60~120	0	0	0	0	0
	30~60	0	0	0	0	0
	10~30	0	0	0	0	0
	0~10	3	1	0	0	4
Within boundaries		53	23	14	7	97
Under estimated	-10~0	0	0	0	0	0
	-30~-10	0	0	3	0	3
	-60~-30	0	0	0	0	0
	-120~-60	0	0	0	0	0
	< -120	0	0	0	0	0
Total # of cases		56	24	17	7	104
TP rate and Accuracy		94.64%	95.83%	82.35%	100.00%	93.27%

Table 6-6: Evaluation results of IDPM-US 29 (2019)

2019 US 29 ALL		Actual CT (minutes)				Overall
		< 30	30 ~ 60	60 ~ 120	≥ 120	
Over estimated	> 120	0	0	0	0	0
	60~120	0	2	0	0	2
	30~60	0	0	0	0	0
	10~30	0	0	0	0	0
	0~10	1	0	0	0	1
Within boundaries		5	9	1	2	17
Under estimated	-10~0	0	0	0	0	0
	-30~-10	0	0	1	0	1
	-60~-30	0	0	1	0	1
	-120~-60	0	0	0	0	0
	< -120	0	0	0	0	0
Total # of cases		6	11	3	2	22
TP rate and Accuracy		83.33%	81.82%	33.33%	100.00%	77.27%

6.5 Summary

This chapter has presented the calibration process and customized methods for developing the IDPM-US 29. An innovative method for transferability assessment under the constraints of very limit incident records from the target highway for model calibration has been developed in this study. The resulting performance of IDPM-US 29 with the specially designed method seems to yield the comparable prediction accuracy, as shown in Table 6-7, with other highways that have a substantially higher number of incident records for model calibration and rule development. For all other highways covered by CHART, having the annual incident frequency comparable to US 29, the development process and methods highlighted in this chapter offer a promising avenue for overcoming their data limitations.

Table 6-7: Performance comparison among all existing incident duration prediction systems

	Accuracy	
Highway	**Training Dataset**	**Testing Dataset**
I-95	79.8%	74.3%
I-495	86.3%	82.1%
I-695	86.9%	82.3%
I-70	86.9%	81.7%
US-29	93.3%	73.0%

Chapter 7: Research Findings and Future Works

7.1 Summary of research findings

Ground in the development experience of the piloting IDPM-I-95 and its application results, this study has further developed IDPM-I-495, IDPM-I-695, IDPM-I-70, and IDPM-US 29, each with distinguishing traffic patterns and roadway features. In view of the uniquely critical role assumed by I-495 and I-695, respectively, in the Washington and Baltimore regions and their large incident records, the design and construction of these two IDPMs mostly follow the same methodology as with IDPM-I-95, with the exception of the calibration of some supplemental prediction rules to reflect some location specific features.

To circumvent the demanding expertise and efforts needed for data quality control and calibration of an IDPM's prediction rules from a large number of incident records, this study has developed an innovative **t**ransferability **a**ssessment **m**ethod (TAM) that allows construction of a new system to take advantage of existing IDPMs' embedded knowledge. For instance, most prediction rules for IDPM-I-70 are not calibrated and trained from its multi-year incident records with the AI-based association rule method developed in IDPM-I-95, a rigorous but time-consuming process. Instead, the developed TAM has been adopted for transferability assessment with respect to all prediction rules in IDPM-I-95, IDPM-I-695, and IDPM-I-495 using the I-70's incident records, and for prioritizing their transferring sequence to IDPM-I-70 if any of them can achieve the preset level of performance. The result of extensive evaluation with multi-year incident records indicates that the performance of IDPM-I-70, developed with such an innovative and efficient method, can yield the prediction accuracy comparable to existing IDPMs that demand much more development resources.

Recognizing that some highways, such as US 29, does not have sufficient incident records for its IDPM development with either the AI-based direct calibration or the TAM for rule transfer from other IDPMs, this study has further developed a second transferability assessment method (named TAM-2) for such roadways to have their IDPMs, based on the knowledge and prediction rules of existing IDPMs with a customized methodology for rule selection and transferring analyses. IDPM-US 29 designed with the customized TAM-2 method, as shown in Chapter 6, is demonstrated to be capable of taking the strengths of existing IDPMs and achieving the comparable level of performance.

In summary, this study has produced reliable IDPMs for four significantly congested highways with uniquely complex traffic and incident patterns. Since these four completed systems, along with IDPM-I-95, have collectively covered two types of beltways (e.g., I-

695), typical commuting freeways (I-95), and a major expressway (US 29), it is expected that those empirically calibrated prediction rules embedded in such IDPMs can serve as the basis for design of a generalized IDPM for all other highways. The two innovative TAMs developed in this study lso offer a set of cost-effective tools for responsible highway agencies to cope with the data quality and deficiency issues that often hinder the progress of IDPM development for highways with either inadequate or not properly recorded incident data.

7.2 Future development tasks

For MDOT SHA to enhance its incident response operations and effectively tackle the resulting non-recurrent congestion patterns on all major highways, further research and development tasks along this line shall include:

- Construct a generalized incident duration prediction system for the entire network covered by CHART, based on the information and knowledge calibrated from IDPM-I-495, IDPM-I-95, IDPM-I-695, IDPM-I-70, and IDPM-US 29.

- Develop a dynamic traffic queue evolution model for estimating the time-varying impact distance during a detected incident's clearance period**.**

- Design a robust traffic diversion model under the constraints of available surveillance systems for estimating the detouring traffic patterns and their impacts on the neighboring local network during a detected incident's clearance period.

Note that it is essential for MDOT SHA to have a generalized IDPM for all its highways in view of the benefits of having a reliable estimate of incident duration for traffic management, and the demanding expertise as well as extensive data needs to develop such a system. Instead of developing an IDM for each highway, one shall develop a generalized IDPM by taking advantage of all prediction rules effectively calibrated for existing IDMs, which include the I-95 freeway corridor partially managed with toll controls; a commuting freeway of I-70 in the Baltimore region; a half-beltway of I-495 within Maryland but receiving significant traffic from Virginia; a complete beltway of I-695 managed solely by CHART; and an expressway of US 29 containing some signalized intersections. Since these five IDMs cover a wide distribution of roadway geometric features, driving population patterns, and the incident response resources/constraints associated with most highway segments covered by CHART's operations, it is expected that their well-calibrated rules for estimating incident duration with transferability and machine learning methods can directly, or with some refinement, be applied to the remaining highways.

As for developing a traffic queue evolution model, its primary purpose is to construct a tool that can reliably predict the traffic queue distance under different types of lane-blockage incidents at different volume levels, based on the estimated incident clearance time. Such traffic queue information associated with a detected incident will enable an incident response team to estimate the impacts on the traffic conditions during the clearance operations and implement the most effective traffic management strategies, such as posting a message of speed reduction or activating on-ramp metering control.

Note that calibrating and operating a dynamic traffic queue model in theory is not a complex task if all highway segments have been deployed with properly spaced traffic sensors (e.g., 0.5 mile on the mainline and .25 mile on the weaving segments) for real-time traffic control. However, nearly every highway administration in the entire country, in practice, suffers from insufficient resources for such sensor deployment and system maintenance as well as operations. As such, the challenge for developing such an imperative dynamic queue prediction model lies in how to integrate very limited sensor data with the information from private sectors such as Google Maps traffic report, or travel time data provided by probing vehicles over sample intervals.

The third model on the recommended development list is an online traffic flow estimation system, designed for the traffic control center to estimate the distribution of freeway traffic flows diverting to neighboring local routes during the incident clearance period, given the identified incident nature and estimated traffic queue impact distance. Providing such information is certainly critical for selecting and activating proper traffic control strategies (e.g., detouring operations and off-ramp signal coordination) so that the incident's impact on the neighboring local networks can be minimized. Responsible traffic agencies can also implement an advanced corridor-wide integrated traffic control to contend with the non-recurrent congestion during the clearance period of major incidents if such valuable information is available in real time.

Calibrating such a dynamic detouring estimation model at the desirable level of performance, however, is also a challenging task, because most highways are not deployed with off-ramp traffic sensors to measure the exiting flows, and most archived freeway incident reports do not include the resulting impact on local routes due to the detouring flows. Hence, it is expected that one may need to adopt an innovative method to collect essential data for such model development with new available technologies (e.g., drone, etc.), supplemented with creatively extracted sample information from any publicly available on-line travel time system.

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Appendices

Appendix A: Classification rules for I-95

Collision with Personal Injury (CPI)

	Classification Rules Description – CPI1		**Case**
IF	[Tow service arrived]	THEN	≥30
IF	[More than 3 vehicles involved]	THEN	≥30
IF	[TOC3 center] OR [TOC4 center] OR [SOC center]	THEN	<30
IF	[Truck involved] OR [Motorcycle involved]	THEN	≥30
IF	[Lanes blocked in tunnel]	THEN	≥30
IF	[Fireboard first arrived]	THEN	<30
IF	[Non-peak hour] AND [Police first arrived]	THEN	≥30
IF	[Peak hour] AND [More 2 vehicles involved]	THEN	≥30
IF	[CHART arrived]	THEN	≥30
	ELSE THEN		<30
IF	([Night] AND [More than 6 response units arrived]) OR [More than 4 vehicles involved]	THEN	≥60
IF	[No tow service arrived] OR [No truck involved]	THEN	<60
IF	[Police first arrived]	THEN	≥60
IF	[More than 1 tow service arrived] OR [Auxiliary lane blocked] OR [More than 1 truck involved] OR [Hazard materials related]	THEN	≥60
IF	[Less than 3 vehicles involved] OR [TOC3 center]	THEN	<60
	ELSE THEN		<60
IF	[Less than 4 response units arrived] OR [No truck]	THEN	<120
IF	[Winter]	THEN	≥120
IF	[More than 2 CHART arrived] OR [More than 6 respond units arrived]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI2		**Case**
IF	[Tow service arrived]	THEN	≥30
IF	[AOC center]	THEN	≥30
IF	[More than 4 response unit arrived]	THEN	≥30
IF	[Dry pavement condition]	THEN	<30
IF	[Winter] OR [Night]	THEN	≥30
	ELSE THEN		<30
IF	[More than 5 vehicles involved]	THEN	≥60
IF	[More than 1 tow service arrived] AND [More than 3 vehicles involved]	THEN	≥60
IF	[More than 6 response units arrived]	THEN	≥60
IF	[No tow service arrived] OR [No truck involved]	THEN	<60
IF	[Medical service arrived] OR [Hazard materials related] OR [Night] OR [Wet pavement condition] OR [Lane blocked in tunnel]	THEN	≥60
	ELSE THEN		<60
IF	[More than 1 truck involved] OR [More than 3 vehicles involved] OR [Hazard materials related] OR [More than 7 response units arrived]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI3		Case
IF	[Tow service arrived] OR [Vehicle jack-knifed] OR [Vehicle overturned] OR [Vehicle lost load]	THEN	≥30
IF	[TOC4 center]	THEN	<30
IF	[SOC center] OR [Truck involved] OR [More than 2 vehicles involved]	THEN	≥30
IF	[TOC3 center]	THEN	<30
IF	[Fireboard first arrived]	THEN	≥30
	ELSE THEN		<30
IF	[Medical service arrived]	THEN	≥60
IF	[More than 8 response units arrived]	THEN	≥60
IF	[No tow service]	THEN	<60
IF	[More than 3 travel lanes blocked]	THEN	≥60
IF	[Weekend] OR [Night]	THEN	≥60
IF	[DRY pavement condition]	THEN	<60
	ELSE THEN		<60
IF	[More than 9 response units arrived]	THEN	≥120
IF	[No truck involved]	THEN	<120
IF	[More than 1 truck involved]	THEN	≥120
IF	[Medical service arrived] OR [Lane blocked in tunnel]	THEN	≥120
	ELSE THEN		<120

Collision with Property Damage (CPD)

	Classification Rules Description – CPD1		Case
IF	[Tow service arrived] OR [Hazard materials related]	THEN	≥30
IF	[AOC center] AND [More than 1 CHART arrived]	THEN	≥30
IF	[AOC center] AND [More than 4 vehicles involved]	THEN	≥30
IF	[Wet pavement condition] AND [More than 1 police arrived] AND [Auxiliary lane blocked] AND [Shoulder blocked]	THEN	≥30
IF	[Dry pavement condition]	THEN	<30
IF	[Weekday]	THEN	<30
IF	[Daytime] AND [Less than 4 vehicles involved]	THEN	<30
IF	[More than 2 vehicles involved] OR [Fireboard arrived] OR [Wet pavement condition] OR [Harford]	THEN	≥30
	ELSE THEN		<30
IF	[Bus involved] OR [Vehicle jack-knifed] OR [Vehicle overturned] OR [Vehicle lost load]	THEN	≥60
IF	[No truck involved]	THEN	<60
IF	[No fireboard arrived] & [No auxiliary lane blocked]	THEN	<60
IF	[More than 1 tow service arrived] OR [Hazard materials related] OR [Chemical wet pavement condition] OR [Snow-ice pavement condition] OR [Night] OR [AOC center] OR [More than 3 CHART arrived]	THEN	≥60
	ELSE THEN		<60
IF	[More than 1 tow service arrived] OR [Chemical wet pavement condition]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD2		Case
IF	[AOC center]	THEN	≥30
IF	[Tow service arrived] AND [Fireboard arrived]	THEN	≥30
IF	[Weekend] AND [Night] AND ([Tow service arrived] OR [More than 3 responders arrived])	THEN	≥30
IF	[Truck involved] AND [More than 4 responders arrived]	THEN	≥30
IF	[More than 5 vehicles involved]	THEN	≥30
	ELSE THEN		<30
IF	[More than 1 tow service arrived]	THEN	≥60
IF	[Wet pavement condition] AND [Fireboard arrived] AND ([Spring] OR [Summer])	THEN	≥60
IF	[More than 3 vehicles involved] AND [More than 4 response units arrived]	THEN	≥60
	ELSE THEN		<60
IF	[No truck involved]	THEN	<120
IF	[More than 7 response units arrived]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD3		Case
IF	[Tow service arrived]	THEN	≥30
IF	[AOC center]	THEN	≥30
IF	[More than 2 vehicles involved] AND [More than 1 police arrived]	THEN	≥30
	ELSE THEN		<30
IF	[No tow service] OR [No fireboard arrived]	THEN	<60
IF	[More than 3 vehicles involved] OR [Truck involved]	THEN	≥60
	ELSE THEN		<60
IF	[More than 3 CHART arrived] OR [More than 8 Response units arrived]	THEN	≥120
IF	[Daytime]	THEN	<120
IF	[Hazard materials related]	THEN	≥120
	ELSE THEN		<120

Appendix B: Classification rules for I-495 (******Italic classification rules* are transferred from the Rule Box)

<u>Collision with Personal Injury (CPI)</u>

	Classification Rules Description – CPI1		**Case**
IF	[Tow service arrived] AND [More than 4 response units arrived]	THEN	≥30
IF	[Shoulder lane blocked] AND [More than 4 response units arrived]	THEN	≥30
IF	[Car overturned] AND ([Weekend] OR [Tow service arrived])	THEN	≥30
IF	[More than 5 vehicles involved] AND [Peak hour]	THEN	≥30
IF	([AM] OR [Fireboard first arrived]) AND [More than 1 police arrived]	THEN	≥30
IF	[Fall] AND [Fireboard first arrived]	THEN	≥30
IF	[Truck involved] AND [Van involved]	THEN	≥30
	ELSE THEN		<30
IF	[Auxiliary lane blocked] AND ([More than 4 response units arrived] OR [More than 1 CHART arrived])	THEN	≥60
IF	[Hazard Material] OR [More than 1 tow service arrived] OR [Bus involved]	THEN	≥60
IF	([More than 2 police arrived] OR [Weekend] OR [Wet Pavement]) AND [Pickup involved]	THEN	≥60
IF	[Truck involved] AND [Tow service arrived]	THEN	≥60
	ELSE THEN		<60
IF	[More than 1 vehicle involved] AND [More than 6 response units arrived]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI2		**Case**
IF	*[Tow service arrived]*	THEN	≥30
IF	([More than 3 response units arrived] OR [Police first arrived] OR [Truck invovled]) AND [More than 3 vehicles involved]	THEN	≥30
IF	([Daytime] OR [More than 2 vehicles involved]) AND [Vehicle overturned]	THEN	≥30
IF	[More than 1 vehicle involved] AND [Motorcycle involved]	THEN	≥30
IF	([Auxiliary lane blocked] AND [Pickup involved]) OR [More than 6 response units arrived]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 1 tow arrived] AND [More than 3 vehicles involved]*	THEN	≥60
IF	*[More than 6 response units arrived]*	THEN	≥60
IF	([Auxiliary lane blocked] OR [Wet Pavement]) AND [More than 5 response units arrived]	THEN	≥60
IF	([Auxiliary lane blocked] OR [Night]) AND [Vehicle overturned]	THEN	≥60
IF	[More than 1 fireboard arrived] OR [Snow-ice pavement]	THEN	≥60
	ELSE THEN		<60
IF	[More than 7 response units arrived] OR [More than 5 vehicles involved]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI3		Case
IF	*[Tow service arrived] OR [Vehicle jack-knifed] OR [Vehicle overturned] OR [Vehicle lost load]*	THEN	≥30
IF	[More than 1 police arrived] OR [More than 5 response units arrived]	THEN	≥30
IF	[More than 3 response units arrived] AND [Auxiliary lane blocked]	THEN	≥30
IF	[Bus involved] OR [Chemical wet pavement condition] OR [More than 1 truck involved]	THEN	≥30
IF	([Pickup involved] OR [Truck involved]) AND [Wet pavement condition]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 8 response units arrived]*	THEN	≥60
IF	([More than 5 response units arrived] OR [Winter] OR [More than 1 tow service arrived]) AND [More than 2 vehicles involved]	THEN	≥60
IF	[Weekend] AND [Fireboard first arrived]	THEN	≥60
IF	[Holiday] AND [Truck involved]	THEN	≥60
	ELSE THEN		<60
IF	*[More than 9 response units arrived]*	THEN	≥120
IF	[More than 1 CHART arrived] AND [Weekend]	THEN	≥120
IF	[Holiday]	THEN	≥120
	ELSE THEN		<120

Collision with Property Damage (CPD)

	Classification Rules Description – CPD1		Case
IF	[Tow service arrived] AND [Fireboard arrived]	THEN	≥30
IF	[Tow service arrived] AND [Police first arrived]	THEN	≥30
IF	[More than 2 CHART arrived] AND [CHART first arrived]	THEN	≥30
IF	([Weekend] OR [Peak hour] OR [More than 2 police arrived] OR [Truck involved] OR [Pickup involved]) AND [More than 4 response units arrived]	THEN	≥30
IF	[Auxiliary lane blocked] AND ([Vehicle overturned] OR [Holiday])	THEN	≥30
IF	([More than 2 vehicles involved] OR [Tow service arrived]) AND [Pickup involved]	THEN	≥30
	ELSE THEN		<30
IF	([More than 4 response units arrived] OR [Weekend] OR [Pickup involved]) AND [Truck involved]	THEN	≥60
IF	[Pickup involved] AND [More than 2 vehicles involved]	THEN	≥60
IF	[Daytime] AND [Fireboard first arrived]	THEN	≥60
IF	[Vehicle jack-knifed]	THEN	≥60
	ELSE THEN		<60
IF	[Truck involved] AND ([More than 5 response units arrived] OR [Auxiliary lane blocked])	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD2		Case
IF	*[Tow service arrived] AND [Fireboard arrived]*	THEN	≥30
IF	([Peak hour] OR [More than 2 CHART arrived]) AND [Truck involved]	THEN	≥30
IF	([Night] OR [More than 4 response units arrived]) AND [More than 1 Police involved]	THEN	≥30
IF	([Weekend] OR [More than 1 vehicle involved]) AND [Tow service arrived]	THEN	≥30
IF	[More than 5 vehicle involved] OR [Pickup involved]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 1 tow services arrived]*	THEN	≥60
IF	([Truck involved] OR [More than 2 vehicles involved]) AND [Night]	THEN	≥60
IF	[More than 2 vehicles involved] AND [Police first arrived]	THEN	≥60
	ELSE THEN		<60
IF	*[More than 7 response units arrived]*	THEN	≥120
IF	[More than 1 tow service arrived]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD3		**Case**
IF	*[Tow service arrived]*	THEN	≥30
IF	[More than 4 response units arrived AND ([Fireboard first arrived] OR [Pickup involved] OR [Wet pavement condition])	THEN	≥30
IF	Vehicle Jack-knifed	THEN	≥30
	ELSE THEN		<30
IF	[More than 1 tow service arrived] OR [Hazard material related]	THEN	≥60
IF	([Peakhour] OR [More than 5 response units arrived]) AND [More than 1 vehicle involved]	THEN	≥60
	ELSE THEN		<60
IF	[More than 6 response units arrived]	THEN	≥120
IF	[Night] AND [Truck involved]	THEN	≥120
	ELSE THEN		<120

Appendix C: Classification rules for I-695 (**Italic classification rules* are transferred from the Rule Box)

Collision with Personal Injury (CPI)

	Classification Rules Description – CPI1		Case
IF	*[Tow service arrived]*	THEN	≥30
IF	*[Fireboard first arrived]*	THEN	<30
IF	[TOC4 Center] AND [No truck involved]	THEN	<30
IF	[More than 1 CHART arrived] AND [Police first arrived]	THEN	≥30
IF	[More than 1 truck involved] AND [More than 3 response units arrived]	THEN	≥30
IF	[Pickup involved] AND ([More than 2 response units arrive] OR [Police arrived])	THEN	≥30
	ELSE THEN		<30
IF	*([Night] AND [More than 6 response units]) OR [More than 4 vehicles involved]*	THEN	≥60
IF	[Snow-iced pavement condition] OR [More than 1 truck involved] OR [More than 7 response units arrived] OR [AOC center]	THEN	≥60
IF	[Pickup involved AND ([Auxiliary lane blocked] OR [Winter])	THEN	≥60
IF	[Weekend] AND [Vehicle overturned]	THEN	≥60
IF	[More than 1 police arrived] AND [More than 1 fireboard arrived]	THEN	≥60
	ELSE THEN		<60
IF	[Truck involved] AND [More than 5 response units arrived]	THEN	≥120
IF	[Lane blocked in toll lane] OR [More than 1 shoulder lane blocked]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI2		Case
IF	*[Tow service arrived]*	THEN	≥30
IF	[Peak hour] AND [More than 4 response units arrived]	THEN	≥30
IF	[Weekend] AND [SOC center]	THEN	≥30
IF	[More than 5 response units arrived]	THEN	≥30
	ELSE THEN		<30
IF	[Night] AND ([More than 1 police arrived] OR [More than 5 response units arrived]	THEN	≥60
IF	[Snow-iced pavement condition] OR ([More than 7 response units arrived] AND [Auxiliary lane blocked])	THEN	≥60
	ELSE THEN		<60
IF	[Wet pavement condition] OR [More than 4 vehicles involved]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI3		Case
IF	*[SOC center] OR [Truck involved] OR [More than 2 Vehicles involved]*	THEN	≥30
IF	*[Fireboard first arrived]*	THEN	≥30
IF	[More than 5 response units arrived] OR [Vehicle overturned] OR [More than 1 shoulder lane blocked]	THEN	≥30
	ELSE THEN		<30
IF	*[Medical service arrived]*	THEN	≥60
IF	*[More than 8 response units arrived]*	THEN	≥60
IF	*[No tow service arrived]*	THEN	<60
IF	[More than 1 tow service arrived] AND ([More than 5 response units arrived] OR [More than 1 CHART arrived])	THEN	≥60
	ELSE THEN		<60
IF	[More than 4 lanes blocked] AND [More than 2 CHART arrived]	THEN	≥120
IF	[Wet pavement condition] AND [More than 2 tow service arrived]	THEN	≥120
	ELSE THEN		<120

Collision with Property Damage (CPD)

	Classification Rules Description – CPI1		Case
IF	*[Tow service arrived] OR [Hazard materials related]*	THEN	≥30
IF	*[No Police] OR ([No fireboard arrived] AND [Peak Hour]*	THEN	<30
IF	([Daytime] AND [More than 4 response units arrived]) OR ([Truck involved] AND [More than 1 police arrived])	THEN	≥30
IF	([Snow-iced pavement condition] AND ([Truck involved] OR [More than 3 response units arrived])) OR ([More than 3 vehicles involved] AND [Fireboard first arrived])	THEN	≥30
IF	[TOC4 center] AND [No Auxiliary lane blocked]	THEN	<30
IF	[Winter] AND [Pickup involved]	THEN	≥30
IF	[Truck involved] AND ([TOC4 center] OR [More than 1 CHART arrived])	THEN	≥30
IF	[More than 2 CHART arrived] OR ([More than 4 response units arrived] AND [Wet pavement condition])	THEN	≥30
IF	[More than 1 CHART arrived] AND [Pickup involved]	THEN	≥30
	ELSE THEN		<30
IF	[Night] AND [More than 5 response units arrived]	THEN	≥60
IF	[More than 6 response units arrived] OR [Truck overturned] OR [Bus involved] OR [Vehicle lost load]	THEN	≥60
IF	([Snow-iced pavement condition] AND [Weekend]) OR [More than 1 truck involved]	THEN	≥60
IF	[More than 4 response units arrived] AND ([Holiday] OR [Pickup involved] OR [More than 3 vehicles involved])	THEN	≥60
	ELSE THEN		<60
IF	[Truck involved AND ([Vehicle overturn] OR [Wet pavement condition] OR [Snow-iced pavement condition])	THEN	≥120
IF	[More than 2 vehicles involved] AND [Fireboard first arrived]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD2		Case
IF	*[Tow service arrived] AND [Fireboard arrived]*	THEN	≥30
IF	[Tow service arrived] AND ([More than 2 vehicles involved] OR [More than 1 auxiliary lane blocked])	THEN	≥30
IF	[Truck overturn] OR [More than 1 shoulder lane blocked] OR [Truck involved] OR [Pickup involved]	THEN	≥30
IF	[Snow-iced pavement condition] OR [Chemical wet pavement condition] OR [Truck jack-knifed] OR [More than 6 response units arrived]	THEN	≥30
	ELSE THEN		<30
IF	*[Weekend] AND [Night] AND [More than 2 vehicles involved] AND [Tow service arrived]*	THEN	≥60
IF	*[Truck involved] AND [More than 5 response units arrived]*	THEN	≥60
IF	[More than 4 response units arrived] AND [Wet pavement condition]	THEN	≥60
IF	[Weekend] AND [Vehicle overturned]	THEN	≥60
	ELSE THEN		<60
IF	[More than 9 response units arrived]	THEN	≥120
IF	[More than 5 response units arrived] AND [Pickup involved]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD3		Case
IF	*[Tow service arrived]*	THEN	≥30
IF	[Night] AND ([More than 1 CHART arrived] OR [Truck involved])	THEN	≥30
	ELSE THEN		<30
IF	[More than 1 shoulder lane blocked] AND [More than 3 response units arrived]	THEN	≥60
IF	[More than 4 vehicles involved] OR [Holiday]	THEN	≥60
	ELSE THEN		<60
IF	*[More than 3 CHART arrived] OR[More than 8 response units arrived]*	THEN	≥120
	ELSE THEN		<120

Appendix D: Classification rules for I-70 (**Italic classification rules* are transferred from the Rule Box)

Collision with Personal Injury (CPI)

	Classification Rules Description – CPI1		Case
IF	*[Tow service arrived]*	THEN	≥30
IF	*[More than 3 vehicles involved]*	THEN	≥30
IF	*[Peak hour] AND [More 2 vehicles involved]*	THEN	≥30
IF	*[Non-peak hour] AND [Police first arrived]*	THEN	≥30
IF	*[Fireboard first arrived]*	THEN	<30
	ELSE THEN		<30
IF	[More than 4 vehicles involved]	THEN	≥60
IF	[More than 1 police arrived] AND [CHART first arrived]	THEN	≥60
IF	*[Snow-ice pavement] OR [More than 1 truck involved] OR [More than 7 respond units arrived] OR [AOC center]*	THEN	≥60
IF	[Tow service arrived] AND [Vehicle overturned] AND [Wet pavement]	THEN	≥60
IF	*[No tow service arrived] AND [No truck involved]*	THEN	<60
	ELSE THEN		<60
IF	*[Less than 4 respond units] OR [No truck involved]*	THEN	<120
IF	[More than 8 respond units arrived]	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI2		Case
IF	*[Tow service arrived]*	THEN	≥30
IF	*[More than 4 response unit arrived]*	THEN	≥30
IF	*[Dry pavement]*	THEN	<30
IF	[Snow-ice pavement]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 6 response units arrived]*	THEN	≥60
IF	*[More than 1 Fireboard arrived] OR [Snow-ice pavement]*	THEN	≥60
IF	*[No tow service arrived] OR [No truck involved]*	THEN	<60
IF	[More than 1 truck involved]	THEN	≥60
	ELSE THEN		<60
IF	*[More than 7 respond units arrived] OR [More than 5 vehicles involved]*	THEN	≥120
IF	*[More than 1 truck involved] OR [More than 3 vehicles involved] OR [Hazard materials related] OR [More than 7 respond units arrived]*	THEN	≥120
IF	*[More than 4 vehicles involved] OR [Wet pavement]*	THEN	≥120
IF	[Truck involved]	THEN	≥120
	ELSE THEN		<120

Collision with Damage Property (CPD)

	Classification Rules Description – CPD1		Case
IF	*[Tow service arrived] AND [Fireboard arrived]*	THEN	≥30
IF	*[More than 2 CHART arrived] AND [CHART first arrived]*	THEN	≥30
IF	*[Wet pavement] AND [More than 1 police arrived] AND [Auxiliary lane blocked] AND [Shoulder lane blocked]*	THEN	≥30
IF	*[More than 2 CHART arrived] OR ([More than 4 respond units arrived] AND [Wet pavement])*	THEN	≥30
IF	*([Daytime] AND [More than 4 respond units arrived]) OR ([Truck involved] AND [More than 1 police arrived])*	THEN	≥30
IF	[Night] AND [Auxiliary lane blocked]	THEN	≥30
IF	[Tow service arrived] AND [More than 2 vehicles involved]	THEN	≥30
IF	[Tow service arrived] AND [More than 1 CHART arrived]	THEN	≥30
IF	([More than 1 police arrived] AND [Wet pavement]) OR [Snow-ice pavement] OR [Chemical wet pavement]	THEN	≥30
IF	*[Dry pavement]*	THEN	<30
	ELSE THEN		<30
IF	*[More than 6 response units arrived] OR [Truck overturned] OR [Bus involved] OR [Vehicle lost load]*	THEN	≥60
IF	[More than 5 response units arrived] OR ([More than 4 response units arrived] AND [More than 2 vehicles involved])	THEN	≥60
IF	[Auxiliary lane blocked] AND [SUV involved]	THEN	≥60
IF	[Truck involved] OR ([More than 2 CHART arrived] AND [Chemical wet pavement])	THEN	≥60
	ELSE THEN		<60
IF	*[Truck involved] AND ([More than 5 respond units arrived] OR [Auxiliary lane blocked])*	THEN	≥120
IF	*[Snow-ice pavement] OR ([Auxiliary lane blocked] AND [Chemical wet pavement])*	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD2		Case
IF	*[Tow service arrived] AND [Fireboard arrived]*	THEN	≥30
IF	*[Snow-ice pavement] OR [Chemical wet pavement] OR [Truck jackknifed] OR [More than 6 respond units arrived]*	THEN	≥30
IF	*([Night] OR [More than 4 respond units arrived]) AND [More than 1 police arrived]*	THEN	≥30
IF	*[Car overturned] OR [More than 1 shoulder lane blocked] OR ([Truck involved] AND [Pickup involved])*	THEN	≥30
IF	[SOC center] AND [More than 1 CHART arrived]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 1 tow service arrived]*	THEN	≥60
IF	*[Truck involved] AND [More than 5 response units arrived]*	THEN	≥60
IF	*([Truck involved] OR [More than 2 vehicles involved]) AND [Night]*	THEN	≥60
IF	[Snow-ice pavement] OR [Chemical wet pavement]	THEN	≥60
IF	More than 2 vehicles involved] AND [More than 1 shoulder lane blocked]	THEN	≥60
	ELSE THEN		<60
IF	*[More than 7 respond units arrived]*	THEN	≥120
IF	*[No truck involved]*	THEN	<120
IF	[Hazard material related] OR [Chemical wet pavement] OR [More than 1 auxiliary lane blocked]	THEN	≥120
	ELSE THEN		<120

Appendix E: Classification rules for US 29 (Italic classification rules* are transferred from the Rule Box)**

Collision with Personal Injury (CPI)

	Classification Rules Description – CPI1		**Case**
IF	*[Tow service arrived]*	THEN	≥30
IF	*[Non-peak hour] AND [Police first arrived]*	THEN	≥30
IF	*[Fireboard first arrived]*	THEN	<30
IF	([SOC center] AND [More 2 respond units arrived]) OR [Auxiliary lane blocked]	THEN	≥30
	ELSE THEN		<30
IF	*[Snow-ice pavement] OR [More than 1 truck involved] OR [More than 7 response units arrived] OR [AOC center]*	THEN	≥60
IF	*[No tow service arrived] OR [No truck involved]*	THEN	<60
IF	([More than 2 police arrived] OR [Weekend] OR [Wet pavement]) AND [Pickup involved]	THEN	≥60
	ELSE THEN		<60
IF	*[More than 1 truck arrived] OR [Chemical wet pavement]*	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPI2		**Case**
IF	[More than 4 response units arrived]	THEN	≥30
IF	[More than 4 lanes blocked] AND [More than 1 shoulder lanes blocked]	THEN	≥30
IF	[More than 3 response units arrived] AND [Car overturned]	THEN	≥30
IF	*[Truck involved]*	THEN	≥30
IF	[Spring] AND [Tow service arrived]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 6 response units arrived]*	THEN	≥60
IF	[More than 5 lane blocked] OR [Truck involved]	THEN	≥60
IF	[More than 2 vehicles involved] OR ([More than 2 response units arrived] AND [TOC3 center])	THEN	≥60
IF	[Pickup involved] OR ([More than 4 respond units arrived] AND [Vehicle overturned]	THEN	≥60
	ELSE THEN		<60
IF	*[Truck involved]*	THEN	<120
IF	[Auxiliary lane blocked]	THEN	≥120
	ELSE THEN		<120

Collision with Damage Property (CPD)

	Classification Rules Description – CPD1		Case
IF	[More than 2 vehicles involved] AND [More than 3 response units arrived]	THEN	≥30
IF	*[Truck involved] AND [More than 1 police arrived]*	THEN	≥30
IF	*[Chemical wet pavement] AND [Police arrived]*	THEN	≥30
IF	([Winter] AND [Tow service arrived]) OR ([TOC3 center] AND [Auxiliary lane blocked])	THEN	≥30
	ELSE THEN		<30
IF	*[More than 7 respond units arrived] OR [Chemical wet pavement]*	THEN	≥60
IF	*([More than 2 vehicles involved] AND [More than 1 Tow service arrived]) OR [TOC3 center]*	THEN	≥60
	ELSE THEN		<60
IF	*[Truck involved] OR [More than 5 respond units arrived] OR [Auxiliary lane blocked] OR [Chemical wet pavement]*	THEN	≥120
	ELSE THEN		<120

	Classification Rules Description – CPD2		Case
IF	*[Tow service arrived] AND [Fireboard arrived]*	THEN	≥30
IF	*[Snow-ice pavement] OR [Chemical wet pavement] OR [Truck jacknifed] OR [More than 6 respond units arrived]*	THEN	≥30
IF	([Fireboard arrived] OR [More than 3 travel lanes blocked]) AND [Police first arrived]	THEN	≥30
	ELSE THEN		<30
IF	*[More than 1 tow service arrived]*	THEN	≥60
IF	*[Truck involved] AND [More than 5 respond units arrived]*	THEN	≥60
IF	[More than 4 lane blocked] OR [Snow-ice pavement] OR [Wet pavement]	THEN	≥60
	ELSE THEN		<60
IF	([More than 5 lane blocked] AND [Snow-ice pavement]) OR [Chemical wet pavement]	THEN	≥120
	ELSE THEN		<120