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Statewide Implementation of Innovative Safety Analysis Tools in Identifying Highway Safety Improvement Projects: Technical Report

Implementation Report 5-6912-01-R1

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COLLEGE STATION, TEXAS

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16. Abstract

The Highway Safety Improvement Program (HSIP) aims to achieve a reduction in the number and severity of fatalities and serious injury crashes on all public roads by implementing highway safety improvement projects. Transportation agencies continuously try to find ways to improve their HSIP. Over the last few years, particular emphasis has been placed on employing advanced safety predictive methods and tools. In 2016, the Texas Department of Transportation (TxDOT) funded research project 0-6912 that developed a) a network screening process for roadway segments, b) preliminary crash analysis and visualization (CAVS) products, and c) a project prioritization tool. TxDOT implementation project 5-6912-01 developed a network screening tool that incorporates the 0-6912 network screening process, and improved and implemented the CAVS process and products to support the diagnosis and countermeasure selection processes at TxDOT.

The network screening tool developed in this project automatically scans all on-system mainlane roadway segments in Texas using a dynamic sliding window method and calculates seven safety performance measures for each scanned segment. The performance measures can be used to rank and determine sites with the highest crash risk for further examination. The CAVS products display crash data and locations where certain types of safety countermeasures can be implemented. Among various improvements, the main benefits realized from the implementation of the CAVS products include an increase in the number of candidate projects identified by TxDOT districts between 31 percent to 57 percent and a reduction in the time and effort required to select projects by 20–50 percent.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The principal investigator of the project was Ioannis Tsapakis and Karen Dixon served as the co-principal investigator.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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LIST OF ACRONYMS, ABBREVIATIONS, AND TERMS

A	Incapacitating injury crash
ADT	Average daily traffic
AWR	Adjusted weighted ranking
B	Non-incapacitating injury crash
CAVS	Crash analysis and visualization
CFR	Code of Federal Regulations
CRIS	Crash Records Information System
DFO	Distance from origin
DOT	Department of Transportation
FHWA	Federal Highway Administration
GE	Google Earth
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
K	Fatal crash
PAWR	Percent adjusted weighted ranking
PM	Performance measure
RHiNo	Road-Highway Inventory Network
SII	Safety improvement index
RTM	Regression to the mean
SPF	Safety performance function
TRF	Traffic Operations Division
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
U.S.C.	United States Code
WC	Work code

CHAPTER 1: INTRODUCTION

The Highway Safety Improvement Program (HSIP) is a core federal-aid, state-administered program designed to reduce fatalities and serious injuries on all public roads through the implementation of highway safety improvement projects (*1*). To obligate HSIP funds, a state department of transportation (DOT) must develop, implement, and update a strategic highway safety plan, produce a program of projects or strategies to reduce identified safety problems, and evaluate its program on a regular basis. The Federal Highway Administration (FHWA) establishes the program requirements in the United States Code (U.S.C.), 23 U.S.C. 148(h) and the code of federal regulations (CFR), 23 CFR 924.15. According to these requirements, each state is required to develop, establish, and report processes to support HSIP planning, implementation, and evaluation activities (*2*).

State agencies are required to have a safety data system to perform problem identification and countermeasure analysis, adopt strategic and performance-based goals, advance data analysis capabilities, determine priorities for the correction of identified safety problems, and establish evaluation procedures. The general guideline is to identify actionable and measurable goals (e.g., reduce the number of fatalities and serious injuries) and perform evaluations using robust data-driven methods that account for traffic volume fluctuations, external factors, and regression to-the-mean (RTM) effects (*3*).[1] As the national safety assessment procedures have evolved, legislation has mandated that the use of safety performance methods be elevated (*1*). These evolving methods tend to provide more reliable results than simple before/after comparisons, which have several limitations and do not account for RTM bias (*2*).

To help agencies move toward this direction, the American Association of State Highway Officials developed the *Highway Safety Manual* (HSM) that provides guidance on how to quantify the impact of roadway design elements on highway safety (*2*). Among several elements, it introduces a roadway safety management process (Figure 1) that encompasses a series of traditional and modern safety analysis methodologies, including crash predictive methods.

[1] RTM is a statistical phenomenon that assumes that the longer the observation period, the closer the sample mean will be to the population mean. For example, at a given site, the average crash frequency during three years will be closer to the true mean (i.e., population mean) compared to the average crash frequency during one month only. Therefore, RTM bias or selection bias occurs when the candidate sites are selected based on short-term trends that may not be representative of actual crash trends of a given facility.

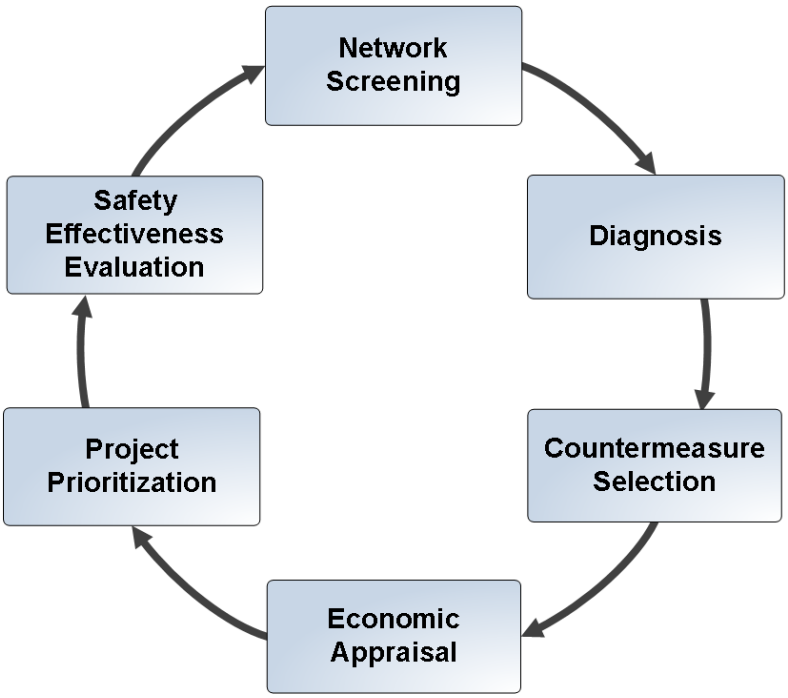


Figure 1. HSM Roadway Safety Management Process (Adapted from HSM [*2*]).

The main components of HSM's cyclical process are:

- Network Screening – Scan roadway network by calculating safety performance measures (PMs) for every segment of the network and identify high risk locations and sites.
- Diagnosis – Review past studies and roadway characteristics to determine crash patterns, understand causes of crashes, and identify safety issues and concerns.
- Countermeasure Selection – Identify risk factors contributing to causes of crashes and select appropriate countermeasures to mitigate safety issues.
- Economic Appraisal – Compare anticipated benefits and project costs of selected countermeasures.
- Project Prioritization – Rank safety improvement projects based on their potential to achieve the greatest reduction in the number and severity of crashes.
- Safety Effectiveness Evaluation – Assess the effectiveness of completed safety improvement projects, groups of similar projects (or countermeasures), or the entire program.

Several transportation agencies, including the Texas Department of Transportation (TxDOT), continuously try to find ways to improve their HSIP. Over the last few years, particular emphasis has been placed on employing HSM predictive methods and tools. For example, in 2016, TxDOT funded research project 0-6912 that tailored HSM's cyclical process to TxDOT needs, objectives, and HSIP requirements and used it as a general framework to develop: a) a network

screening process for roadway segments, b) crash analysis and visualization (CAVS) products to support the diagnosis and countermeasure selection processes, and c) a project prioritization tool (*4*). The study focused on improving and streamlining four components of the general framework: network screening, diagnosis, countermeasure selection, and project prioritization. The main benefits gained from the use of the 0-6912 research products included an increase in the number of HSIP projects identified by TxDOT districts by up to 57 percent and a reduction in the time and effort required to select projects by 20–50 percent. Based on these results, TxDOT funded this implementation project (5-6912) to:

- Develop a network screening tool that incorporates the 0-6912 network screening process for roadway segments.

- Improve and implement the 0-6912 CAVS process and products to support the diagnosis and countermeasure selection processes within TxDOT's HSIP.

The remaining chapters of this report describe the activities performed to address these objectives:

- **Chapter 2: Network Screening for Segments** – This chapter presents a network screening tool that incorporates the network screening process developed in research project 0-6912. This process can be used in the future by TxDOT to identify high risk segments that have the highest potential to realize a reduction in crash frequency and severity through the implementation of HSIP projects.

- **Chapter 3: Crash Analysis and Visualization Products** – This chapter presents the CAVS tool and the products developed to enhance the diagnosis and countermeasure selection processes at TxDOT. The CAVS products were used by TxDOT districts during the 2018 HSIP.

- **Chapter 4: Synopsis and Recommendations** – This chapter provides a synopsis of this project and recommendations stemming from the work performed and lessons learned throughout this project.

CHAPTER 2:
NETWORK SCREENING FOR SEGMENTS

2.1 INTRODUCTION

This chapter presents a network screening tool that incorporates the network screening process developed for roadway segments in research project 0-6912 (*4*). Network screening is the first part of the HSM roadway safety management process (Figure 1) that encompasses modern safety assessment data-driven procedures. The goal of network screening is to identify and rank sites from most likely to least likely to realize a reduction in crash frequency by implementing appropriate countermeasures. Figure 2 shows the five major steps included in network screening for segments.

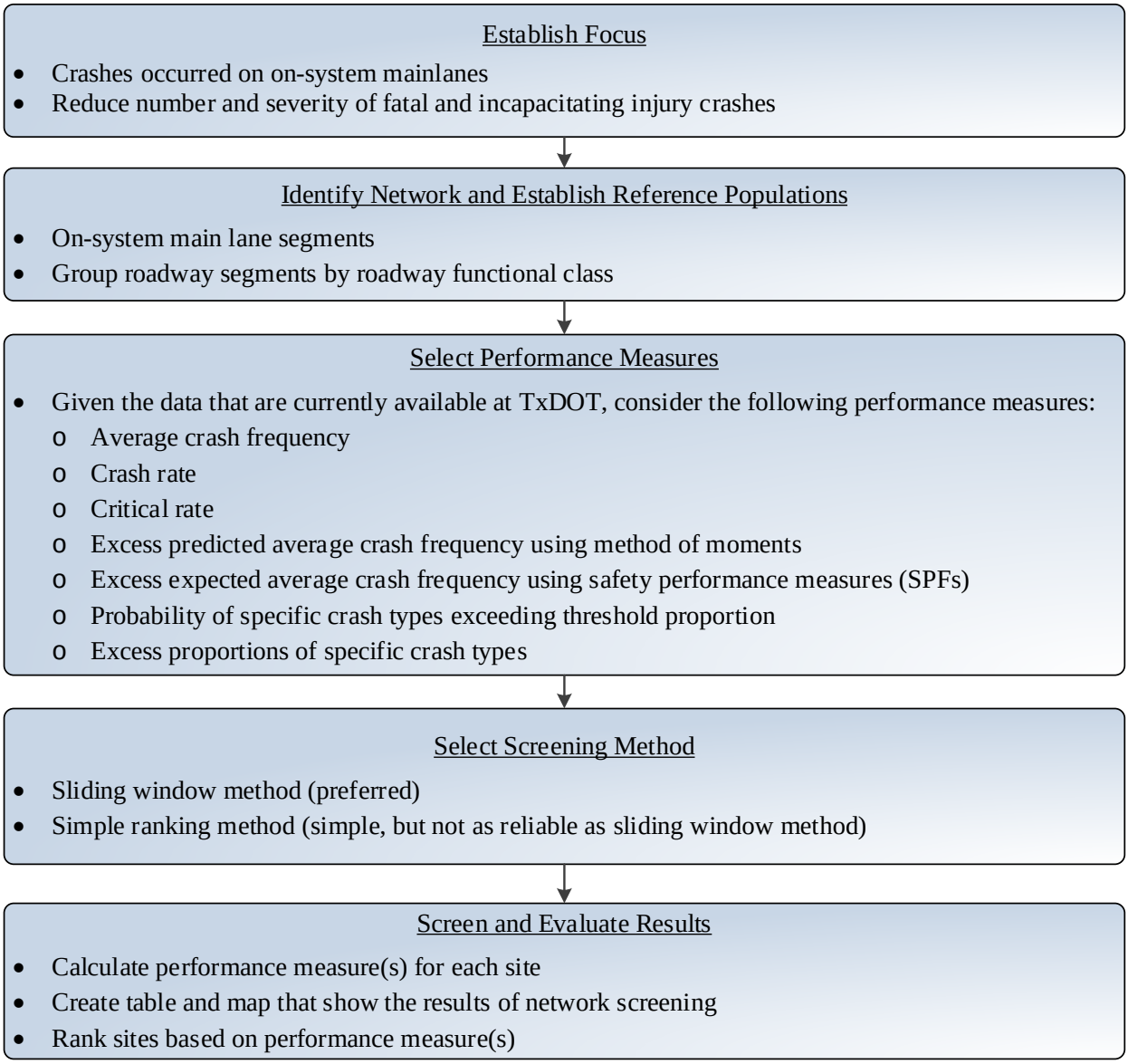


Figure 2. Main Steps of Network Screening Process for Roadway Segments.

Figure 3 shows a detailed flow chart of the network screening process that was incorporated into the tool. Each of the five steps is represented as a pool of interconnected activities and events. Figure 4 shows the legend that describes the elements of the flowchart. Researchers developed the network screening tool in ArcGIS. Figure 5 shows a screenshot of the tool that consists of four toolboxes. Each toolbox contains several ArcGIS models. Most models are numbered in the order that they have to be executed. The remaining sections of this chapter describe the five major steps involved in network screening and present the ArcGIS models developed to execute each step.

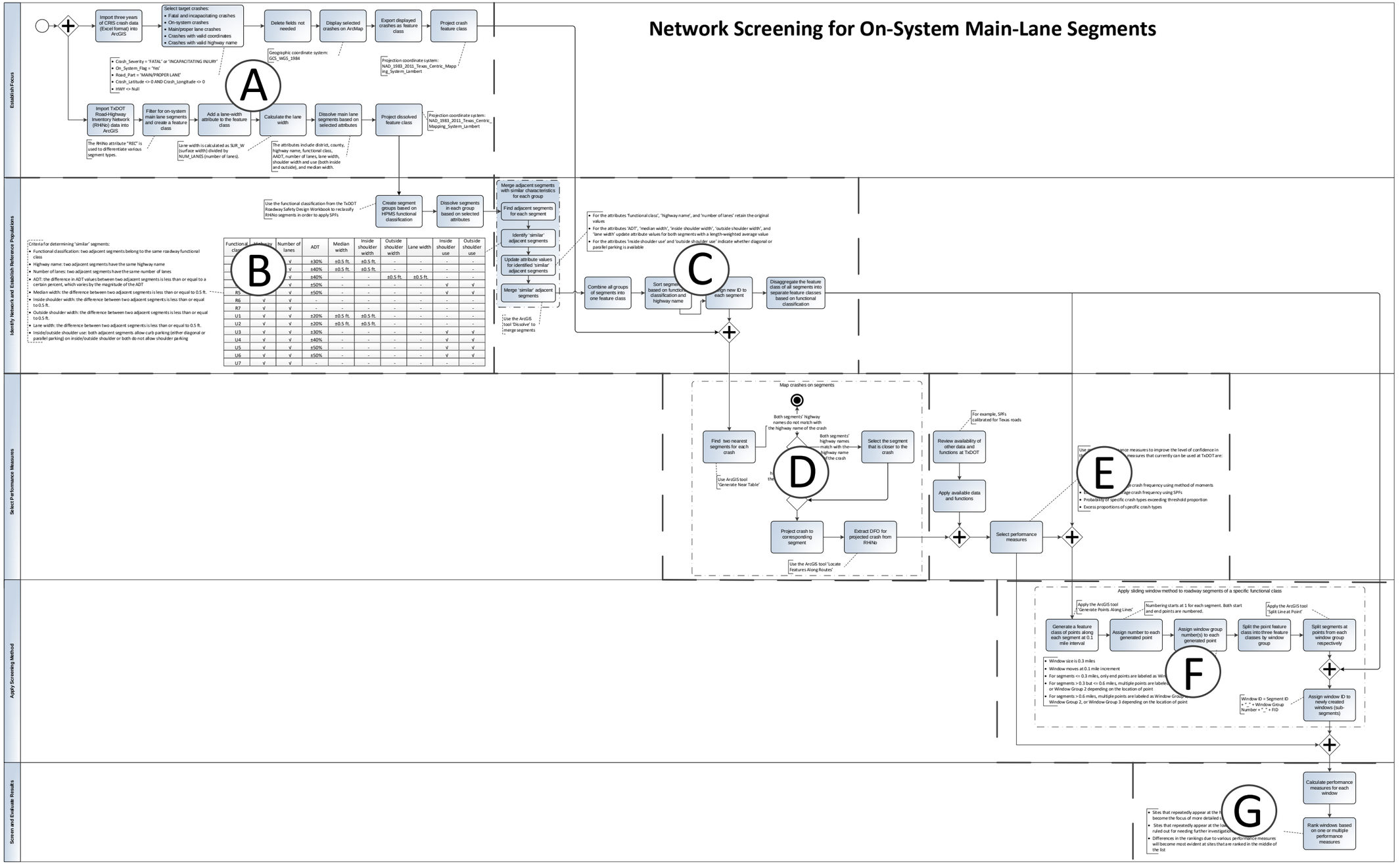


Figure 3. Network Screening Flowchart for On-System Main-Lane Segments.

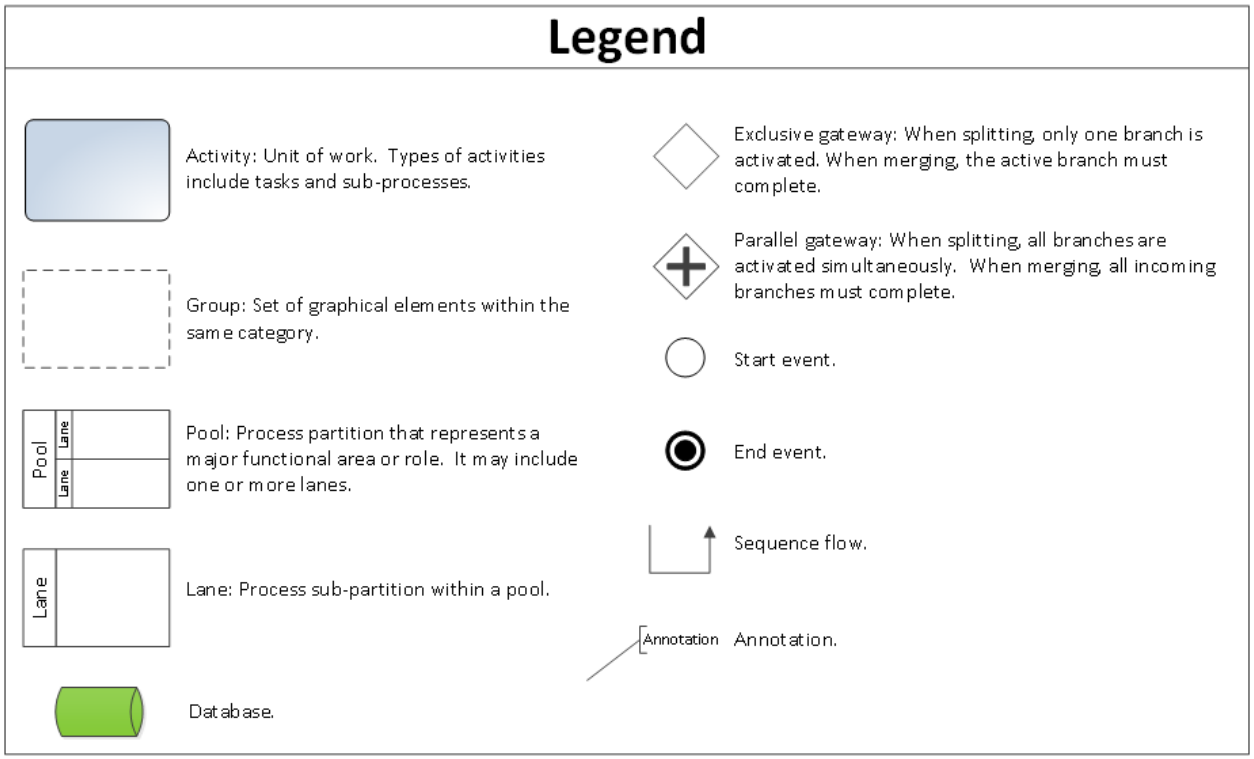


Figure 4. Legend of Network Screening Flowchart.

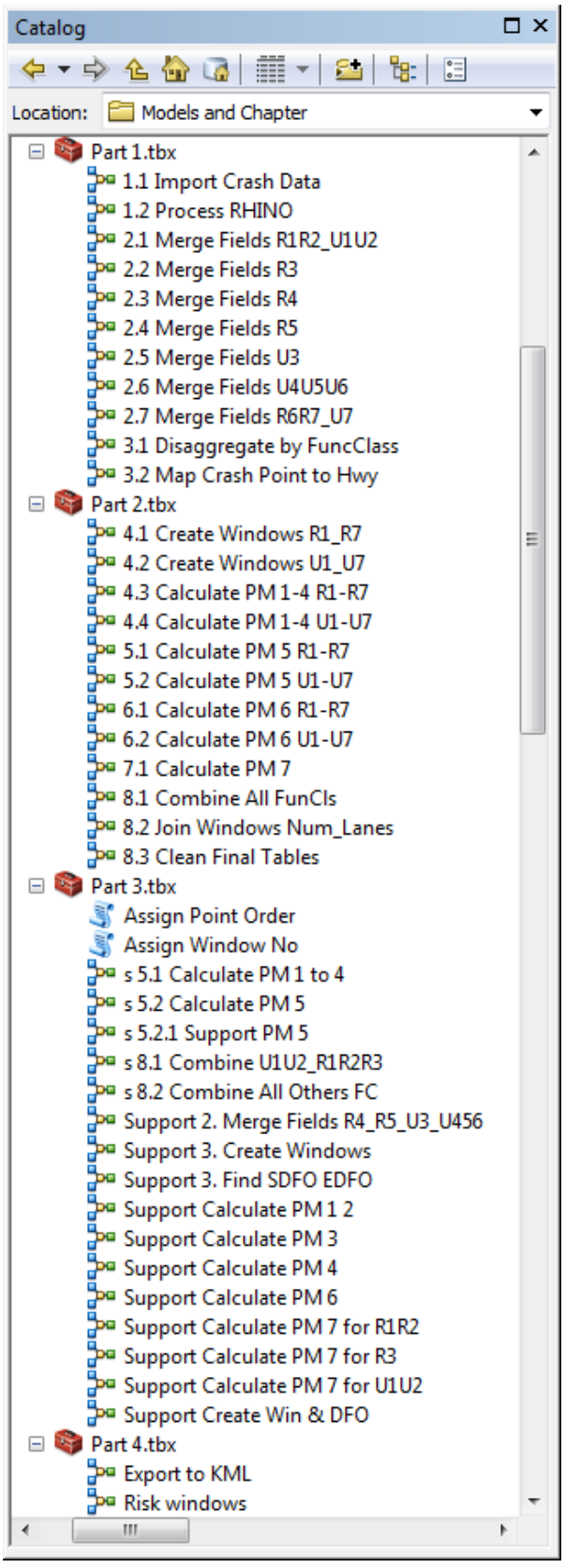


Figure 5. Network Screening Tool.

2.2 ESTABLISH FOCUS

This step identifies the goal and the intended outcome of the HSIP for roadway segments. Researchers selected on-system mainlane segments as the target network based on the existing TxDOT roadway and crash data that can be used as input in the network screening analysis. The intended outcome is to rank sites based on their potential for reducing the number and severity of fatal (K) and incapacitating injury (A) crashes. To address this objective, TxDOT crash records information system (CRIS) and road-highway inventory network (RHiNo) data must be processed as described below and shown in Figure 6:

- Crash data processing (Figure 7 shows the ArcGIS model that processes crash data):
    - Import three years of crash data into ArcGIS in line with the three-year data period considered in the annual HSIP call of TxDOT.
    - Select target crashes using crash data attributes. In TxDOT's HSIP, the target crashes are KA crashes that occurred on on-system mainlane segments. The target crashes must include valid geographic coordinates and highway names. Non-incapacitating injury (B) crashes also need to be included for the calculation of two performance measures; however, they are not considered as a main target crash type.
    - Delete attributes that are not needed for network screening, including district, county, control section, mile point, distance from origin (DFO), date, functional classification, bridge detail, surface conditions, weather conditions, light conditions, manner of collision, first harmful event, object struck, contributing factors, unit number, and direction of travel.
    - Select KAB crashes that a) occurred on on-system TxDOT mainlanes, b) have valid latitudes and longitudes (i.e., not zero or null), and c) are not intersection related.
    - Display selected crashes on ArcMap using their coordinates and the geographic coordinate system GCS_WGS_1984.
    - Export displayed crashes as a feature class.
    - Project the crash feature class to the projected coordinate system NAD_1983_2011_Texas_Centric_Mapping_System_Lambert.

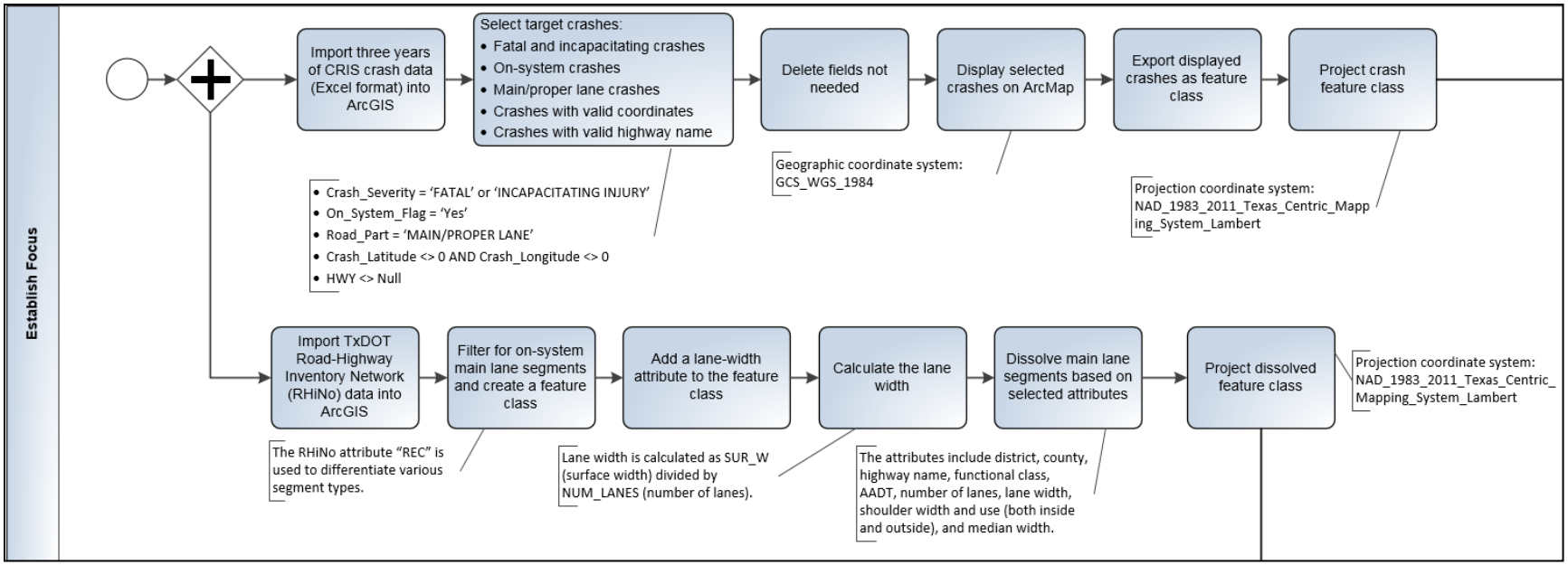


Figure 6. Zoomed-In View of Network Screening Flowchart (Part A).

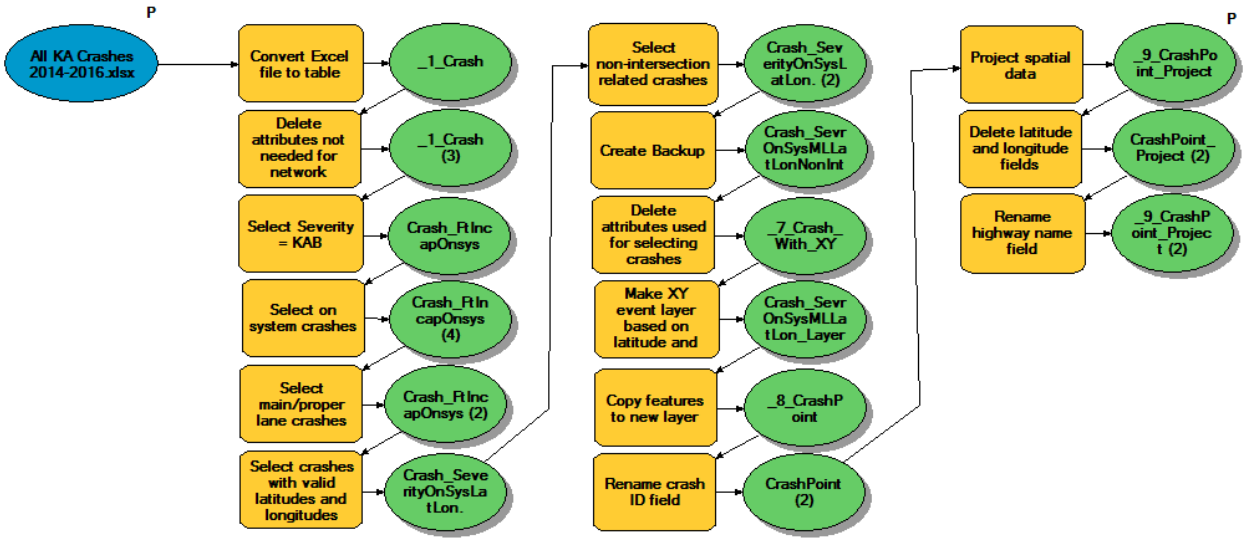


Figure 7. Overview of ArcGIS Model that Processes Crash Data.

- RHiNo data processing (Figure 8 shows an overview of the model that processes RHiNo data):
  - Import TxDOT RHiNo data into ArcGIS.
  - Filter for on-system mainlane segments and create a feature class from selected segments.
  - Add a new attribute, called lane width, and calculate the lane width by dividing the segment surface width (SUR_W in RHiNo) by the number of lanes (NUM_LANES in RHiNo).
  - Merge (dissolve) adjacent mainlane segments that have the same district name, county name, highway name, functional classification, average daily traffic (ADT), number of lanes, lane width, shoulder width, shoulder use (both inside and outside), and median width.
  - Project the feature class of dissolved segments to the projected coordinate system NAD_1983_2011_Texas_Centric_Mapping_System_Lambert.
  - Select road groups for the following functional classes:
    - R1, R2, U1, U2
    - U3
    - U4, U5, U6
    - R3
    - R4
    - R5
    - R6, R7, U7

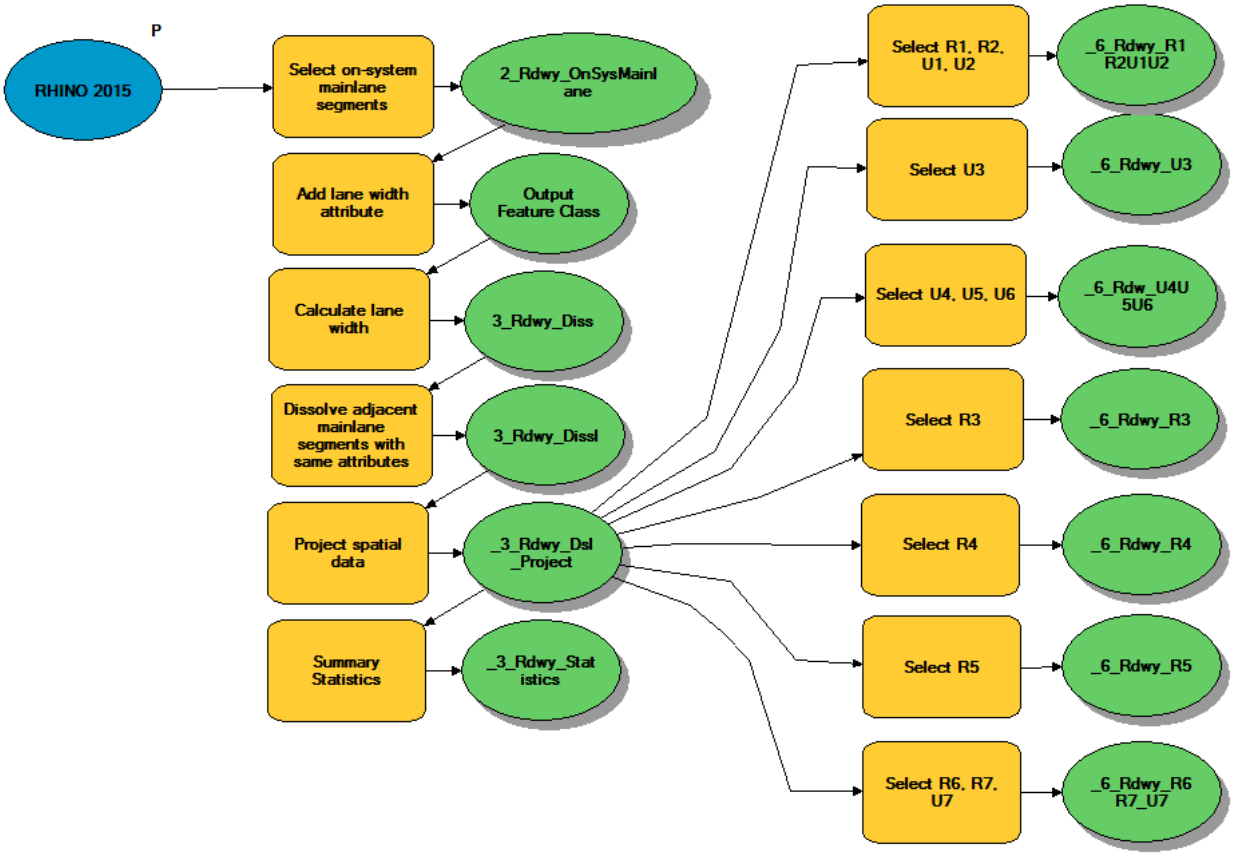


Figure 8. Overview of ArcGIS Model that Processes RHiNo Data.

The products from this process are a projected ArcGIS feature class containing three years of fatal and incapacitating injury crashes, and a projected ArcGIS feature class of on-system mainlane segments.

2.3 IDENTIFY NETWORK AND ESTABLISH REFERENCE POPULATIONS

The network of interest includes all on-system mainlane RHiNo segments in Texas based on the focus established in the previous step. Considering that KA crashes are rare, many RHiNo segments experience no crashes. When segments do not contain any crashes (zero), it becomes difficult to identify high risk segments. To overcome this challenge, adjacent segments need to be combined if they are on the same highway and share similar attributes. Table 1 presents these attributes that are unique to each functional class.

Table 1. Criteria for Identifying Similar Adjacent Segments (*4*).

Functional class	Highway name	Number of lanes	ADT	Median width	Median Type*	Inside shoulder width	Outside shoulder width	Lane width	Inside shoulder use	Outside shoulder use
R1	√	√	±30%	±0.5 ft	√	±0.5 ft	-	-	-	-
R2	√	√	±40%	±0.5 ft	√	±0.5 ft	-	-	-	-
R3	√	√	±40%	-	√	-	±0.5 ft	±0.5 ft	-	-
R4	√	√	±50%	-	-	-	-	-	√	√
R5	√	√	±50%	-	-	-	-	-	√	√
R6	√	√	-	-	-	-	-	-	-	-
R7	√	√	-	-	-	-	-	-	-	-
U1	√	√	±20%	±0.5 ft	√	±0.5 ft	-	-	-	-
U2	√	√	±20%	±0.5 ft	√	±0.5 ft	-	-	-	-
U3	√	√	±30%	-	-	-	-	-	√	√
U4	√	√	±40%	-	-	-	-	-	√	√
U5	√	√	±50%	-	-	-	-	-	√	√
U6	√	√	±50%	-	-	-	-	-	√	√
U7	√	√	-	-	-	-	-	-	-	-

*Median type is needed for calculating performance measure excess predicted average crash frequency using safety performance functions (SPFs).

These attributes are selected based on the results of a sensitivity analysis conducted by Dixon et al. (*5*). According to this study, these attributes were identified as high priority for having a significant impact on crash occurrence in a crash modification factor (CMF). The thresholds selected for each attribute were later determined based on a study by Geedipally et al., who tested various combinations of thresholds for aggregating segments (*6*). The only exception is the ADT thresholds that were adopted by published work from FHWA (*7*). The criteria include the following:

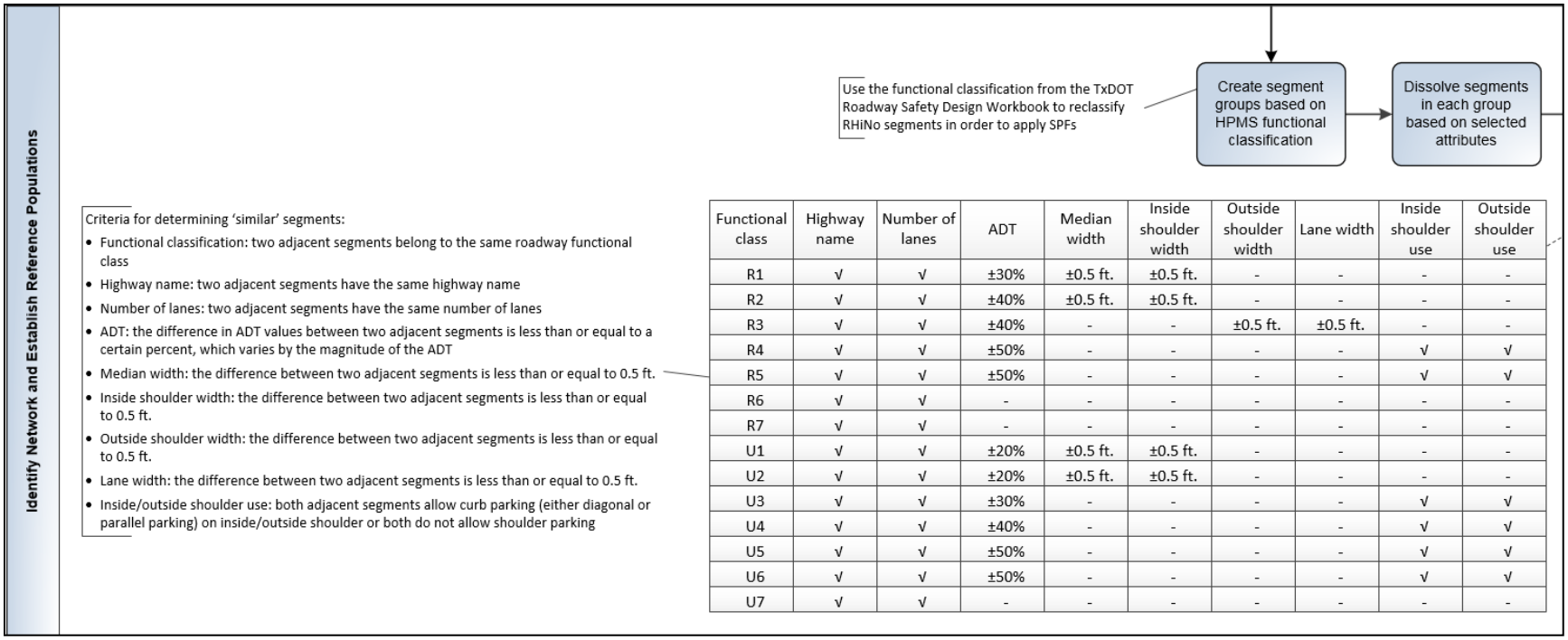
- Functional classification: two adjacent segments belong to the same roadway functional classification.
- Highway name: two adjacent segments have the same highway name.
- Number of lanes: two adjacent segments have the same number of lanes.
- ADT: the difference in ADT values between two adjacent segments is less than or equal to a certain percent, which varies by the magnitude of the ADT.
- Median width: the difference between two adjacent segments is less than or equal to 0.5 ft.
- Inside shoulder width: the difference between two adjacent segments is less than or equal to 0.5 ft.

- Outside shoulder width: the difference between two adjacent segments is less than or equal to 0.5 ft.
- Lane width: the difference between two adjacent segments is less than or equal to 0.5 ft.
- Inside/outside shoulder use: both adjacent segments allow curb parking (either diagonal or parallel parking) on inside/outside shoulder or both do not allow shoulder parking.

Processing the data involves the following steps that are also shown in Figure 9 and Figure 10:

- Group segments obtained from the previous step based on the functional classification:
    - R1, R2, U1, U2
    - U3
    - U4, U5, U6
    - R3
    - R4
    - R5
    - R6, R7, U7
- Merge (dissolve) segments in each group based on selected attributes from Table 1.
    - Find, for each segment, the adjacent segments.
    - Identify similar adjacent segments based on the criteria listed in Table 1.
    - Update attribute values for identified similar adjacent segments.
    - Merge (dissolve) similar adjacent segments.
- Combine all groups of segments into one ArcGIS feature class.
- Sort segments based on functional classifications and highway names.
- Assign ID to the sorted segments.
- Disaggregate the feature class into separate feature classes based on functional classifications.

Figure 11 through Figure 14 show the process for each group of segments. Note that criteria for determining similar adjacent segments have not been established for functional classes R6, R7, and U7. The products from this major step are feature classes of dissolved segments of all 14 functional classifications.



Functional class	Highway name	Number of lanes	ADT	Median width	Inside shoulder width	Outside shoulder width	Lane width	Inside shoulder use	Outside shoulder use
R1	√	√	±30%	±0.5 ft.	±0.5 ft.	-	-	-	-
R2	√	√	±40%	±0.5 ft.	±0.5 ft.	-	-	-	-
R3	√	√	±40%	-	-	±0.5 ft.	±0.5 ft.	-	-
R4	√	√	±50%	-	-	-	-	√	√
R5	√	√	±50%	-	-	-	-	√	√
R6	√	√	-	-	-	-	-	-	-
R7	√	√	-	-	-	-	-	-	-
U1	√	√	±20%	±0.5 ft.	±0.5 ft.	-	-	-	-
U2	√	√	±20%	±0.5 ft.	±0.5 ft.	-	-	-	-
U3	√	√	±30%	-	-	-	-	√	√
U4	√	√	±40%	-	-	-	-	√	√
U5	√	√	±50%	-	-	-	-	√	√
U6	√	√	±50%	-	-	-	-	√	√
U7	√	√	-	-	-	-	-	-	-

Figure 9. Zoomed-In View of Network Screening Flowchart (Part B).

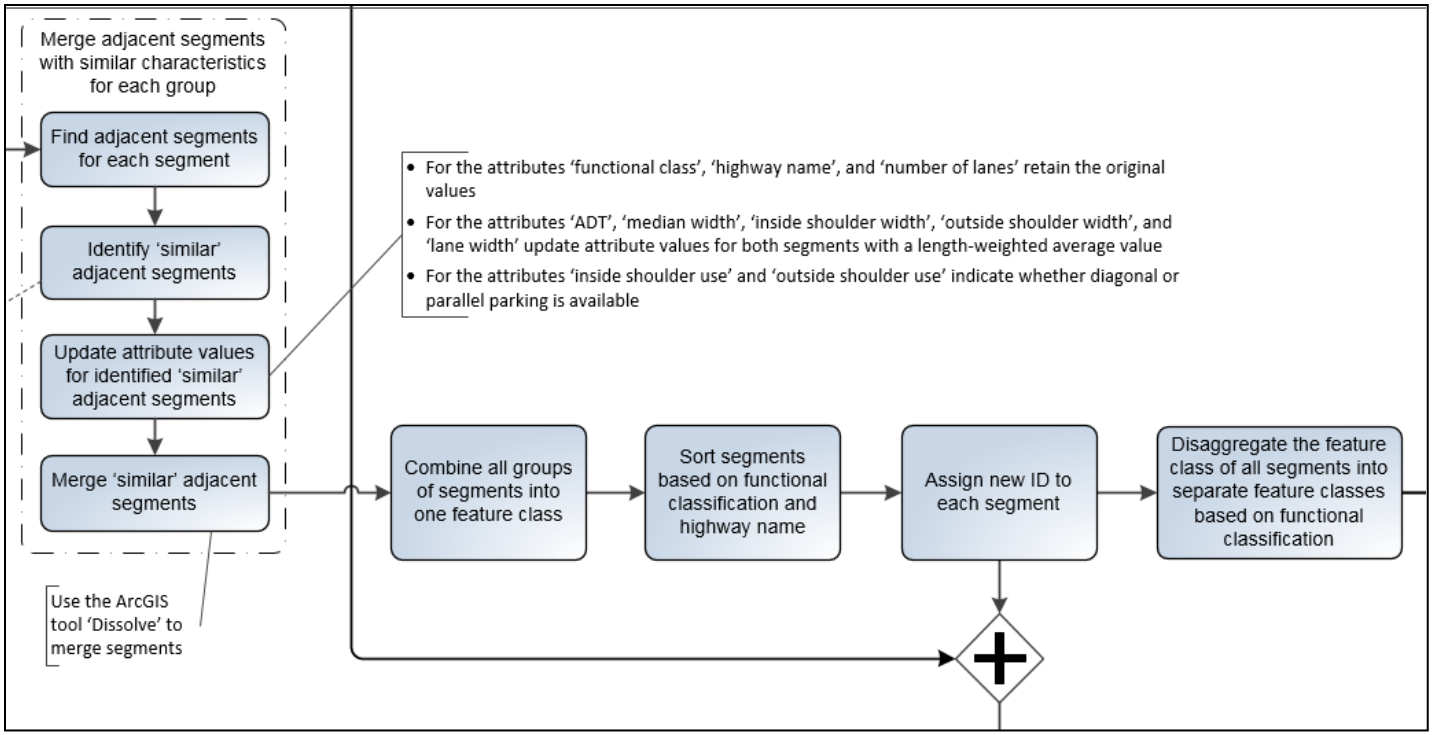


Figure 10. Zoomed-In View of Network Screening Flowchart (Part C).

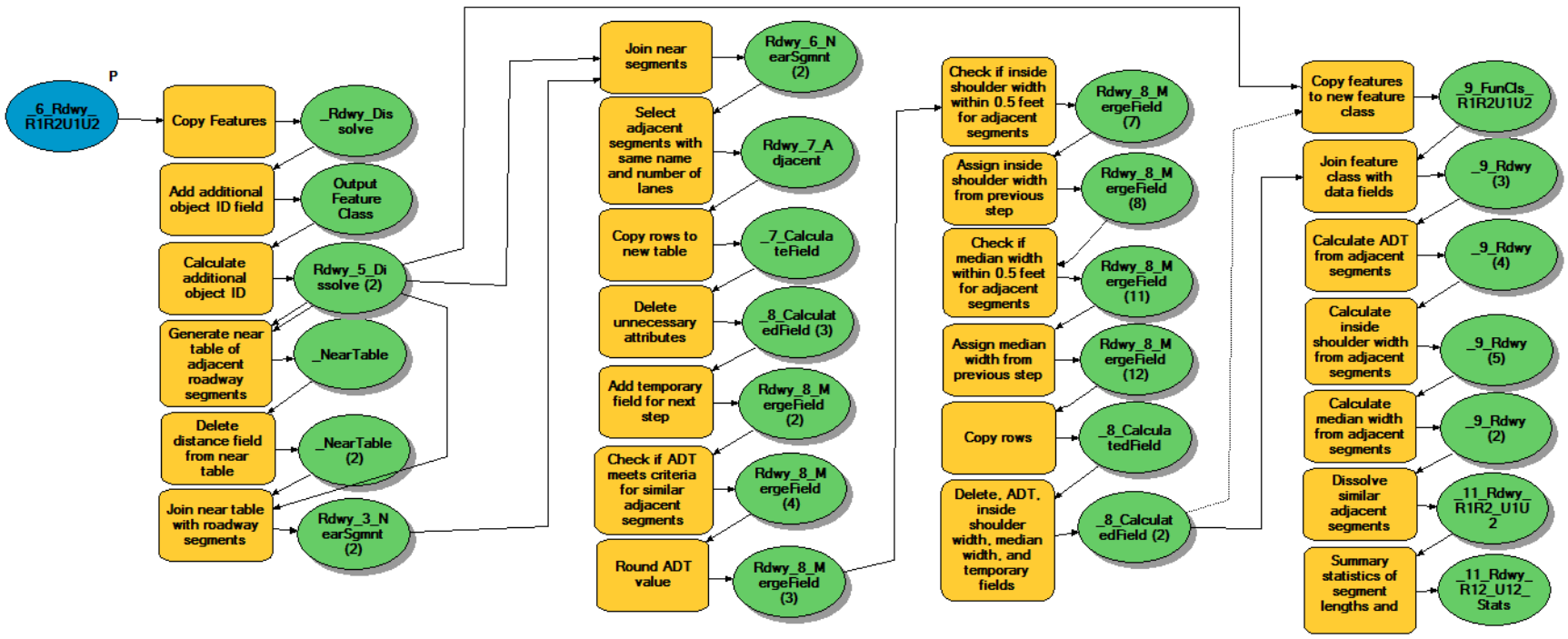


Figure 11. Process to Identify Similar Adjacent Segments for Functional Classes R1, R2, U1, and U2.

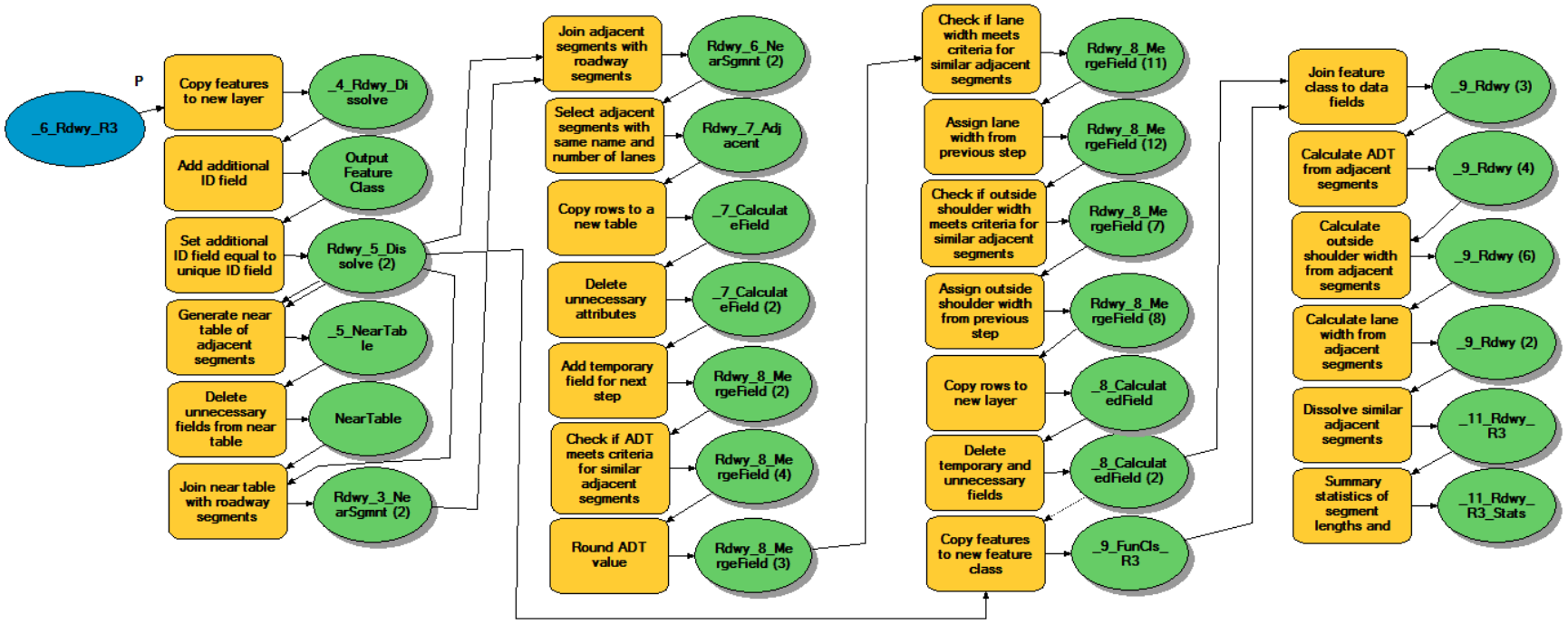


Figure 12. Process to Identify Similar Adjacent Segments for Functional Class R3.

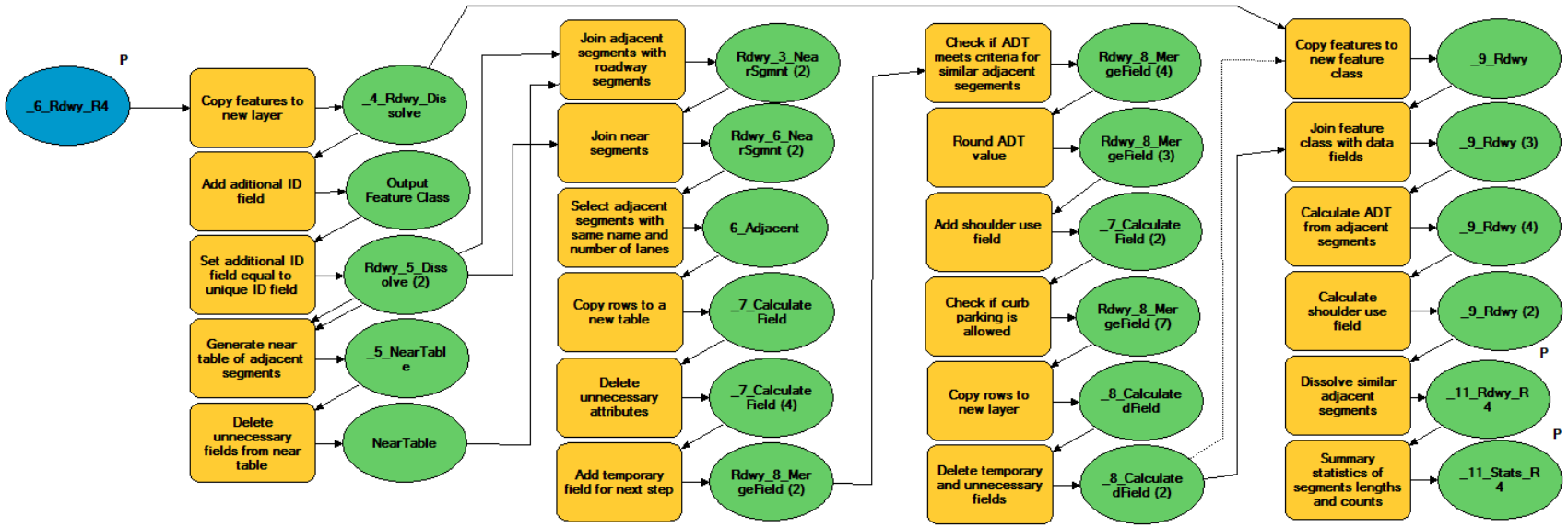


Figure 13. Process to Identify Similar Adjacent Segments for Functional Classes R4, R5, U3, U4, U5, and U6.

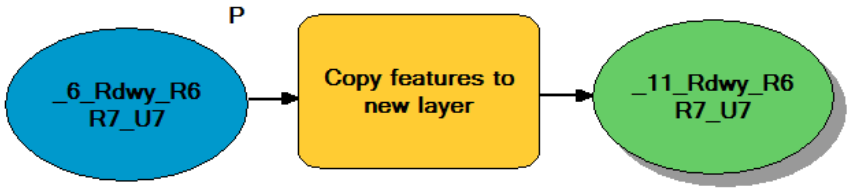


Figure 14. Process to Prepare Segments for Functional Classes R6, R7, and U7.

Following the aggregation of RHiNo segments, researchers developed 34 reference populations based on the methodology developed by Geedipally et al. (*6*). Geedipally et al. formed 20 groupings by accounting for the 14 urban and rural functional classes and three traffic volume levels (low, medium, and high). In this project, researchers created additional roadway groupings by accounting for the number of lanes as well. Table 2 shows the 34 groupings and their main characteristics (number of RHiNo segments and number of KA crashes).

Table 2. Roadway Groupings for Assessing Crash Risk.

Functional Class	Number of Lanes	Low Volume				Medium Volume				High Volume			
		Group #	ADT	# of Segments	# of KA Crashes	Group #	ADT	# of Segments	# of KA Crashes	Group #	ADT	# of Segments	# of KA Crashes
R1 + R2	>=4	1L	<30,000	508	816	-	-	-	-	1H	>=30,000	380	644
R3	<=3	2L	<7,500	1,934	1,164	-	-	-	-	2H	>=7,500	356	294
	>3	3L	<7,500	1,403	564	-	-	-	-	3H	>=7,500	2,160	1,868
R4	<=3	4L	<2000	1,398	552	4M	2,000-4,000	1199	802	4H	>=4,000	1,081	1,050
	>3	5L	<2000	182	35	5M	2,000-4,000	296	76	5H	>=4,000	527	313
R5	<=4	6L	<400	2,989	428	6M	400-2,000	5691	1912	6H	>=2,000	2,258	1,254
R6 + R7	<=4	7L	<400	3,222	216	7M	400-1,000	1172	166	7H	>=1,000	496	86
U1 + U2	<=4	8L	<50,000	1,008	1,027	8M	50,000-100,000	431	724	8H	>=100,000	60	98
	>4	9L	<50,000	275	224	9M	50,000-100,000	575	898	9H	>=100,000	992	2,783
U3 + U4	<=2	10L	<2,500	305	53	10M	2,500-15,000	2,104	1,401	10H	>=15,000	281	408
	>2	11L	<2,500	96	15	11M	2,500-15,000	2,884	1,961	11H	>=15,000	2,687	5,424
U5 + U6	<=6	12L	<1,000	278	23	12M	1,000-5,000	1,115	360	12H	>=5,000	546	438
U7	<=6	13L	All	27	-	-	-	-	-	-	-	-	-

2.3 SELECT PERFORMANCE MEASURES

The HSM provides a list of 13 performance measures (*3*) that can be used to perform network screening. Based on the established focus and TxDOT's data availability, research project 0-6912 (*4*) determined that the seven performance measures listed in Table 3 can be calculated to perform the network screening analysis:

Table 3. Applicable Performance Measures.

Performance Measure	Description
PM1: Crash Frequency	Number of crashes for a given road segment or intersection over a specified analysis period. Sites with higher number of total crashes (or a particular severity) are ranked first.
PM2: Crash Rate	Number of crashes per million miles of travel. Crash rate analysis typically uses exposure data in the form of traffic volumes or roadway mileage to determine relative safety compared to other similar facilities.
PM3: Critical Rate	The critical crash rate is calculated for each site and compared to the observed number of crashes. If the observed number of crashes for the given site is higher than the critical rate, this site is marked for further analysis.
PM4: Excess Predicted Average Crash Frequency Using Method of Moments	The observed crash frequency at each site is modified and compared to the average crash frequency of the reference population. Analysts can adjust sites' crash frequency to partially account for RTM effects.
PM5: Probability of Specific Crash Types Exceeding Threshold Proportion	The probability that the long-term proportion of a specific crash type exceeds a threshold proportion. Sites are prioritized based on the probability that the true proportion of a particular crash type or severity is greater than a prescribed threshold proportion.
PM6: Excess Proportion of Specific Crash Types	Difference between the observed proportion of a specific crash type for a site and the threshold proportion for the reference population.
PM7: Excess Predicted Average Crash Frequency Using SPFs	Difference between the observed crash frequency and the predicted crash frequency derived from an appropriate SPF.

Table 4 shows the main strengths and limitations of each performance measure.

Table 4. Strengths and Limitations of Select Performance Measures.

Performance Measure	Strengths	Limitations
PM1: Crash Frequency	• Simple	• Does not account for RTM bias • Does not estimate a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics • Does not account for traffic volume • Does not identify low-volume collision sites where low cost countermeasures could be easily applied
PM2: Crash Rate	• Simple • Could be modified to account for severity if a relative severity based crash count is needed	• Does not account for RTM bias • Does not estimate a threshold to indicate sites experiencing more crashes than predicted for sites with similar characteristics • Comparisons cannot be made across sites with significantly different traffic volumes • May mistakenly prioritize low volume, low collision sites
PM3: Critical Rate	• Reduces exaggerated effect of sites with low volumes • Accounts for variance in crash data • Estimates a threshold for comparison	• Does not account for RTM bias
PM4: Excess Predicted Crash Frequency Using Method of Moments	• Estimates a threshold for comparison • Accounts for variance in crash data • Ranks different types of sites in one list • Method concepts are similar to EB methods	• Does not account for RTM bias • Does not account for traffic volume • Some sites may be identified for further study because of unusually low frequency of non-target crash types • Ranking results are influenced by reference populations; sites near boundaries of reference populations may be over-emphasized
PM5: Probability of Specific Crash Types Exceeding Threshold Proportion	• Can also be used as a diagnostic tool • Accounts for variance in crash data • Not affected by RTM bias	• Does not account for traffic volume • Some sites may be identified for further study because of unusually low frequency of non-target crash types
PM6: Excess Proportion of Specific Crash Types	• Can also be used as a diagnostic tool • Accounts for variance in crash data • Not affected by RTM bias	• Does not account for traffic volume • Some sites may be identified for further study because of unusually low frequency of non-target crash types
PM7: Excess Predicted Crash Frequency Using SPFs	• Accounts for traffic volumes • Estimates a threshold for comparison	• Results may not fully capture effects of RTM bias

Prior to calculating the performance measures, the crashes obtained from the earlier data processing must be mapped onto their corresponding on-system mainlane segments. To do so, several activities are carried out as described below and shown in Figure 15 and Figure 16:

- Determine two nearest segments for each crash.
- Identify the segment where the crash occurred by comparing highway names:
    - If only one segment's highway name matches with the highway name of the crash, the segment is identified as the correct corresponding segment.
    - If both segments' highway names match with the highway name of the crash, the segment that is closer to the crash is identified as the correct corresponding segment.
    - If both segments' highway names do not match with the highway name of the crash, no segments are identified for the crash.
- Project each crash to the corresponding RHiNo segment.
- Extract a new DFO for each projected crash from the routed version of RHiNo. The new DFO is different than the one included in CRIS for every crash. The DFO in CRIS is determined using the latest version of the RHiNo that is available at TxDOT when a crash is entered in CRIS. For example, most of the 2018 crashes were mapped and a DFO was extracted for every crash based on the 2017 RHiNo, while the majority of the 2019 crashes where mapped using the 2018 version of RHiNo. As the RHiNo database is updated from one year to the next, some segments are added, deleted, and DFOs might slightly change along a route. This means that the DFO at a specific location of a road may differ among different versions of RHiNo. These differences can create challenges when attempting to map and analyze crashes that happened in different years. The approach described here partially overcomes these challenges.

Figure 17 and Figure 18 show the tools used to process the data in this step.

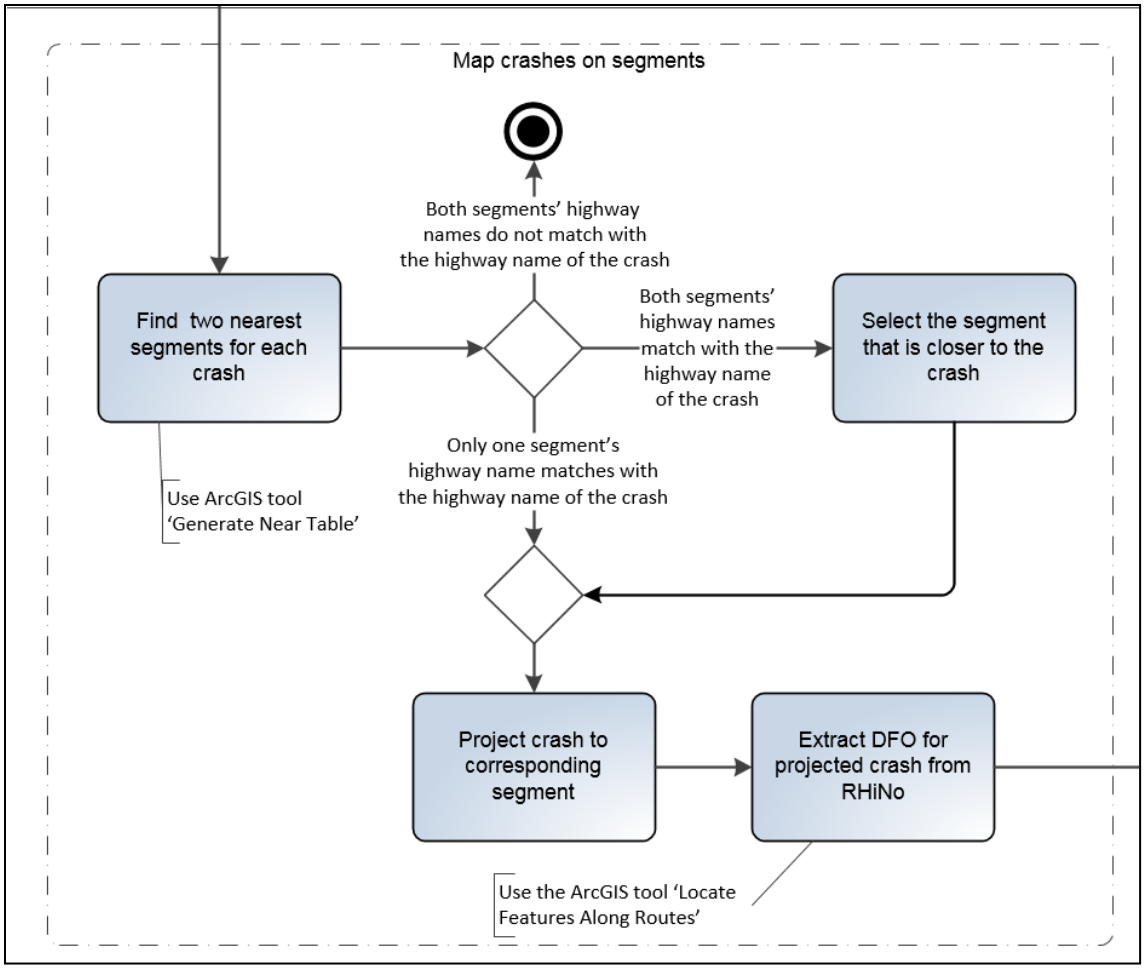


Figure 15. Zoomed-In View of Network Screening Flowchart (Part D).

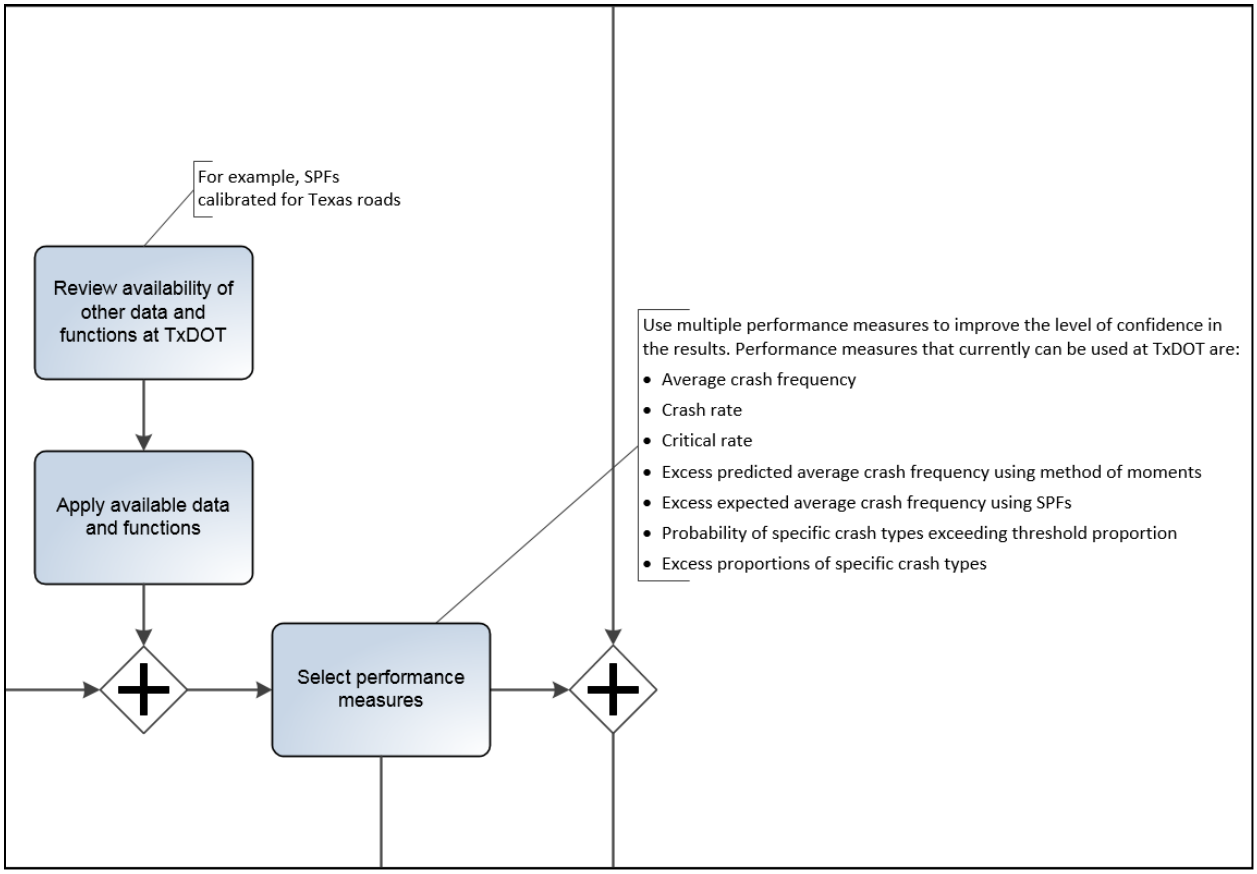


Figure 16. Zoomed-In View of Network Screening Flowchart (Part E).

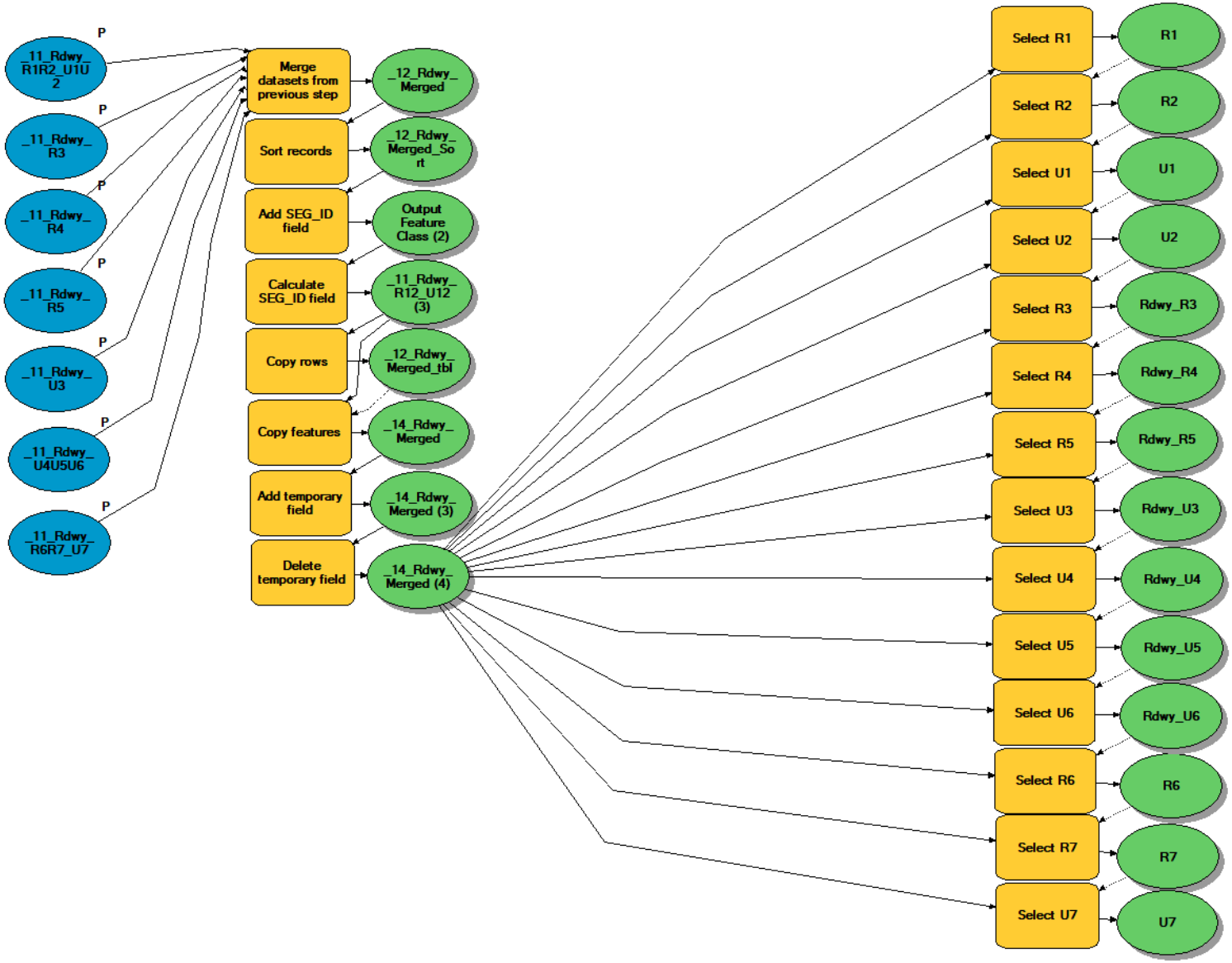


Figure 17. Process to Merge Segments from Previous Step and Disaggregate Them by Functional Class.

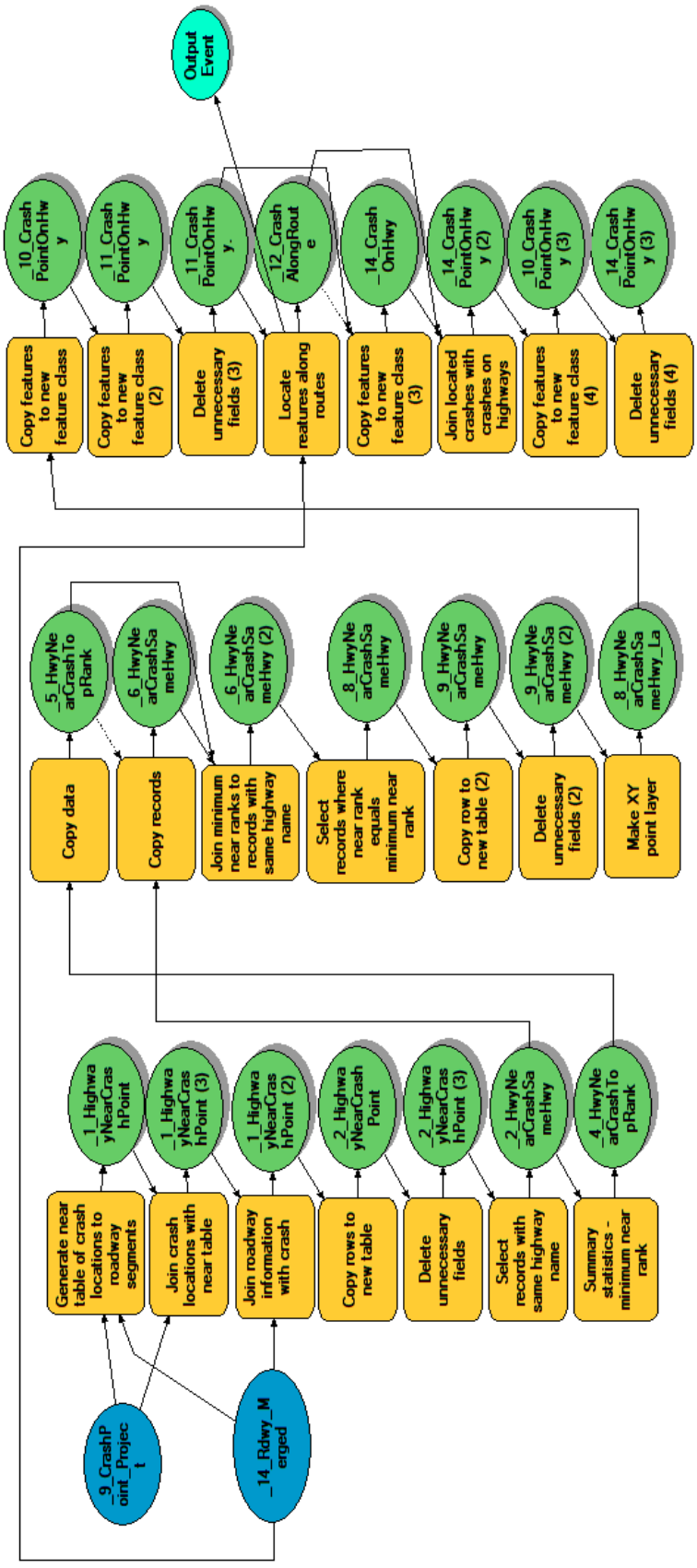


Figure 18. Process to Map Crash Locations to Highway Network.

2.4 SELECT SCREENING METHOD

Research project 0-6912 concluded that among the three sliding methods (sliding window, simple ranking, and peak search) described in the HSM, the sliding window method is the most appropriate to perform network screening for segments in Texas. In this method, a window of a certain length is conceptually moved along a study segment from one end to another at specified increments. The selected performance measures are then calculated for each position of the window. From all the windows analyzed, the windows are ranked based on the values of performance measures. Figure 19 shows an example of conducting the sliding window method using a window length of 0.3 miles and an increment distance of 0.1 miles.

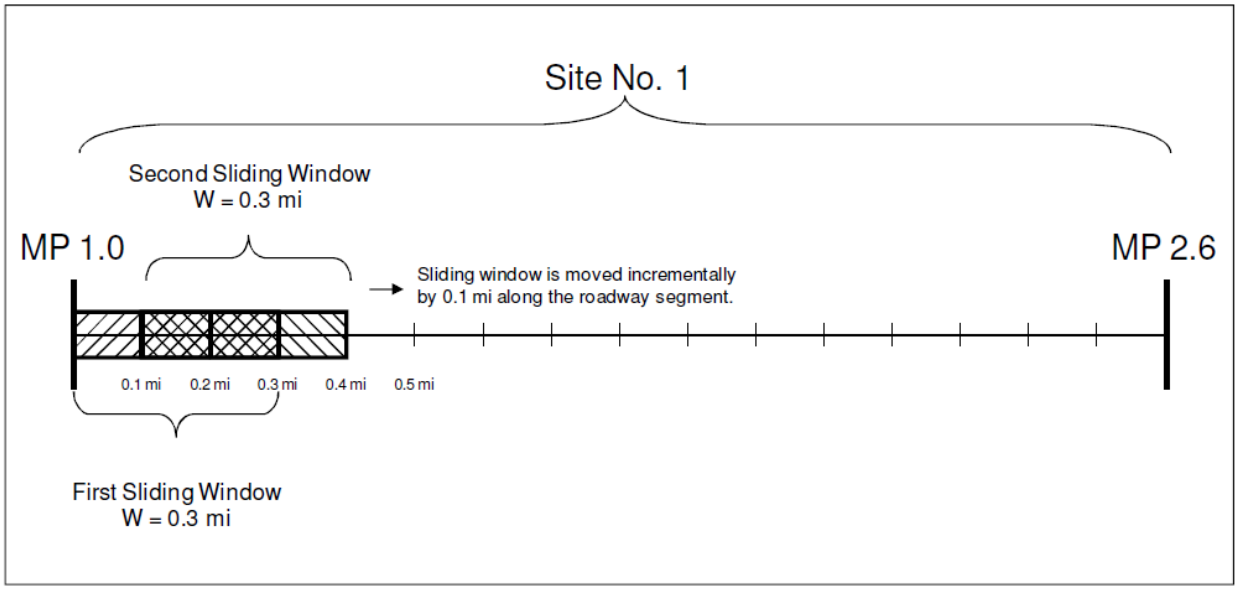


Figure 19. Illustration of the Sliding Window Method (*8*).

Figure 20 shows the main activities involved in the sliding window method. Figure 21 shows the ArcGIS model that applies the sliding window method. The main steps involved in this process are described below:

- Generate a feature class of points along each segment at specific length intervals that users can define (e.g., 0.1-mile). Users also need to define the size of each roadway window (e.g., 0.3 miles). It is assumed that each window moves along a roadway segment at the selected length increment (i.e., by 0.1-mile).
- Assign a number to each generated point, starting at one.
- Assign window group number(s) to each generated point.
    - For segments shorter than 0.3 miles, only end points are labeled as Window Group 1.
    - For segments between 0.3 and 0.6 miles, multiple points are labeled as Window Group 1 or Window Group 2 depending on point locations.

- For segments that are longer than 0.6 miles, multiple points are labeled as Window Group 1, or Window Group 2, or Window Group 3 depending on point locations.

- Disaggregate the point feature class into three feature classes by window group number.
- Split on-system mainlane segments at points from each window group, respectively.
- Assign window ID to the subsegments obtained from the previous step.

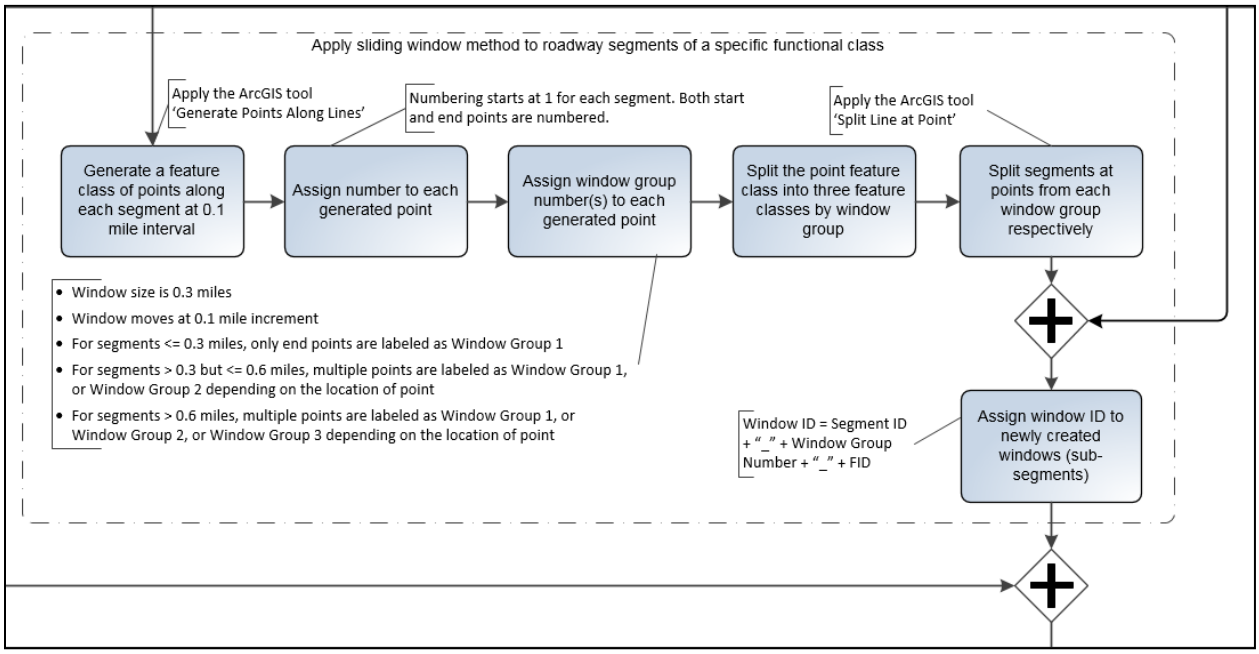


Figure 20. Zoomed-In View of Network Screening Flowchart (Part F).

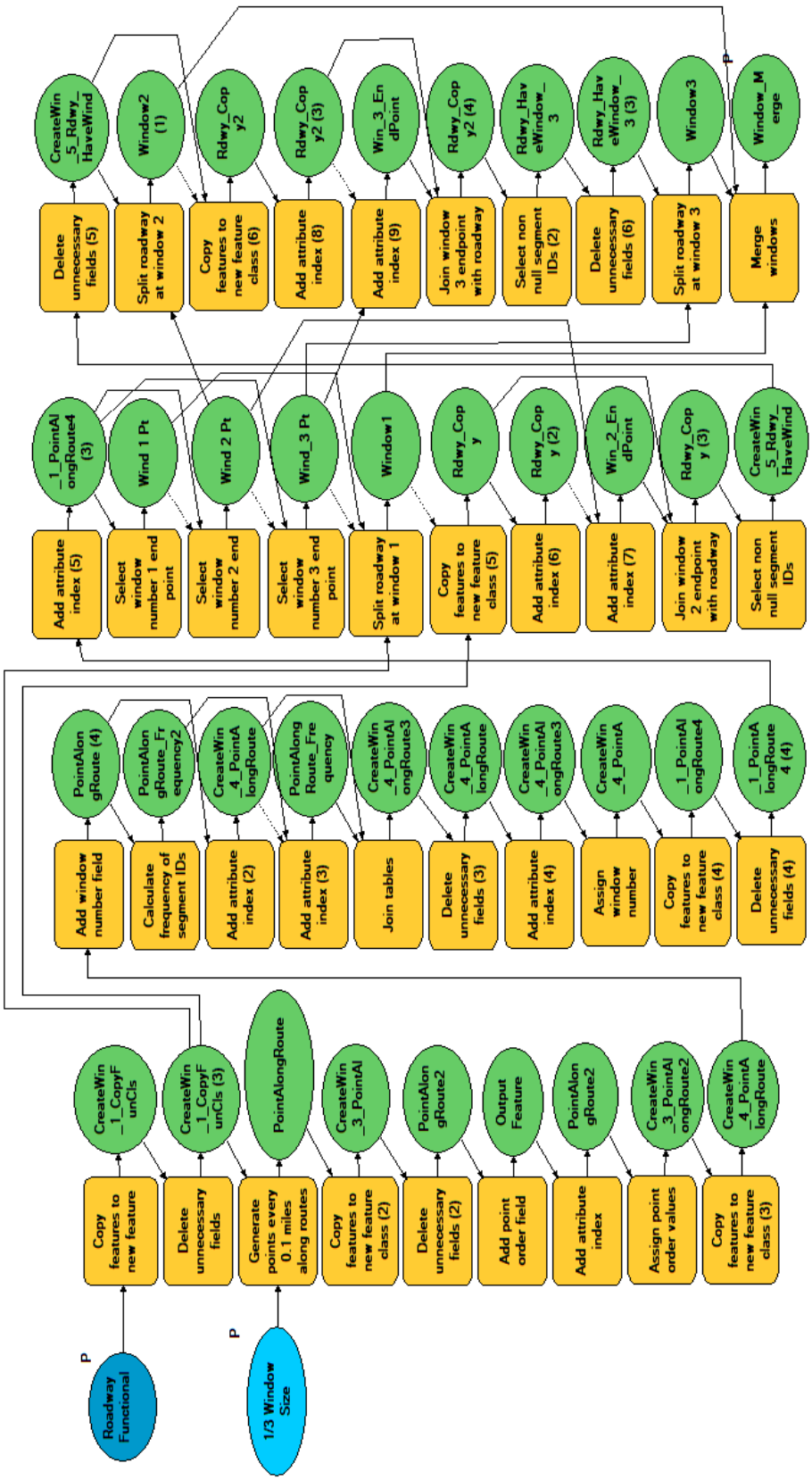


Figure 21. Process of Creating Screening Windows.

The product from this step is a list of 0.3-mile windows developed from the processed on-system mainlane segments.

2.5 SCREEN AND EVALUATE RESULTS

The next step in the flowchart (Figure 22) is to calculate the performance measures separately for each window based on the formulas provided in Table 5. Figure 23 through Figure 28 show the ArcGIS models that calculate the seven performance measures, respectively.

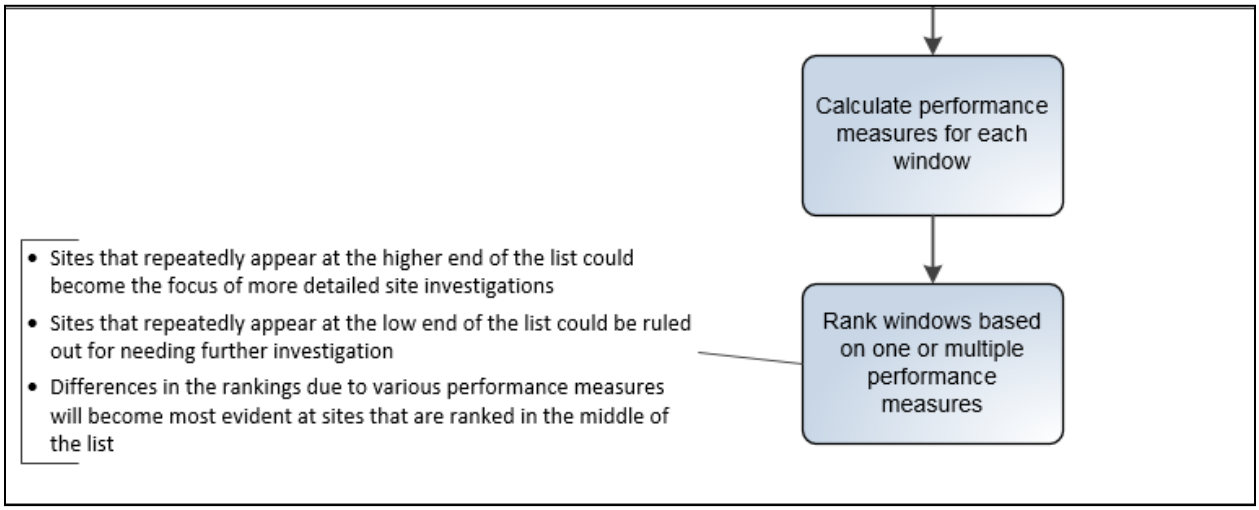


Figure 22. Zoomed-In View of Network Screening Flowchart (Part G).

Table 5. Calculations of Seven Performance Measures.

Performance Measure	Calculations
PM1: Crash Frequency	Total number of observed KA crashes along roadway window *i* during the analysis period.
PM2: Crash Rate	*Main calculation:* $$R_i = \frac{N_{observed,i(total)}}{Exp_i}$$ *Subcalculations:* $$Exp_i = \left(\frac{ADT_i}{1{,}000{,}000}\right) \times n \times 365$$ *where*, R_i =Observed crash rate at window *i* $N_{observed,i}$ =Total number of observed KA crashes at window *i* Exp_i =Exposure for window *i* ADT_i=Average daily traffic at window *i* *n* =Number of years (3) of crash data
PM3: Critical Rate	*Main calculation:* $$R_{cr,i} = R_a + \left(P \times \sqrt{\frac{R_a}{Exp_i}}\right) + \left(\frac{1}{2 \times Exp_i}\right)$$ *Subcalculation:* $$R_a = \frac{\sum_{i=1}(ADT_i \times R_i)}{\sum_{i=1}(ADT_i)}$$ If $(R_i - R_{cr,i}) > 0$ then review intersection *i* further. where, $R_{cr,i}$ =Critical crash rate for window i R_a =Weighted average crash rate for reference population *P* =P-value for corresponding confidence level (1.645 for 95 percent confidence level)

Performance Measure	Calculations
PM4: Excess Predicted Average Crash Frequency Using Method of Moments	*Main calculation:* $$PI = N_{observed,i(adj)} - N_{observed,rp}$$ *Subcalculations:* $$N_{observed,i(adj)} = N_{observed,i} + \frac{N_{observed,rp}}{Var(N)} \times \left(N_{observed,rp} - N_{observed,i}\right)$$ $$Var(N) = \frac{\sum_{i=1}^{n}\left(N_{observed,i} - N_{observed,rp}\right)^2}{n_{windows,rp} - 1}$$ $$N_{observed,rp} = \frac{\sum_{i=1}^{n} N_{observed,i}}{n_{windows,rp}}$$ *where,* PI_i =Potential for Improvement for window *i* $N_{observed,\ i(adj)}$ = Adjusted observed number of crashes per year for window *i* $N_{observed,\ rp}$= Average crash frequency per reference population *Var(N)* =Variance $n_{windows,rp}$=Number of windows per reference population

Performance Measure	Calculations
PM5: Probability of Specific Crash Types Exceeding Threshold Proportion	*Main calculation:* $$Prob\left(\frac{p_i > p_i^*}{N_{observed,i,KA}, N_{observed,i,KAB}}\right) = 1 - betadist(p_i^*, \alpha + N_{observed,,KAi}, \beta + N_{observed,i,KAB} - N_{observed,i,KA})$$ *Sub-calculations:* $$\alpha = \frac{\overline{p_i^*}^2 - \overline{p_i^*}^3 - s^2(\overline{p_i^*})}{Var(N)}$$ $$\beta = \frac{\alpha}{\overline{p_i^*}} - \alpha$$ $$\overline{p_i^*} = \frac{\sum p_i}{n_{sites}}, if\ N_{observed,i} \geq 2$$ $$Var(N) = \left(\frac{1}{n_{windows,rp} - 1}\right) \times \left(\sum_{i=1}^{n}\left(\frac{N_{observed,i,KA}{}^2 - N_{observed,i,KA}}{N_{observed,i,KAB}{}^2 - N_{observed,i,KAB}}\right) - \left(\frac{1}{n_{windows,rp}}\right) \times \left(\sum_{i=1}^{n}\frac{N_{observed,i,KA}}{N_{observed,i,KAB}}\right)\right)$$ $$p_i^* = \frac{\sum N_{observed,i,KA}}{\sum N_{observed,i,KAB}}$$ $$p_i = \frac{N_{observed,i,KA}}{N_{observed,i,KAB}}$$ *where,* p^*_i =Threshold proportion p_i =Observed proportion of crashes for window *i* $N_{observed,i,KA}$= Number of observed target (KA) crashes at window *i* $N_{observed,i,KAB}$ = Number of observed KAB crashes at window *i* *Var(N)* =Variance, equivalent to the square of the standard deviation, s^2 $\overline{p_i^*}$ =Mean proportion of target (KA) crashes $N_{windows,rp}$ = Number of windows per reference population

Performance Measure	Calculations
PM6: Excess Proportion of Specific Crash Types	*Main calculation:* $$p_{diff} = p_i - p_i^*$$ *Subcalculations:* $$p_i = \frac{N_{observed,i}}{N_{observed,i(total)}}$$ $$p_i^* = \frac{\sum N_{observed,i}}{\sum N_{observed,i(total)}}$$ *where*, p_i = Observed proportion p^*_i = Threshold proportion
PM7: Excess Predicted Average Crash Frequency Using SPFs	*Main calculation:* $$Excess(N) = \overline{N_{observed,i}} - \overline{N_{predicted,i}}$$ *Subcalculations:* $$\overline{N_{predicted,i}} = \frac{\sum_{y=1}^{3}(N_{predicted,i,y})}{3}$$ $$\overline{N_{observed,i}} = \frac{\sum_{y=1}^{3}(N_{observed,i,y})}{3}$$ *where*, *Excess(N)*= Excess predicted average crash frequency for window *i* $\overline{N_{predicted,i}}$ = Predicted average crash frequency over 3 years for window *i* $\overline{N_{observed,i}}$= Observed average crash frequency over 3 years for window *i* $N_{predicted,i,y}$= Observed crash frequency for year *y* and window *i* $N_{observed,i,y}$= Observed crash frequency for year *y* and window *i* The $N_{predicted,i,y}$ is calculated using SPFs from the TxDOT *Roadway Safety Design Workbook* (*9*).

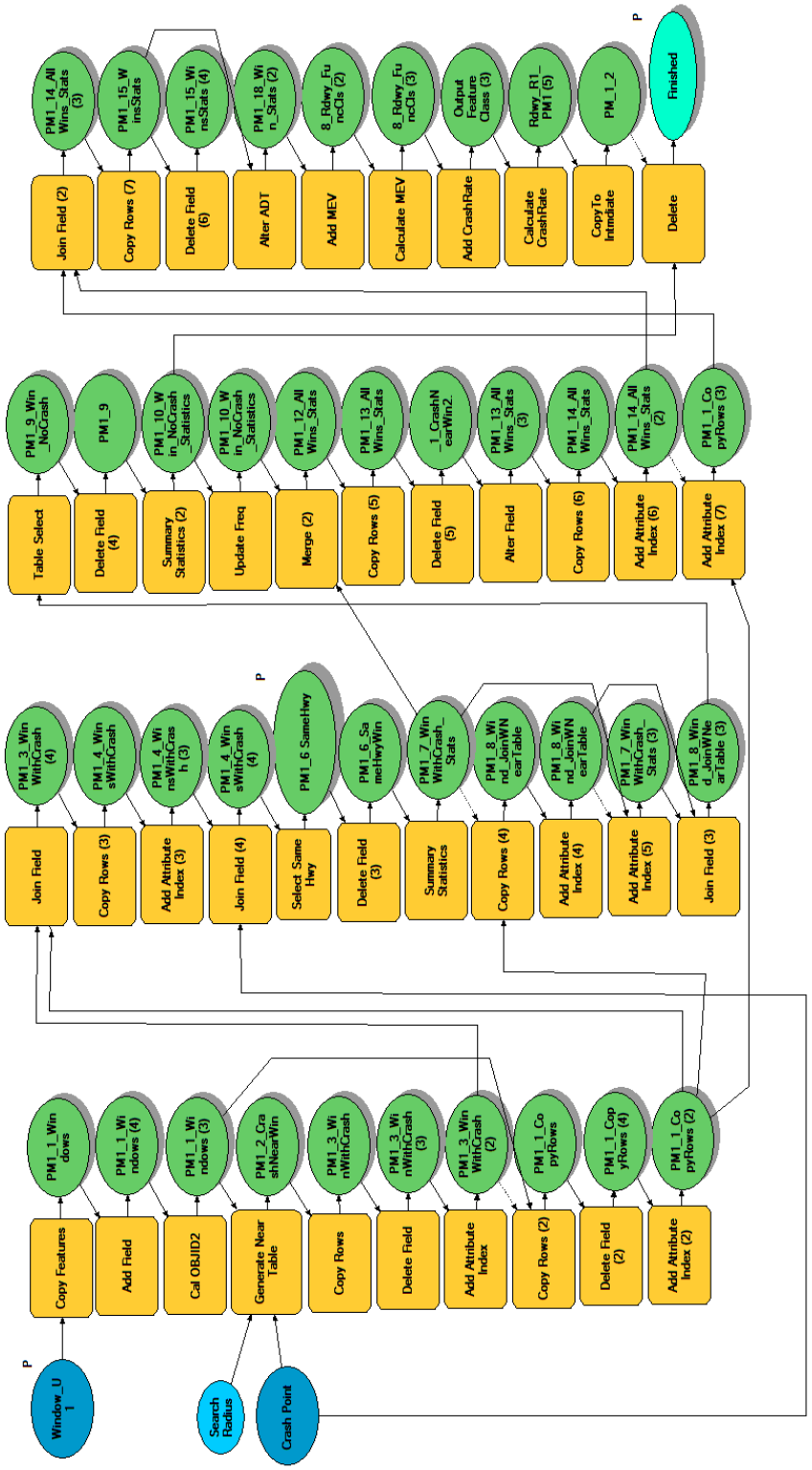


Figure 23. Process to Calculate Average Crash Frequency (PM1) and Crash Rate (PM2).

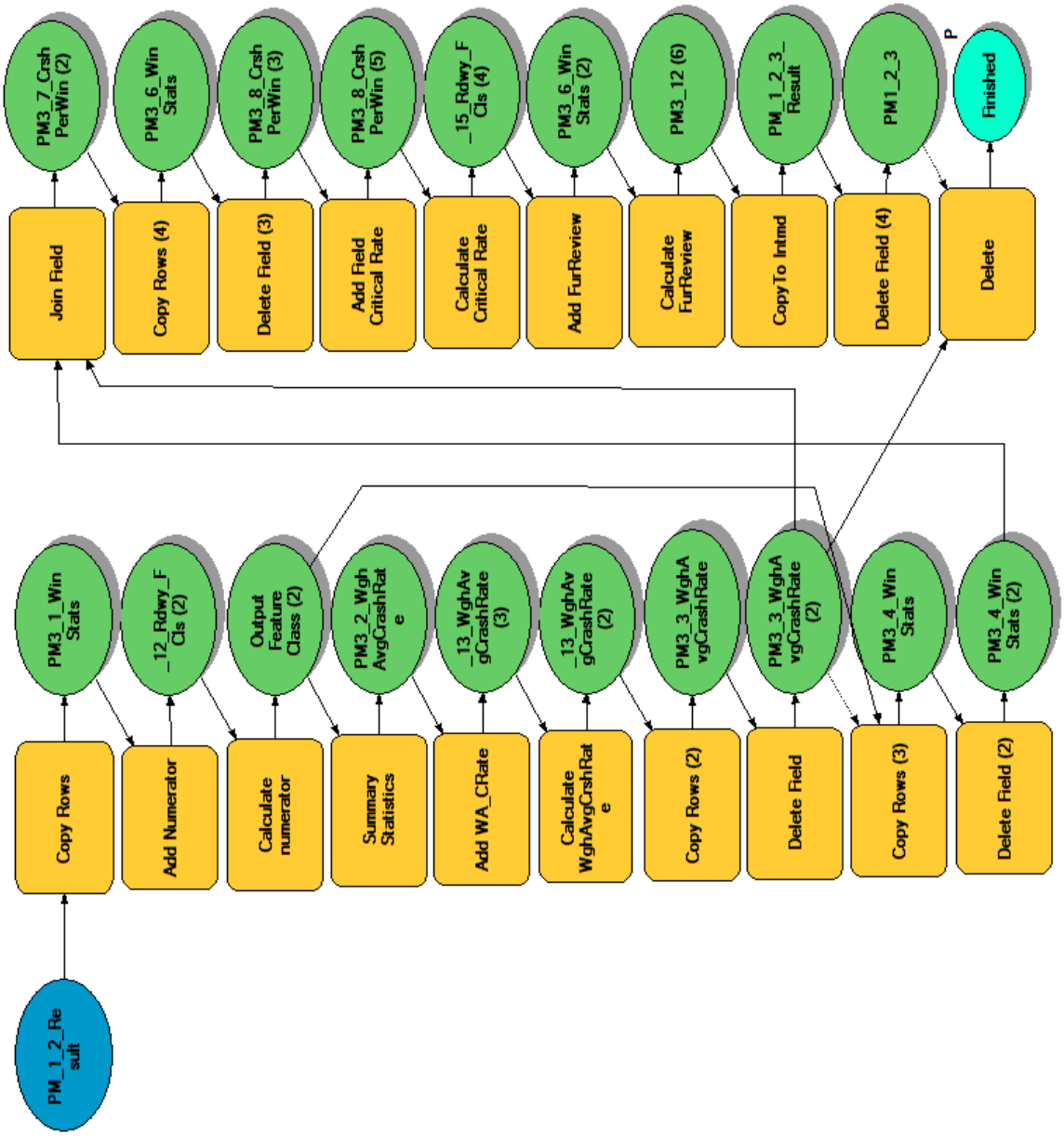


Figure 24. Process to Calculate Critical Rate (PM3).

Figure 25. Process to Calculate Excess Predicted Average Crash Frequency Using Method of Moments (PM4).

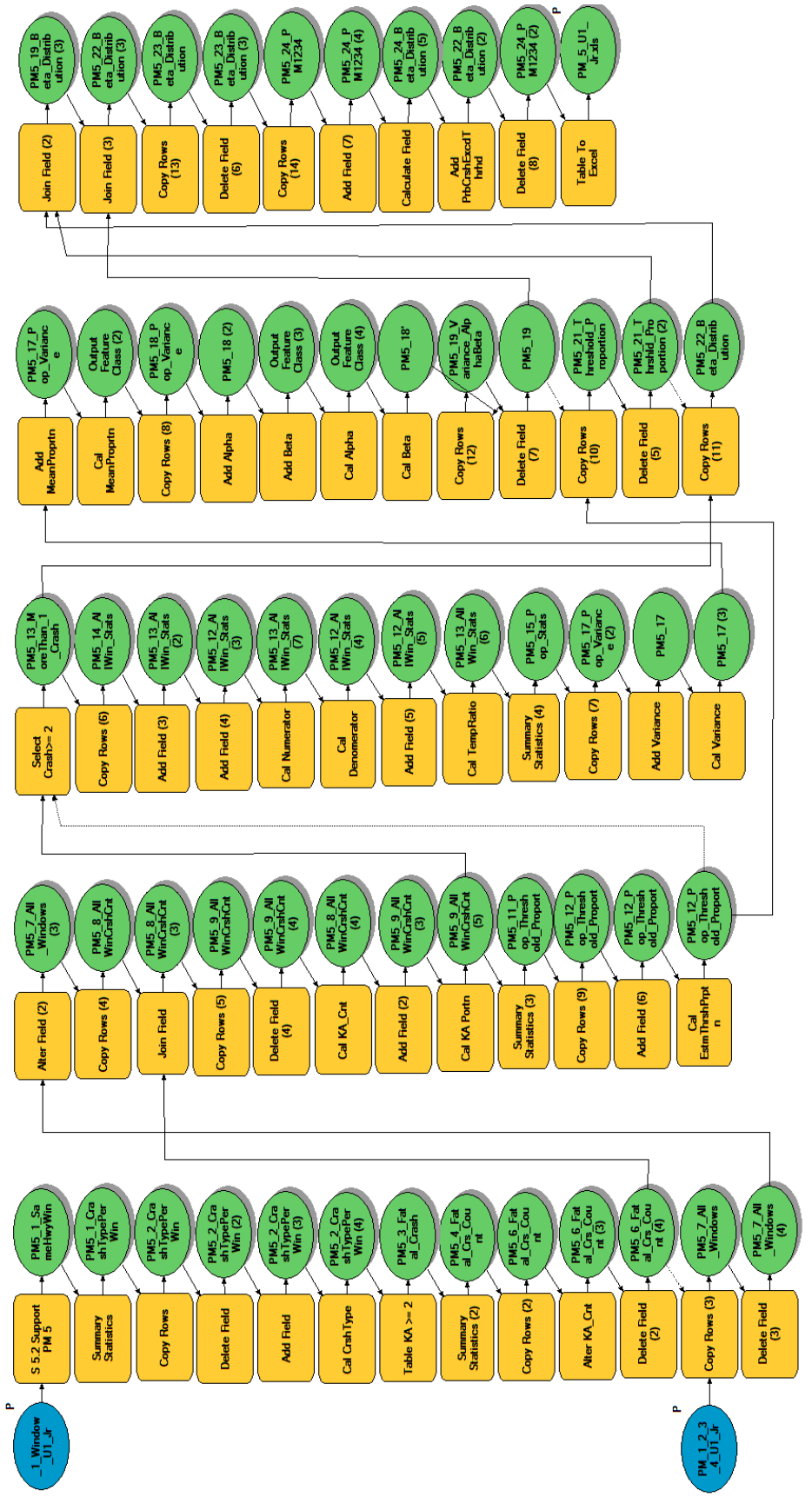


Figure 26. Process to Calculate Probability of KA crashes Exceeding Threshold Proportion (PM5).

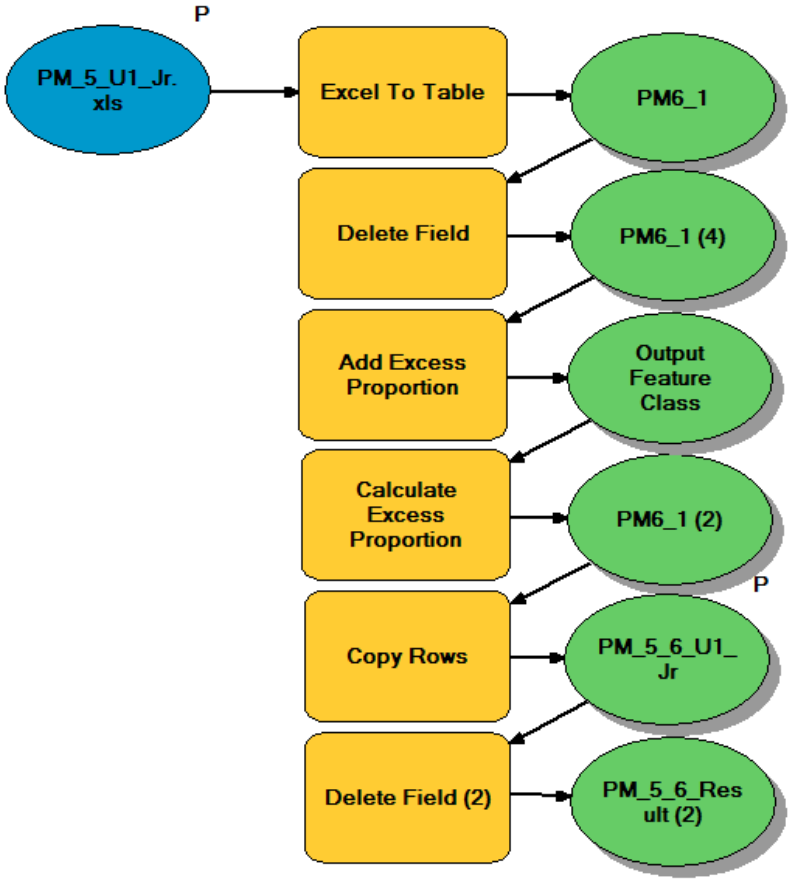


Figure 27. Process to Calculate Excess Proportion of KA Crashes (PM6).

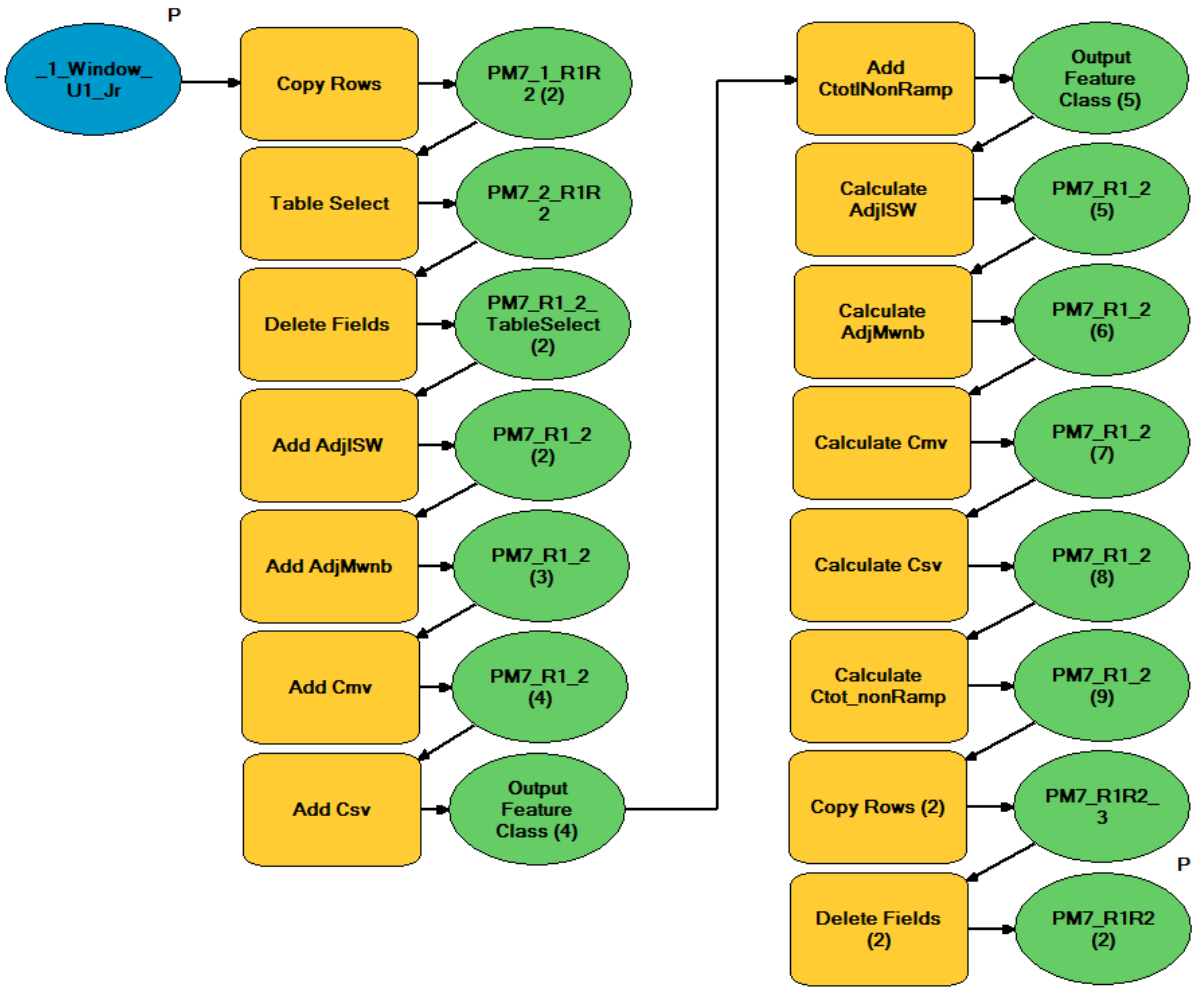


Figure 28. Process to Calculate Excess Predicted Average Crash Frequency Using SPFs (PM7).

In the final step, the windows are ranked based on one or multiple performance measures. One simple approach is to create several rankings of windows, one ranking for every performance measure. The windows appearing on the top of each list can be considered for further examination. However, this can be a time-consuming process because it requires analysts to separately develop and review multiple rankings of windows. Further, some performance measures may yield significantly different rankings that may cause confusion to analysts. For example, some windows may be ranked in the top 5 percent based on the average crash rate (PM2), but the same windows may be ranked lower in the list based on a different performance measure.

The differences in rankings produced by the seven performance measures are due to the fact that each performance measure accounts for different factors and has its own strengths and weaknesses as shown in Table 4. Based on the pros and cons of each performance measure, research project 0-6912 assigned different weights to each measure as listed in Table 6.

Table 6. Performance Measure Weights (*4*).

Performance Measure	Weight
PM1: Average Crash Frequency	0.1
PM2: Crash Rate	0.1
PM3: Critical Rate	0.2
PM4: Excess Predicted Average Crash Frequency Using Method of Moments	Not used in adjusted weighted ranking (AWR)
PM5: Probability of KA Crashes Exceeding Threshold Proportion	0.4
PM6: Excess Proportion of KA Crashes	0.2
PM7: Excess Predicted Average Crash Frequency Using SPFs	Not used in AWR

The weights (second column) sum up to one (1.0) and are used to calculate an AWR for every window. The AWR is calculated as follows:

$$AWR_i = 0.1 \times Rank_{i,PM1} + 0.1 \times Rank_{i,PM2} + 0.2 \times Rank_{i,PM3} + 0.4 \times Rank_{i,PM5} + 0.2 \times Rank_{i,PM6}$$

where,

AWR_i = Adjusted weighted ranking for window i.

$Rank_{i,PMk}$ = Ranking of window i according to performance measure k.

Even though researchers calculated, where applicable, all seven performance measures, two performance measures were not included in the calculation of AWR. The ranking based on PM4 *Excess Predicted Average Crash Frequency Using Method of Moments* yielded counterintuitive results compared to the remaining performance measures, so it was not included in the AWR calculation. Further, PM7 *Excess Predicted Crash Frequency Using SPFs* was calculated only for windows that have specific roadway characteristics (e.g., certain number of lanes and median

type) for which SPFs are provided in *TxDOT Roadway Safety Design Workbook* (*8*). As a result, some windows could not be ranked based on PM7, so researchers decided to exclude PM7 from the AWR calculation.

After calculating the AWR, researchers calculated separately within each group, the percent adjusted weighted ranking (PAWR) for every window. This calculation was based on a comparison of the rank of a window to the rank of other windows within the same group. At the end of the analysis, each window had a PAWR value which ranged between 0 percent to 100 percent. The lower the PAWR value, the higher the crash risk of a window.

To classify the crash risk of a window within each grouping, researchers followed the same methodology that Geedipally et al. developed (*6*). According to this methodology, each window was classified as a low, moderate, high, or very high crash risk window.

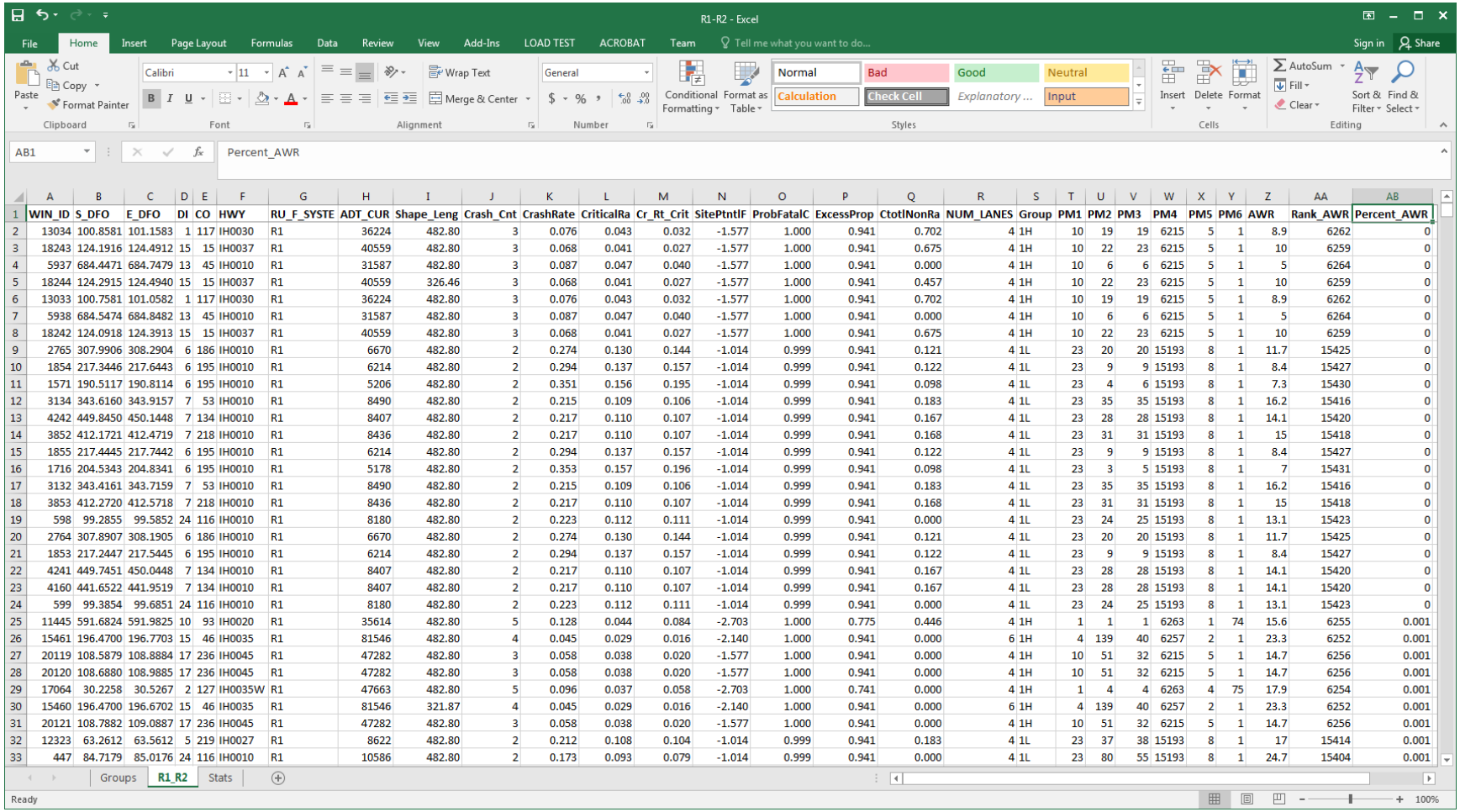
To determine the thresholds among the four levels of crash risk, researchers compared the PAWR values within each grouping and plotted cumulative percentage graphs. Inflection points were identified for each graph. Inflection points are the percentiles at which the relationship between cumulative percentages and PAWR change. For example, a very high crash risk was assigned to windows from 0 to the 5^{th} percentile. Windows with PAWR between the 5^{th} and 15^{th} percentiles were labeled as high crash risk. Between the 15^{th} and 80^{th} percentile, a moderate crash risk was assigned, and the windows with PAWR greater than the 80^{th} percentile were deemed as having a low crash risk. This method was repeated for each roadway grouping and a risk assessment was assigned to every window. Each of the 34 groupings contain low, moderate, high, and very high crash risk windows.

2.6 NETWORK SCREENING PRODUCTS

After performing network screening for on-system mainlanes, researchers developed Excel files and maps that show the results of the analysis. The two products are described below.

2.6.1 Data Tables

The network screening analysis was performed for approximately 806,000 windows that were divided into 34 different roadway groupings (Table 2). Because the total number of windows is high and the corresponding size of the files that contain the results is large, the review of the windows can be a challenging task for TxDOT districts. To facilitate the review process and make it more efficient, researchers extracted only the high and very high crash risk windows and saved them in an Excel format (Figure 29).



WIN_ID	S_DFO	E_DFO	DI	CO	HWY	RU_F_SYSTE	ADT_CUR	Shape_Leng	Crash_Cnt	CrashRate	CriticalRa	Cr_Rt_Crit	SitePtntlF	ProbFatalC	ExcessProp	CtotlNonRa	NUM_LANES	Group	PM1	PM2	PM3	PM4	PM5	PM6	AWR	Rank_AWR	Percent_AWR
13034	100.8581	101.1583	1	117	IH0030	R1	36224	482.80	3	0.076	0.043	0.032	-1.577	1.000	0.941	0.702	4	1H	10	19	19	6215	5	1	8.9	6262	0
18243	124.1916	124.4912	15	15	IH0037	R1	40559	482.80	3	0.068	0.041	0.027	-1.577	1.000	0.941	0.675	4	1H	10	22	23	6215	5	1	10	6259	0
5937	684.4471	684.7479	13	45	IH0010	R1	31587	482.80	3	0.087	0.047	0.040	-1.577	1.000	0.941	0.000	4	1H	10	6	6	6215	5	1	5	6264	0
18244	124.2915	124.4940	15	15	IH0037	R1	40559	326.46	3	0.068	0.041	0.027	-1.577	1.000	0.941	0.457	4	1H	10	22	23	6215	5	1	10	6259	0
13033	100.7581	101.0582	1	117	IH0030	R1	36224	482.80	3	0.076	0.043	0.032	-1.577	1.000	0.941	0.702	4	1H	10	19	19	6215	5	1	8.9	6262	0
5938	684.5474	684.8482	13	45	IH0010	R1	31587	482.80	3	0.087	0.047	0.040	-1.577	1.000	0.941	0.000	4	1H	10	6	6	6215	5	1	5	6264	0
18242	124.0918	124.3913	15	15	IH0037	R1	40559	482.80	3	0.068	0.041	0.027	-1.577	1.000	0.941	0.675	4	1H	10	22	23	6215	5	1	10	6259	0
2765	307.9906	308.2904	6	186	IH0010	R1	6670	482.80	2	0.274	0.130	0.144	-1.014	0.999	0.941	0.121	4	1L	23	20	20	15193	8	1	11.7	15425	0
1854	217.3446	217.6443	6	195	IH0010	R1	6214	482.80	2	0.294	0.137	0.157	-1.014	0.999	0.941	0.122	4	1L	23	9	9	15193	8	1	8.4	15427	0
1571	190.5117	190.8114	6	195	IH0010	R1	5206	482.80	2	0.351	0.156	0.195	-1.014	0.999	0.941	0.098	4	1L	23	4	6	15193	8	1	7.3	15430	0
3134	343.6160	343.9157	7	53	IH0010	R1	8490	482.80	2	0.215	0.109	0.106	-1.014	0.999	0.941	0.183	4	1L	23	35	35	15193	8	1	16.2	15416	0
4242	449.8450	450.1448	7	134	IH0010	R1	8407	482.80	2	0.217	0.110	0.107	-1.014	0.999	0.941	0.167	4	1L	23	28	28	15193	8	1	14.1	15420	0
3852	412.1721	412.4719	7	218	IH0010	R1	8436	482.80	2	0.217	0.110	0.107	-1.014	0.999	0.941	0.168	4	1L	23	31	31	15193	8	1	15	15418	0
1855	217.4445	217.7442	6	195	IH0010	R1	6214	482.80	2	0.294	0.137	0.157	-1.014	0.999	0.941	0.122	4	1L	23	9	9	15193	8	1	8.4	15427	0
1716	204.5343	204.8341	6	195	IH0010	R1	5178	482.80	2	0.353	0.157	0.196	-1.014	0.999	0.941	0.098	4	1L	23	3	5	15193	8	1	7	15431	0
3132	343.4161	343.7159	7	53	IH0010	R1	8490	482.80	2	0.215	0.109	0.106	-1.014	0.999	0.941	0.183	4	1L	23	35	35	15193	8	1	16.2	15416	0
3853	412.2720	412.5718	7	218	IH0010	R1	8436	482.80	2	0.217	0.110	0.107	-1.014	0.999	0.941	0.168	4	1L	23	31	31	15193	8	1	15	15418	0
598	99.2855	99.5852	24	116	IH0010	R1	8180	482.80	2	0.223	0.112	0.111	-1.014	0.999	0.941	0.000	4	1L	23	24	25	15193	8	1	13.1	15423	0
2764	307.8907	308.1905	6	186	IH0010	R1	6670	482.80	2	0.274	0.130	0.144	-1.014	0.999	0.941	0.121	4	1L	23	20	20	15193	8	1	11.7	15425	0
1853	217.2447	217.5445	6	195	IH0010	R1	6214	482.80	2	0.294	0.137	0.157	-1.014	0.999	0.941	0.122	4	1L	23	9	9	15193	8	1	8.4	15427	0
4241	449.7451	450.0448	7	134	IH0010	R1	8407	482.80	2	0.217	0.110	0.107	-1.014	0.999	0.941	0.167	4	1L	23	28	28	15193	8	1	14.1	15420	0
4160	441.6522	441.9519	7	134	IH0010	R1	8407	482.80	2	0.217	0.110	0.107	-1.014	0.999	0.941	0.167	4	1L	23	28	28	15193	8	1	14.1	15420	0
599	99.3854	99.6851	24	116	IH0010	R1	8180	482.80	2	0.223	0.112	0.111	-1.014	0.999	0.941	0.000	4	1L	23	24	25	15193	8	1	13.1	15423	0
11445	591.6824	591.9825	10	93	IH0020	R1	35614	482.80	5	0.128	0.044	0.084	-2.703	1.000	0.775	0.446	4	1H	1	1	1	6263	1	74	15.6	6255	0.001
15461	196.4700	196.7703	15	46	IH0035	R1	81546	482.80	4	0.045	0.029	0.016	-2.140	1.000	0.941	0.000	6	1H	4	139	40	6257	2	1	23.3	6252	0.001
20119	108.5879	108.8884	17	236	IH0045	R1	47282	482.80	3	0.058	0.038	0.020	-1.577	1.000	0.941	0.000	4	1H	10	51	32	6215	5	1	14.7	6256	0.001
20120	108.6880	108.9885	17	236	IH0045	R1	47282	482.80	3	0.058	0.038	0.020	-1.577	1.000	0.941	0.000	4	1H	10	51	32	6215	5	1	14.7	6256	0.001
17064	30.2258	30.5267	2	127	IH0035W	R1	47663	482.80	5	0.096	0.037	0.058	-2.703	1.000	0.741	0.000	4	1H	1	4	4	6263	4	75	17.9	6254	0.001
15460	196.4700	196.6702	15	46	IH0035	R1	81546	321.87	4	0.045	0.029	0.016	-2.140	1.000	0.941	0.000	6	1H	4	139	40	6257	2	1	23.3	6252	0.001
20121	108.7882	109.0887	17	236	IH0045	R1	47282	482.80	3	0.058	0.038	0.020	-1.577	1.000	0.941	0.000	4	1H	10	51	32	6215	5	1	14.7	6256	0.001
12323	63.2612	63.5612	5	219	IH0027	R1	8622	482.80	2	0.212	0.108	0.104	-1.014	0.999	0.941	0.183	4	1L	23	37	38	15193	8	1	17	15414	0.001
447	84.7179	85.0176	24	116	IH0010	R1	10586	482.80	2	0.173	0.093	0.079	-1.014	0.999	0.941	0.000	4	1L	23	80	55	15193	8	1	24.7	15404	0.001

Figure 29. Example of Network Screening Results.

Table 7 shows the attributes of each window included in the Excel spreadsheets.

Table 7. Attributes Included in Network Screening Spreadsheet.

• Highway Name • Start DFO • End DFO • Number of Lanes • District Number • County Number • Roadway Grouping • Roadway Functional Class • ADT • Window Length • PM1 (Average Crash Frequency) • Rank by PM1 • PM2 (Crash Rate) • Rank by PM2 • PM3 (Critical rate) • Rank by PM3	• PM4 (Excess Predicted Average Crash Frequency using Method of Moments) • Rank by PM4 • PM5 (Probability of Specific Crash Types Exceeding Threshold Proportion) • Rank by PM5 • PM6 (Excess Proportion of Specific Crash Types) • Rank by PM6 • PM7 (Excess Predicted Average Crash Frequency Using SPFs) • Rank by PM7 • Adjusted Weighted Rank • Rank by AWR • Percent Adjusted Weighted Rank

These attributes were extracted from RHiNo and account for KA crash data. TxDOT can use some of these attributes to further explore the results and perform additional analysis, if needed.

2.6.2 Maps

Using the network screening results, researchers developed maps in both shapefile and Google Earth® (GE) formats. The map shown in Figure 30 displays the high crash risk (PAWR=5–15 percent) windows in yellow and the very high crash risk (PAWR=0–5 percent) windows in red.

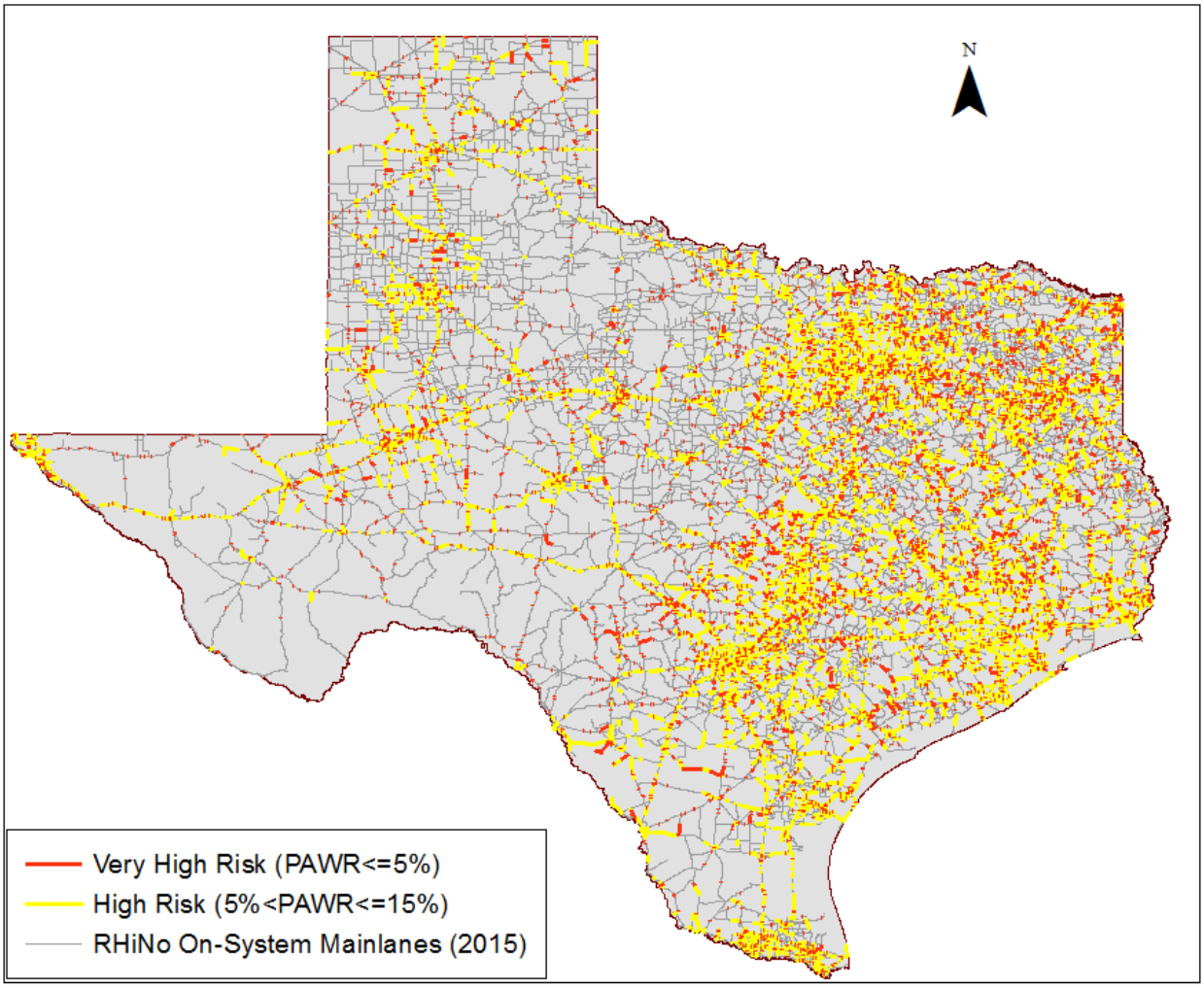


Figure 30. High Risk and Very High Risk Windows.

Separate GE layers were developed for each TxDOT district. The layers can be displayed in the background while TxDOT staff review the CAVS data to identify HSIP projects. The combined use of both types of layers (network screening and CAVS data) can better inform the HSIP project selection process and make it more efficient.

CHAPTER 3:
CRASH ANALYSIS AND VISUALIZATION PRODUCTS

3.1 INTRODUCTION

This chapter presents the CAVS products that can be used to enhance the diagnosis and countermeasure selection processes at TxDOT (see Figure 1). The purpose of the diagnosis process is to develop a basic understanding of crash patterns, causes of collisions, and existing roadway characteristics at high risk sites that were identified from network screening. The knowledge gained from diagnostic activities can be used as the foundation for selecting appropriate countermeasures that have the greatest potential to address the safety problems and concerns at each site examined.

For several years, TxDOT staff used spreadsheets and other simple tools to diagnose safety problems, identify appropriate countermeasures, and select candidate HSIP projects. As safety assessment methods evolve and more agencies have started to use new modern tools, there was a need to incorporate new elements into TxDOT's HSIP, so as to improve and streamline the diagnosis and countermeasure selection processes described above. Further, there was a need to ensure that all participating TxDOT districts had access to the same CAVS tools.

To address these needs, TxDOT research project 0-6912 developed a basic CAVS process and preliminary visualization products to assist TxDOT districts in identifying candidate HSIP projects. Figure 31 shows the 0-6912 CAVS process. The main functionality of these preliminary products was to display crash data and crash locations where certain types of safety countermeasures or work codes (WCs) can be implemented. After using the preliminary CAVS products, TxDOT district officials reported several benefits. The amount of time and resources needed to complete project identification activities decreased on average by 20–50 percent compared to previous years (*4*). Further, the total number of projects submitted by all districts to the 2017 HSIP increased by 57 percent compared to those submitted in the 2013 HSIP (*4*).

Considering the benefits realized by TxDOT districts from the use of the 0-6912 preliminary CAVS products, TxDOT project 5-6912 aimed to further improve and implement the CAVS products in the 2018 HSIP.

3.2 CAVS TOOL

The 0-6912 basic CAVS process shown in Figure 31 involved processing and analyzing crash and roadway data in Microsoft Office Excel and ArcGIS. Though researchers had automated several steps of the process by creating ArcGIS tools and models, the development of the 0-6912 preliminary CAVS products (4,050 files in total) that were used in the 2017 HSIP required six to eight hours. Further, updating the process and tools by deleting old WCs and adding new WCs required additional time.

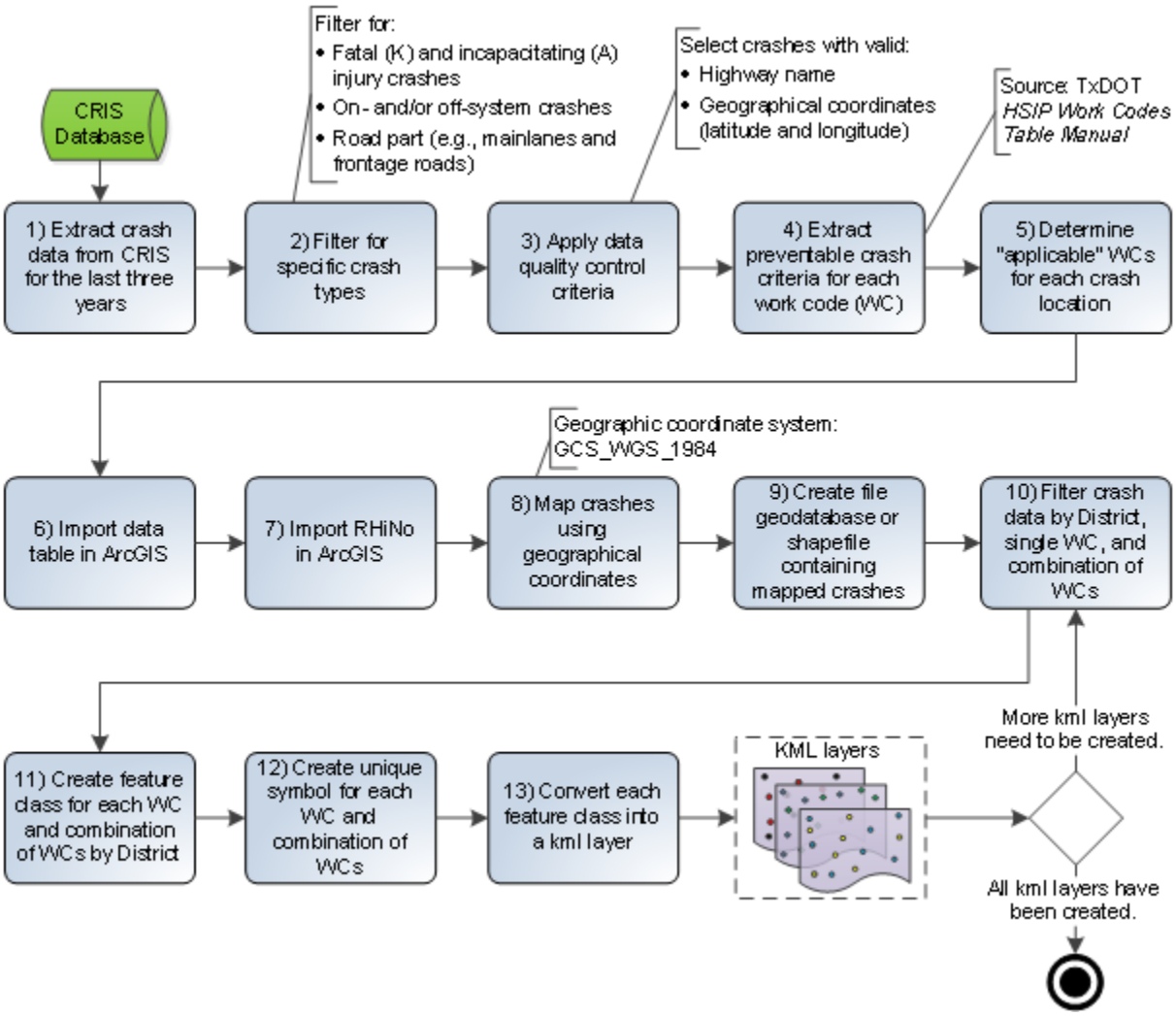


Figure 31. Basic 0-6912 CAVS Process (*4*).

The CAVS products have been diversely used over the last few years by both TxDOT and the Texas A&M Transportation Institute (TTI) not only to select HSIP projects, but to support various functions and analyses that involve safety diagnostic activities, selection of countermeasures, and safety effectiveness evaluations of implemented projects. Because of the wide use of the CAVS products by different users and for various purposes, one researcher objective was to make the development of the CAVS products more efficient to be able to respond to potential requests for CAVS data in a timely manner. Another objective was to incorporate filtering criteria in the development process so that CAVS products could be tailored to specific user needs and preferences easily and efficiently. To address these objectives, researchers developed through a different initiative a windows application that is shown in Figure 32.

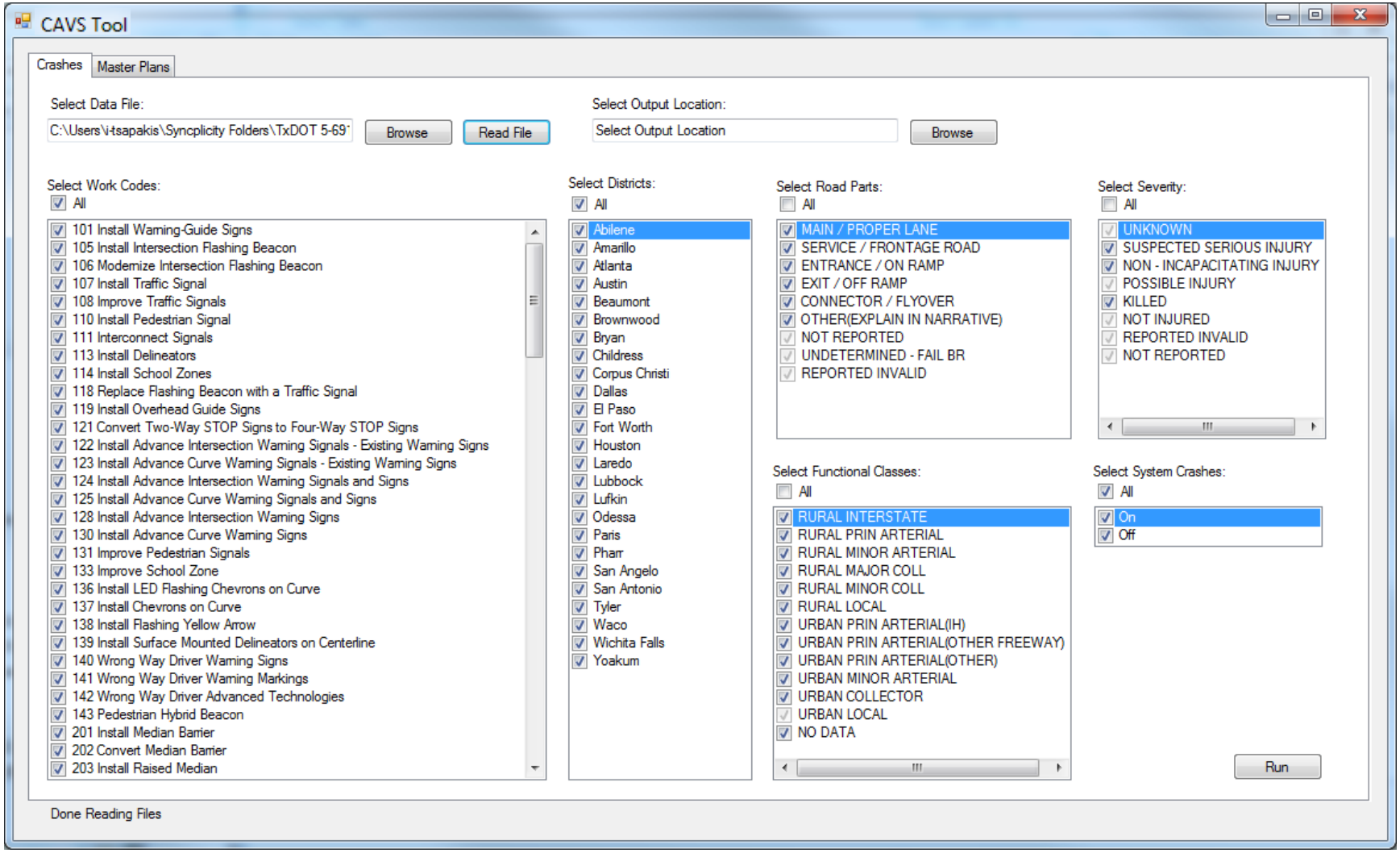


Figure 32. Screenshot of CAVS Tool.

TTI used this application to develop CAVS products for all 25 TxDOT districts as part of the 2018 HSIP call. To use the CAVS Tool, analysts have to follow the steps described below:

- **Step 1** – Extract crash data from CRIS for the analysis period. The data are saved in an Excel file. The Excel file must have specific structure and contain the following crash attributes: Crash ID, Crash Severity, TxDOT District, County, Highway, Control Section, Milepoint, DFO, Year, Date, Latitude, Longitude, Functional System, On System Flag, Bridge Detail, Surface Condition, Weather Condition, Light Condition, Road Part, Manner of Collision, First Harmful Event, Object Struck, Roadway Related, Intersection Related, Crash Contributing Factor List, Vehicle Unit Number, and Vehicle Direction of Travel.

  These attributes are used to determine whether the preventable crash criteria of each WC are met given the conditions and characteristics of every crash included in the Excel file. The preventable crash criteria of each WC are provided in TxDOT *HSIP Work Codes Table* (*10*). To accelerate the data extraction process, researchers developed and saved a data extraction report in MicroStrategy. Whenever crash data need to be extracted, TTI members, who have access to MicroStrategy, modify the period for which data are needed and run the report.

- **Step 2** – Import the Excel file using the Browse button shown at the top left of Figure 32.

- **Step 3** – Select a location to save the produced CAVS folders and files using the Browse button shown at the top center of Figure 32.

- **Step 4** – Apply filtering criteria that include:

  - Work Codes – The tool includes a series of single WCs and combinations of WCs. CAVS products will be developed only for the WCs selected by the user.

  - Districts – The tool includes a list of all 25 TxDOT districts. CAVS products will be developed only for the districts selected by the user.

  - Road Part – The tool includes a list of 12 different road parts that are included in CRIS. These road parts are shown in Figure 32. CAVS products will be developed only for the road parts selected by the user.

  - Functional Class – The tool includes a list of roadway functional classes divided by rural/urban designation. CAVS products will be developed only for the functional classes selected by the user.

  - Crash Severity – The tool includes all crash severities that are available in CRIS. CAVS products will be developed only for the crash severities selected by the user.

  - Road System – Users have the option to select whether they would like CAVS products to be developed for on-system crashes, off-system crashes, or both.

- **Step 5** – Press the Run button shown at the bottom right of Figure 32.

- **Step 6** – Press the OK button in a new window that appears (Figure 33) to open the folder that contains the produced CAVS products. The pop-up window shown in Figure 33 notifies the user that the analysis has been completed. The message also shows the total run time of the analysis. In this example, the development of 3,425 files (=137 files * 25 districts) was completed in 2 minutes and 23 seconds.

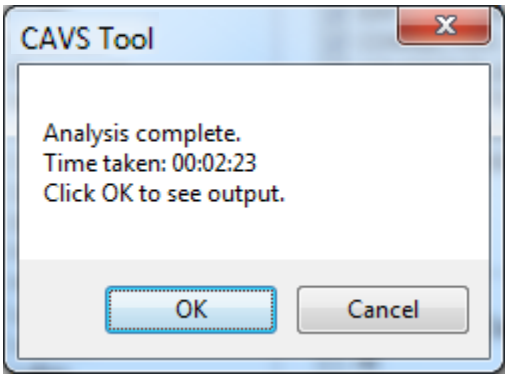


Figure 33. Output Message of CAVS Tool.

The CAVS products are described in the next section.

3.3 CAVS PRODUCTS

The CAVS products mainly include GE layers (kml format) and Excel files that contain crash data. The products developed during the 2018 HSIP call were organized by TxDOT district in separate folders. Figure 34 shows the parent folder that contains the CAVS products developed for on-system crashes. Separate folders contained the CAVS products for off-system crashes.

As shown in Figure 34, the parent folder contains a text document called Selection Criteria and 25 subfolders—one subfolder for each district. The text document stores the user's selection criteria based on which CAVS products were developed. In other words, the text file lists the selected WC(s), TxDOT districts, road part(s), functional class(-es), crash severity(-ies), and road system(s).

Each district subfolder contains several GE layers and one Excel file. These products are separately described in the two subsections that follow.

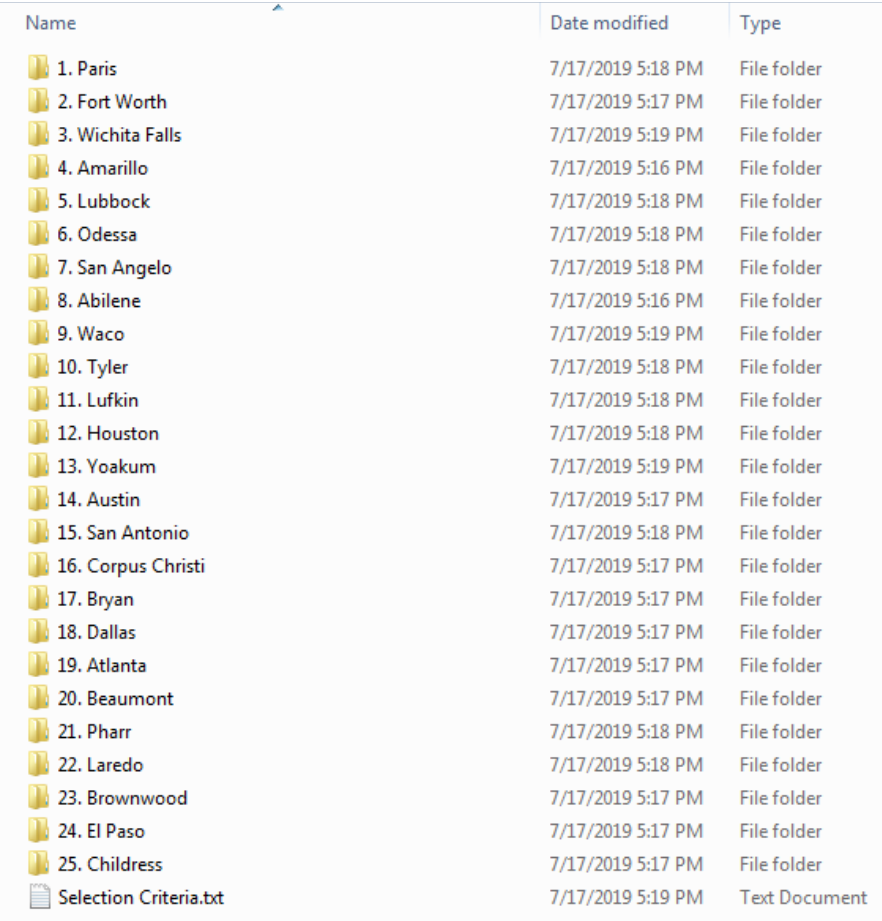


Figure 34. Parent Folder Containing CAVS Products.

3.3.1 GE Layers

For the 2018 HSIP call, TTI developed separately for each TxDOT district a set of 137 kml layers for on-system crashes and another set of 137 kml layers for off-system crashes. The layers in each set can be grouped as follows:

- Layers displaying crashes by applicable WC(s):
    - 76 layers – Each layer displays the KA crashes that meet the preventable crash criteria of a single work code (or countermeasure). In other words, this WC could in theory prevent the types of KA crashes included in the layer. For example, Figure 35 shows KA crashes that occurred in the Fort Worth District. In theory, these crashes could have been avoided if warning guide signs (work code *101 Install Warning Guide Signs*) had been installed. However, in the absence of a comprehensive roadway/roadside infrastructure data inventory at TxDOT, the preventable crash criteria of each WC do not account for the existence or absence of a particular countermeasure at each crash location. Users need to identify whether the countermeasure of interest (e.g., warning guide signs in the example above) actually exists at the subject sites.

    - 52 layers – Each layer displays the KA crashes that meet the preventable crash criteria of multiple work codes (or countermeasures). Similar to the 76 layers described above, each layer shows the locations of KA crashes that (in theory) could have been prevented if the countermeasures of interest had been implemented.

- Layers displaying crashes by crash severity:
    - A layer that shows all fatal (K) crashes within a district.
    - A layer that shows all suspected serious injury (A) crashes within a district.
    - A layer that shows all non-incapacitating injury (B) crashes within a district.
- Layers displaying crashes by road part:
    - A layer that shows all KA crashes that occurred on mainlanes within a district.
    - A layer that shows all KA crashes that occurred on connectors-flyovers within a district.
    - A layer that shows all KA crashes that occurred on entrance-exit ramps within a district.
    - A layer that shows all KA crashes that occurred on frontage roads within a district.
    - A layer that shows all KA crashes that occurred on other road parts within a district.

These layers can be overlaid with the first group of layers to identify crashes that happened on a particular road part in which users may be interested. This is particularly useful in the case of frontage road crashes that are often snapped on the centerline of a road making the distinction between frontage road crashes and mainlane crashes challenging. These layers help overcome this issue.

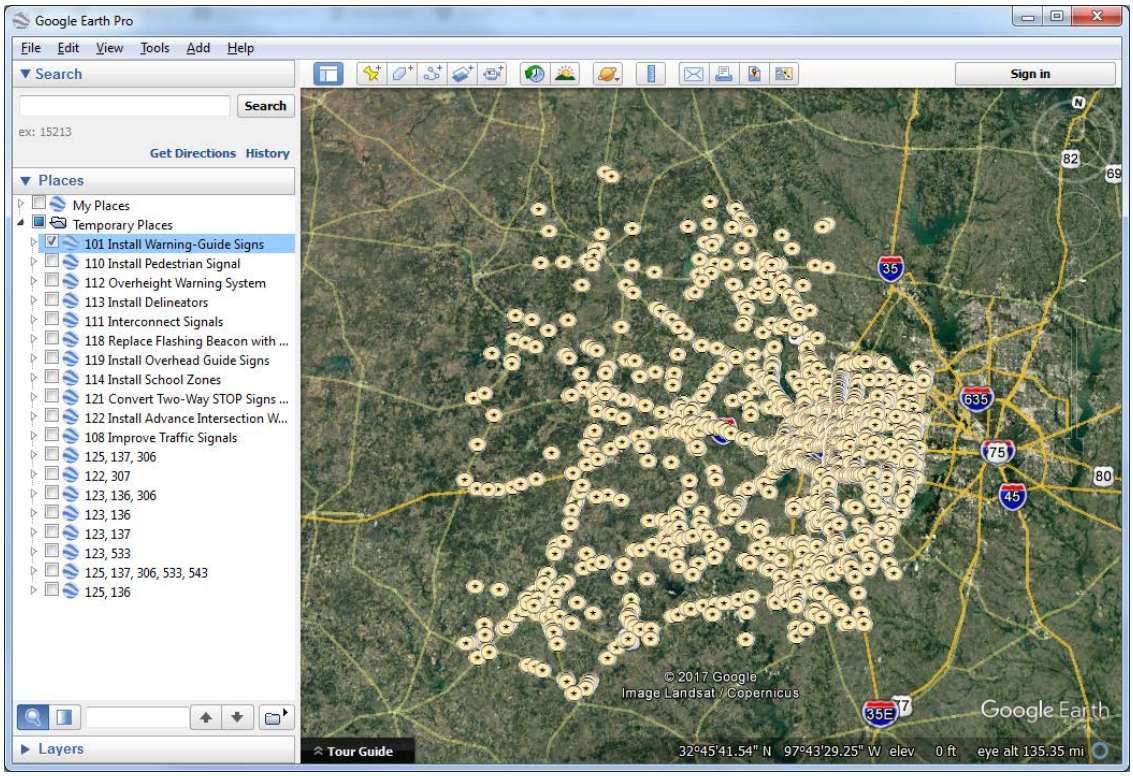


Figure 35. GE Layer – Work Code 101 Install Warning Guide Signs (Fort Worth District).

In coordination with TxDOT, TTI selected to develop kml layers mainly because GE offers a multitude of tools that can be used to perform many activities that are involved in the diagnosis and countermeasure selection processes. The main reasons for developing GE layers are provided below:

- Provide panoramic 360° view of roadways (i.e., Google street view) and the surroundings. Although street view cannot replace actual field visits and observations, it can be used, under certain circumstances, to identify what countermeasures have already been implemented and perform relevant diagnostic activities such as determining:
  - Geometric design characteristics.
  - Roadway and roadside characteristics (e.g., signs, signals, ITS, lighting, sight distances).
  - Pavement conditions.
  - Traffic access control characteristics.
  - Roadway consistency.
  - Land uses.
  - Evidence of problems (skid marks, damaged roadside objects).

- Allow users not only to visualize locations of point and line features, but open and see the attribute table of each feature contained in a layer. This functionality enables users to easily find crash- and roadway-specific data (i.e., data contained in a crash report or in the RHiNo database) that otherwise requires engineers to use other platforms to access this information, hence spend more time in gathering data. Figure 36 shows four zoomed-in views of a crash attribute table that is displayed after clicking on a crash point in the layer (work code 101) shown in Figure 35.

  The tables contain crash attributes (Figure 36a and Figure 36b) and indicates whether the preventable crash criteria of single work codes (Figure 36a, Figure 36b, and Figure 36c) and combinations of work codes (Figure 36c and Figure 36d) are met. The table provides both a short description (e.g., dry) and the corresponding CRIS numeric code (e.g., 1) for 22 crash attributes (e.g., surface condition).

- Provide secure and easy access to crash reports. The attribute table of each crash contains a URL link (Figure 36a) that opens the police report prepared for every crash and uploaded to CRIS. Users are allowed to access these reports after they log into the CRIS website using their credentials, if available. The crash reports are often used to review information and data that are not contained in the attribute tables of GE layers. For example, some of the information that is typically used for diagnostic purposes include but is not limited to, number and type of vehicles involved, speed limit, intersecting road, investigator's narrative opinion of what happened in the crash scene, and field diagram of the crash. Figure 37 shows an example of a field diagram provided in a crash report.

- Offer a user-friendly interface that does not require advanced knowledge in geographic information systems and computer programming. TxDOT district and area office staff have been using GE for several years and are familiar with the functionality and the tools of the software. This minimized the need for providing extensive training to end users.

- Allow short render-times without requiring significant computational and memory resources.

- Provide a ruler that can be used to measure roadway characteristics (e.g., road width, lane width, shoulder width). This tool proved to be useful for determining narrow roads and assessing the applicability of countermeasures that involve roadway widening.

- Provide tools that allow users to customize the symbology of the layers and add point and line features, as needed.

- Provide the ability to view layers on any device such as smartphone, tablet, laptop, and desktop.

- Allow users to view GE layers without having to purchase expensive and proprietary software.

- Provide the ability to show historical imagery that is useful for reviewing past roadway/roadside conditions and geometric configurations.

- Provide a search tool that can be used to easily find and zoom into roads of interest.

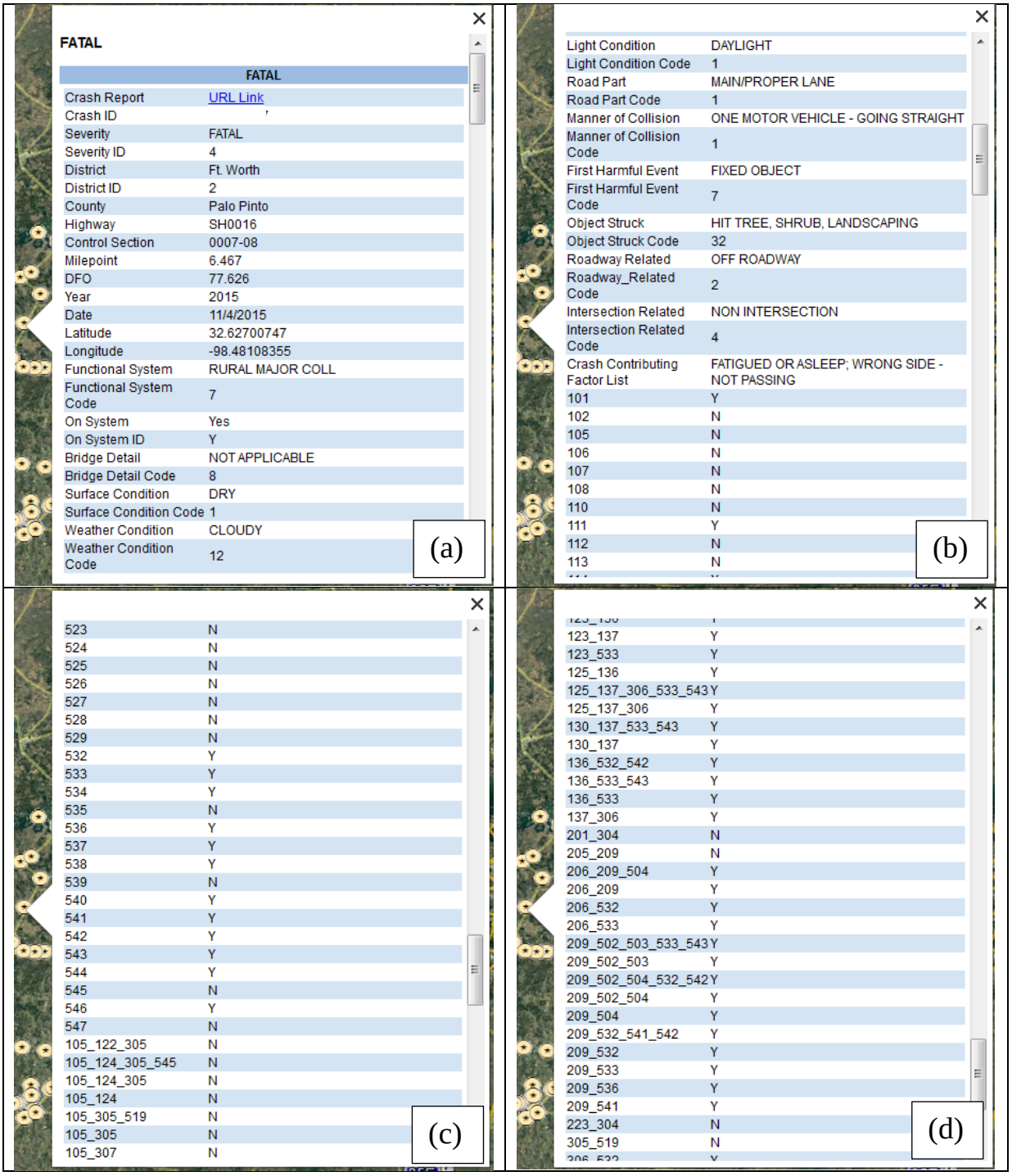


Figure 36. Zoomed-in Views of a Crash Attribute Table Displayed in a GE Layer.

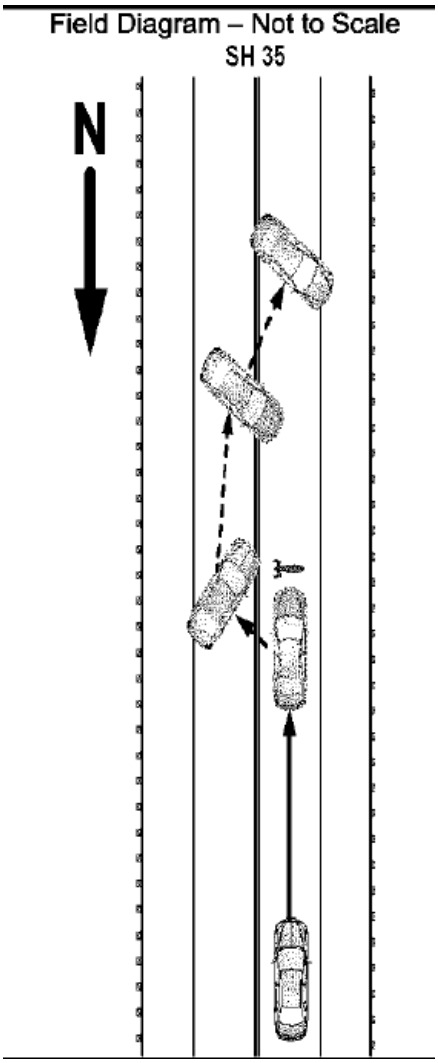


Figure 37. Example of a Field Diagram Included in a Crash Report.

3.3.2 Excel Files

Each district subfolder includes an Excel file that contains data for all KAB crashes that occurred within a district during the analysis period. The Excel file allows users to further review and process crash data and develop charts, graphs, summary tables, and other aggregate statistics that may be useful in the diagnosis process.

Each line within these spreadsheets contains data for a single crash. The data included the crash attributes shown in Figure 36 (one attribute per column) and 130 additional columns that correspond to work codes. Each of the 130 columns indicated with a Y (i.e., yes) or N (i.e., no) whether the preventable crash criteria of every single WC and combination of WCs were met.

3.4 EFFECTIVENESS OF CAVS PRODUCTS

TTI has been assisting various TxDOT districts with the HSIP project selection process over the last four years. In the context of the 2014 HSIP, TTI assisted the Corpus Christi District to

develop a small number of simple PDF maps and layers that had limited functionality compared to the CAVS products. The use of these basic informational products proved beneficial for the district. Note that the district relied on the use of spreadsheets prior to 2014. The main benefits realized from the use of these basic maps and layers during the 2014 HSIP are summarized below:

- 129 percent increase in the average safety improvement index (SII) of the projects awarded. This is the most important benefit as the increased SII values of the projects funded are indicative of possible reduction in the number of crashes resulting in significant cost savings.

- 198 percent and 385 percent increase in the number of projects submitted and awarded, respectively.

- Reduced time and effort to complete the project identification process by 30–40 percent.

Following the Corpus Christi example, more districts employed similar visualization tools and techniques to enhance the safety project selection process as part of the 2015 HSIP. Similar to the benefits stated above, many district officials reported relevant improvements such as increase in the number of candidate projects identified and decrease in the time and effort required to select candidate projects.

In 2016, TTI developed and disseminated a series of preliminary CAVS products (as described earlier) to all TxDOT districts that participate in the program. This allowed the creation of a level playing field within TxDOT's HSIP and also provided the opportunity to test these preliminary products statewide and identify potential shortcomings and areas for improvement. Upon completion of the 2016 HSIP, the Traffic Operations (TRF) Division received 1,394 candidate projects from all TxDOT districts. That is an increase of about 31 percent (Table 8) over the total number of projects (1,067) submitted to the 2013 HSIP, when districts used spreadsheets or their own visualization products to select candidate HSIP projects. Table 8 does not show data from the 2014 and 2015 HSIPs, because a small number of districts had already started to use preliminary CAVS products during these two years.

Table 8. Improvement Achieved Before and After Using CAVS Products Statewide.

HSIP Year*	Total Number of Projects Submitted	Improvement
2013 HSIP (Before)	1,067	-
2016 HSIP (After)	1,394	30.6% ↑
2017 HSIP (After)	1,680	57.5% ↑
2018 HSIP (After)	1,434	34.4% ↑

* Data from the 2014 and 2015 HSIPs are not included because some districts used the CAVS products during these two years.

Further, at a peer exchange conducted in June 2016, district officials reported that the amount of time and resources needed to complete project identification activities decreased on average by 20–50 percent compared to previous years. Peer exchange participants also provided ideas for improving the CAVS products. Based on the positive experience and feedback received from district officials, TTI modified the CAVS process accordingly and provided improved CAVS products to all TxDOT districts as part of the 2017 HSIP. The total number of projects (1,680) submitted by all districts to the 2017 HSIP increased by 57 percent compared to those submitted in the 2013 HSIP (Table 8). Following the 2017 HSIP, TTI made additional improvements to the CAVS process and products and developed them as part of the 2018 HSIP call. The total number of projects (1,434) submitted by all districts to the 2018 HSIP increased by 34 percent compared to those submitted in the 2013 HSIP (Table 8).

CHAPTER 4:
SYNOPSIS AND RECOMMENDATIONS

4.1 SYNOPSIS

Several transportation agencies, including TxDOT, continuously try to find ways to improve their HSIP. Over the last few years, emphasis has been placed on employing advanced safety predictive methods and tools. In 2016, TxDOT funded research project 0-6912 that tailored HSM's cyclical process to TxDOT needs, objectives, and HSIP requirements and used it as a general framework to develop: a) a network screening process for roadway segments, b) preliminary CAVS products to support the HSIP project selection process, and c) a project prioritization tool (*4*). Based on the benefits realized from the use of the 0-6912 network screening and CAVS products, TxDOT funded implementation project 5-6912 to:

- Develop a network screening tool that incorporates the 0-6912 network screening process for roadway segments.
- Improve the CAVS process and products and implement them to support the diagnosis and countermeasure selection processes during the 2018 HSIP call.

The data-driven network screening tool developed in this project automatically scans all on-system mainlane roadway segments using the sliding window method. According to HSM, this is the most appropriate method to screen segments (*3*). In this method, a window of a certain length (e.g., 0.3 miles) is conceptually moved along a roadway segment from one end to another at specified increments (e.g., 0.1 miles). Seven safety performance measures are calculated for each position of the window:

- PM1: Crash Frequency.
- PM2: Crash Rate.
- PM3: Critical Rate.
- PM4: Excess Predicted Average Crash Frequency Using Method of Moments.
- PM5: Probability of Specific Crash Types Exceeding Threshold Proportion.
- PM6: Excess Proportion of Specific Crash Types.
- PM7: Excess Predicted Average Crash Frequency Using SPFs.

After scanning the entire network, the sites can be ranked based on one or multiple performance measures. The goal is to further review the sites with the highest crash risk, determine potential crash patterns, understand causes of crashes and risk factors, identify safety problems, and select appropriate countermeasures that can mitigate the safety issues at each site.

The CAVS products can help TxDOT staff perform some of these diagnostic activities and select candidate HSIP projects. The CAVS products mainly include GE layers and Excel files. The GE layers display crashes by applicable WC(s), crash severity, and road part (e.g., mainlane, frontage roads, ramps). The Excel files include all crash data along with all single WCs and combinations of WCs that can theoretically prevent each observed crash.

Preliminary versions of CAVS products were used during the 2016 and 2017 HSIP calls. Researchers improved the CAVS process and products and developed them for all 25 districts to support the diagnosis and countermeasure selection processes during the 2018 HSIP call. The use of the CAVS products over the last three HSIP calls (2016–2018) showed that TxDOT districts were able to identify and submit more candidate HSIP projects easier and more efficiently compared to previous years when districts did not use CAVS products. Specifically, the total number of candidate projects submitted by all districts to the 2016, 2017, and 2018 HSIPs increased by 31 percent (1,394 projects), 57 percent (1,680 projects), and 34 percent (1,434 projects), respectively, compared to the 2013 HSIP (1,067 projects) when districts did not use the CAVS products. Further, district officials reported a reduction in the time and effort required to select candidate projects by 20–50 percent.

4.2 RECOMMENDATIONS

Researchers developed the following recommendations for implementation at TxDOT:

- **Incorporate network screening process into HSIP**. TxDOT should consider making the network screening process a standard practice in its HSIP and other functions that require identification of hot-spot locations. One potential strategy for further consideration would be to allocate a specific percent of the HSIP funds to construct safety improvement projects at high-risk locations identified through network screening analysis. A similar strategy would be to award a specific percent or number of HSIP projects to improve these high-risk sites. In both strategies, TxDOT would perform network screening and identify the sites that have the highest potential to realize a reduction in the number and severity of serious injury crashes. For the selected sites (e.g., top 1 percent), the TRF Division could request districts to identify and submit HSIP projects. Incorporating advanced safety performance measures and data-driven systemic safety analyses into the program can minimize, to the extent possible, dependence on human discretion, the effects of RTM, and retrospective examination of historical crash data. Crash predictive methods will allow TxDOT to apply safety funds in places with the greatest potential to reduce fatal and serious injury crashes.

- **Implement network screening for segments**. TxDOT should conduct a statewide implementation of segment network screening to support its HSIP. The network screening tool developed in this project can be used to perform network screening analysis. The network screening products should be tested by all TxDOT districts and modified, if necessary, based on districts' feedback. The products should be used along with the CAVS layers and data to improve the project identification process at TxDOT.

- **Incorporate CAVS process and products into HSIP and other safety-related business processes and practices**. The CAVS products have already been tested by

districts during the last three HSIP calls, while some districts have been using them since 2014. Based on the positive feedback received from district and area office staff and the benefits realized from the use of these products, TxDOT should consider developing the CAVS products not only to support its HSIP but also other relevant activities and programs that involve reviewing crashes, identifying contributing factors, and selecting countermeasures. With that said, the CAVS products should be developed multiple times throughout a year (e.g., quarterly) to support various functions at the division, district, and area office levels. Overall, developing and providing all districts with the same tools and products will make the project selection process more efficient, create a level-playing field within the HSIP, and increase district participation in the program.

- **Incorporate HSM roadway safety management process into HSIP**. TxDOT should adopt the HSM general safety management process presented in Chapter 1. It encompasses a series of rigorous safety assessment methods and tools that can make current TxDOT processes and practices more efficient and effective. The framework can be included in TxDOT's *HSIP Manual* and in relevant HSIP documents that are typically published every year when the HSIP call is issued.

- **Develop intersection inventory**. TxDOT should geolocate all intersections in the state and develop a comprehensive intersection database. The database should include, at a minimum, the Model Inventory of Roadway Elements – Fundamental Data Elements, as well as other attributes that can be used to support network screening for intersections, safety effectiveness evaluations, and intersection-related safety analysis. Data should be separately collected for each approach of an intersection.

- **Provide training on the use of the 5-6912 project deliverables**. The TRF Division should provide training to district and area office staff on how to use the network screening and CAVS products.

- **Assess the need for calibrating existing SPFs and develop new SPFs**. TxDOT's *Roadway Safety Design Workbook* does not provide SPFs for all types of roads. The SPFs were developed several years ago and can be used to predict only KAB and possible injury crashes. TxDOT should validate the accuracy of existing SPFs and assess the need for calibrating them. In addition, there is a need to develop new SPFs for use in network screening. SPFs that predict KAB crashes would be in line with the HSIP goal.

- **Assess the need for collecting more roadway inventory and other types of data**. RHiNo has limited roadway inventory and ADT data for certain road parts such as ramps, U-turns/turnarounds, connectors, and off-system roads. Further, it does not contain some data attributes (e.g., number of driveways, land use, curb miles) that are required to calculate some SPFs included in TxDOT's *Roadway Safety Design Workbook*. If TxDOT selects to calibrate and use existing SPFs, additional data need to be collected. If new SPFs are developed for Texas, TxDOT needs to assess whether existing RHiNo data attributes can fully support the calculation of the new SPFs or additional data need to be collected.

- **Update process of geolocating frontage road crashes in CRIS**. It is difficult to determine whether a crash happened on the left or the right frontage road using existing crash coordinates stored in CRIS. There is a need to update the process of geolocating frontage road crashes and generating their geographic coordinates that are stored in CRIS. TxDOT should make necessary changes to this process so that frontage road crashes are mapped to the centerline of the correct (right or left) frontage road, not the centerline of mainlanes.

- **Save the version of RHiNo that is used to determine the DFO of each crash in CRIS**. CRIS does not currently store the version of RHiNo that was used to extract the DFO of each crash. As DFOs may change along a route from one RHiNo version to the next, mapping crashes on the incorrect version of RHiNo may result in inaccurate crash locations that can affect the reliability and accuracy of network analysis. A potential strategy to address this challenge is to store in a new CRIS data attribute (e.g., [DFO_RHiNo_Year]) the version or year of RHiNo that is used to determine the DFO of each crash.

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