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16. ABSTRACT

This research study developed performance indices or metrics, for difficulty as well as risk of a collision in performing maintenance operations associated with roadside features. Maintenance activities associated with roadside features are classified, and a Difficulty Index and a Collision Risk Index are developed. These two indices can be computed for each work order based on parameters that were identified after considering a large dataset as well as results of a survey from relevant Caltrans personnel. The results and the indices developed can enable Caltrans personnel to use objective data and measures for decision-making in planning and scheduling a maintenance operation. The results can also be used in allocating resources in terms of personnel and equipment, considering additional safety measures, and deciding if and what type of lane closure is necessary in order to reduce the risk of collision and injury potential to personnel and roadside workers.

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Research to Develop Performance Measures for Maintenance of Roadside Features

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Report Number: CA21-3289

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Division of Research, Innovation and System Information

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EXECUTIVE SUMMARY

Problem, Need, and Purpose of Research

Maintenance of roadside features can expose Caltrans workers to live traffic, increasing their safety risks. Furthermore, maintenance of certain features can be more difficult, requiring more time and increasing the potential time exposure of workers to traffic and roadway hazards. At present, there is no quantitative method of assessing the difficulty of maintaining such features and the safety risks of such operations. The purpose of this research project was to address the following research questions:

- Can using the data that is available in different data sources and the literature provide a basis to develop a simple metric or metrics to assess the difficulty of maintenance operations associated with roadside features?
- Can such data be used to develop risk indices that can assess the hazard risks to the workers performing such maintenance operations?

The overall goal was to be able to prioritize certain classes of maintenance operations based on their difficulty as well as on the injury or hazard risks from live traffic to the workers performing such operations. The expected outcome includes improved safety and increased efficiency in the planning and scheduling of maintenance operations.

Background

This work is in response to a need outlined by Caltrans related to evaluating the development of performance indices or metrics, for difficulty or risk of performing maintenance operations associated with roadside features. This need was identified after the completion of a first phase study that identified roadside features where maintenance workers are exposed to more time near live traffic or that their maintenance effort can be reduced due to re-design or policy modifications.

Two of Caltrans' stated goals are:

- Safety and Health: To provide a safe transportation system for workers and users; to promote health through active transportation; and to reduce pollution in communities.
- Stewardship and Efficiency: "Money counts"; to responsibly mange California's transportation-related assets.

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Development of proper performance measures for maintenance of roadside features is consistent with and positively affects both the safety and efficiency goals of Caltrans. It will improve the safety of highway workers, as well as the efficiency of operations, by providing metrics to properly prioritize, schedule, and plan relevant maintenance tasks based on performance measures that would improve safety and efficiency of operations.

Overview of the Work and Methodology

The work performed in this research study involved utilizing a systematic approach using available data sources combined with the experience base of Caltrans personnel and application of methods from data-science involving developing data pipelines for data reconciliation. The methodology and the research approach used consisted of five tasks, as depicted in Figure i.1.

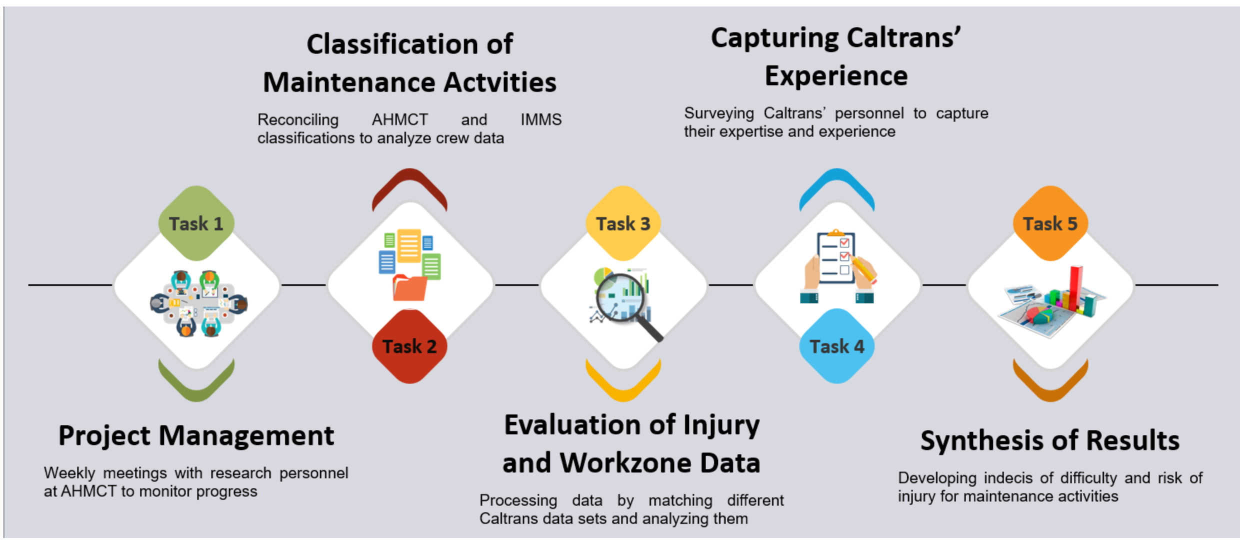

Figure i.1: Research approach and tasks

The first task in the research approach involved integrating Caltrans customers as part of project management through a project panel to guide the research. Task 2 involved the classification of maintenance activities associated with roadside features. The results were then combined in Tasks 3 and 4, with data obtained through data harvesting from available sources and a survey of Caltrans maintenance personnel. The information captured through data pipelines was then analyzed using data synthesis to develop a metric for difficulty index in performing a relevant maintenance task, as well as a metric for measuring injury risk to workers when performing such tasks.

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Major Results

The major results of this research study include:

1. Classification of certain maintenance activities associated with roadside features.
2. Determination of factors that are most significant in the difficulty of performing these maintenance activities.
3. Determination of factors that are most significant in the risk of collisions and potential hazards to highway workers.
4. Recommendations in the form of metrics or indices for assessing the level of difficulty and risk of hazards in performing maintenance or installation operations.

The result of this work enables Caltrans personnel to use objective data and measures for decision-making in planning and scheduling a maintenance operation. The results can also be used in allocating resources in terms of personnel and equipment, considering additional safety measures, and deciding what type of lane closure (if any) is necessary in order to reduce the risk of injury to its personnel and roadside workers.

The maintenance functions considered are listed in Table i.1.

Table i.1: Maintenance functions evaluated

Maintenance function
Pavement repair (crack sealing, patching, and slab replacement, etc.)
Guardrail repair, shoulder repair, sink hole repair, etc.
Litter, Debris, and Graffiti removal
Road Sweeping
Sign Installation and repair
Pavement striping and marking
Landscaping-Vegetation control
Landscaping – tree pruning
Landscaping - tree removal
Landscaping - fire hazard reduction
Landscaping - erosion protection
Landscaping - avalanche control system
Irrigation repair (Irrigation valve, lateral line repair, controller wires, etc.)
Snow removal and control
Traffic Control
Rock blasting
Bridge repair, structural steel painting, bracing, and temporary bridge installation
Culvert and drain cleaning
Hazardous spill cleaning
Storm damage and emergency incidents
Public facilities maintenance including safety roadside rest areas, weigh stations, park and ride lots, and vista points, etc.
Tunnels, tubes, and pumping plants maintenance

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These maintenance functions were mapped into the Integrated Maintenance Manual System (IMMS) and were classified based on five categories: lane closure requirements, crew size, site access difficulty, time duration, and mile length of operation. The results for the top ten maintenance activities in each of these categories are listed in Table i.2. Each column in this table has the top ten maintenance activities with either the highest or the longest of the five categories.

Table i.2: A classification of maintenance activities

(Note: Maint. Stands for Maintenance)

Top 10 activities with the highest proportion of lane closure

Activity	Description
C95040	Test/sample manhole
F20050	Maintenance site corrective measure
F50003	Eval/develop de-icing criteria
F80201	Oversight drain clean contract
F80003	Sampling and testing contract
F80002	Drainage contract
B30010	Sub seal/jack slab rigid pavement
YD0000	Work for others d family
F30220	Construction compliance inspection
YA0000	Work for others a family

Top 10 activities with the largest crew size per work order

Activity	Description
W54083	Drug testing
W56038	Physical exmntns and licensing
W30059	(Student) meta
W51036	Special events/honor guard
W10058	(Instrctr)legally mandated trng
T41100	Receiving/issuing materials
W55038	Emrgncy trnsprtn empl. 1st aid
W40059	(Student) other training
W10059	(Student)legally mandated trng
W10049	Tailgate safety meeting

Top 10 activities with the highest access difficulty score

Activity	Description
C20010	Mechanical control
U80010	Fixed satcom - repair/replace
F80001	Oversight of construct contract
C93050	Clean cattleguard
F40150	Slide material hauling
F90103	Closure of existing site
S31010	Repair/replace rock fall protection
R91000	Avalanche control
R30110	Repair/replace fixed hardware
R10000	Snow removal

Top 10 activities with the longest average duration

Activity	Description
S31040	Rock scaling
F40050	Snow hauling (stormwater)
A30010	Dig out flex pavement
J70040	Maintenance toll plaza
F40210	Snow hauling (stormwater)
A21010	Profile grinding flex pavement
W52056	Legal tort cases – dscvry. rprt.
A20010	Overlay/leveling flex pavement
M30010	Repair/replace pvmt. markers
B31010	Slab replacement rigid pavement

Top 10 activities with the longest average mile-length

Activity	Description
F60030	Remove Acid/removal oversight
C20010	Mechanical control
F80002	Drainage contract
K20120	Night inspection sign lighting
F50005	Veg mgmt. & chem usage plans
C30020	Tree inspection
F10007	Employee specialized/training
M10120	Night inspection striping
K10120	Night inspection HWY lighting
M20120	Night inspection markings

Once the above classification was developed and the five categories that are most relevant in terms of difficulty in performing a maintenance activity were identified, Caltrans conducted a survey of its maintenance crews to determine the importance of each of these categories. This research study then used this data and developed weight factors for each of these categories representing their relative importance in the maintenance activities. This research study then developed the following simple equation as an Index of Difficulty (ID) that can be used in prioritization of these maintenance activities:

$$
\begin{aligned}
\text{Index of Difficulty} = {} & 4.66 \times \text{Lane closure score} + \\
& 4.47 \times \text{Number of crew score} + \\
& 4.41 \times \text{Access score} + \\
& 4.25 \times \text{Duration score} + \\
& 4.01 \times \text{Mile-length score} + \\
& 3.92 \times \text{LEMO costs score}
\end{aligned}
$$

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Using the Index of Difficulty, the top ten maintenance activities from the group under consideration, in descending order of ID scores, are calculated and listed in Table i.3.

Table i.3: Top 10 maintenance activities with the highest overall ID scores (in descending order).

Activity	Description
A30010	Dig out flex pavement
A50010	Seal (all other) flex pavement
M10010	Repair/replace striping
F20050	Drain cleaning
A20010	Overlay/leveling flex pavement
S31040	Rock scaling
M30010	Repair/replace pvmt. markers
F40050	Snow hauling (stormwater)
R10000	Snow removal
C95040	Test/sample manhole

This research study performed a second classification of maintenance activities based on collision risks. Data from an Advanced Highway Maintenance and Construction Technology (AHMCT) injury database was matched with other data sources. These data sources considered are depicted in Figure i.2.

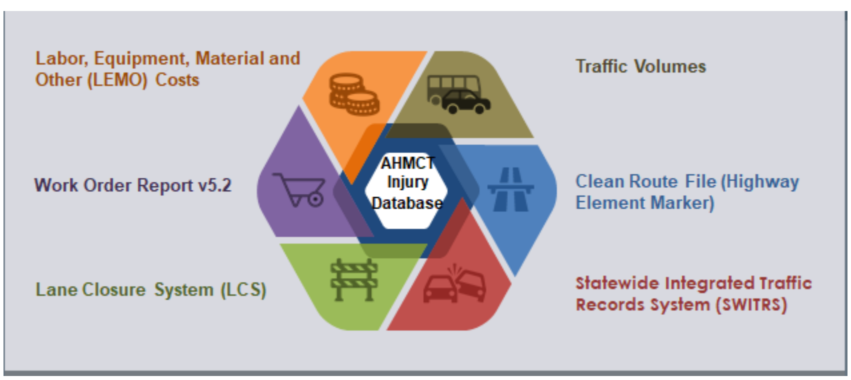

Figure i.2: Data sources used in developing the injury index.

A final data set that corresponds to each maintenance work order with lane closures data, traffic volumes (AADT, Truck AADT), road features (Clean Route File), collision reports (SWITRS), and collision density is created. The resulting data set consists of 2,046,709 work orders for different activities between 2013 to 2018. A statistical analysis was performed on the results, and various performance

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metrics were considered. It was found that it was more relevant to develop a collision risk index, rather than an injury index, since the latter would require information on temporal and spatial relationships on roadway worker locations at any instant in time. Even in determining a collision risk index, it was found that many features of a maintenance activity could influence the risk of a collision. These features are the variables to consider for any work-orders and are depicted in Figure i.3. These features include variables such as route, time of day, day of the week, type of roadway surface, and so on.

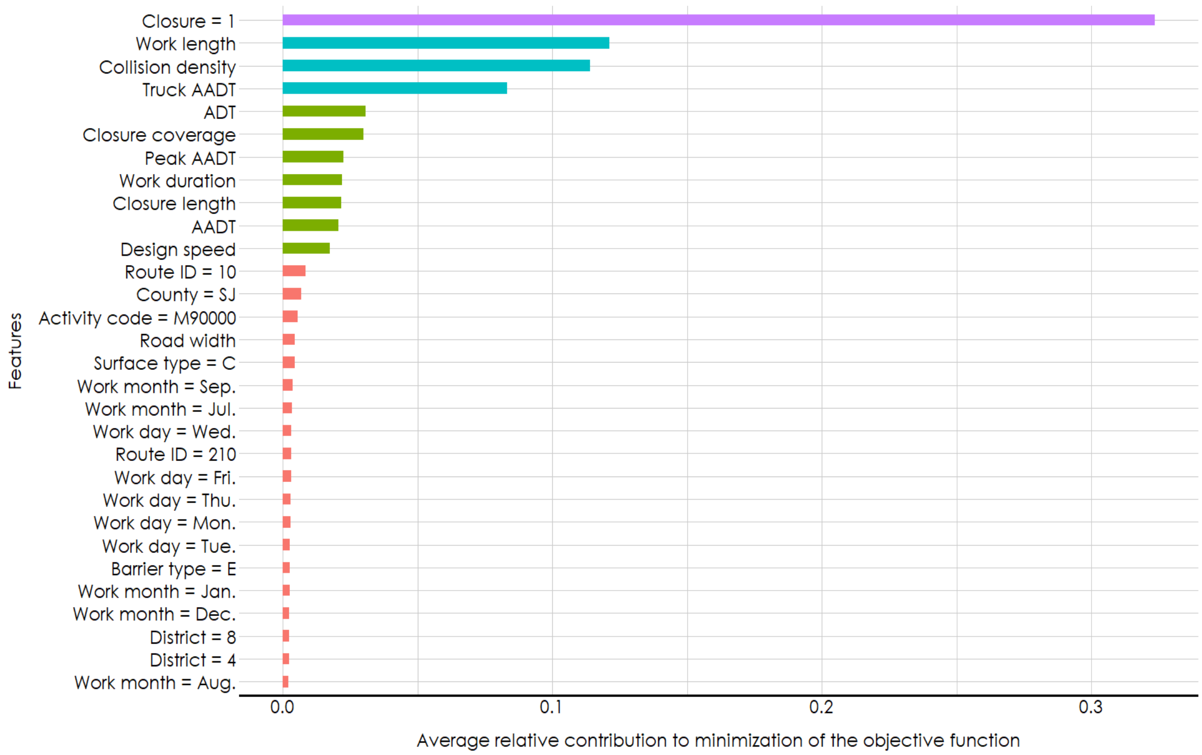

Figure i.3: Features considered in injury risk evaluation.

In Figure i.3, the value of 1 for the closure variable denotes that the work order considered requiring a lane closure; if no lane closure was required, the closure value would be set to zero. Furthermore, surface type C and barrier type E indicate concrete surface and the barrier type. Calculating and assigning all these variables to define a collision risk index, however, is complicated. It is clear from Figure i.3 that the top four variables affecting the collision risk are existence or lack of lane closure, work length, collision density, and the truck percentage of the Annual Average Daily Traffic (truck AADT) volume. Using these four variables, the following Collision Risk Index (CRI) was developed:

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$$p = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \cdots + \beta_4 x_4)}}$$

In this Collision Risk equation, "p" is the probability of a collision that can lead to an injury, with values ranging between 1 (for a collision) and 0 for a no-collision probability. The variables x_i's are defined as follows:

- $x_1 = 1$ if a work order requires lane closure and $x_1 = 0$ otherwise.
- x_2 is the length of the scheduled work order in miles.
- x_3 is the collision density i.e., the number of historical collisions per 2-mile segments of the work order route.
- x_4 is the truck percentage of the annual average daily traffic volume.

The values of the parameters β_i for i=1,…,4, can be determined for each work order as described in detail in chapter 3 of this report. As an example, we consider a work order of activity type K10010 (repair/replace highway lighting) that is scheduled for route 5 in San Diego County between postmile R10.0 and R27.0. Assuming that this work order requires a lane closure, the average truck AADT is 4,695.848, and the average collision density is 89 accidents per mile, then the values of the β_i parameters are given by the following table:

Coefficient	Feature	Value
$\boldsymbol{\beta_1}$	Lane closure	1.731
$\boldsymbol{\beta_2}$	Work length	0.030
$\boldsymbol{\beta_3}$	Collision density	0.002
$\boldsymbol{\beta_4}$	Truck AADT	-3.77E-07

The Collision Risk Index is then calculated as:

$$p = \frac{1}{1 + e^{-(-5.262 + 1.731(1) + 0.3(17) + 0.002(89) - 0.000000377(4695.848))}} \cong 0.85,$$

The p value of 0.85 means that a roadside work zone collision is more likely than not with a probability of approximately 85%.

Recommendations

Based on the results obtained in this research study, the following recommendations are made:

1. In evaluating and prioritizing maintenance functions associated with maintaining roadside safety features, consider including the use of the Index of Difficulty as part of the workflow.

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2. In assignment of personnel, allocating appropriate equipment, and estimating the cost of relevant maintenance operations, consider including the use of the Index of Difficulty.
3. For maintenance functions with high values of Index of Difficulty, consider design or operational changes, and/or policy modifications that can lead to improvement in the operation, reducing the value of this index when appropriate.
4. Consider pilot studies that can be used to evaluate the efficacy of the Collision Risk Index developed in this research study.
5. Once the efficacy of the Collison Risk Index is established, then for maintenance operations with reasonable Collision Risk Index, consider additional safety precautions.
6. Consider follow-up research to develop a decision-support tool with a dashboard that would allow ease of evaluation of Collision Risk Index and Index of Difficulty for field operations within Caltrans.

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LIST OF EQUATIONS

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
AHMCT	Advanced Highway Maintenance and Construction Technology
API	Application Programming Interface
Caltrans	California Department of Transportation
CHP	California Highway Patrol
DOT	Department of Transportation
DRISI	Division of Research, Innovation and System Information
IMMS	Integrated Maintenance Manual System
LASSO	Least Absolute Shrinkage and Selection Operator
LCS	Lane Closure System
LEMO	Labor, Equipment, Material, and Other
MLE	Maximum Likelihood Estimation
PDO	Property Damage Only
PeMS	Performance Measurement System
PM	Postmile
SMOTE	Synthetic Minority Over-sampling Technique
SR	State Route
SWITRS	Statewide Integrated Traffic Records System

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Acronym	Definition
TIMS	Transportation Injury Mapping System
XGBoost	Extreme Gradient Boosting

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Chapter 1: INTRODUCTION

Advanced Highway Maintenance & Construction Technology (AHMCT) research center has performed this research study to evaluate the feasibility of developing operational difficulty and safety indices or metrics for maintenance operations associated with roadside safety features. The work was performed in response to a need outlined by the California Department of Transportation (Caltrans) customers following the completion of a first phase study that identified roadside features whose maintenance operations either expose workers to more time near live traffic or the operation's duration could be reduced by policy modifications and potential redesign opportunities. Identifying and understanding the factors that contribute to the risk of hazard to workers on roadside maintenance operations is the basis of a proper safety analysis for different maintenance activities.

Problem

Caltrans had requested the development of performance measures to evaluate the difficulty and safety risks of maintenance operations on roadside features. This problem was motivated due to lack of operational performance metrics that can be used to evaluate the difficulty and safety risks to highway maintenance workers in prioritizing, scheduling, and considering additional safety precautions for maintenance operations. The first phase of this research had identified roadside features whose maintenance exposes workers to more time near live traffic, as well as features whose maintenance can be reduced due to redesign or policy modifications. The second phase, which is the subject of the present research study, is focused on developing risk indices or other relevant metrics. These metrics or indices will have the potential to be used in prioritizing and scheduling maintenance operations for such roadside features to increase ease of operations and improve the safety of highway workers, as well as the traveling public, by evaluating or potentially considering additional safety precautions.

Objectives

The goal of this research was to develop performance measures to evaluate and compare ease of operations and safety risks of maintenance operations on roadside features. The specific objectives were to see if risk indices or other relevant metrics can be developed to be used in prioritizing and scheduling

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maintenance operations for roadside features. Additional insights revealing the effects of maintenance operation features, roadside features, and environmental features (e.g., location-specific features) are included in the analysis.

The expected outcomes included improved safety, increased efficiency in design and selection of roadside features, and in planning and scheduling of maintenance operations. Various data sources were considered to investigate the effects of a wide range of features on safety and difficulty of maintenance operations. The experience and expertise of Caltrans personnel are also sources of data captured from detailed meetings and survey analysis.

Scope

The scope of this research study included the following tasks:

- Classification of Caltrans' maintenance operations to investigate whether certain families of activities expose workers to more harms,
- Collection and evaluation of relevant data sources related to Caltrans work zone activities such as work orders, lane closures, traffic volumes, collisions, and road features,
- Capturing the experience of Caltrans personnel involved in roadside maintenance operations,
- Development of a data pipeline to match various Caltrans data sources to consolidate data and derive insight by visualizing high-level observations,
- Evaluation of different analytical models to estimate the risk of injury for Caltrans roadside maintenance operations,
- Development of an index based on the analytical model to predict and demonstrate the risk of injury for different maintenance operations,
- Prototype an analytical tool for Caltrans personnel that implements the result of the risk analysis.

Background

Development of proper performance measures for maintenance of roadside features is consistent with, and positively affects, both the safety and efficiency goals of Caltrans. It will improve the safety of highway workers as well as the efficiency of operations by providing metrics to properly prioritize, schedule, and plan relevant maintenance tasks based on performance measures that would improve the safety and efficiency of operations.

The need for the development of proper performance measures capturing the risk of injury to Caltrans personnel on roadside maintenance operations was

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evident after the completion of the first phase of this study. In the first phase, AHMCT identified roadside features for which maintenance operations exposed workers to safety risks; however, no quantitative method was developed to measure this risk for different maintenance activities. This research study aimed to employ various relevant Caltrans data sources and analytical methods to develop metrics or indices measuring ease of operations and the risk of hazards to Caltrans workers on roadside maintenance operations.

Literature

The Bureau of Labor Statistics reports that from 2003 to 2017, 1,844 workers have lost their lives at road construction sites. This is nearly equivalent to an average of 123 fatalities in the U.S. each year [1]. The same source identifies California with 76 deaths among the top 5 states with the most worker deaths at construction sites. Particularly, it was reported that between 2003 to 2017, 142 'Highway maintenance workers' had a fatal accident at roadside work sites in California.

In California, the number of work zone fatalities has not seen a decline in the last ten years. Figure 1.1and Figure 1.2 show that the number of work zone fatalities and the number of worker fatalities at work zones from 2009 to 2018 has increased in the last decade [2]. Therefore, a research study analyzing the factors contributing to the safety of workers in work zones for maintenance operations of roadside features was needed. In fact, Caltrans recognized this need after the completion of the first phase of the Performance Measures for Roadside Features study, which identified maintenance operations exposing workers to safety risks [3].

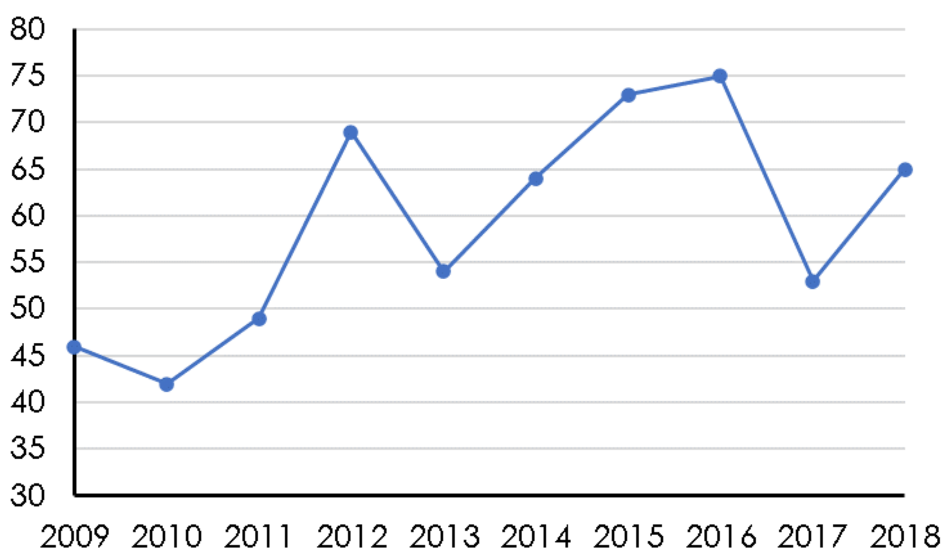

Figure 1.1: Number of work zone fatalities in California.

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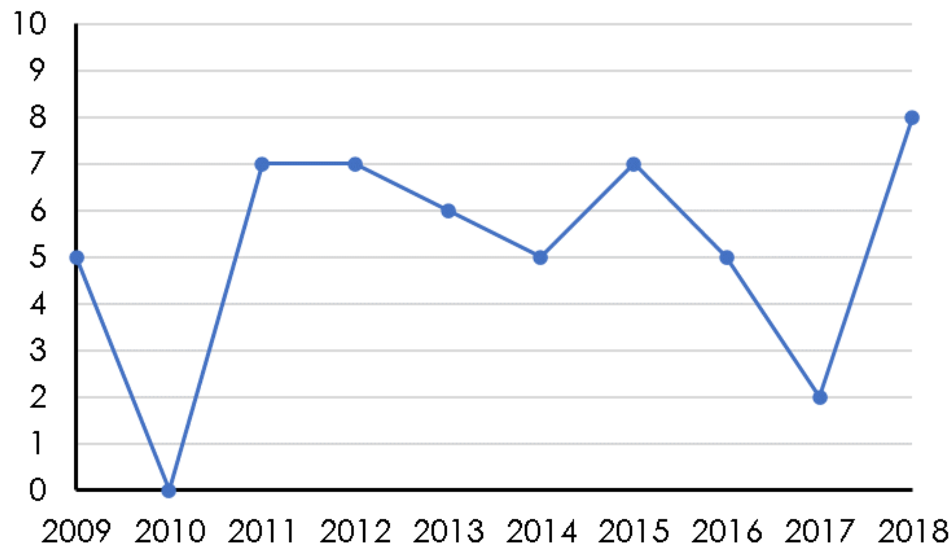

Figure 1.2: Number of workers fatalities in California roadside work zones.

In this line of research, [4] studied the effects of factors listed in Table 1.1 on the severity of work zone injuries. This study used accident reports of the California Work Zone Injury Data base for a 10-year period between 1998 to 2007. The severity of injuries to Caltrans personnel was measured in terms of different injury severity scores, i.e., Abbreviated Injury Scale (ALS) and Injury Severity Scale (ISS), modified number of workdays, and lost time days. The study adapted and implemented multiple regression analyses, e.g., logistic regression and Cox proportional hazard model, and found that roadside operations with moving lane closures, short-term duration, and on-foot workers in non-peak hours are the riskiest group of activities. These results are extended in [5] to develop an index predicting the risk of injury to workers using the same set of features.

The current research extends the number of features from various data sources and identifies major factors affecting the probability of a work zone collision. In addition, this research differentiates between Caltrans' various roadside maintenance operations, and thus the final risk index will take the specific operations into account when estimating the level of risk.

Table 1.1: Work zone features considered in [4]

Feature names	Value description
Time of day	Peak/Non-peak hours
Location type	Highway, ramp, moving closure, …
Environment/Weather	Dry, wet, icy, …

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Feature names	Value description
Type of accident	Pedestrian, motor vehicle, bicycle, …
Work zone intrusion angle	Rear end, head-on, …
Activity type	On foot/Inside vehicle
Work zone duration	Short-term, Long-term, Mobile, …
Personal protective equipment	Yes/No

In addition to the above studies which analyzed roadside work zone injuries of the state of California, [6] employed similar statistical analyses to [4] and [5] for work zone collisions gathered over a four-year period from 2013 to 2016 from rural and urban interstate highways in New York, Indiana, Michigan, and Pennsylvania. Furthermore, [7] studied the effects of roadway geometry, weather condition, lighting condition, age, gender, driving under the influence, and residence code on the severity of work zone injuries in Florida for a three-year period between 2002 to 2004. [8] considered traffic management features such as lane shift design, lane splits, and detours in addition to work zone design parameters in analyzing the safety of workers in Indiana highway work zones. [9] implemented logistic regression analysis to identify major factors among driver characteristics, environmental conditions, crash road conditions, and other crash information that may contribute to high-severity crashes in Kansas highway work zones. The Texas Department of Transportation also considered analyzing the characteristic and configuration of its work zones on 77 fatal crashes between 2003 and 2004.

In this research, an extensive number of features describing maintenance activities, work zone configuration, closure characteristics, road features, and traffic volumes are considered for analysis. Different statistical models are developed and tested to pick the most accurate model in estimating the chance of collision and its severity.

Research Methodology

The research approach integrated Caltrans customers using a project panel consisting of key Caltrans stakeholders for guiding the research combined with a data-driven methodology. The data-driven methodology utilized data from highway collisions and worker exposure through existing Caltrans and AHMCT injury and accident databases [10]. The project panel met periodically to guide the research and redirect it to meet the goals of the Caltrans customers. The following data sources were utilized in this research:

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1. Integrated Maintenance Management System (IMMS) describing different maintenance operations.
2. Labor, Equipment, Materials, and Other (LEMO) costs containing features such as date, duration, and the activity type of each maintenance work order.
3. Work Order Report v5.2 containing postmile information about each maintenance work order.
4. Lane Closure System (LCS) data via Performance Measurement System (PeMS) describing the characteristic of road closures on state routes.
5. Statewide Integrated Traffic Records System (SWITRS) containing information about crash site and condition at the time of collision.
6. Traffic volume data in terms of Annual Average Daily Traffic.
7. Data describing road features, such as number of lanes, type of pavement, etc., from "Caltrans Clean Road File."

These data sets are integrated and matched based on location (postmile) and date (plus time if available) information. The resulting database is able to describe various characteristics of work zone accidents and provide a comprehensive set of features for statistical analysis of risk for different roadside maintenance operations. In addition to these databases, the experience of Caltrans personnel regarding additional features was captured via a survey and was considered in the final analyses when reporting the results.

Multiple statistical analyses and machine learning methods under different configurations are implemented in order to develop an accurate model capable of predicting the probability of a work zone collision and classifying its severity. The most accurate model is selected as the basis of a final index predicting the level of risk associated with different roadside maintenance operations.

Overview of Research Results and Benefits

The key deliverable of this project is a report that includes:

1. Classification of relevant maintenance activities.
2. Determination of factors that are most significant in the difficulty of performing the relevant maintenance operations.
3. Determination of factors that are most significant in causing injuries to highway workers.
4. Recommendations in the form of metrics or indices for assessing the level of difficulty and risk of hazards in performing maintenance or installation operations.

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The result of this work enables Caltrans to use objective data and measures for decision making in planning and scheduling a maintenance operation, allocating resources in terms of personnel and equipment, considering additional safety measures, and deciding what type of lane closure (if any) is necessary in order to reduce the risk of injury to its personnel and roadside workers.

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Chapter 2: CLASSIFYING MAINTENANCE OPERATIONS

The Integrated Maintenance Management System (IMMS) describes different maintenance activities and identifies the purpose and requirements of those activities. The long list of various Caltrans maintenance operations is categorized into 17 different families in the IMMS manual. Each maintenance activity is identified by a 6-character code, e.g., A20010. The first letter of this code, here A, identifies the family grouping of the activity. Mr. Kenneth Murray from Caltrans provided AHMCT with a spreadsheet containing employee counts for each maintenance activity code from 2010 to 2018. Because of major changes in activity codes in 2013, cross-referencing employee counts to activity codes for years prior to 2013 was not possible, and thus the focus of this research is limited to the employee data for 2013 to 2018.

Table 2.1 shows IMMS classification of maintenance activities. The family grouping column identifies the class name of these activities, which is denoted by the first character of their activity code. The family primary function describes the activities categorized in each family grouping. The last column describes the availability of employee count data for each family grouping.

Table 2.1: IMMS classification of maintenance activities.

Family grouping	Family primary function	Notes
A	Flexible pavement	No notes
B	Rigid pavement	No employee count data provided. Assumed that crew is similar to family A.
C	Lateral support for pavement, vegetation control activities, shoulder activities, and erosion and drainage activities	Drywell activities cleaning crew data is not available.
D	Litter, debris, graffiti, spill, hazmat, and sweeping activities	Only spill activities crew data is available.
E	Landscaping activities, vegetation control activities, and irrigation activities	No notes
F	Storm water management	No crew count is available

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Family grouping	Family primary function	Notes
G	Roadside rest, vista, and park activities	Some crew counts are missing.
H	Bridge activities	No notes
J	Tunnel, tube and pump plant activities, and Tow services (traffic control)	No crew count is available.
K	Sign installation and repair activities	No crew count is available.
M	Guardrail activities, Marking and Stripping activities, and Traffic control activities	No notes
R	Snow removal and control activities	No notes
S	Some erosion activities, and emergency storm and flood activities	No notes
T	Caltrans offices and facilities activities	No crew count is available.
U	Caltrans communication facilities activities	No crew count is available
W	Caltrans training activities	No notes
Y	Caltrans work for other departments	No crew count is available.

The research proposal submitted by AHMCT considered a different classification system for the evaluation of risk. This list categorized IMMS maintenance activity codes into a small set of maintenance functions for which Caltrans provided the responsible maintenance crew team. Table 2.2 shows these categories and the crew team responsible for each category.

Table 2.2: AHMCT classification of maintenance activities.

Maintenance function	Responsible crew
Pavement repair (crack sealing, patching, and slab replacement, etc.)	Highway Maintenance & Bridge Maintenance Crews
Guardrail repair, shoulder repair, sink hole repair, etc.	Highway Maintenance, Functional & Special Crews
Litter, Debris, and Graffiti removal	Highway Maintenance, Landscape Maintenance, & Special Crews
Road Sweeping	Highway Maintenance &

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Maintenance function	Responsible crew
	Sweeping Crews
Sign Installation and repair	Special Crews
Pavement striping and marking	Special Crews
Landscaping-Vegetation control	Landscape Maintenance
Landscaping – tree pruning	Tree Crews
Landscaping - tree removal	Tree Crews
Landscaping - fire hazard reduction	Landscape Maintenance & Tree Crews
Landscaping - erosion protection	Highway Maintenance & Stormwater Crews
Landscaping - avalanche control system	Highway Maintenance
Irrigation repair (Irrigation valve, lateral line repair, controller wires, etc.)	Landscape Maintenance & Electrical Crews
Snow removal and control	Highway Maintenance
Traffic Control	Highway Maintenance
Rock blasting	Highway Maintenance
Bridge repair, structural steel painting, bracing, and temporary bridge installation	Bridge Maintenance Crews
Culvert and drain cleaning	Highway Maintenance & Stormwater Crews
Hazardous spill cleaning	Highway Maintenance
Storm damage and emergency incidents	Highway Maintenance
Public facilities maintenance including safety roadside rest areas, weigh stations, park and ride lots, and vista points, etc.	Highway Maintenance & Landscape Maintenance
Tunnels, tubes, and pumping plants maintenance	Tunnels and Tubes Crews

Reconciling AHMCT and IMMS Classifications

Since maintenance crew information and employee counts were reported for different classifications, unifying these classifications was necessary to determine the responsible crew team for each activity code. To that end, each activity code in the IMMS manual was investigated to identify the corresponding classification in this work. Figure 2.1 shows an example of such a relationship where an AHMCT classification corresponds to multiple IMMS families. Conversely, in Figure 2.2, multiple AHMCT classifications correspond to a single family in the IMMS manual.

In particular, Figure 2.1 shows that the proposed erosion protection category corresponds to multiple maintenance activity codes in different IMMS families. In

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Figure 2.1, erosion protection encompasses activities such as repairing, replacing, or cleaning curbs, dikes, ditches, channels, drainages, and manholes. It also includes some activities in the erosion and sediment control table, such as drain stenciling, drainage inlet inspection, and drainage inlet cleaning. Patrolling sand drifts and eroded rocks, removing/repairing minor slides, and repairing/replacing rock fall protection are examples of the IMMS S family activities that may be also categorized as erosion protection.

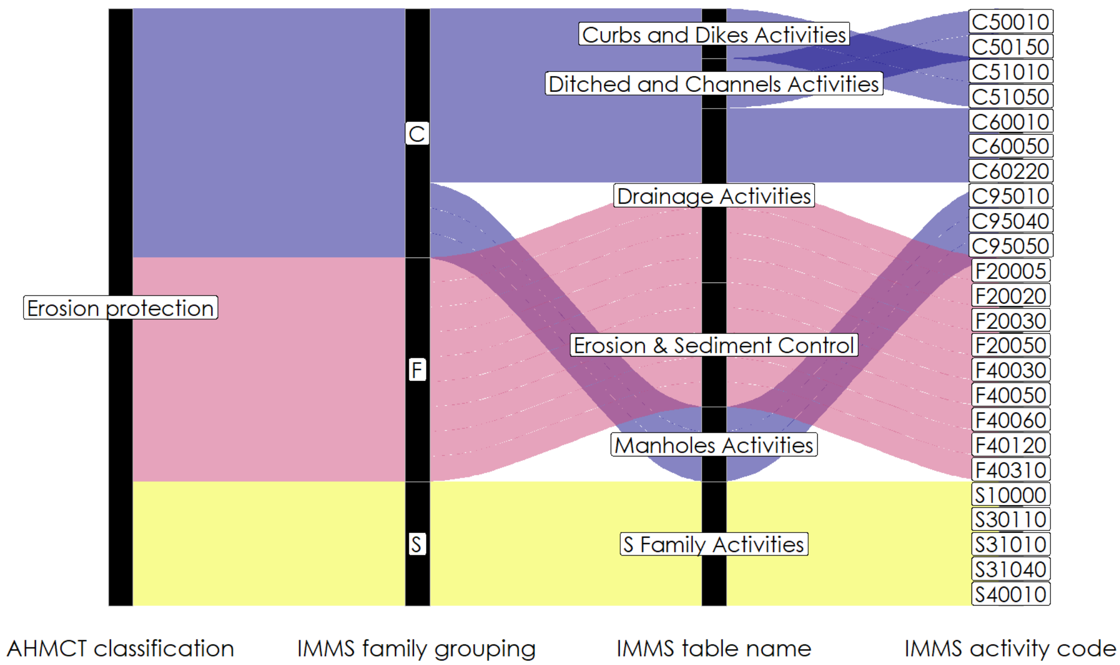

Figure 2.1: Example of the relationship between AHMCT and IMMS classifications.

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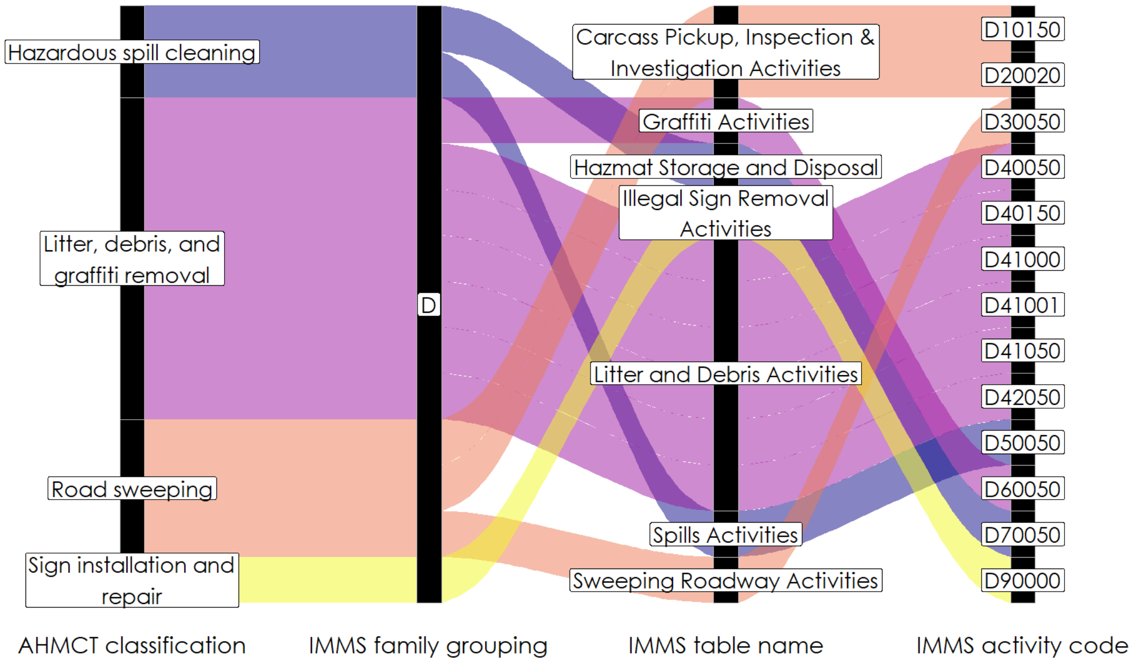

Figure 2.2: Example of the relationship between AHMCT and IMMS classifications.

Figure 2.2 demonstrates the opposite case in which different maintenance functions proposed may correspond to one IMMS family. IMMS activities, such as carcass pickup and road sweeping, may be categorized as road sweeping activities in AHMCT classification. Illegal sign removal activities, which in IMMS manual belong to D family of activities, are classified as part of sign installation and repair maintenance function in AHMCT classification.

An overview of this relationship between AHMCT classification of maintenance functions and IMMS classification of maintenance activities is given in Figure 2.3. For clarity and simplification, Figure 2.3 only displays this relationship with respect to AHMCT classification categories and IMMS family groupings, and IMMS table names and activity codes are excluded from this plot. A full breakdown of this plot for each AHMCT maintenance function and IMMS activity code is given in Appendix A.

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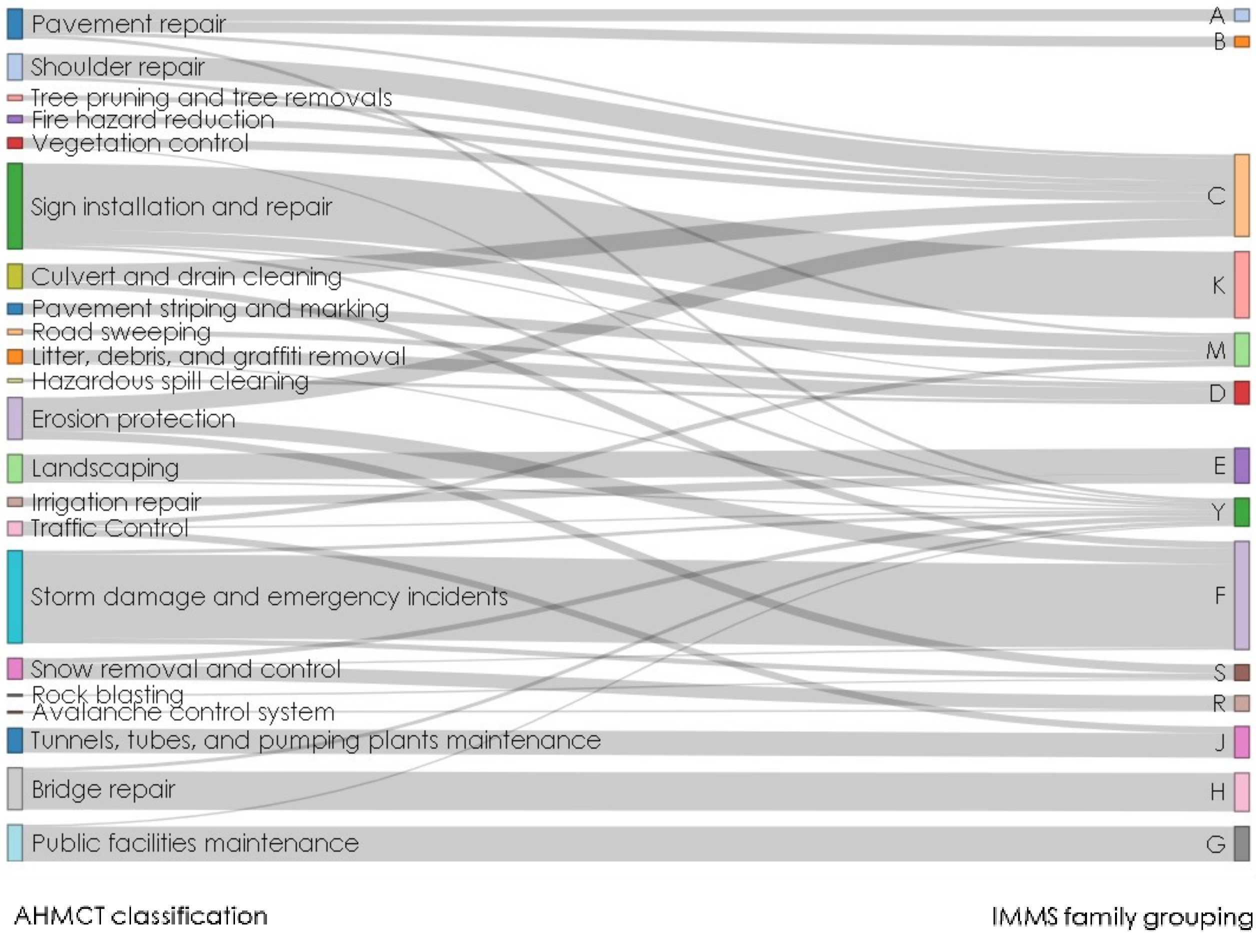

Figure 2.3: Overview of the relationship between AHMCT and IMMS classifications.

Identifying Maintenance Crews

Table 2.2 lists the maintenance crew responsible for carrying out maintenance functions classified by AHMCT. Given the relationship between IMMS and AHMCT classification (outlined, for example, in Figure 2.3), identifying the crew team for each IMMS activity code is possible.

To that end, Figure 2.4 plots the information given in Table 2.2 to identify different maintenance functions for which each maintenance crew is responsible. For example, Figure 2.4 shows that three different crew teams, i.e., highway maintenance crews, special crews, and landscaping maintenance crews, are responsible for the various maintenance activities classified by litter, debris, and graffiti removal. This figure also demonstrates that a crew team may be assigned to different maintenance operations. For example, the highway maintenance crew is responsible for many different maintenance functions, such as avalanche control system, snow removal and control, and litter, debris, and graffiti removal.

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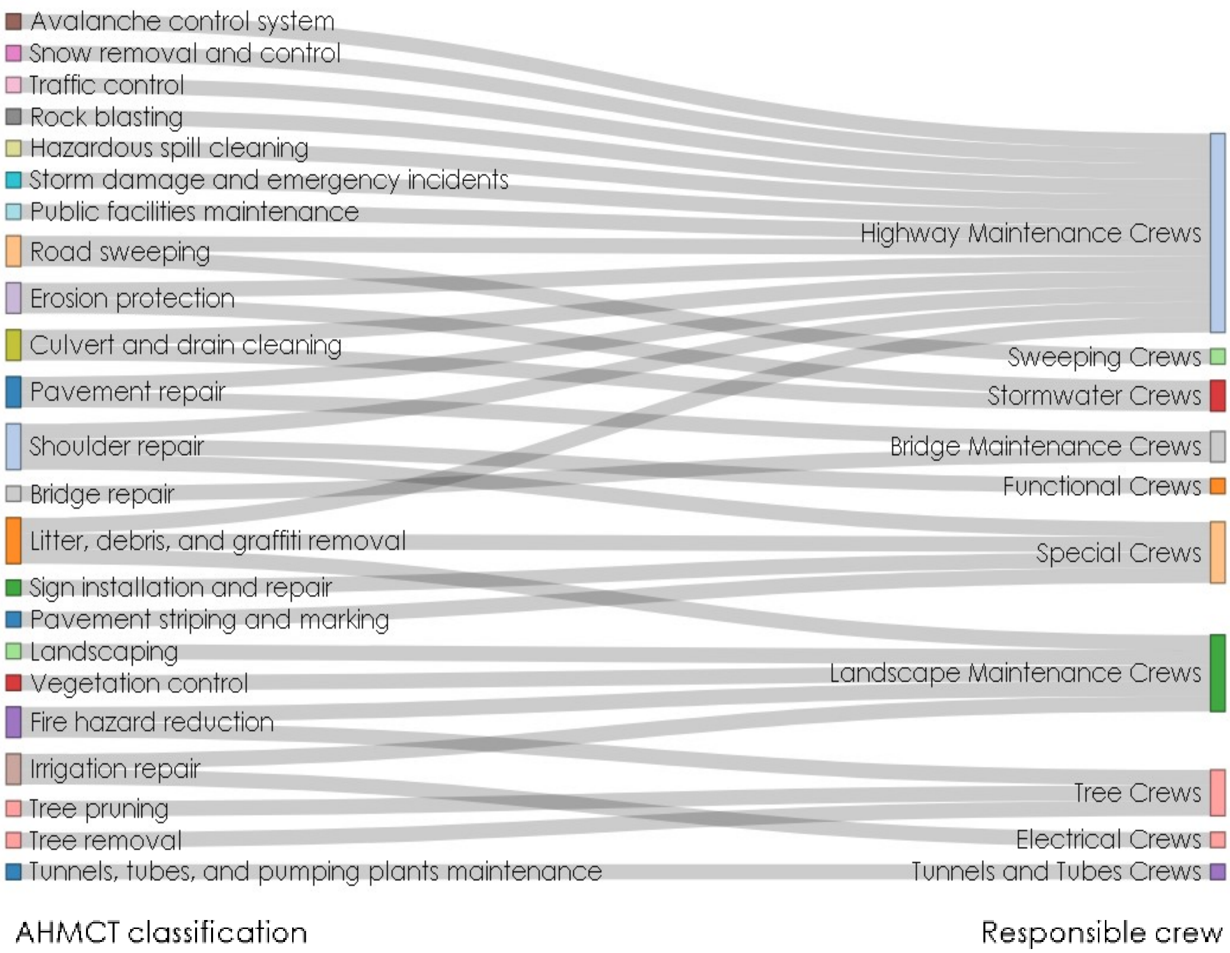

Figure 2.4: Maintenance crews based on the AHMCT classification.

The relationship between IMMS maintenance activities and the proposed AHMCT maintenance functions, as well as the relationship between the AHMCT maintenance functions and different maintenance crews, are determined. Therefore, the crew team responsible for each activity in the IMMS classification may be known. Figure 2.5 shows how this relationship may be constructed. For example, activity code D42050, which is described as illegal encampment debris removal in the IMMS manual, may employ highway maintenance crews, landscaping maintenance crews, or special crews.

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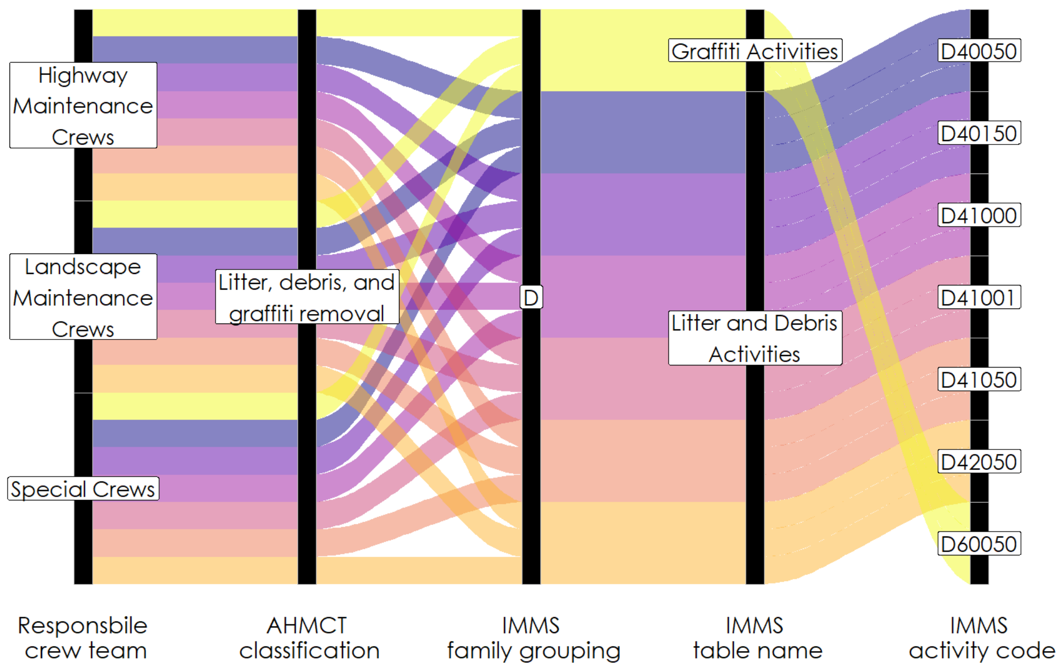

Figure 2.5: Maintenance crews for AHMCT and IMMS classifications.

These relationships do not necessarily hold true for every activity code. It may be the case that landscaping maintenance crews play no part in graffiti activities. However, in absence of data identifying the crew responsible for each activity code, relationships such as those presented in Figure 2.5 serve as a source revealing the best estimate of the crew team responsible for each activity code listed in the IMMS manual.

Building this relationship is necessary because, hereafter, all the data sources used in this study only include the IMMS activity codes. Therefore, analyzing crew size, estimating cost, difficulty, and risk of injury for the IMMS activity codes can also be translated to the AHMCT proposed maintenance functions.

Analyzing Crew Size

The following plots and analyses on the crew size for each activity code in the IMMS manual are based on the employee counts data provided by Caltrans as discussed in Table 2.2. Total worker counts were available for some of the activity codes between 2010-2019 which was one year beyond other data that was between 2013 and 2018. However, the IMMS manuals and thus maintenance activity codes changed in 2013. Therefore, the analyses in this section are limited to years 2013 to 2019 rather than to 2013 to 2018.

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Figure 2.6 and Figure 2.7 show the maintenance total worker counts by Caltrans districts. In Figure 2.6, the height of each bar is proportional to the number of total workers in that district. This figure identifies District 7, which includes Los Angeles and Ventura counties and has the highest number of maintenance workers. District 9 employs the least number of workers for maintenance activities. Similarly, Figure 2.7 also shows the number of total workers in each district. District 7 assigns more than 25,000 workers for maintenance activities while District 9 assigns less than 5,000. Note that the number of total workers assigned to maintenance activities does not directly correspond to the number of Caltrans employees for two main reasons. First, the number of total workers for each activity (and also in each district) are determined by aggregating the number of workers that are assigned to different activities. Therefore, some *employees* may be counted multiple times since they might have been assigned to different activities. Second, some of the workers might not be Caltrans employees as they might be external contractors.

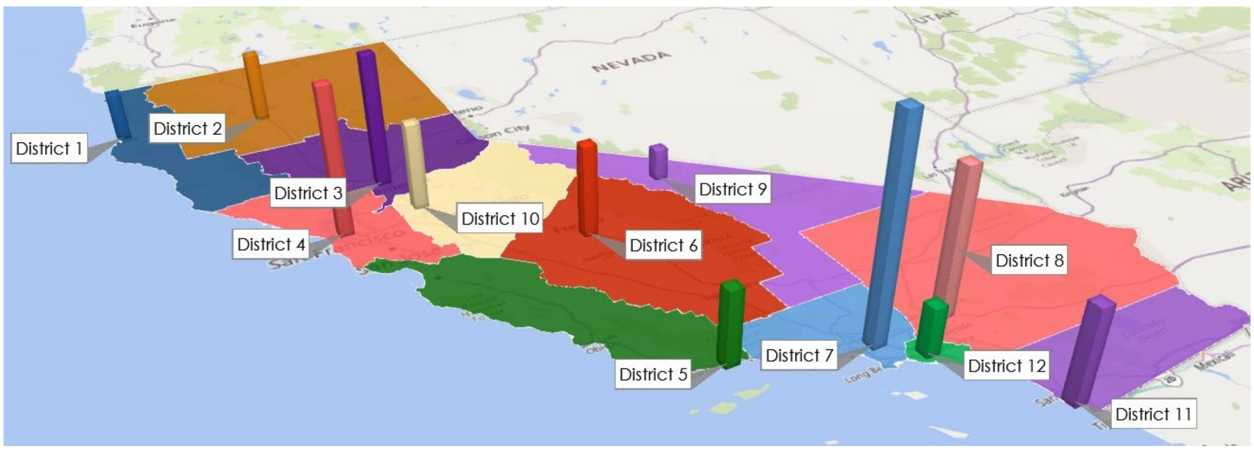

Figure 2.6: Map of maintenance worker counts by district.

To observe the annual trend in number of total workers, the worker counts for years between 2013 to 2019 are grouped by their IMMS family and aggregated. Figure 2.8 shows that the number of maintenance workers across almost all IMMS families has increased from 2013 to 2019. In particular, Figure 2.8 separates five IMMS families, C, W, D, M, and F, from the rest. These families employ the highest number of workers. IMMS family C consist of maintenance activities on lateral support, roadside vegetation, fences, ditches and channels, curbs and dikes, drainages, walls, bike paths, sidewalks, cattleguards, drywells, and manholes. IMMS family W consists of training and field auxiliary service activities. IMMS family D denotes carcass pickup, sweeping, litter and debris removal as well as spill cleaning, graffiti removal, hazmat storage, and illegal sign removal activities. The M family refers to marking and striping activities as well as maintenance activities related to signs, delineators, guardrails, barriers, and attenuators. Finally, the F

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family grouping in IMMS manual consists of all the storm-water management activities.

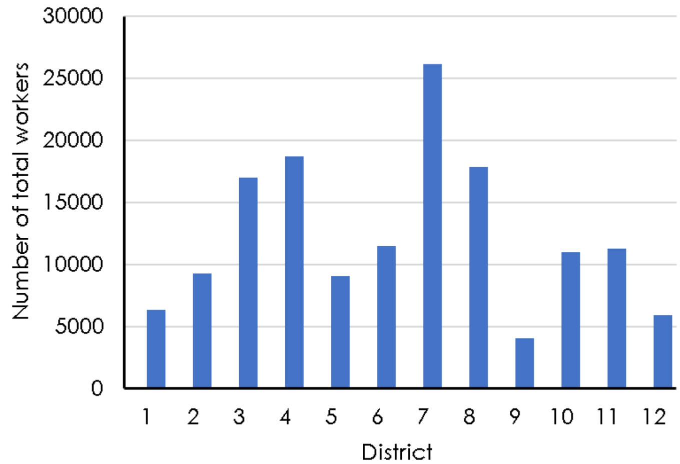

Figure 2.7: Number of assigned maintenance workers by district.

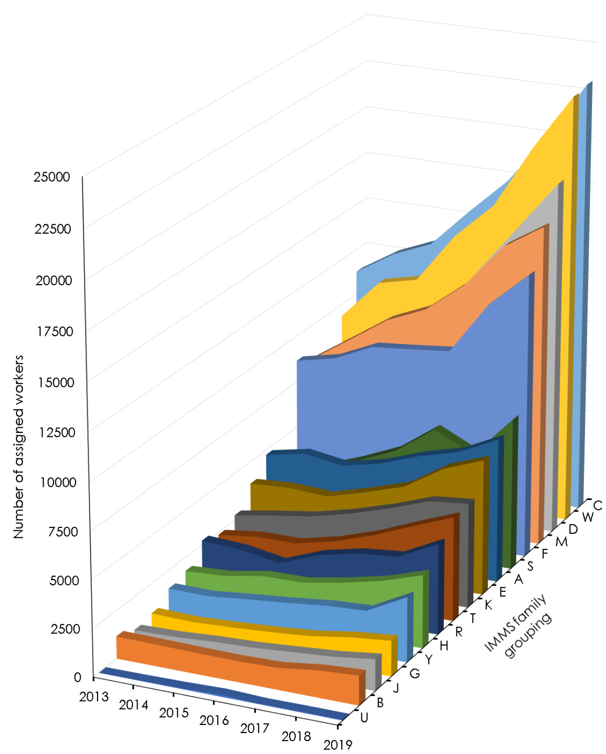

Figure 2.8: Number of total assigned workers by IMMS family grouping.

The worker counts can be further investigated by plotting the annual trend in number of workers for each IMMS activity code. For example, Figure 2.9 shows the trend in the number of workers for different activities in IMMS family grouping A, which consists of maintenance activities for flexible pavements. As can be seen,

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for flexible pavement activities, patching potholes has required an increasing number of workers in the last seven years, while the crew size for sealing flexible pavements has remained steady.

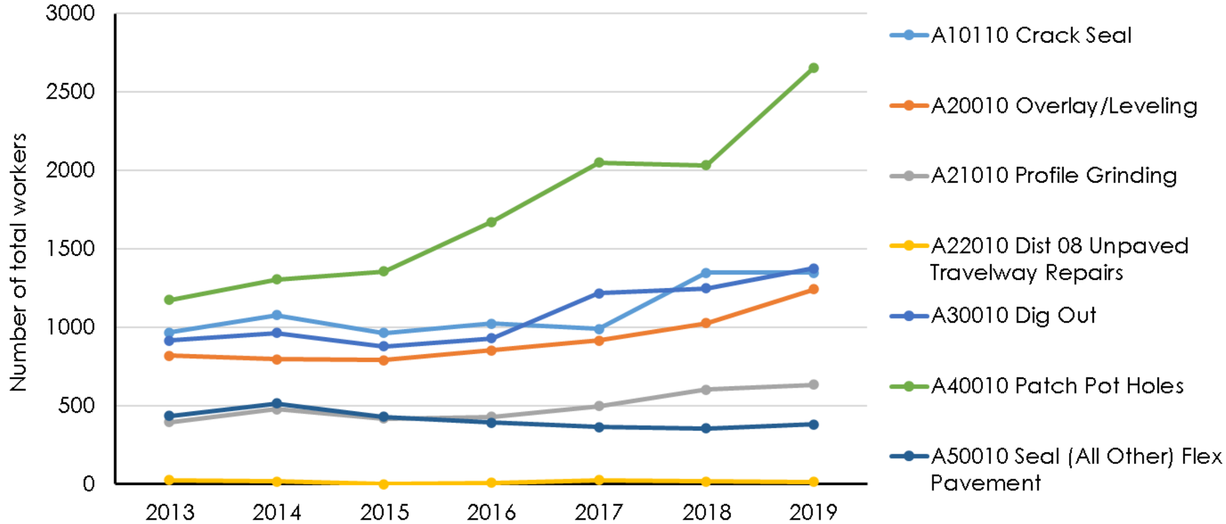

Figure 2.9: Employee counts for IMMS family A (flexible pavement).

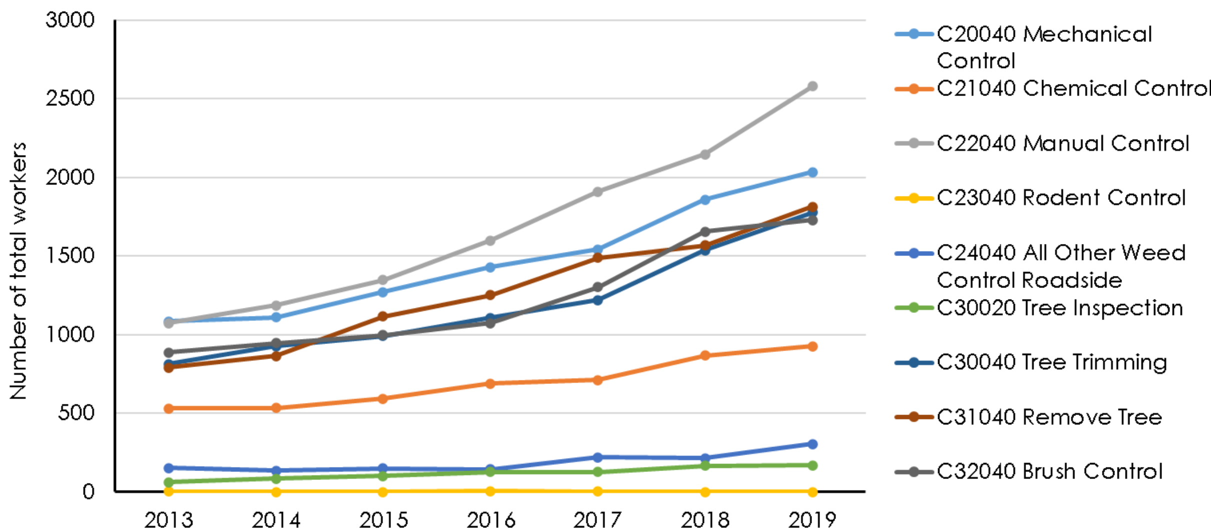

Figure 2.10: Employee counts for IMMS family C (roadside vegetation control).

Similarly, Figure 2.10 shows the trend in the number of workers for some of the activities in IMMS family grouping C. The activities plotted in Figure 2.10 belong to the roadside vegetation control table in family C. The roadside vegetation control activities can be divided into three groups. The first group, which consists of rodent control, tree inspection, and weed control activities, requires the least number of employees, and this number does not change significantly between 2013 to 2019.

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The second group, with only one activity, chemical control, employs more workers when compared to the activities in the first group. In addition, the increase in the number of workers for this group can be described as moderate. The third group consists of manual control, mechanical control, tree removal, brush control, and tree trimming activities. This group, which is assigned the highest number of workers, also shows a significant increase in the number of workers.

Figure 2.9 and Figure 2.10 are included here as examples of the analysis on the crew size for each maintenance activity. The complete set of such figures is presented in Appendix B.

As a result of this analysis, the maintenance activity codes with the most extreme change in the number of workers from 2013 to 2019 can be identified. Two performance measures may be considered for this investigation. First, considering 2013 as the baseline size of crew for each activity, the net change in the number of workers in 2019 with respect to the baseline can be considered as a performance measure for identifying the most demanding activities in terms of the number of workers. Table 2.3 and Table 2.4 list the top 10 and the bottom 10 maintenance activities according to his measure.

Table 2.3: Top 10 activities with the most increase in net number of workers.

Activity code	Activity description	IMMS table	Net change in employee counts
W10059	(Student) Legally Mandated	Training & Field Auxiliary Services Activities	2800
W10049	Tailgate Safety Meeting None	Training & Field Auxiliary Services Activities	2551
F10003	Employee Tailgate Meetings	Storm Water Management-Training	2526
T40010	Repairs/Maintenance	Maintenance Facilities Activities	2171
S20000	Storm Patrol	S Family Activities	2137
D40050	Litter Control Roadway/Lndscp	Litter & Debris Activities	2121
W40059	(Student) Other Training	Training & Field Auxiliary Services Activities	1987
M90000	Emergency Traffic Control	Miscellaneous	1552

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Activity code	Activity description	IMMS table	Net change in employee counts
C22040	Manual Control	Roadside Vegetation Activities	1505
A40010	Patch Potholes	Flexible Pavement Activities	1482

Table 2.4: Bottom 10 activities with the most increase in net number of workers.

Activity code	Activity description	IMMS table	Net change in employee counts
M91000	Physical Highway Inventory	Miscellaneous	-4
YJ0000	Other Structures	Normal Maintenance Activities for Other Departments	-6
C96010	Repair/Replace	Radiator Water Site Activities	-7
B30010	Sub Seal/Jack Slab Rigid Lane Pavement	Rigid Pavement Activities	-8
A22010	Dist. 08 Unpaved Travel-way Repairs	Flexible Pavement Activities	-11
YT0000	Support	Normal Maintenance Activities for Other Departments	-11
K10140	Group Relamp	Calibrate/Repair Test Equipment	-23
B31010	Slab Replacement Rigid Lane	Rigid Pavement Activities	-33
E22040	Pruning Linear	Landscaping Activities	-40
A50010	Seal (All Other) Flex Pavement	Flexible Pavement Activities	-54

The net change in the number of workers identifies the activities that had the largest crew size change. This measure is not necessarily reflective of the change in crew size assigned to an activity relative to its initial size in 2013. In addition, the baseline worker counts are not available for some of the activities prior to 2016. This might be due to missing data or the fact that the IMMS manual and its activity codes updated again in 2016. Regardless of the reason, a more appropriate performance measure capable of capturing the change in employee counts

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relative to its initial size and handling missing information is the slope of change in the number of workers for each activity. This is achieved by fitting a trendline to worker counts for each activity between 2013 to 2019. For example, consider the activities in roadside vegetation control table of the IMMS manual plotted in Figure 2.10. For each activity in Figure 2.10, a trend line, e.g., a linear regression model with only one predictor (slope), can be fitted to estimate the magnitude of change in worker counts between 2013 to 2019. Figure 2.11 shows the trendline, the equation (intercept and slope), and the variation (grey hashed area) for each activity in roadside vegetation control table of IMMS manual. In particular, Figure 2.11 identifies activity C22040: manual control as the the activity with the largest change in the number of workers with respect to its initial size.

Performing the same analysis over all activities allows for sorting maintenance operations based on the relative change in size of their maintenance crews. Table 2.5 and Table 2.6 list the top 10 and bottom 10 activities according to this measure.

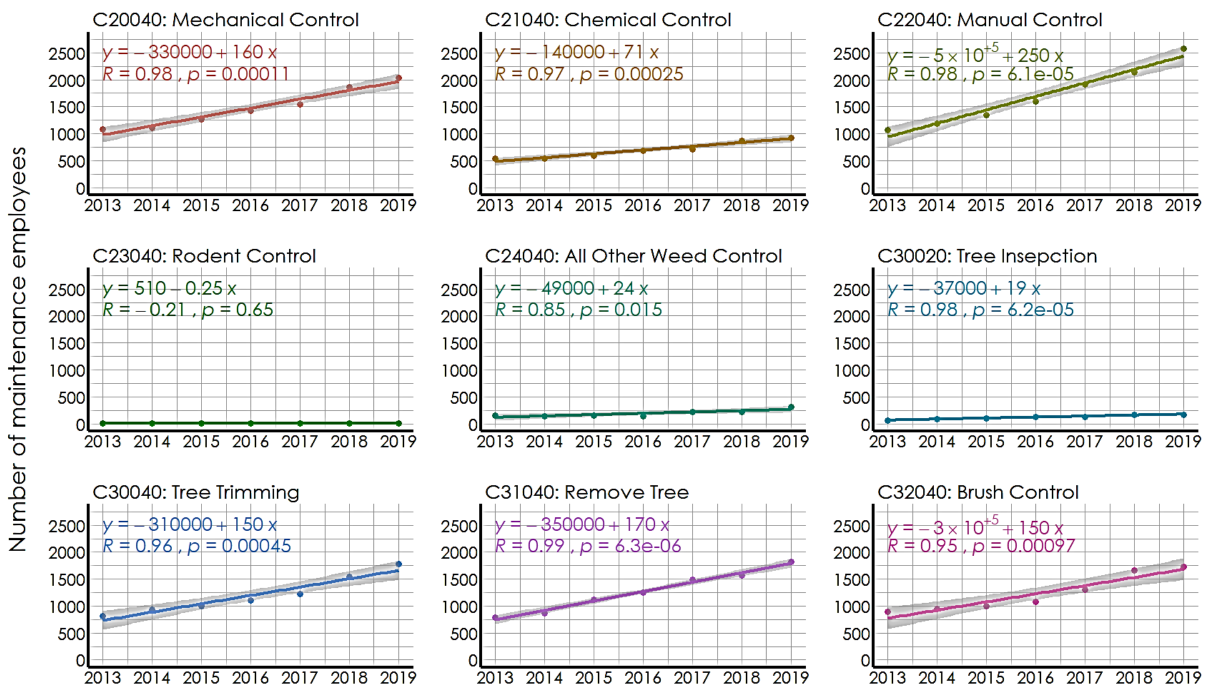

Figure 2.11: Slope of worker count change for IMMS family C (roadside vegetation control).

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Table 2.5: Top 10 activities with the largest slope in number of workers.

Activity code	Activity description	IMMS table	Slope
D40150	Road Patrol/Debris Pickup	Litter & Debris Activities	948
W10059	(Student) Legally Mandated	Training & Field Auxiliary Services Activities	448
W10049	Tailgate Safety Meeting None	Training & Field Auxiliary Services Activities	415
F10003	Employee Tailgate Meetings	Storm Water Management-Training	410
W56038	Physical Examinations & Licensing None	Training & Field Auxiliary Services Activities	371
T40010	Repairs/Maintenance	Maintenance Facilities Activities	354
D40050	Litter Control Roadway/Lndscp	Litter & Debris Activities	351
D10150	Carcass Pickup	Carcass Pickup/Inspection & Investigation Activities	346
S20000	Storm Patrol	S Family Activities	333
W40059	(Student) Other Training	Training & Field Auxiliary Services Activities	314

Table 2.6: Bottom 10 activities with the largest slope in number of workers.

Activity code	Activity description	IMMS table	Slope
YT0000	Support	Normal Maintenance Activities for Other Departments	-1.1
F70110	Repair/Replace of Treatment Bmp	Storm Water Management-Contract Oversight	-1.7
Y50001	Permits – Inspection	Work for Others	-2.1
F70201	Treatment and Field Bmps Support Staff	Storm Water Management-Contract Oversight	-2.3
U61010	Repair/Replace repeater	Caltrans Roadside Repeater Installations (Rr) Activities	-3
F80002	Drainage Contract	Storm Water Management-Waste Management	-3
B10110	Crack Seal Rigid Pavement	Rigid Pavement Activities	-3.5
F40030	Erosion/Sediment Control Support Purchases	Storm Water Management-Administration	-4.5
A50010	Seal (All Other) Flex Pavement	Flexible Pavement Activities	-20

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Activity code	Activity description	IMMS table	Slope
W92038	Meetings with Labor Union Representatives	Training & Field Auxiliary Services Activities	-80

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Chapter 3:
DATA COLLECTION AND DATA PIPELINE

In order to identify the factors contributing to risk of collision for a particular maintenance operation, a number of potential factors were investigated. These factors characterize various aspects of different maintenance operations. In this chapter, each data set and its features, the clean-up process to filter corrupted data points or impute missing information, and the matching procedure by which these different data sets merged are described in detail.

Labor, Equipment, Materials, and Other (LEMO)

This data set primarily describes the person-hours, labor cost, equipment cost, and material costs of each maintenance work order. It was accessed as part of IMMS Reports Production in IMMS Dashboard. The IMMS Reports Production consists of various data sets, including the Statewide LEMO Budgets Edition, in which the following features are reported for every maintenance work order.

Table 3.1: Statewide LEMO budgets edition features.

Feature name	Description
Dist	District
Region	Caltrans region
Unit	No data
Work Order No	A unique number assigned to each maintenance order
Activity	6-character IMMS activity code
IMMS Project Code	No data
E-FIS Project ID	No data
E-FIS Reporting Code	No data
Maint Type	No data
Pri	No data
Month	Date of the work order in month
Workdate	Date of the work order, e.g., 18-JAN-2013
Compdttm	Complete date time
Hours	Person-hours of a work order
P.Y.'s	No data
Labor	Labor cost
Equipment	Equipment cost
Material	Material cost
LEM Total	Total cost

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In Table 3.1, no data refers to lack of information about the meaning or description of a particular feature value. In addition, although work order number is a unique number assigned to each maintenance work order, a work order may consist of different activities in the span of multiple work dates. Therefore, a work order number cannot be used as a unique key for this data set. 'Compdttm' was assumed to provide the completion date of a work order and thus its duration; however, upon further investigation, it became apparent that this assumption may not be accurate since, in most cases, completion date referred to a date months after the last work date reported for a work order. Therefore, it was decided that the duration of a work order may only be captured by person-hours reported under feature name 'hours.'

The Statewide LEMO Budgets Edition reported 5,406,475 maintenance work orders between 2013 to 2018. As discussed earlier, this number does not show the total number of unique work orders between 2013 to 2018. For simplification and dimension reduction, the data set was aggregated by grouping work order numbers, activity codes, and work dates. Each row in the resulting data set, which is reduced to 3,651,497 cases, refers to a data point that can be identified uniquely by a combination of work order number, activity code, and work date. Furthermore, this aggregation allows for later analysis on the cost and duration of each maintenance activity in Chapter 4:.

Work Order Report v5.2

This dataset, which is part of IMMS Reports Production in IMMS Dashboard, describes roadside maintenance work orders by identifying the state route and postmile information for each roadside maintenance work order. The following features are included in this dataset:

Table 3.2: Work order report v5.2 features.

Feature name	Description
Wono	Work order number
Crew	No data
Activity	6-character IMMS activity code
Activity Descr.	A brief description for the activity code
IMMS Unit ID	In case of roadside work order, a string in form of <district>-<county>-<route ID><route suffix>, e.g., 03-YOL-005
From PM	Postmile of the beginning location of a work order in the form of <postmile prefix>PM <postmile>, e.g., RPM 14.2
To PM	Same as above
Total Prod	No data
Um	No data
Comments	Additional comments about the work order

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Table 3.2, no data refers to have missing information about the meaning or description of a particular feature value. 'Wono' refers to the work order numbers described in Table 3.1. The IMMS unit ID feature consists of different coding formats possible for roads, bridges, and other structures. The only format that could be recognized and interpreted was of the form <district>-<county>-<route ID><route suffix>. The district was given in a two-digit number between 01 to 12. Counties were given in two- or three-letter abbreviated form. Route numbers were given in a three-digit form, followed by a single letter for route suffix (if any). The postmile information was of the form <postmile prefix>PM <postmile>. The postmile prefix was given in the form of a single letter (if any). No postmile suffix information is given in these data sets, which make matching procedures with other data sets considerably harder and less accurate.

The Work Order Report v5.2 includes 1,814,729 data points between 2013 to 2018. Similar to the Statewide LEMO Budget Edition data set, the work order numbers in this set are also not unique. After removing the data points for which the work order number or the postmile information was missing, the size of Work Order Report v5.2 was reduced to 983,226 maintenance work orders, which can be uniquely identified by a combination of work order number and activity code.

Matching LEMO and Work Order Data Sets

Matching the Statewide LEMO Budgets Edition (LEMO data set) with Work Order Reports v5.2 (Work Order data set) has two benefits. It allows for filtering roadside maintenance activities since the Work Order data set is reduced to only roadside activities. In addition, the resulting merged data set will describe each maintenance work order by the following important features: Activity code, Activity description, Work date, Location (District, County, Route, Postmile), Duration, and LEM (Labor, Equipment, Material) costs.

Recall that every maintenance work order in the Work Order data set was uniquely identified by a combination of work order number and activity code. These two features are also included in the LEMO data set. Therefore, a unique identifier could be created to merge the two data sets based on work order numbers and activity codes. The resulting data set includes 2,046,798 data points. This is equivalent to 983,199 unique work order numbers. A final clean-up, removing any rows with missing information for activity code, work date, county, route ID, and postmile, reduced the final size of the merged data set to 2,045,765 data points. To ease the notation, this merged data set is referred to as LEMO_WorkOrder data set. All the following data sets introduced in this chapter are matched to LEMO_WorkOrder data set because the criteria of a match often involve matching location, date, and activity type of the work order with any other feature, e.g., lane closure.

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Lane Closure System

The lane closure data sets describe various types of lane closures implemented by Caltrans on California state routes. This data set known, as Lane Closure System (LCS) is accessible as part of the Performance Measurement System (PeMS). The following features are reported for every state route lane closure.

Table 3.3: Lane closure system features.

Feature name	Description
ID	No data
Log #	No data
District	Caltrans district
Fwy-Dir	Route information of the closure in the form of <route type><route ID>-<direction of travel>, e.g., US101-S
Begin County (End County)	County information in the form of an odd number
Begin Abs PM (End Abs PM)	Absolute postmile (not restarting at county lines)
Begin State PM (End State PM)	Postmile
Length	Length of closure in miles
Status	Approve, canceled, saved, pending, rejected, returned
DTM Area	No data
Work Type	Describes the type of work, e.g., bridge, pavement, …
Start Date (End Date)	Requested start (end) date and time
Status 1097	Whether first cone placement information was reported
Status 1097 Date	First cone placement date and time
Status 1098	Whether last cone pickup was reported
Status 1098 Date	Last cone pickup date and time
Duration	Describes the duration of closure by the following values: standard, long term, or intermittent
Request Date	Date and time of closure request submission
Last Update	Date and time of the last update on the status of the closure
Emerg. Close	Whether the closure is emergency or not
Cozeep Mazeep	Whether the closure involved cozeep or mazeep
EA Number	No data
Has Detour Map	Whether a detour route was considered for the closure
Chart Table	No data
Clearance Impact	No data

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Feature name	Description
Meeting Place	No data
Estimated Delay	No data
Outside Chart Hours	No data
Submitter (Inspector or Supervisor)	6 fields for names of closure request submitter, its supervisor, and 4 inspectors
Permit	No data
Cost Center	No data
Status 1022	Whether the closure was canceled
Status 1022 Date	Date and time of closure cancelation
Remarks	Comment on some specifics of the closure
Type	Describes the type of closure by the following values: full, lane, moving, one-way
Facility	Describes the location type of the closure by the following values: connector, freeway, on ramp, off ramp, …
Closure Lanes	Number of closed lanes
Total Lanes	Number of total lanes in the route
DB ID	A unique ID given to each closure

In Table 3.3, no data refers to missing values and lack of information about the meaning or description of a particular feature. The route and postmile information that is provided by Fwy-Dir and Begin State PM are not complete. No route suffix, postmile prefix, or postmile suffix is given. Although direction of travel was given as N, E, S, W, this information cannot be converted to postmile suffix values directly. This problem manifests itself in matching the LCS data set with the LEMO_WorkOrder in which route and postmile information are not provided in either data source accurately.

The LCS data set lists 3,920,892 closure requests between the years 2013 to 2018. For the purposes of this research study, only closure requests with approved status were considered. In addition, closures with missing information about route ID, postmile (at the start or the end of closure), county (beginning county or end county), and start date (or end date) were removed from the data sets. These features are necessary to match closures with maintenance work orders described in the LEMO_WorkOrder data set. This clean-up process reduced the size of the LCS data set to 2,547,591 approved lane closures between the years 2013 to 2018.

It was assumed at first that the first letter of the ID feature in the LCS data set, which can be one of C, E, M, N, P, S, T, W, and X, refers to the type of closure where C stands for construction, P for permit and M for maintenance. However, this assumption turned out not to be entirely correct as later analysis found any

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one of the above codes may match with a maintenance work order. Furthermore, the Work Type feature in the LCS does not necessarily indicate a maintenance activity. In fact, no unifying key could be identified that can match lane closures work type and maintenance activity codes. This is also the case for matching lane closures and work orders, as no keys exist such that the corresponding closure of a maintenance work order can be identified. These challenges will make any matching of lane closures and maintenance work orders considerably more difficult and less accurate.

Matching LCS and LEMO_WorkOrder Data Sets

Since there is no common key in the LCS and LEMO_WorkOrder data set, matching work orders and lane closures is only possible by matching the location and date of each work order to lane closures. To match the date of a maintenance work order and a closure, the 'Workdate' feature of the LEMO_WorkOrder data set must fall within the start and end date of a closure. However, a closure's start date is indicated by two different fields: Start Date and Status 1097 Date. Start date in the LCS data set refers to the requested start date of a closure when the request is submitted, while the status 1097 date refers to the date the first cone of a lane closure was placed [11]. It was assumed that whenever the status 1097 date was available for a closure, this date was used in place of the requested start date as the 'true' start date. This is also the case for closure end date with a minor difference. The LCS data set reports a requested end date and a Status 1098 Date, which refers to the date the last cone of a lane closure was picked up [11].

In addition to these dates, the LCS data set also reports a Status 1022 Date which refers to the date of closure cancelation (if applicable) [11]. To determine a consistent end date for lane closures, it was assumed that whenever status 1022 date was available, this date was used as the end date. Otherwise, the status 1098 date was considered to indicate the end date. If neither status 1022 date nor status 1098 date were available, the requested end date was used as the 'true' end date. Therefore, a work order matches a closure in date if the work date of the work order is between the true start date of the closures and end dates.

Another challenge in matching the location of maintenance work orders and lane closures arises because of the missing information in reporting postmile features, such as route suffixes, postmile prefixes, and postmile suffixes in LCS data sets, in addition to postmile suffixes in the LEMO_WorkOrder data set. Moreover, since postmiles restart at county lines, to properly match work order and closure's postmiles, the beginning and end counties of work orders and closures also need to be matched. In most cases, the beginning and end counties of work order and closures are similar. However, there are edge cases that cause additional

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problems. An example of such case is given in Figure 3.1 where cones locate the beginning and end of lane closure, and work signs identify the beginning and end of the work zone. If a closure partially covered a work zone across the county line, then matching the beginning and end of lane closure and work order becomes more complex since start county for lane closures matched the end county of the work order and not the beginning of the county.

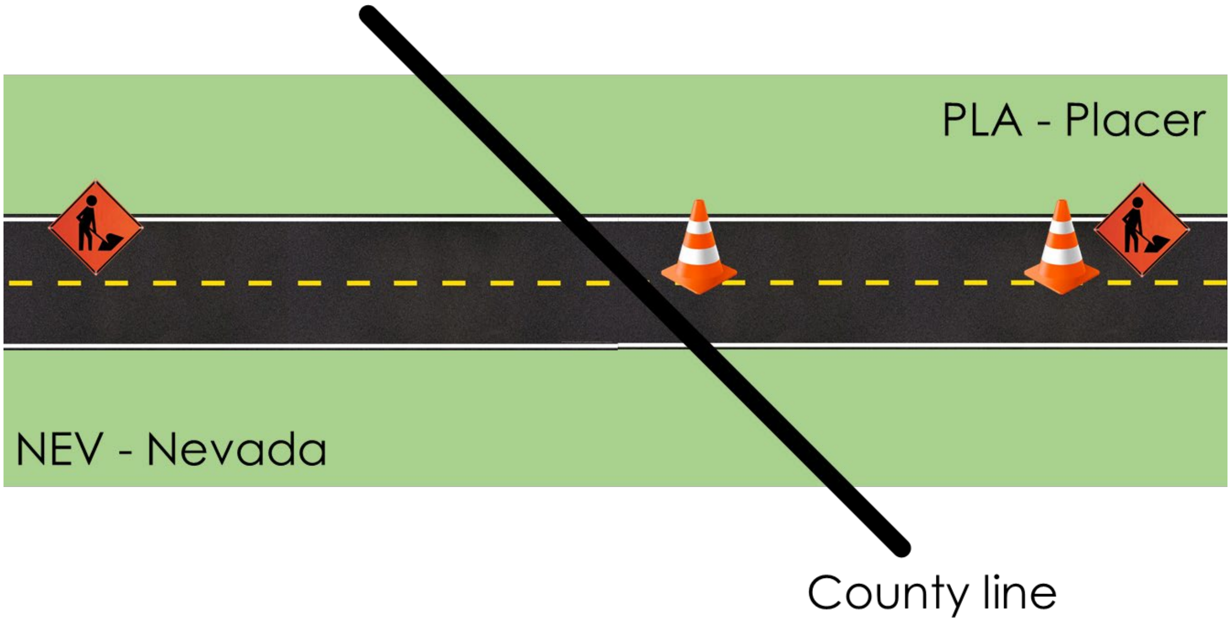

Figure 3.1: Matching closure and work order edge cases.

To ease the matching, odometer values are used in place of postmiles. Odometers do not restart at county lines and do not depend on route suffix, postmile prefix, and postmile suffix. Caltrans Postmile Services provides a web query tool that converts postmile values to odometer and geocoordinates given county, route ID, route suffix, postmile prefix, postmile, and postmile suffix [12]. Not all this information is available for every postmile provided in LEMO_WorkOrder and LCS data sets. However, Caltrans Postmile Services can estimate the closest valid postmile with a probability. Therefore, using this service will allow for incomplete postmiles to be converted to odometers or geo-coordinates except for the service only work via single web queries, which is not an efficient way to convert millions of postmiles.

Caltrans also has another web service for conversion of postmiles to odometers that is accessible through an API at PostmileWebService

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(http://geo.dot.ca.gov/pmws/services/PostmileWebService[1]). This tool can be used via http post requests where the request and the response are in xml formats. A code in Python was developed to generate xml requests per each postmile in LEMO_WorkOrder and LCS data set, and parse the response to odometer or geocoordinates. Although the service can be accessed via http post request for batch conversion, unlike the Caltrans Postmile Services web tool, the API cannot estimate the closest postmile without complete information. Therefore, for each postmile where the service could not produce a valid odometer (or geocoordinate), all potential permutations of route suffix, postmile prefix, and postmile suffix are tried via the API, and the first valid response is assumed to indicate the actual odometer. Even after this procedure, there are still cases for which no valid odometer values could be found. A preliminary investigation found that most of these cases are in-route sections that have since been relinquished.

Using odometer values instead of postmiles allows for easy comparison of locations for work orders and lane closures. The location-matching problem reduces to matching the route ID and finding whether there is an intersection between the odometer values of lane closures and work orders.

The entire matching procedure can be summarized in the following fashion. First, the LCS data set is filtered by the work order route ID and matching date intervals. Then, the odometers values for beginning and end of the work order and the closures in the filtered data set are checked to identify any intersection. The algorithm described here produces 595,530 matching closures. The length of intersection in terms of percentage of work order that is covered by the lane closure is also evaluated and is added to the matching data set as an additional feature. Since many work orders and lane closures are of zero length, no coverage threshold for eliminating closures could be determined.

The process described here for converting postmiles to odometers (or geocoordinates) by and large are applied multiple times to match work orders to traffic volumes, route features in Caltrans Clean Road File, and collision reports.

Traffic Volume Data

The traffic volume data in terms of annual average daily traffic (AADT) is available as part of the Traffic Census Program at Caltrans [13]. These traffic

[1] This web site is an API and will not open using a browser. It works via sending an http post request.

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volumes are available at the [Traffic Census Program wesite (https://dot.ca.gov/programs/traffic-operations/census)](https://dot.ca.gov/programs/traffic-operations/census) for years between 2013 to 2018. The AADT report consists of the following features.

Table 3.4: Average annual daily traffic (AADT) volume.

Feature name	Description
Dist	District
Route	Route information in the form of <route ID> <route suffix>
County	Abbreviated code for counties
Postmile	Postmile information in the form of <Postmile prefix> <postmile> <postmile suffix>
Description	A description of the route section
Back Peak Hour	Estimate of traffic volume during peak hours south and west of the location
Back Peak Month	Average daily traffic for the month of heaviest traffic flow south and west of the location
Back AADT	Average annual daily traffic south and west of the location
Ahead Peak Hour	Estimate of traffic volume during peak hours north and east of the location
Ahead Peak Month	Average daily traffic for the month of heaviest traffic flow north and east of the location
Ahead AADT	Average annual daily traffic north and east of the location

Traffic counting is generally performed by electronic counting instruments moved from location to location. The resulting counts are compensated for seasonal influence, weekly variation, and other variables. Then, the compensated counts are estimated to an annual average daily traffic [14]. The counting device reports traffic counts on two legs: ahead (north and east) and back (south and west) of the device.

Along each route, multiple traffic volumes are reported. For example, along State Route 1 (SR 1), 280 separate traffic volumes are reported. The mean distance between the locations of these reported volumes is nearly 2.31 miles. Therefore, the traffic volumes are dense enough, i.e., the reported locations are close enough, to estimate the traffic volume for any point along each route.

The traffic volume data in the form of AADT does not contain any information about the type of vehicle counted. However, there was reason to suspect that heavier truck traffic might correspond with the risk of collision at roadside work zones. In the work zone fatal crashes and fatalities reported by the Bureau of Labor Statistics, truck-involved fatal crashes counted for between 15 to 30 percent of fatalities from 2013 to 2018 [2]. Therefore, in addition to AADT volumes for all vehicles, the percentage of truck vehicles included in the AADT volumes is

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also explored as potential contributing factors to risk of injury to workers operating near live traffic at roadside work zones.

As part of the Traffic Census Program, Caltrans also reports truck annual average daily traffic volumes which are accessible at [Traffic Census Program wesite (https://dot.ca.gov/programs/traffic-operations/census)](https://dot.ca.gov/programs/traffic-operations/census) for years between 2013 to 2018. Table 3.5 lists the features reported in truck annual average daily traffic data set.

Table 3.5: Truck Average Annual Daily Traffic (AADT) volume.

Feature name	Description
RTE	Route information <route ID><route suffix>
DIST	District
CNTY	Abbreviated county code
POSTMILE	Postmile information in the form of <Postmile prefix><postmile><postmile suffix>
LEG	Ahead or back traffic
Description	A description of the route section
VEHICLE AADT TOTAL	AADT
TRUCK AADT TOTAL	AADT for trucks
TRUCK % TOT VEH	Truck percentage of total traffic
TRUCK AADT TOTAL % By Axle (2, 3, 4, 5+)	Percentage of total traffic by axle number
TRUCK AADT By Axle (2, 3, 4, 5+)	Average annual daily traffic by axle number
EAL 2-WAY (1000)	Equivalent axle loading (EAL) to represent two-way travel
YEAR VER/EST	Identifies the year the truck percent were verified (V) or estimated (E)

In Table 3.5, TRUCK AADT TOTAL % By Axle (2, 3, 4, 5+)(and TRUCK AADT By Axle (2, 3, 4, 5+)) refers to truck percentage (volume) of AADT by axle number. The Truck AADT data set includes separate columns for each axle number. EAL 2-WAY is evaluated for two-way traffic and is reported in thousands. YEAR VER/EST reports the latest year that the data reported was estimated (E) or verified (V). For

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example, a value of 07V indicates that the traffic volumes reported for that location were last verified in 2017 [15].

The Truck AADT data set is less dense than the AADT data set. In other words, truck traffic volumes are reported for locations that are farther from each other with respect to the AADT data set. For example, in contrast to the AADT report, only 137 truck traffic volumes were reported for SR 1. The average distance between each counting instrument was 4.82 miles. Therefore, although the Truck AADT data set is not as dense as the AADT data set, its density is sufficiently high to estimate the traffic volumes for any points along each route.

Matching Traffic Volumes and LEMO_WorkOrder Data Sets

As it was discussed in the matching process of LCS and LEMO_WorkOrder data sets, converting postmiles to odometer values reduces the complexity of the matching process. Fortunately, the postmiles reported in AADT or Truck AADT data sets do not usually have missing information, and all postmile and route sub-features, such as route suffix, postmile prefix, and postmile suffix, are reported when appropriate. Therefore, conversion of these postmiles to odometer values was considerably easier since no permutation of missing suffixes or prefixes was necessary.

Figure 3.2 shows a potential configuration of maintenance work orders and reported traffic volume locations. For the work order denoted in this figure, the traffic volumes reported by device 1 through 4 are relevant to evaluate the effect of traffic on the collision risk of a work order. In this particular configuration, if the direction of travel were from west to east, the back AADT volume at the start of the work order is equivalent to the ahead AADT reported by device 1. The ahead AADT volume at the start of the work order is equivalent to the back AADT reported by device 2. Similarly, the back AADT at the end of the work order is equivalent to the ahead AADT reported by device 3, while the ahead AADT is estimated by the back AADT of device 4.

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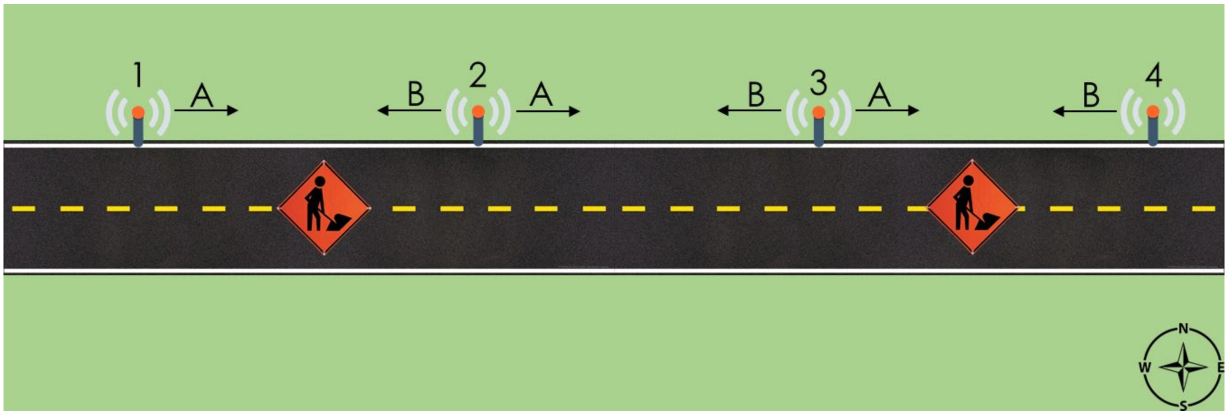

Figure 3.2: Possible configuration of work order and traffic volumes.

In order to determine the traffic volumes corresponding to a particular work order, first, the AADT data is filtered for the year and the route ID of the work order. Next, traffic volumes are sorted according to their odometer values from smallest to largest. The placement of the beginning and end of a work order relative to traffic volume odometers is then determined. Furthermore, all the AADT numbers between the beginning and end of the work order, in addition to the last AADT reported before the beginning of the work order and the first AADT reported after the end of the work order, are saved. Since no postmile suffix for work orders were available, the odometer values are evaluated after assuming left alignment and assuming right alignment for postmile suffix. This procedure also results in some edge cases where the work order corresponds to the beginning (or end of) a route. In these cases, back (ahead) AADT does not exist for the beginning (end) of the work order (for example, assuming west to east direction of travel).

Clean Route File

The road features at the location of work order, such as median type, barrier type, surface type, or whether the route was divided or not, were available as part of a data set in a comma separated value file (csv) referred to as Highway Element Marker. Table 3.6 lists the features available in this file.

Table 3.6: Highway element marker features.

Feature name	Description
ID	A unique ID for each data point
DISTRICT_CODE	District code
COUNTY_CODE	Abbreviated county code
ROUTE_NAME	Route ID
ROUTE_SUFFIX_CODE	Route suffix
PM_PREFIX_CODE	Postmile prefix code
BEGIN_PM_AMT	Beginning postmile of the marker

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Feature name	Description
END_PM_AMT	End postmile of the marker
PM_SUFFIX_CODE	Postmile suffix code
ELEMENT_ID	No data
BEGIN_OFFSET_AMT	No data
END_OFFSET_AMT	No data
BEGIN_DATE	No data
END_DATE	No data
CREATE_DATE	No data
CREATE_USER_NAME	No data
SEG_ORDER_ID	No data
LENGTH_MILES_AMT	Postmile length of the marker
LEFT(RIGHT)_EFF_DATE	No data
LT(RT)_SURF_TYPE_CODE	A character code for surface type
LT(RT)_SURF_TYPE_DESC	Description of the surface code; for example, bridge deck, concrete, …
LT(RT)_LANES_AMT	Number of lanes
LT(RT)_THROUGH_LANES_AMT	No data
LT(RT)_ROADWAY_USE_CODE	A character code describing the usage
LT(RT)_ROADWAY_USE_DESC	Description of the roadway use code; for example, railroad, bus lane, conversion only, …
LT(RT)_SPEC_FEATURES_CODE	A character code for special features
LT(RT)_SPEC_FEATURES_DESC	Description of special features of the road; for example, tunnel, auxiliary lane, …
LT(RT)_O(I)_SHD_TOT_WIDTH_AMT	Outside (inside) total shoulder width
LT(RT)_O(I)_SHD_TRT_WIDTH_AMT	Outside (inside) TRT shoulder width
LT(RT)_TRAV_WAY_WIDTH_AMT	Travel way width
LT(RT)_SIG_CHG_IND	No data
MEDIAN_EFF_DATE	No data
MEDIAN_TYPE_CODE	A character code for median type
MEIDAN_TYPE_DESC	Description of the median type code; for example, sawtooth, separate grades, …
CURB_LANDSCAPE_CODE	A digit indicating whether the median was curbed or not and its type
CURB_LANDSCAPE_DESC	Description of the curb code; for example, curbed median, curbed with shrubs, …
MEDIAN_BARRIER_CODE	A character code for barrier type
MEDIAN_BARRIER_DESC	Description of the barrier type code; for example, concrete barrier, metal beam, …
MEDIAN_WIDTH_AMT	Median width
MEDIAN_WIDTH_VAR_CODE	No data

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Feature name	Description
MEDIAN_SIG_CHG_IND	No data
M_ROADWAY_USE_CODE	A character code for median usage type
M_ROADWAY_USE_DESC	Description of median usage code; for example, railroad, conversion only, …
CITY_CODE	No data
HIGHWAY_GROUP_CODE	A character code for division of the road
HIGHWAY_GROUP_DESC	Description of the highway group code; for example, divided highway, undivided highway, …
HIGHWAY_ACCESS_CODE	No data
HIGHWAY_ACCESS_DESC	No data
ACESS_EFF_DATE	No data
ACESS_SIG_CHG_IND	No data
TERRAIN_CODE	A character code for terrain type
TERRAIN_DESC	Description of terrain code; for example, flat, mountainous, …
DESIGN_SPEED_AMT	The design speed in miles per hour
NON_ADD_CODE	No data
PROFILE_CODE	No data
ADT_AMT	Average daily traffic
CHANGE_PER_MILE_AMT	No data
LANDMARK_SHORT_DESC	A short description of the element in the road
POPULATION_CODE	A character code for population code; U for urban, and R for rural.
LAST_SIG_CHG_DATE	No data
RECORD_DATE	No data
UPDATE_DATE	No data
UPDATE_USER_NAME	No data
MAINT_SVC_LVL_CODE	No data
EQUATE_CODE	No data
BREAK_DESC	No data
TOLL_FOREST_CODE	A code indicating whether the road is a forest highway
TOLL_FOREST_DESC	Description of the forest code; for example, forest highway, none, …
NATIONAL_LANDS_CODE	A character code for type of national landscape
NATIONAL_LANDS_DESC	Description of national landscape code; for example, national forest, national recreation area, …

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Feature name	Description
SCENIC_FREEWAY_CODE	A character code for type of scenic freeway
SCENIC_FREEWAY_DESC	Description of the scenic freeway, for example, national forest, national monument, …
EXTRACT_DATE	No data

This data set appears to be even denser than the AADT and Truck AADT data sets. For example, SR 1 in this data set is divided into 2,385 segments. The average length of the SR 1 segments is divided into is 0.26 miles. Therefore, determining the corresponding segment(s) for each work order would follow a similar process to matching AADT and LEMO_WorkOrder data sets.

Also note that in Table 3.6, no data refers to both missing information and lack of information about meaning or description of the given values in a particular column. In addition, all feature names start with 'THY_,' which are eliminated in Table 3.6 for simplification. Moreover, some of the features are reported for both the right and the left alignment as denoted by 'RT' or 'LT' in feature names.

Matching Highway Elements and LEMO_WorkOrder Data Sets

To determine the roadway features corresponding to the work order, the work order beginning and end postmile should be matched with the corresponding segments in the Clean Route File data set. The procedure is similar to the one described for matching traffic volumes and LEMO_WorkOrder data sets.

Statewide Integrated Traffic Records System (SWITRS)

The final item in need of identification is which work orders correspond with a collision and resulted in injury or fatality. To that end, the statewide integrated traffic records system, which summarizes the collision reports submitted to California Highway Patrol (CHP) [16], is used to find collisions that match with a work order, primarily in date and location. The SWITRS data set is accessible via the Transportation Injury Mapping System at [TIMS (https://tims.berkeley.edu/)](https://tims.berkeley.edu/).

Table 3.7: SWITRS features.

Feature name	Description
CASE_ID	A unique ID for each collision
ACCIDENT_YEAR	The year of the collision

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Feature name	Description
PROC_DATE	Date the record was processed
JURIS	Jurisdiction code
COLLISION_DATE	The date of collision
COLLISION_TIME	A 4-digit number indicating the 24-hour time of the collision
OFFICER_ID	No data
REPORTING_DISTRICT	No data
DAY_OF_WEEK	A numeric code for day of the week
CHP_SHIFT	A numeric code for CHP's 24-hour shifts
POPULATION	A numeric code indicating population level
CNTY_CITY_LOC	A 4-digit code indicating county and city code of the collision
SPECIAL_COND	A numeric code indicating special conditions of the collision
BEAT_TYPE	No data
CHP_BEAT_TYPE	A numeric code indicating the type of the road
CITY_DIVISION_LAPD	No data
CHP_BEAT_CLASS	No data
PRIMARY_ROAD	The road collision occurred on
SECONDARY_ROAD	A secondary reference road for the collision
DISTANCE	Offset distance from the secondary road
DIRECTION	Direction of the offset from the secondary road
INTERSECTION	Indicates whether a collision occurred at an intersection
WEATHER_1	The weather condition at the time of the collision
WEATHER_2	The weather condition at the time of the collision, if a second description is necessary
STATE_HWY_IND	Indicates whether a collision occurred on a state highway
CALTRANS_COUNTY	County of the collision
CALTRANS_DISTRICT	District of the collision
STATE_ROUTE	Route ID
ROUTE_SUFFIX	Route suffix

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Feature name	Description
POSTMILE_PREFIX	Postmile prefix
POSTMILE	Postmile
LOCATION_TYPE	A character code for location type of the collision
RAMP_INTERSECTION	A numeric code indicating the proximity of collision to intersections or ramps
SIDE_OF_HWY	A character code indicating the side of highway the collision occurred on
TOW_AWAY	No data
COLLISION_SEVERITY	The injury level severity of the collision
NUMBER_KILLED	Counts fatalities of the collision
NUMBER_INJURED	Counts the injured parties of the collision
PARTY_COUNT	Count total parties involved in the collision
PRIMARY_COLL_FACTOR	Primary collision factor
PCF_CODE_OF_VIOL	No data
PCF_VIOL_CATEGORY	Violation category (primary reason) of the collision
PCF_VIOLATION	Corresponds to violation categories
HIT_AND_RUN	A character code indicating the felony level of the collision
TYPE_OF_COLLISION	A character code describing the collision type
MVIW	Motor vehicle involved with the collision
PED_ACTION	A character code indicating the pedestrian type of involvement in the collision
ROAD_SURFACE	Road surface condition
ROAD_COND_1	A character code describing the obstruction or other conditions of the road
ROAD_COND_2	A character code describing secondary conditions of the road
LIGHTING	A character code describing the lighting condition
CONTROL_DEVICE	Whether a control device was used
CHP_ROAD_TYPE	No data

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Feature name	Description
PEDESTRIAN_ACCIDENT	indicates whether the collision involved a pedestrian
BICYCLE_ACCIDENT	indicates whether the collision involved a bicycle
MOTORCYCLE_ACCIDENT	indicates whether the collision involved a motorcycle
TRUCK_ACCIDENT	indicates whether the collision involved a big truck
NOT_PRIVATE_PROPERTY	indicates whether the collision occurred on private property
ALCOHOL_INVOLVED	indicates whether the collision involved a party that had been drinking
STWD_VEHTYPE_AT_FAULT	indicates the Statewide Vehicle Type of the party who is at fault
CHP_VEHTYPE_AT_FAULT	indicates the CHP Vehicle Type of the party who is at fault
COUNT_SEVERE_INJ	counts victims in the collision with degree of injury of 2
COUNT_VISIBLE_INJ	counts victims in the collision with degree of injury of 3
COUNT_COMPLAINT_PAIN	counts victims in the collision with degree of injury of 4
COUNT_PED_KILLED	Counts the victims in the collision with party type of 2 and degree of injury is 1
COUNT_PED_INJURED	Counts the victims in the collision with party type of 2 and degree of injury is 2, 3, or 4
COUNT_BICYCLIST_KILLED	Counts the bicyclist fatalities
COUNT_BICYCLIST_INJURED	Counts the injured bicyclist
COUNT_MC_KILLED	counts victims in the collision with statewide vehicle type of C or O and degree of injury of 1
COUNT_MC_INJURED	counts victims in the collision with statewide vehicle type of C or O and degree of injury of 2, 3, or 4
PRIMARY_RAMP	2-character code indicating the location of the collision with respect to ramps

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Feature name	Description
SECONDARY_RAMP	2-character code for describing secondary ramp
LATITUDE	Latitude
LONGITUDE	Longitude

Additional details about the description of feature values are available at TIMS (https://tims.berkeley.edu/). In Table 3.7, no data refers to both missing information and lack of information about meaning or description of a particular feature.

The complete SWITRS data set after filtering non-state route collisions consists of 1,064,309 collisions between 2013 to 2018. This is achieved by filtering collisions for which STATE_HWY_IND is equal to 'Y.' The SWITRS data set requires a significant clean-up process. In particular, all the date type features are reported as eight-digit numbers in the form of 'yyyymmdd'. Collision times are reported as four-digit numbers in the form of 'hhmm'. The county is not identified explicitly, and must be derived from the CNTY_CITY_CODE feature using the first two digits which denote the county code. Finally, the locations of state route collisions are not always provided in the form of state route and postmile. The state route and postmile information of the majority of collisions is missing.

The SWITRS data set is important for evaluating the risk to injury for each maintenance activity since, in addition to determining the risk of collision, it also provides features evaluating the severity of the collision. Therefore, matching this data set with the LEMO_WorkOrder data set is of significant importance to this research study and the basis of the risk analysis in Chapter 5.

Matching SWITRS and LEMO_WorkOrder Data Sets

As discussed above, the location information in the SWITRS data set is not given in a single format. Only 414,558 collisions out of 1,064,309 reports in the SWITRS data set have postmile information. Out of remaining 649,751 collisions, 614,171 cases come with geocoordinate information. However, there are 35,580 collisions that do not have any location information. In Matching LCS and LEMO_WorkOrder Data Sets subsection, the procedure and the code by which postmiles can be converted to geocodes or odometer values were discussed. The same Caltrans web services are capable of converting geocoordinates to odometer values.

Therefore, it seems that converting postmiles and geo-coordinates to odometers may allow for calculation of a unified location feature for each collision. However, several challenges related to this conversion remain. In particular, geo-coordinates reported in the SWITRS data set are not accurate

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because, for the most part, they are reported up to four-decimal places instead of the typical six. This lower level of accuracy results in less accurate conversions. The Caltrans web query tool is capable of refining its conversion if it is supplied with the route number. However, for collisions where no postmile information was available, the STATE_ROUTE information, i.e., the route ID, is also missing. The information about the state route in these cases are captured by the two features: PRIMARY_ROAD and SECONDARY_ROAD, but the input format is not consistent within the data set. For example, the following are some of the formats that can be observed in this data set: RTE 10, I-5 N/B, SR-62, STATE ROUTE 120, SR-118 W/B TO RINALDI ST, INTERSTATE 605, US-50 E/B, etc. In addition, the state route portion of the location is not always reported as the primary road. Therefore, to extract the route information in order to improve the coordinate to odometer conversion, the numeric part of the primary road (and the secondary road, if any) is extracted and used as additional input for odometer conversion. Note that, because of limited accuracy in geo-coordinate (four-decimal place), the Caltrans web query tool returns the closest equivalent odometer and postmile. The tool also returns a distance from the given geo-coordinate and the closest postmile and odometer. A threshold of 2,640 ft (0.5 mile) is considered for the accuracy of this conversion. Therefore any odometer values which were distanced farther than this threshold from the given geo-coordinates were removed. This process reduced the data set to 931,292 cases from the original 1,064,309.

After the conversion, matching collisions and maintenance work orders by route ID, work date (collision date), and odometer values is possible. The process is similar to the procedure discussed in Matching LCS and LEMO_WorkOrder Data Sets. For each collision, the LEMO_WorkOrder data set is filtered for the collision's route ID. The reduced data set is filtered further for work dates that equal the collision date. Finally, the odometer value of the collision is checked to see if it is located between the beginning and end odometer of the work order.

However, this matching procedure does not produce accurate results. Most work orders do not continue during the night hours, but there are collisions that match with a work order in location and date but have occurred at 1:00 AM. This is not an easy problem to solve since no time information is reported for the work orders. In fact, matching collision and work orders by location and date results in more than 200,000 matched collisions. This is not a reasonable amount since it would mean that nearly a quarter of all collisions between 2013 to 2018 are work zone related.

To rectify this problem, two more criteria are considered to further filter the matched collisions. First, ROAD_COND_1 and ROAD_COND_2 can identify a work zone collision by indicating 'D' as their value, which denotes a 'construction or repair zone.' This is extremely helpful and reduces the number of matched

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collisions significantly. In fact, considering this criterion, the number of matched collisions reduces to 37,037 cases.

However, it is not clear what exactly constitutes a work zone collision in the SWITRS data set. For example, do all lane closures, especially moving closures and zero length closures, change the road condition? This question motivated matching collisions with work orders that match a lane closure themselves. Moreover, since the lane closures are reported with start and end time, the collision time can also be checked to be within the closure interval. This criterion reduced the number of collisions to 73,058. Since the primary criterion for matching in this case is the existence of a lane closure, the resulting data set is expected to be biased toward collisions that match work orders that require lane closures.

Matching LEMO_WorkOrder with Collision Density

Along each route, some places are more prone to accidents than others. This might be due to different reasons such as intersections, ramps, road width suddenly changes, sudden turns, etc. In the data sets collected and processed thus far, there is no feature that can capture the overall effect of location on the risk of collision. However, using the SWITRS data set, one could construct such a feature based on the number of collisions that occurred in a specific segment of the road. To this end, each route must be divided into a sequence of segments, and frequency of collision in each segment should be evaluated.

The Clean Route File marks different elements of a road, including its starting and end postmile, along its length. In Matching Highway Elements and LEMO_WorkOrder Data Sets, element postmiles were converted to odometer values, and thus, the length of any route can be evaluated by odometer. Each route is then divided into two-mile segments. To count the number of collisions per each segment, the corresponding segment for each collision is found using the location of the collision in odometer, which is available as a result of Matching SWITRS and LEMO_WorkOrder Data Sets.

This process results in another data set where the number of collisions per each two-mile segment of each route is evaluated. For example, Figure 3.3 shows the frequency of collisions for SR 1 for a sequence of two-mile segments in LA County.

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In Figure 3.3, the frequencies are generated from the SWITRS data set for collision between the years 2011 to 2018.

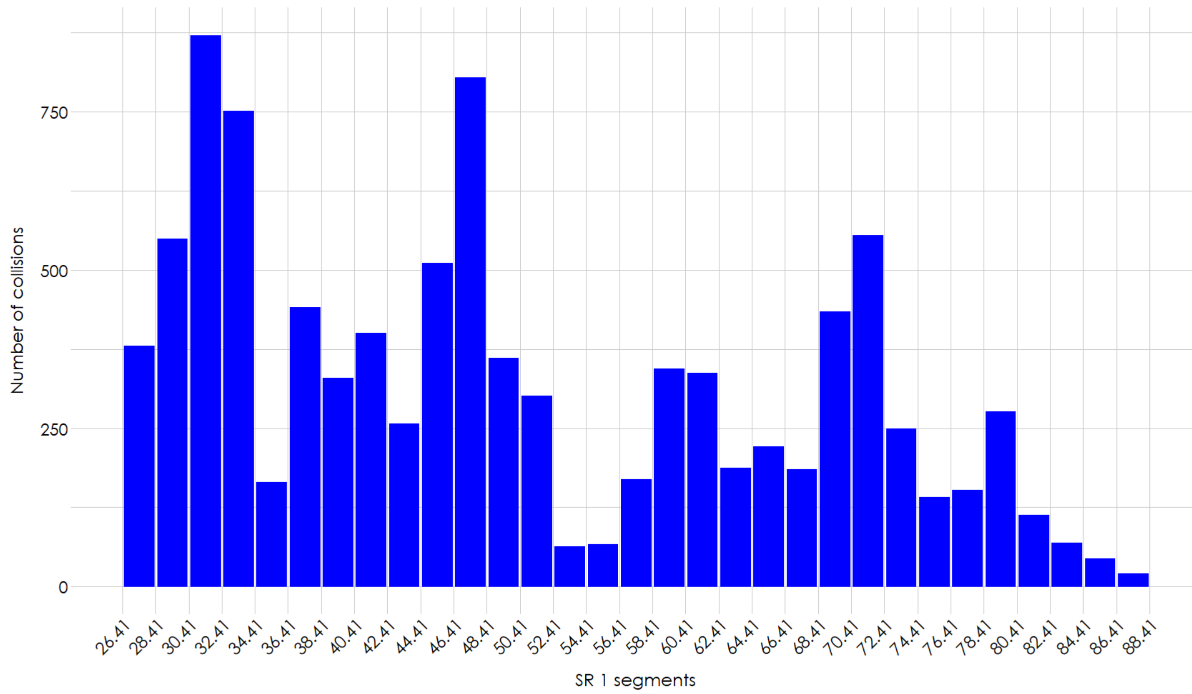

Figure 3.3: Collision density for SR 1 in LA County.

The final step is to match these densities with work order reports in the LEMO_WorkOrder data set. The matching process is similar to Matching Highway Elements and LEMO_WorkOrder Data Sets. Since a work order sometimes may intersect with more than one route segment, the collision density corresponding to that work order is assumed to be equivalent to the average collision densities across matching segments.

Data Pipeline

A final data set that corresponds each maintenance work order with lane closures data, traffic volumes (AADT, Truck AADT), road features (Clean Route File), collision reports (SWITRS), and collision density is created. The resulting data set consists of 2,046,709 work orders between the years 2013 to 2018 for different activities. This translates to 983,199 unique work order numbers, 231,011 unique closures, and 16,891 unique collisions.

The matching process, in its purest form without dimension reduction and clean-up processes, also produces 268 features for each work order number. Not all of these features provide useful information for analysis, and this number is significantly reduced for the analysis in later chapters.

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The final data pipeline can be summarized as follows:

1. Match the Statewide LEMO Budget Edition data set with Work Order Report v5.2 by the process described in Matching LEMO and Work Order Data Sets. The resulting LEMO_WorkOrder data set identifies each work order with a work order number, an activity code, and a work date. It also has information about the location of the work order (postmile).
2. Convert all the postmile information in the LEMO_WorkOrder data set and the Lane Closure System (LCS) to odometers. Given the odometer values, using the process described in Matching LCS and LEMO_WorkOrder Data Sets, the corresponding lane closure for each work order can be found (if any). In this research study, a tolerance of 0.25 miles was considered for odometer comparisons. Furthermore, since no postmile suffixes are provided in the LEMO_WorkOrder data set, this information is disregarded in the matching process. Therefore, there might be cases where the work order is on one side of the road and the lane closure is applied to the opposite side. However, since these mismatches must happen at the same time and in the same location, it is expected that their contribution to the error of the matching process will be negligible. Also, after the matching process, the route alignment (postmile suffix) for some of the work orders becomes available.
3. Convert all traffic volumes reported locations to odometer. Then, using the process described in Matching Traffic Volumes and LEMO_WorkOrder Data Sets, find the AADT and Truck AADT volumes per each work order. A tolerance of 0.25 miles was considered for this matching in comparison of odometers. Also, for most traffic volume's postmile, postmile suffix (route alignment) is not reported, and the left and right odometer match. However, this is not true for all reported traffic volumes, and thus, two sets of odometer values for right and left alignment are generated. A number of work orders match with a closure, and as a result, their alignment can be determined. This alignment is used in matching traffic volumes and work orders. For work orders with absolutely no information on the alignment, traffic volumes' odometer for both alignments are matched with the work order.
4. All postmile information in the Clean Route File should be converted to odometer values. Given the odometer values, route features for each work order's state route can be matched by the process described in Matching Highway Elements and LEMO_WorkOrder Data Sets. Here, a tolerance of 0.25 miles is also applied when comparing odometer values. In addition, the Clean Route File reports the sum of its features separately for the left and right alignment as can be seen in Table 3.6. For a majority of locations, the features in the right and left alignment of

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the Clean Route File are similar, and thus one of them can be matched with a work order. Otherwise, if no alignment is available for the work order, via, for example, a matching closure, the feature is skipped, and a null value is returned. This assumption is justified since, much of the time, the features for both alignments are similar.

5. All postmile and geocoordinate information in the SWITRS data set is converted to odometer values. Then, matching work orders and collisions can be done using the process described in Matching SWITRS and LEMO_WorkOrder Data Sets. Moreover, collision densities for each work order can also be determined by the process in Matching LEMO_WorkOrder with Collision Density. Similar to previous steps, a tolerance of 0.25 is considered for odometer comparisons. When alignment information for collisions or work orders is not available, both alignments are considered when matching work orders and collisions.

Capturing the Experience of Caltrans Personnel

The AHMCT research center developed a survey to collect input from Caltrans employees in order to develop performance measures for roadside maintenance activities. The questionnaire surveyed Caltrans personnel on factors affecting the difficulty and risk of injury for different maintenance activities. The survey also gathered information about the Caltrans preference with respect to the performance and expected characteristics of a prototype decision toolbox for implementation of the results of this study. The questionnaire is presented in Appendix C: Performance Measures for roadside features questionnair. In the next chapter, the results of this survey related to the development of indices estimating the level of difficulty and risk of collision are presented. The rest of survey results were related to a follow-up study that was planned to develop the prototype of a decision toolbox are eliminated from this report.

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Chapter 4:
SYNTHESIS OF RESULTS

In this chapter, synthesis of the results captured from the various data sets discussed in Chapter 3: are presented. The figures and tables presented in this chapter are summarized to the most significant cases, or their scope is limited to a subset of data. This limitation is necessary because plotting the data in its entirety can produce plots that are easily readable. However, the analysis required to generate these figures and plots is already done at AHMCT over the entire data set, and thus, generating new figures or tables does not necessitate additional analysis.

Distribution of Maintenance Activities

Figure 4.1 shows the proportion of maintenance work orders in each district between 2013 to 2018. Districts 7 and 4 combines for more than 30% of all maintenance work orders, whereas Districts 2 and 9 account for less than 5% of all maintenance work orders. Each district can be looked at more closely to investigate how maintenance activities are distributed in each district.

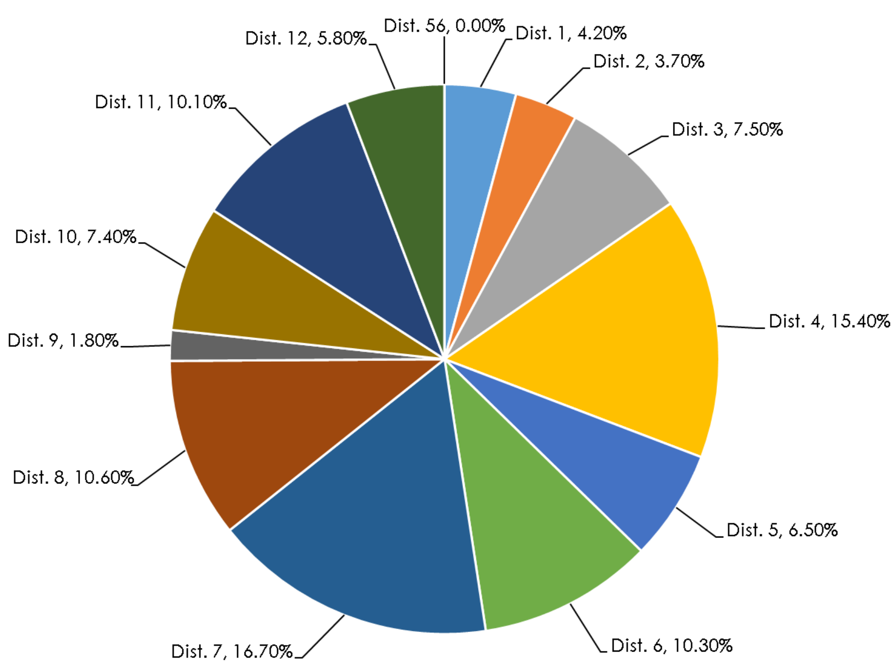

Figure 4.1: Proportion of maintenance work order in each district.

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To that end, Figure 4.1 shows the distribution of IMMS maintenance groupings in each district. The size of each bubble is proportional to the frequency of work orders of a particular family in each district. Moreover, Figure 4.2 identifies which family of maintenance activities were the most frequent from 2013 to 2018 by labeling the top 3 most frequent family in each district. For example, in District 4, the most frequent family of activities was the D family, which consists of sweeping, carcass pickups, and litter control type activities. Figure 4.2 shows that the most frequent family of activities across all districts belong to the D (cleaning activities), M (sign and marking activities), C (shoulder activities), and E (landscape activities) families.

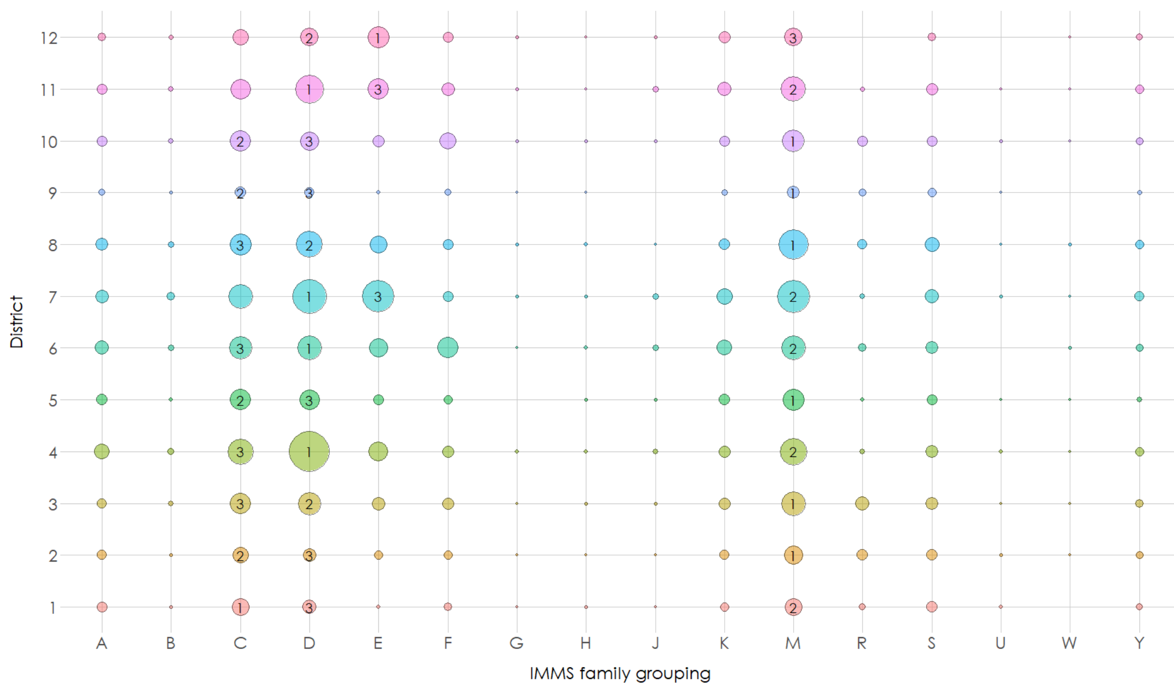

Figure 4.2: Distribution of IMMS family groupings in each district.

Looking one step further into each district, the detailed distribution of maintenance activity codes can be evaluated. For example, Figure 4.3 plots the distribution of IMMS maintenance activity codes in District 4 for the top 3 families identified in Figure 4.2. It is observed that the most frequent activity in District 4 is D40050, which identifies litter control activities. This activity is followed by M40010 (repair/replace signs) and D60050 (graffiti removal), respectively. Similar figures can be generated for the entirety of activities in each district. In summary, Table 4.1 lists the top 3 most frequent activities in each district.

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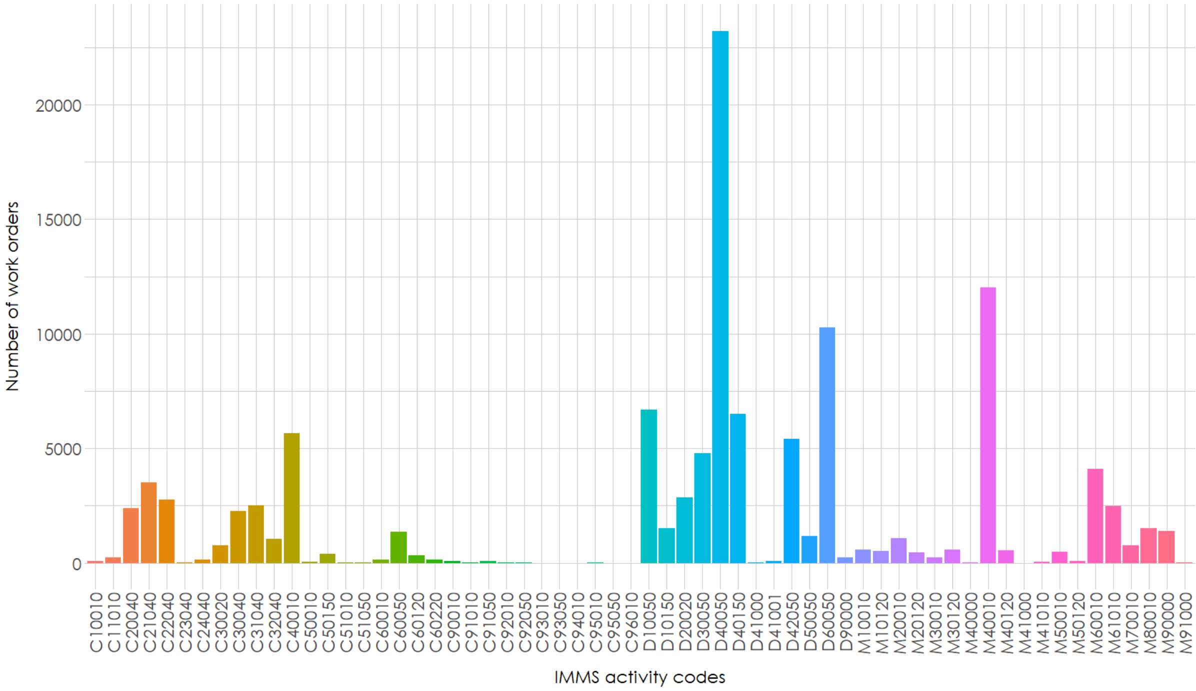

Figure 4.3: Distribution of IMMS activities in District 4.

Table 4.1: Top 3 most frequent activities by district.

District	Top 3 frequent activities (in descending order)	District	Top 3 frequent activities (in descending order)
1	Repair/replace signs, debris/carcass pick-up, and sweep HWY/shoulder	7	Manual control landscape, chemical control landscape, and repair/replace signs
2	Repair/replace signs, night inspection HWY lighting, and snow removal	8	Repair/replace signs, debris/carcass pick-up, and repair/replace guardrail
3	Repair/replace signs, debris/carcass pick-up, and repair/replace guardrail	9	Storm patrol, repair/replace signs, and debris/carcass pick-up
4	Litter control, debris/carcass pick-up, and repair/replace signs	10	Field activity/facility BMPS, repair/replace signs, and debris/carcass pick-up
5	Repair/replace signs, supervisor area inspection, and litter control	11	Repair/replace signs, supervisor area inspection, and irrigation system repair lndsc.

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District	Top 3 frequent activities (in descending order)	District	Top 3 frequent activities (in descending order)
6	Field activity/facility BMPS, repair/replace signs, and repair/replace fence	12	Chemical control landscape, repair/replace signs, and repair/replace guardrail

Similar results can be derived for counties instead of districts. Table 4.2 shows the proportion of maintenance work orders by each county. Counties where this proportion was less than 2% were removed. As expected, Los Angeles County's demand for roadside maintenance exceeds other counties by a significant margin.

Table 4.2: Proportion of maintenance work orders by county.

County	Proportion of maintenance work orders (in descending order)
Los Angeles	0.15
San Diego	0.09
San Bernardino	0.06
Orange	0.06
Riverside	0.05
Kern	0.04
Alameda	0.04
Fresno	0.03
Santa Clara	0.03
Contra Costa	0.02
Tulare	0.02
Sacramento	0.02
Ventura	0.02

Analysis of Cost and Duration for Each Activity

In this section, the IMMS maintenance activities are analyzed with respect to their cost and duration (in person-hour). This analysis was considered because it was assumed that cost and duration of an activity may indicate the level of difficulty associated with that activity. In other words, it was assumed that some aspects of the level of difficulty for each activity may be captured by the activity's duration and cost.

To that end, the LEMO_WorkOrder data set is grouped by each IMMS activity code, and then it is aggregated by adding the costs to evaluate the total cost of the activity between 2013 to 2018. Aggregation may also be done by taking the average of costs to evaluate the mean cost associated with each activity from 2013 to 2018. Table 4.3 and Table 4.4 show the top 10 costliest activities with respect to total cost and average cost, respectively. In most cases, the activities

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in Table 4.3 differ from those in Table 4.4. This might be due to frequency of each activity. In Distribution of Maintenance Activities, it was observed that some activities are significantly more frequent than others. Therefore, even if the activity itself is not costly on average (e.g., E11040 is the 58th activity in terms of average cost per work order), its high frequency may result in high total costs after a long period of time (E11040 was the third most frequent maintenance activity from 2013 to 2018).

Table 4.3: Top 10 costliest activities in terms of total cost.

Activity	Description	Total cost (in descending order)
E11040	Manual control landscape	$21,035,574
F20051	Sweep HWY/shoulder	$17,403,396
D40050	Litter control	$17,226,607
D10050	Debris/carcass pick-up	$13,273,295
A30010	Dig out flex pavement	$12,004,197
M40010	Repair/replace signs	$10,135,632
M10010	Repair/replace striping	$9,775,686
C20040	Mechanical control roadside	$8,633,209
R10000	Snow removal	$8,548,644
E30010	Irrigation system repair lndscp	$8,418,412

Table 4.4: Top 10 costliest activities in terms of average cost.

Activity	Description	Average cost (in descending order)
A50010	Seal (all other) flex pavement	$7,372.23
A30010	Dig out flex pavement	$5,572.98
A20010	Overlay/leveling flex pavement	$4,672.16
YA0000	Work for others a family	$3,638.08
F40020	Install soil stab/sediment/rsp.	$3,581.38
M10010	Repair/replace striping	$3,532.96
A21010	Profile grinding flex pavement	$3,473.70
C24040	All other weed control rdsd.	$3,430.40
A22010	D08 unpaved travelway repairs	$3,337.74
B21010	Overlay/leveling rigid pavement	$3,116.82

A similar type of analysis is also applied to the duration of work orders in the LEMO_WorkOrder data set. The data set is grouped by IMMS activity codes and is aggregated by adding durations to evaluate the total person-hours of each activity code from 2013 to 2018. The average person-hour of each activity is evaluated by changing the aggregation function from addition to a sample

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mean. Table 4.5 and Table 4.6 show the top 10 most time-consuming activities with respect to total and average person-hours, respectively. The majority of the top 10 most time-consuming activities in terms of total person-hours are also the top 10 with respect to total cost. This confirms the previous observation that the most demanding activities in maintenance operations are not the ones with the highest cost or the most time-consuming (in terms of average cost or duration). In fact, the most frequent activities turn out to demand the most person-hours and the largest budget in Caltrans.

Table 4.5: Top 10 most time consuming activities in terms of total person-hour.

Activity code	Description	Total person-hours (in descending order)
E11040	Manual control landscape	490,319.41
D40050	Litter control	383,693.98
F20051	Sweep HWY/shoulder	357,924.30
D10050	Debris/carcass pick-up	291,829.90
M40010	Repair/replace signs	193,388.75
E30010	Irrigation system repair lndsc.	191,299.31
C20040	Mechanical control roadside	183,674.75
A10110	Crack seal flex pavement	155,676.25
C30040	Tree trimming	154,944.40
C10010	Lateral support - native matl.	145,525.25

Table 4.6: Top 10 most time consuming activities in terms of average person-hour.

Activity Code	Description	Total person-hours (in descending order)
A30010	Dig out flex pavement	60.11
S33000	Blasting	59.00
S31040	Rock scaling	58.02
J60060	Scheduled lane change channelizers	56.44
S31010	Repair/replace rock fall protection	50.67
U60040	Comm site - maintenance	49.00
A21010	Profile grinding flex pavement	48.49
J60040	Maintenance channelizers	48.00
YS0000	Work for others S family	47.77
B31010	Slab replacement rigid pavement	46.08

Building on the previous analyses, it might be insightful to identify those activities that rank high with respect to average cost and average duration and

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are sufficiently frequent. Figure 4.4 identifies the most time-consuming, costly, and frequent activities. In Figure 4.4, the size of each bubble is proportional to the frequency of that activity between 2013 to 2014. Colored bubbles indicate that the corresponding activity was among the top 25% with respect to the frequency. The horizontal dashed red line marks the third quartile cutoff value, and thus the bubbles above it belong to the top 25% with respect to average cost. The vertical dashed red line marks the third quartile cutoff value, which means the bubbles to the right of the dashed red line belong to the top 25% with respect to average person-hour. Therefore, the labeled activities in Figure 4.4 are among the top 25% with respect to duration, cost, and frequency. These activities and their descriptions are given in Table 4.7.

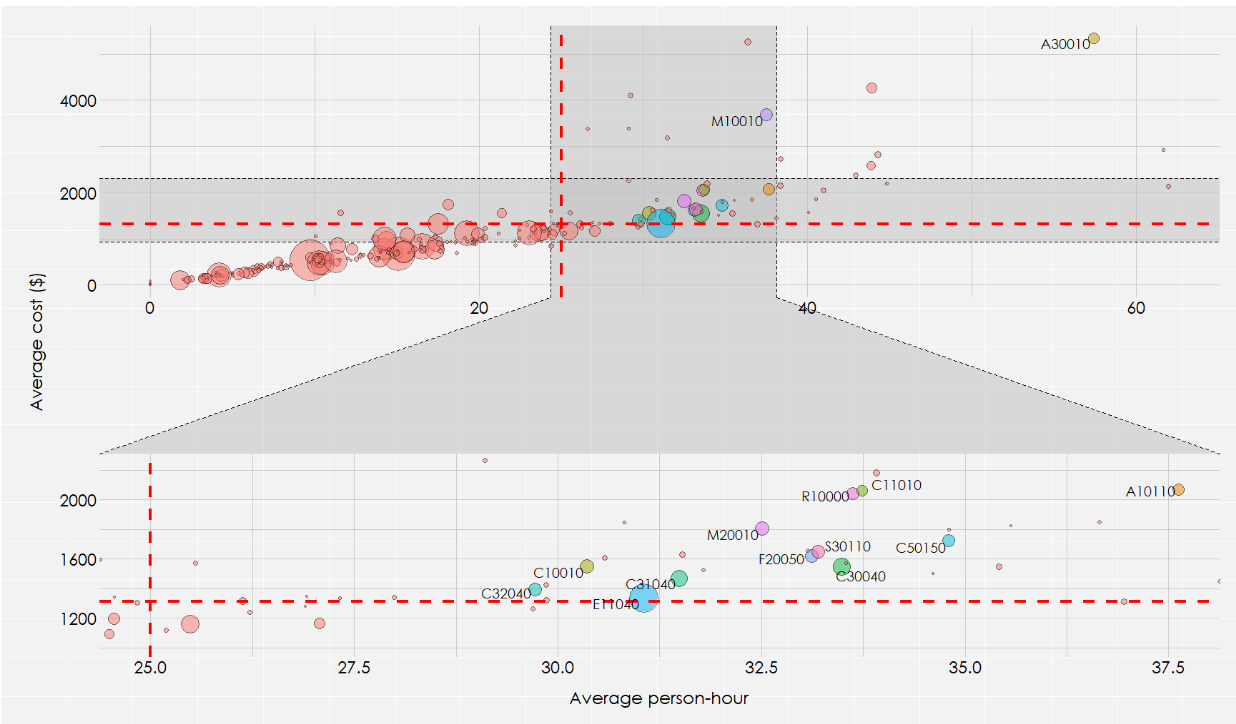

Figure 4.4: The most time-consuming, costly, and frequent activities.

Table 4.7: The most time-consuming, costly, and frequent activities.

Activity	Description
A30010	Dig out
M10010	Repair/replace striping
A10110	Crack seal
C11010	Lateral support-import material
R10000	Snow removal
M20010	Repair/replace markings
C50150	Clean ditches and channels

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Activity	Description
S30110	Minor slide/slip remove/repair
F20050	Drainage inlet cleaning
C10010	Lateral support-native material
C30040	Tree trimming
C31040	Remove tree
C32040	Brush control
E11040	Manual control landscaping

Analysis of Lane Closures for Each Activity

To investigate which activities frequently require lane closures, LEMO_WorkOrder data set is matched with the LCS data set using the process described in Chapter 3:. To increase clarity of the reported results, the data sets are grouped by the IMMS family grouping (instead of IMMS activity codes) which reduces the dimensions of data sets significantly.

First, the family groupings that required a lane closure most of the time were identified. Figure 4.5 shows the number of lane closures implemented by activities belonging to different IMMS family groupings. As expected, the most frequent activities also require the greatest number of closures. Particularly, family D matches with the greatest number of lane closures, which consists of road cleaning activities, such as road sweeping, carcass pickup, and litter control.

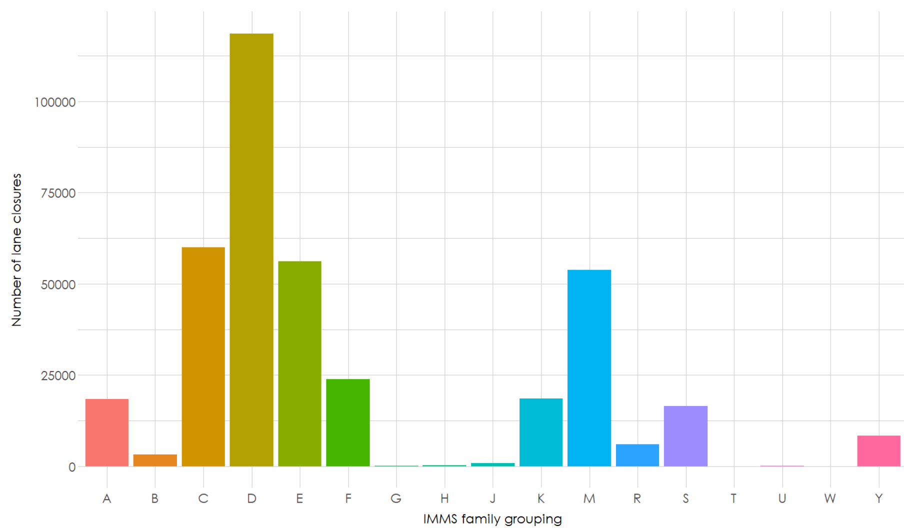

Figure 4.5: Number of lane closures by IMMS family grouping.

Table 4.8 lists the top 10 activities, which required the greatest number of lane closures between the years 2013 to 2018. Note that it was assumed that Activity D10050 and Activity D40150 refer to the same operation and thus their closure numbers are aggregated and collapsed under D40150 activity code. As it was

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demonstrated before for the cost and duration of work orders, normalizing for frequency changes the results dramatically. Also note that number of closures in this table are revised to exclude construction activities and are limited to approved lane closures.

Table 4.8: Top 10 activities with the greatest number of lane closures.

Activity	Description	Number of lane closures	Number of work orders
D40050	Litter control roadway/landscape	24217	63742
D40150	Road patrol/debris pickup	20692	56850
M40010	Repair/replace signs	18058	93615
E11040	Manual control landscape	15584	44257
D30050	Sweep hwy/shoulder	14977	31217
D60050	Graffiti removal all assets	11695	30859
D20020	Supervisor area inspection	11488	30835
E12040	Chemical control landscape	8974	30084
M60010	Repair/replace guardrail	8616	33196
E30010	Irrigation system repair landscape	8457	22986

For example, Figure 4.6 shows the fraction of work orders that required lane closures. In comparison to Figure 4.5, the distribution of lane closures has changed significantly. In particular, consider Family D, which in Figure 4.5 was identified as a group of activities that are associated with the greatest number of closures. Figure 4.6 demonstrates that this family does not require lane closures most of the time. In fact, the fraction of times a lane closure was necessary for family D is just below 50%. However, it turns out that Families H and B, which consist of bridge and rigid pavement activities, require lane closures more than 60% of the time.

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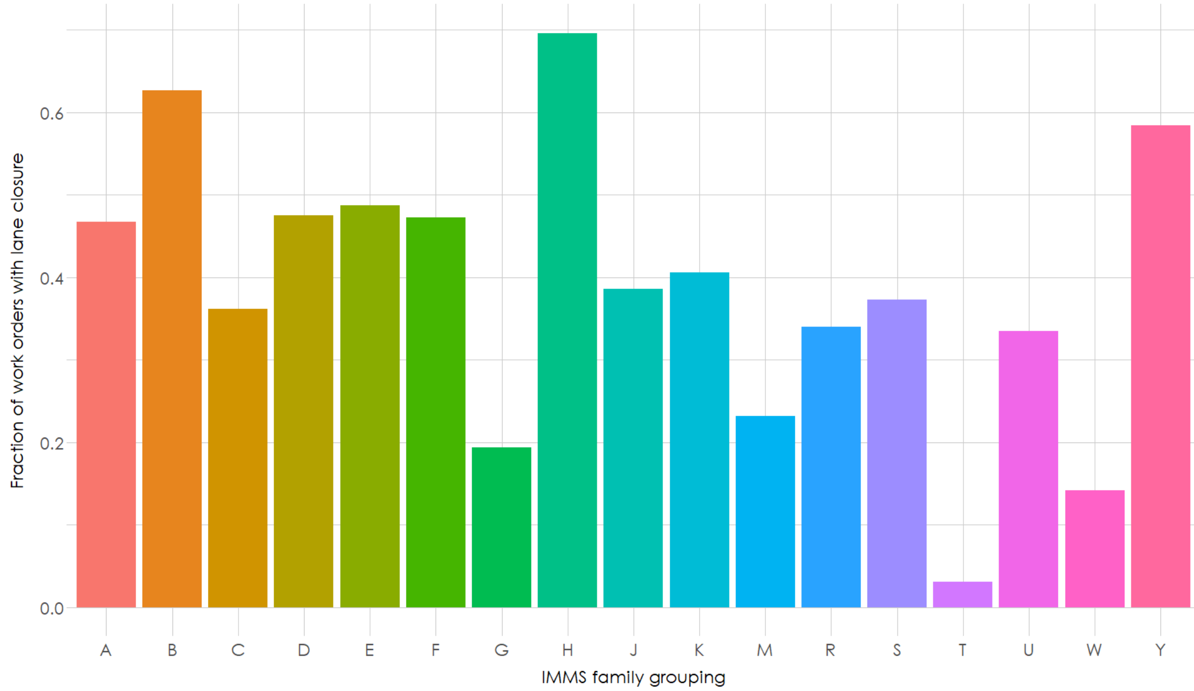

Figure 4.6: Fraction of work orders that required a lane closure.

Each closure has set attributes that change the geometry of the road and affect the traffic, and thus the risk of collision and injury, differently. Here, some of the relationships between work orders and these attributes are explored.

In Figure 4.7, the size of each bubble is proportional to the number of closures of a particular type for each IMMS family grouping. As expected, most lane closures across all family types are lane closures followed by full closures. However, for activities in IMMS families C, D, E, and M, a considerable portion of lane closures are of the moving type. In this figure, NA refers to closures for which closure type was missing.

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Figure 4.7: Closure type by IMMS family grouping.

Since most road closures are lane closures, it might be interesting to see how frequent it is for each family to close more than one lane. To that end, the width of the 'violin' in Figure 4.8 at, for example, 2 indicates the proportion of closures in a particular family that closed two lanes. Typically, most IMMS activities only close one lane. However, Figure 4.8 shows that rigid pavement activities (Family B) often require lane closures of more than one lane. This is also true for the U family, which refers to Caltrans facilities repair and inspection activities.

In addition to the number of lanes, a closure's length may also affect the risk of injury in roadside work zones. Therefore, a similar analysis to Figure 4.8 is carried for closure length.

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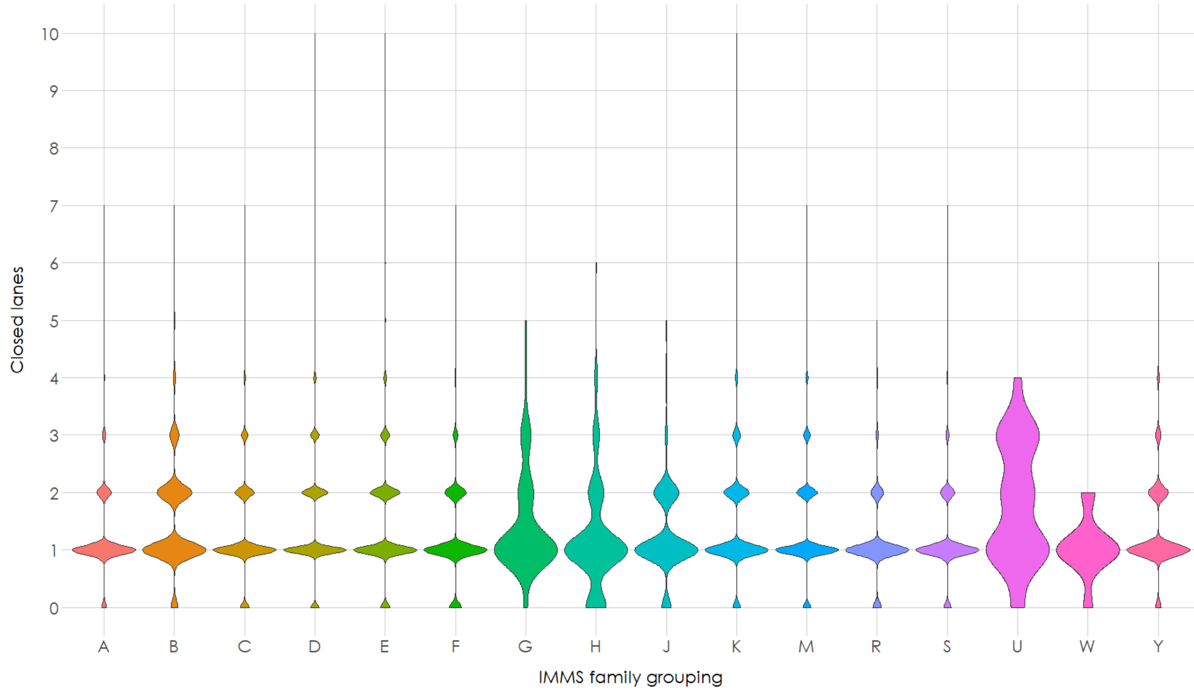

Figure 4.8: Number of lanes closed by IMMS family grouping.

Figure 4.9 shows a violin plot for distribution of closure lengths for each IMMS family grouping. The y-axis denotes the closure length (in miles). The width of the violin along the y-axis indicates the frequency of closures of a length denoted by the y-axis. Excluding G (vista and scenic related activities) and U (Caltrans facility-related activities) families, which are less frequent than others, Figure 4.9 shows that rigid pavement activities (B) and snow removal activities (R) require lengthier closures when compared to other maintenance families.

The duration of each closure may also be a factor in estimating the risk to injury since one could argue that longer closures expose workers to live traffic for longer periods of time. In the LCS data set, the duration of lane closures is divided into three categories: standard, long-term, and intermittent. In Figure 4.10, the size of each bubble is proportional to the number of collisions of a particular duration for each IMMS family grouping. Across all IMMS maintenance families, the most frequent closures are of standard duration. However, it should be noted that for families C, D, E, F, K, and M, a considerable portion of closures are long-term. Moreover, the activities in IMMS families C, D, E, and M also employ intermittent closures more than other maintenance activities.

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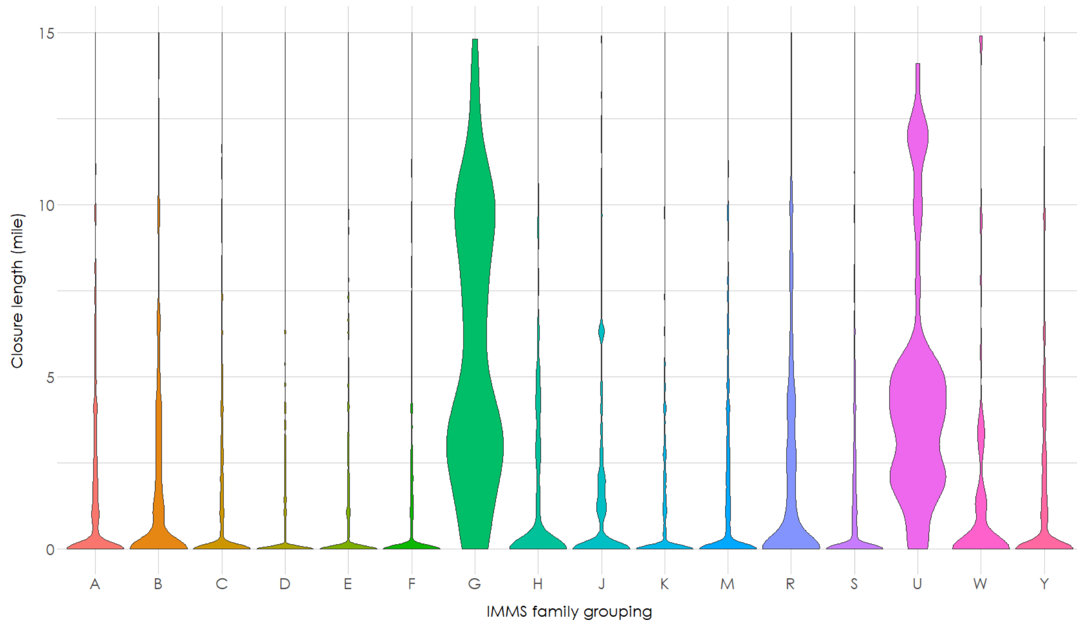

Figure 4.9: Closure length by IMMS family grouping.

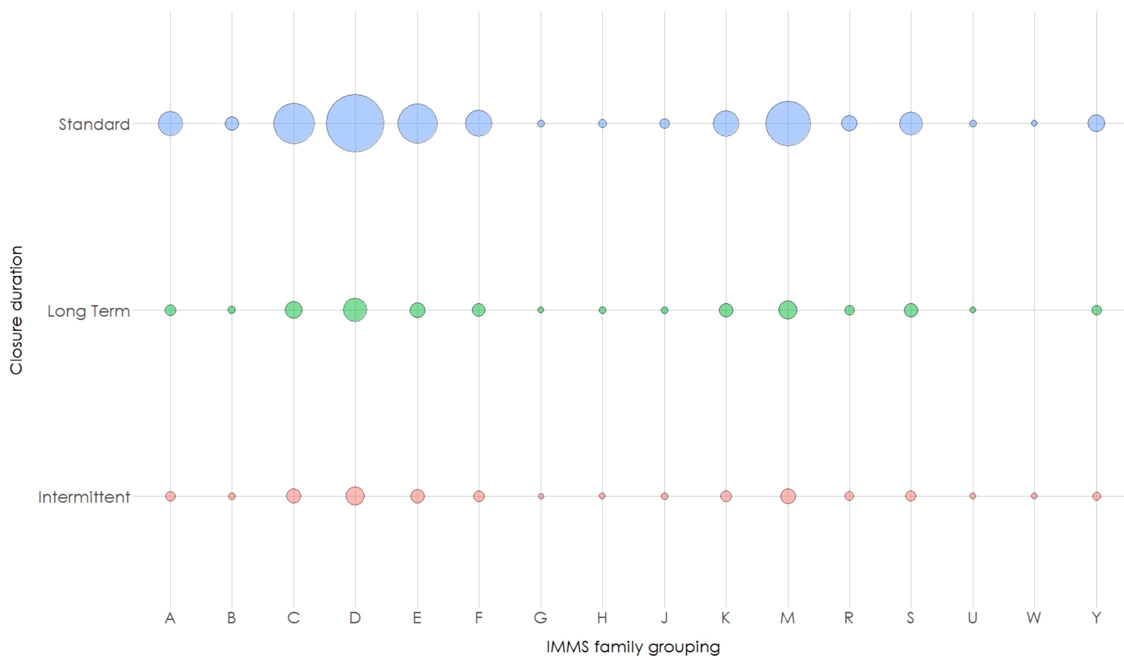

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Figure 4.10: Closure duration by IMMS family grouping.

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Analysis of Collision Reports for each Activity

To identify which activities correspond with more collisions or result in more severe injuries and fatalities, the LEMO_WorkOrder data set and the SWITRS data set are matched using the process described in Chapter 3: In matching these collisions, in addition to matching location and date, the road condition of the collision should indicate a construction or repair zone.

Figure 4.11 shows that maintenance activities that make up Families D, E, C, and M, result in more collisions than the rest of maintenance activities. Moreover, a larger portion of collisions in these families result in symptomatic injuries or fatalities. The SWITRS data set classifies the severity of each collision on a 0-4 scale where 0 denotes Property Damage Only (PDO), 1 denotes fatality, 2 is for severe injuries, 3 indicates visible injury, and 4 shows complaint of pain. In Figure 4.11, the label fatality or symptomatic injury identifies a collision with severity 1-4.

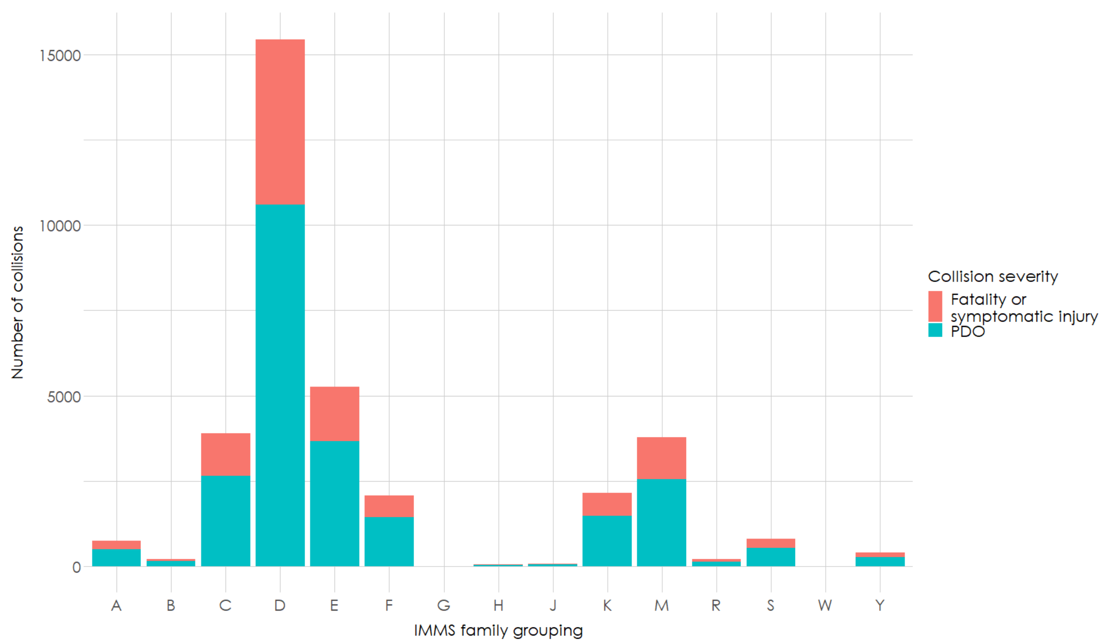

Figure 4.11: Number of collisions by IMMS family grouping.

To identify the IMMS activity codes that correspond to the greatest number of collisions, Table 4.9 lists the top 10 activities that resulted in the greatest number of collisions from 2013 to 2018.

Since collisions that correspond with each activity are often not numerous, taking this analysis one step further by evaluating the proportion of collisions that result in fatality or symptomatic injury for each activity might not be reasonable. For example, numerous activities have been matched with only one collision from 2013 to 2018. If that collision results in any kind of injury, the proportion of collisions

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that result in any kind of injury for that specific activity will be 100%, which is not representative of real-world situation. Therefore, in this section, the analysis of the relationship between work orders and collisions is limited to the total number of collisions for each activity and the proportion of collisions resulting in fatality or symptomatic injury for IMMS family groupings.

Table 4.9: Top 10 activities with the highest number of collisions.

Activity	Description	Number of collisions
D40150	Road patrol/debris pickup	5076
D40050	Litter control roadway/lndscp.	3846
E11040	Manual control	2458
D60050	Graffiti removal all assets	2416
D30050	Sweeping roadways	2081
D40150	Road patrol/debris pickup	2037
E30010	Irrigation system repair	1773
D20020	Supervisor area inspection	1321
M40010	Repair/replace	1137
C20040	Mechanical control	775

Analysis of the SWITRS Collision Reports

In this section, the relationship between the features that are included in the SWITRS data set (see Table 3.7) and the number and severity of collision are investigated. These collisions matched a work order from the LEMO_WorkOrder data set using the process described in Chapter 3. Moreover, each collision's road condition indicates a construction or repair zone accident.

The SWITRS data set consists of many features which may contribute to the severity of collision. Features such as lighting condition, weather condition, and surface condition (dry, wet, etc.) could potentially affect the collision occurrence and its severity. However, these features are not available for every work order, and therefore cannot be evaluated for work orders that do not match a collision. Their effect on the occurrence of the collision cannot be captured with existing data sets, and thus their analysis is not included here.

The following analysis only includes those features that can be evaluated for all the maintenance activities in the LEMO_WorkOrder data set.

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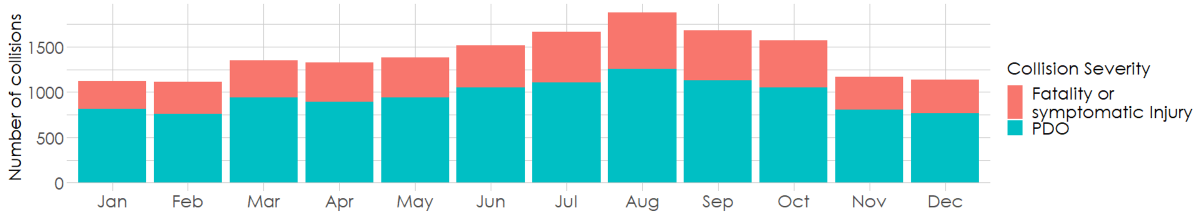

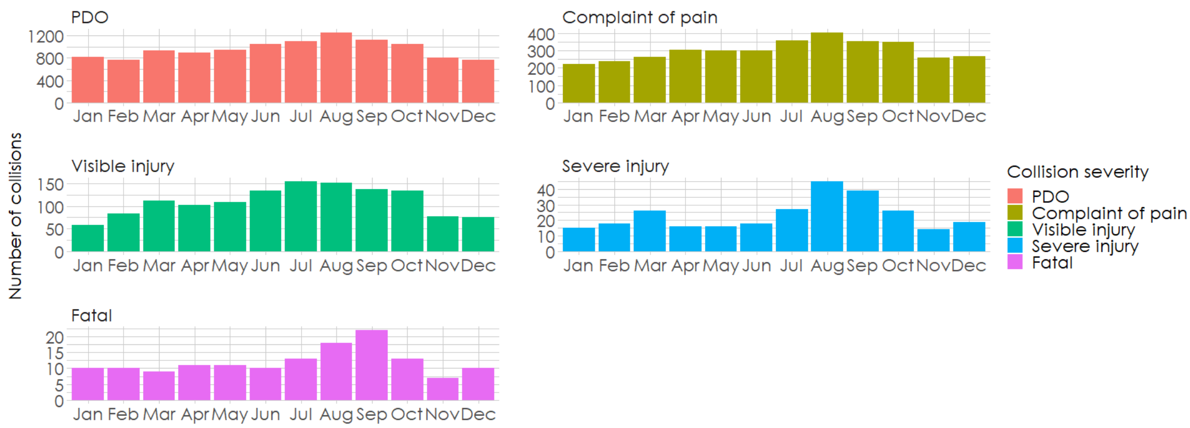

Figure 4.12: Number and severity of collision by month.

Figure 4.12 shows the number and severity of collisions by month. Since, as part of the LEMO_WorkOrder data set, work date of each work order is available, the month of the work order can also be evaluated. This feature may capture the effect of season on the risk to injury of each work order. Notice that while the number of collisions reaches its highest point in August, the number of collisions that result in fatality peak in September.

Similar analysis with respect to the day of week can also be done. In Figure 4.13, the number and severity of collision is plotted for each day of the week. A general trend can be observed in Figure 4.13. On weekdays, the number and severity of collisions is higher in comparison to weekends. However, there is an exception. For collisions that result in fatality, this observation does not hold. In fact, the number of collisions on Sunday nearly equal those of Monday, Wednesday, and Friday.

Another feature in the SWITRS data set that can also be evaluated for every work order is the location type of the collision. This information is available as part of the Clean Route File. Figure 4.14 shows the number and severity of collisions by different location types. This figure suggests that the number and severity of collisions on or near ramps increases. However, this is not true for collisions that result in severe injuries. Figure 4.14 shows that most collisions of this type happen at intersections.

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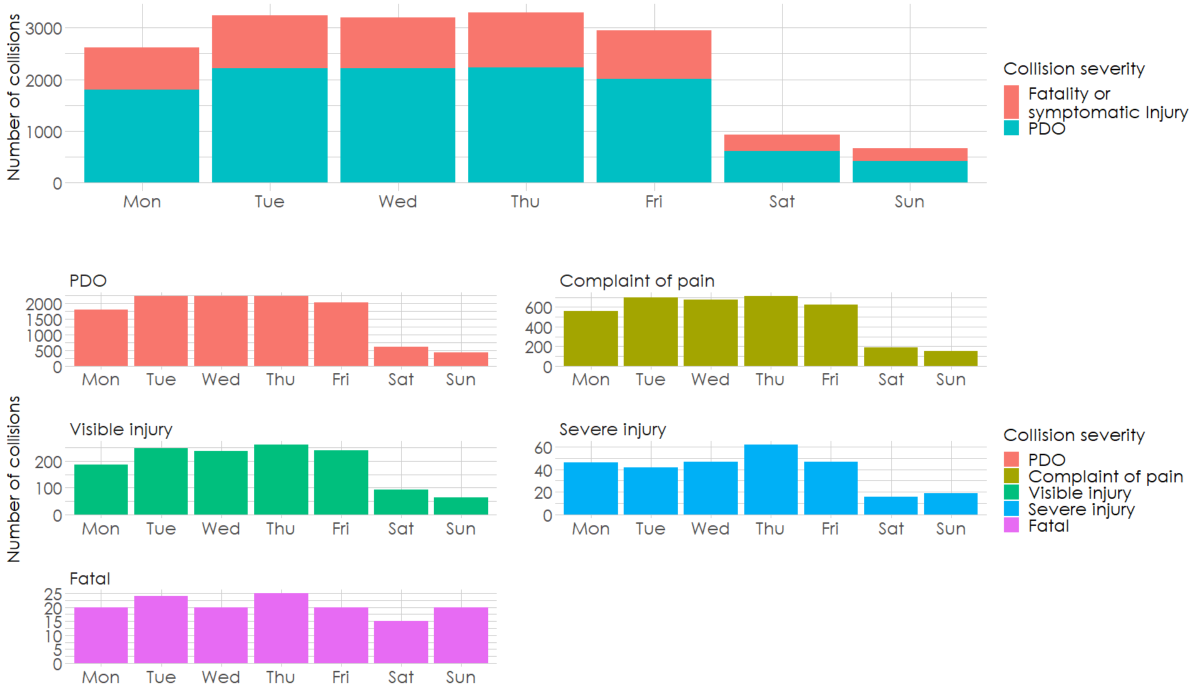

Figure 4.13: Number and severity of collisions by day of week.

Figure 4.14: Number and severity of collisions by location type.

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Analysis of Collision Reports and Road Features

Caltrans' Clean Route File describes various elements of a road by marking its beginning and end postmile. Some of these elements are surface type, median type, division type, number of lanes, design speed, etc. These features are matched with the LEMO_WorkOrder data set using the process described in Chapter 3: Since LEMO_WorkOrder and SWITRS are also matched, the relationship between number and severity of collisions and route features can be explored.

For example, Figure 4.15 shows the effect of surface type on number and severity of collisions. The y-axis denotes the number of collisions per mile of a particular surface type. Therefore, Figure 4.15 suggests that bridge decks are host to the greatest number of collisions per mile. This is true for all levels of collision severity.

Figure 4.15: Number and severity of collisions by surface type.

Another feature of the Clean Route File data set is the median type. Similar to Figure 4.15, Figure 4.16 shows the effects of median type on number and severity of collisions. The y-axis in this figure indicates the number of collisions per mile of the median type. Figure 4.16 shows that most accidents occur on the striped pavement. However, this figure also suggests that a higher portion of collisions that result in fatality or symptomatic injury are actually associated with separate structures.

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Figure 4.16: Number and severity of collision by median type.

Figure 4.17: Number and severity of collisions by road division type.

Figure 4.17 shows the number and severity of collisions with respect to the road division. Number and severity of collisions for independent alignment (left) roads are higher than the divided highways. This is not expected as it is not obvious why

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one alignment in split roads should be the scene of more accidents when compared to the opposite alignment. However, Figure 4.17 suggests that this result is consistent for any type of severity.

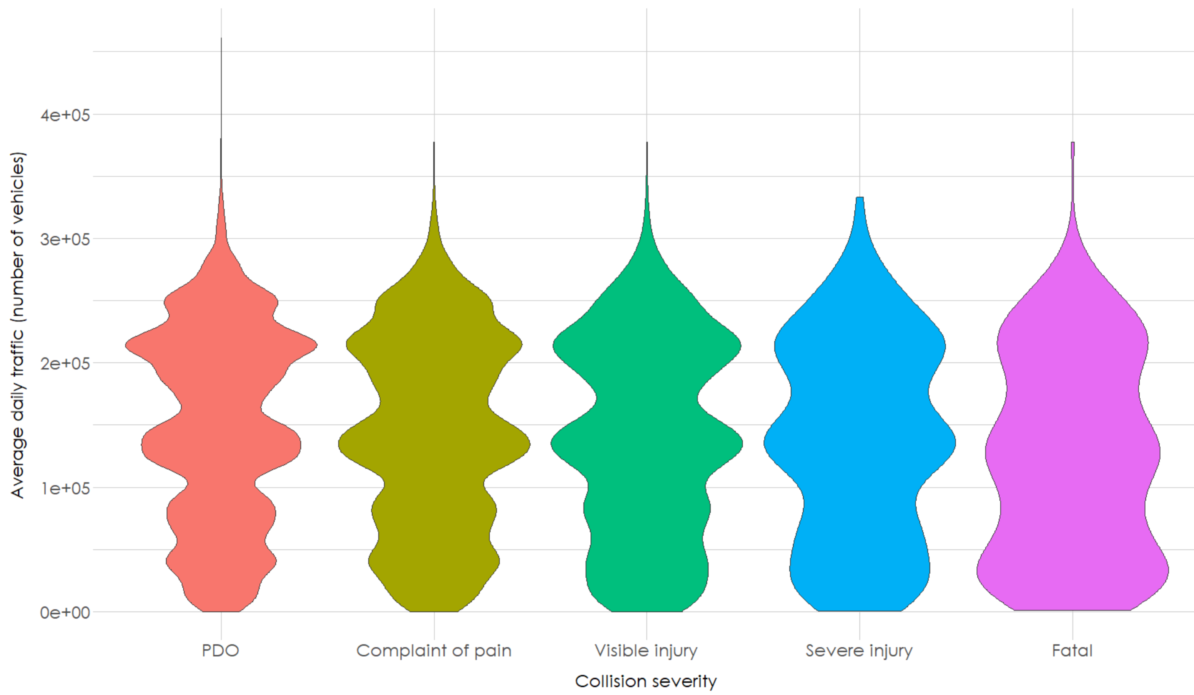

Figure 4.18: Distribution of collision severity by ADT.

Figure 4.18 shows how collision severity is distributed over the average daily traffic (ADT). For each level of severity, the width of the violin along the y-axis indicates the proportion of collision. Based on this figure, it should be noted that collisions with fatalities occur in areas where average daily traffic is lower. In fact, Figure 4.18 suggests that, as the average daily traffic decreases, a higher proportion of accidents result in more severe injuries.

Another unexpected result is given in Figure 4.19. Whereas the overall collision density increases, the severity of work zone collisions decreases. Figure 4.19 shows that for all of the collision severity levels, the increase in the overall collision density does not translate to an increase in work zone collisions.

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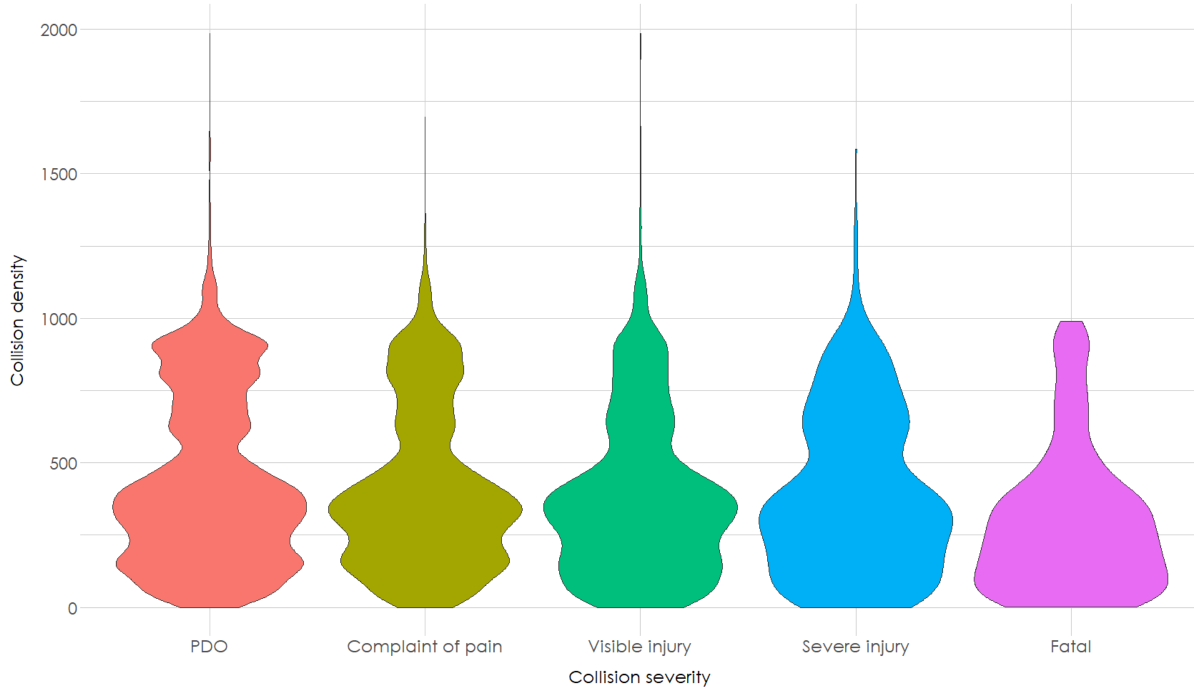

Figure 4.19: Distribution of collision severity by collision density.

Survey Results

In this section, the results of a survey of Caltrans' relevant personnel are presented. The goal of the survey was to capture Caltrans institutional knowledge to improve the design of two performance measures. The first is an index for estimating and predicting the risk of hazard for roadside maintenance activities. The second is an index estimating the level of difficulty associated with each maintenance activity. The full questionnaire is given in Appendix C: Performance Measures for roadside features questionnair. The survey was performed by a Caltrans project panel. It should be noted that the results presented here are limited to the development of indices of difficulty and risk of hazards. The additional questions regarding the development of a prototype decision toolbox were included for consideration in a follow-up research study. The questions asked in the survey and the results based on responses are summarized below.

Question 1: In your experience, does the number of people in a crew affect the level of difficulty to complete a typical maintenance task performed by your group?

More than 90% of respondents indicated that the number of personnel in a crew can affect the difficulty of a task. This is demonstrated in Figure 4.20.

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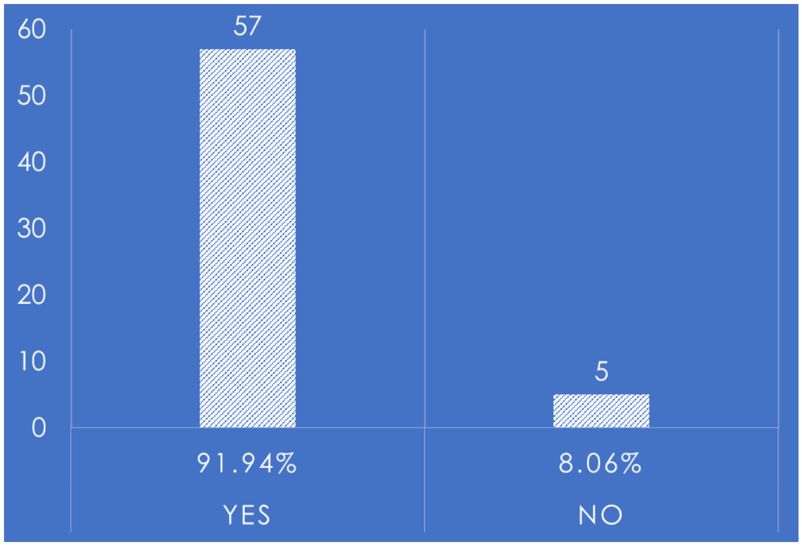

Figure 4.20: Response to survey question 1.

1. If yes, please indicate the level of importance.

Respondents generally indicated that the number of crew is an important factor in assessing the difficulty of a maintenance activity. Figure 4.21 shows that nearly 90% of respondents suggested that the number of the crew is either extremely important or very important to the level of difficulty.

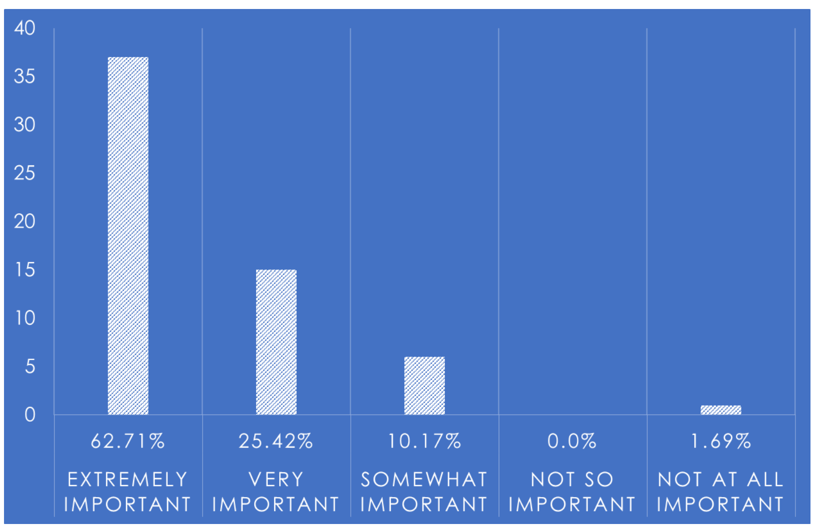

Figure 4.21: Response to survey question 2.

2. Please indicate how important these factors are when assessing difficulty.

Figure 4.22 shows the response of Caltrans personnel to survey question three. To assess this response more carefully, a weighted average based on the number of people and the score they have given to each factor is evaluated (Extremely

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important = 5, Not at all important = 1). Given these scores, the most important factor turned out to be lane closure, followed by access to site, duration, mile-length, and LEMO costs.

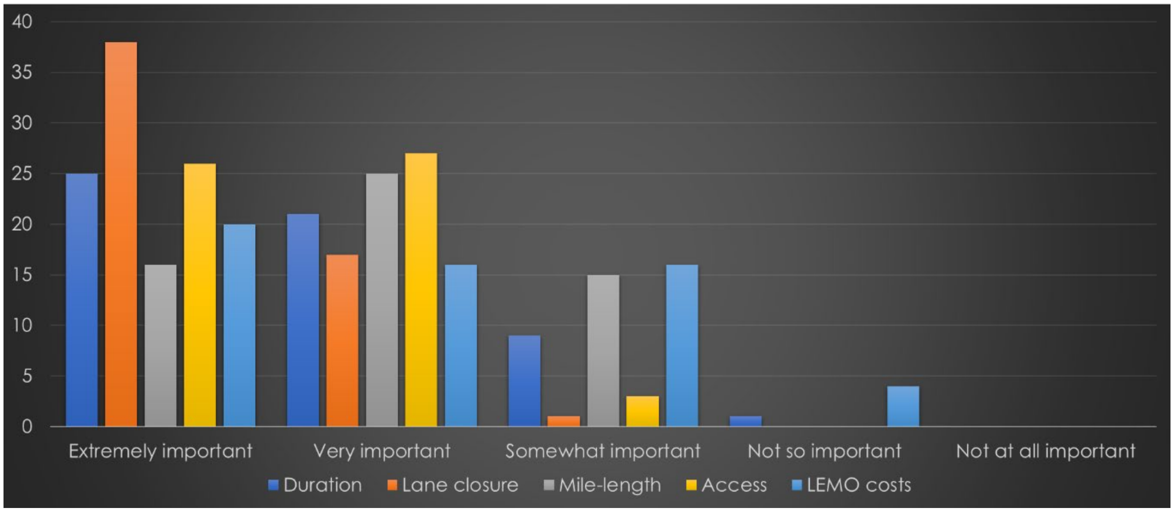

Figure 4.22: Response to survey question 3.

3. Do you see any factor that has NOT been listed that you feel plays a part in determining the Level of Risk in maintenance activities? Please list any missing Risk Factor and corresponding data source.

Table 4.10 shows the response of Caltrans personnel to this question. Caltrans personnel identified crew experience, appropriate staff level, proper equipment, and close-by events as additional parameters that can influence the risk of hazard in maintenance activities. Unfortunately, adequate data sources for evaluating these parameters were not identified by the respondents. However, data on some of these features are already available as part of the various data sources introduced in Chapter 3:: time of year (month or work date), location type (ramp, intersection, etc.), road width and shoulder width, roadside type (barrier type, median type, surface type), duration of work (person-hours), and location (postmile, route, county).

Table 4.10: New features proposed by Caltrans' personnel.

Proposed feature	Number of respondents
Crew experience	5
Appropriate Staff Level	4
Proper Equipment	3
Close-by events (e.g., sport events)	3
Time of year	2

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Proposed feature	Number of respondents
Night work	2
PPE (personal protective equipment)	1
On-Foot Exposure Time	1
Location: curves, tunnels	1
Road width, Shoulder width	1
Fatigue-in-person-hours	1
Political pressure	1
Contractor availability	1
Material availability	1
Environmental activism	1
Roadside type	1
Duration of work	1
Worker's last scheduled time-off	1
Invasive weeds	1
Mechanical or Manual	1
PY factor	1
Quality matrix	1
Road access	1
Emergency response	1
Location: county/road/postmile	1

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Chapter 5: LEVEL OF DIFFICULTY

In this chapter, maintenance activities identified in the IMMS tables are classified with respect to a level of difficulty developed by analyzing the results of the survey described in Survey Results. The factors affecting the level of difficulty for each roadside maintenance activity are determined to be the work order duration (in person-hours), work length (in miles), presence of lane closure, access to work order site, LEMO costs, and the number of crew. The survey scores also determine the importance of each factor, where 1 denotes a not at all important factor and 5 denotes an extremely important factor. The eventual score of each factor is evaluated by taking a weighted average of the survey results. Table 5.1 shows the weighted average importance score of each factor in influencing the level of difficulty with respect to Caltrans personnel's expertise and opinion.

Table 5.1: Importance of factors affecting the level of difficulty.

Factor	Importance score
Lane closure	4.66
Number of crew	4.47
Access	4.41
Duration	4.25
Mile-length	4.01
LEMO costs	3.92

Roadside maintenance activities can be classified with respect to these factors allowing for evaluation of the difficulty level associated with each maintenance activity. In order to determine a unifying level of difficulty, consider the following formula

Equation 1: Index of difficulty

$$\begin{aligned}\text{Level of difficulty} &= 4.66 \times \text{Lane closure score} + 4.47 \times \text{Number of crew score}\\ &+4.41 \times \text{Access score} + 4.25 \times \text{Duration score} + 4.01 \times \text{Mile-length score}\\ &+3.92 \times \text{LEMO costs score},\end{aligned}$$

Where each factor's score is evaluated according to the following concepts.

Lane Closure Difficulty Score

The difficulty score of each maintenance activity, with respect to lane closure, is evaluated by the proportion of work orders that required a lane closure. An overview of this analysis is presented in Analysis of Lane Closures for Each Activity. Here, Table 5.2 lists the top 20 activities with the highest proportion of lane closure implementation. Such a score automatically is in a [0-1] range.

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Table 5.2: Top 20 activities with the highest proportion of lane closure.

Activity	Description	Total frequency	Proportion with lane closure
C95040	Test/sample manhole	1	1
F20050	Maint. site corrective measure	2	1
F50003	Eval/develop de-icing criteria	1	1
F80201	Oversight drain clean contract	4	1
F80003	Sampling and testing contract	6	0.833333
F80002	Drainage contract	35	0.685714
B30010	Sub seal/jack slab rigid pvmnt.	87	0.655172
YD0000	Work for others d family	331	0.643505
F30220	Construction compliance inspection	12	0.583333
YA0000	Work for others a family	502	0.569721
YB0000	Work for others b family	76	0.565789
B10110	Crack seal rigid pavement	668	0.561377
B31010	Slab replacement rigid pavement	607	0.518946
D40050	Manual control landscape	2	0.5
F10004	General meetings (mgmt./support)	4	0.5
U61040	Repeater - maintenance	2	0.5
Y50001	Inspection - permits	119	0.495798
D30050	Sweep HWY/shoulder	31217	0.479771
K20000	Inventory update sign lighting	237	0.472574
A50010	Seal (all other) flex pavement	1262	0.469097

Number of Crew Difficulty Score

Data on crew personnel size is available for some of the IMMS maintenance activities from the year 2013 to 2018. The average crew size is divided by the frequency of each activity from 2013 to 2018 as an indicator of the number of crew per each maintenance work order. Due to missing information regarding the crew size for every activity, 32 activities are excluded from this analysis. Table 5.3 shows the top 20 activities with the highest crew size per each roadside maintenance work order. This factor is also scaled to be in the range [0-1].

Table 5.3: Top 20 activities with the highest crew size per each work order.

Activity	Description	Avg. crew size	Crew size per work order
W54083	Drug testing	764.7142857	1
W56038	Physical exmntns and licensing	330.75	0.432514478
W30059	(Student) meta	327.1428571	0.427797497
W51036	Special events/honor guard	321.1	0.419895386

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Activity	Description	Avg. crew size	Crew size per work order
W10058	(Instrctr)legally mandated trng	256.2857143	0.335139174
T41100	Receiving/issuing materials	227.5714286	0.297590136
W55038	Emrgncy trnsprtn empl. 1st aid	220.125	0.287852606
W40059	(Student) other training	204.4404762	0.2673423
W10059	(Student)legally mandated trng	201.5803571	0.263602186
W10049	Tailgate safety meeting	162.038961	0.211894774
M94020	Pre-op emergency equipment	155.0714286	0.202783486
K70025	PM check TOS equipment	142.8571429	0.186811134
K70011	3rd party damage TOS equipment	123.1428571	0.161031197
G10010	Facility repair roadside rest	122.8095238	0.160595305
T40010	Repairs/maintenance maintenance stn	99.6043956	0.130250471
K40025	Pm check traffic signal	88.85714286	0.116196525
J20040	Maintenance tunnels & tubes	68.28571429	0.089295722
G21040	Grounds maintenance vista point	67	0.087614422
G41040	Grounds maintenance park & ride	61.7142857	0.08070241
K50011	3rd party damge flashng beacon	60	0.078460676

Access Difficulty Score

In Caltrans' Clean Route File, highway access type is coded by E, F, C, or S denoting, respectively, Expressways, Freeways, Conventional highways, and One-way city streets. The difficulty of managing access to work site is assumed to be according to the following order: Expressway >> Conventional highway >> Freeway >> One-way city street. No established method of converting ordinal variables to numerical equivalents exists.

For the purposes of this research study, however, it is assumed that the level of difficulty associated with each type of access is 4 for Expressway, 3 for Conventional Highway, and 2 for Freeways and 1 for One-way city streets. A sample average score indicating the level of difficulty associated with each activity with respect to a location access type is determined using the proportion of maintenance activities for each access type location. The scores are then scaled to a range between [0-1]. Table 5.4 shows the top 20 activities with the highest access difficulty score.

Table 5.4: Top 20 activities with the highest access difficulty score.

Activity	Description	Access difficulty score
C20010	Mechanical control	1
U80010	Fixed satcom - repair/replace	1
F80001	Oversight of construct contract	0.722222222
C93050	Clean cattleguard	0.704326923

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Activity	Description	Access difficulty score
F40150	Slide material hauling	0.625
F90103	Closure of existing site	0.583333333
S31010	Repair/replace rock fall protection	0.540816327
R91000	Avalanche control	0.53654485
R30110	Repair/replace fixed hardware	0.53432701
R10000	Snow removal	0.524197451
Y50001	Inspection - permits	0.521008403
S33000	Blasting	0.51627907
S10000	Sand/rock patrol	0.507977066
R22000	Apply anti-icer	0.502549395
C94010	Repair/replace drywell	0.5
C95040	Test/sample manhole	0.5
C96010	Repair/replace water site	0.5
F40210	Snow hauling (stormwater)	0.5
F50006	NPDES permit related activity	0.5
F60030	Remove Acid/removal oversight	0.5

Duration Difficulty Score

For evaluating a difficulty score based on duration of each roadside maintenance work order in terms of person-hours, the average duration of each activity scaled to a range of [0-1] is considered as the difficulty score. Table 4.6 in Analysis of Cost and Duration for Each Activity lists the top 10 activities with the highest average person-hours. Here, Table 5.5 expands those results by including the top 20 activities and scaling the average duration to a range between [0-1].

Table 5.5: Top 20 activities with the highest average duration score.

Activity	Description	Duration difficulty score
S31040	Rock scaling	1
F40050	Snow hauling (stormwater)	0.994993079
A30010	Dig out flex pavement	0.927692676
J70040	Maintenance toll plaza	0.806522856
F40210	Snow hauling (stormwater)	0.723244682
A21010	Profile grinding flex pavement	0.713987228
W52056	Legal tort cases – discovery rprt.	0.709740113
A20010	Overlay/leveling flex pavement	0.707580373
M30010	Repair/replace pvmt. markers	0.707447299
B31010	Slab replacement rigid pavement	0.692653648
S40010	Major slide/slip remove/repair	0.661870168
R11000	Snow hauling	0.653656392
Y20001	Work for communications	0.646730515

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Activity	Description	Duration difficulty score
B10110	Crack seal rigid pavement	0.618919275
F40310	Repair/replace existing cntrls.	0.618433541
S33000	Blasting	0.614973678
A10110	Crack seal flex pavement	0.607319154
M10010	Repair/replace striping	0.604600455
R40000	Chain control	0.596060189
S32050	Bench cleaning	0.591200925

Mile-Length Difficulty Score

The analysis here is similar to the previous section. To determine the mile-length difficulty score of each roadside maintenance activity, the average mile-length of each activity is calculated and is scaled to a range between [0-1]. Table 5.6 shows the top 20 activities with the highest mile-length difficulty score.

Table 5.6: Top 20 activities with the highest mile-length difficulty score.

Activity	Description	Mile-length difficulty score
F60030	Remove Acid/removal oversight	1
C20010	Mechanical control	0.961359211
F80002	Drainage contract	0.79119423
K20120	Night inspection sign lighting	0.757610416
F50005	Veg mgmt. & chem usage plans	0.723433565
C30020	Tree inspection	0.609560586
F10007	Employee specialized/training	0.567653697
M10120	Night inspection striping	0.562708577
K10120	Night inspection HWY lighting	0.55588357
M20120	Night inspection markings	0.545464587
M40120	Night inspections signs	0.537990966
F30003	Oversight/inspect field activity	0.523891299
M10010	Repair/replace striping	0.520160157
D20020	Supervisor area inspection	0.489505373
S10000	Sand/rock patrol	0.486785777
S20000	Storm patrol	0.478076343
M91000	Physical HWY inventory update	0.476346976
M30120	Night inspection pvmnt. markers	0.474573887
H74040	Other paint activities	0.465333414
R20000	Cover snow & ice on pavement	0.46129017

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Cost Difficulty Score

The results of survey indicates that LEMO costs are the least important factors affecting the difficulty of a particular roadside maintenance operation. Nevertheless, LEMO costs are still believed to be relatively important, and thus the average LEMO costs per each maintenance work order scaled to a range between [0-1] is considered as cost difficulty score of roadside maintenance activities. Table 4.4 in Analysis of Cost and Duration for Each Activity lists the top 10 activities with the highest average costs. Here, Table 5.7 expands those results by including the top 20 activities and scaling the costs to a range of [0-1].

Table 5.7: Top 20 activities with the highest LEMO costs difficulty score.

Activity	Description	LEMO costs difficulty score
A30010	Dig out flex pavement	1
A50010	Seal (all other) flex pavement	0.984641428
A20010	Overlay/leveling flex pavement	0.797567651
F40060	Install new controls	0.765888693
G41040	Grounds mtce. park & ride	0.741649847
M10010	Repair/replace striping	0.688209303
F40020	Install soil stab/sediment/rsp.	0.630845831
F40030	Erosion/sed cntrl. supp purchase	0.630234722
B21010	Overlay/leveling rigid pavement	0.594741647
F40050	Snow hauling (stormwater)	0.546193941
A21010	Profile grinding flex pavement	0.525330268
B10110	Crack seal rigid pavement	0.50930837
M30010	Repair/replace pvmt. markers	0.483342442
B31010	Slab replacement rigid pavement	0.442007327
F40010	Repair/replace soil/sediment/rsp.	0.42253432
F40210	Snow hauling (stormwater)	0.41033579
E14040	All other control landscape	0.406460692
F40310	Repair/replace existing cntrls.	0.399835593
S31040	Rock scaling	0.399484973
A10110	Crack seal flex pavement	0.386108413

Classification of Maintenance Activities by Level of Difficulty

In this section, IMMS roadside maintenance activities are classified with respect to Equation 1. The activity with the largest index value has the highest difficulty based on the factor identified in Table 5.1. Below, Table 5.8 lists the top 20 activities with the highest difficulty score.

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Table 5.8: Top 20 activities with the highest overall difficulty score.

Activity	Description	Overall difficulty score
A30010	Dig out flex pavement	11.76758291
A50010	Seal (all other) flex pavement	10.70184479
M10010	Repair/replace striping	10.63860454
F20050	Drain cleaning	10.2101947
A20010	Overlay/leveling flex pavement	9.757010148
S31040	Rock scaling	9.591033229
M30010	Repair/replace pvmt. markers	9.153518021
F40050	Snow hauling (stormwater)	9.146972584
R10000	Snow removal	8.727143721
C95040	Test/sample manhole	8.574667441
A21010	Profile grinding flex pavement	8.425535308
B10110	Crack seal rigid pavement	8.407376691
A10110	Crack seal flex pavement	8.311323882
F40030	Erosion/sed control supp purchase	8.22245399
S40010	Major slide/slip remove/repair	8.187688761
F80002	Drainage contract	8.185839434
F40060	Install new controls	7.95378104
C11010	Lateral support - import matl.	7.776721221
F80003	Sampling and testing contract	7.736751453
R40000	Chain control	7.689041702

Since crew data for some maintenance activities were not available, the overall score could only be evaluated for 200 maintenance activities. The complete, sorted list is included in Appendix D: Classification of Maintenance Activities with Respect to Difficulty The overall difficulty score in Table 5.9 does not consider the crew size numbers in order to allow for evaluation of the difficulty score for all of maintenance activities. This complete list is also included in Appendix D: Classification of Maintenance Activities with Respect to Difficulty

Table 5.9: Top 20 activities with the highest overall difficulty score without considering the effects of number of crew.

Activity	Description	Overall difficulty score
A30010	Dig out flex pavement	11.77227544
A50010	Seal (all other) flex pavement	10.70889605
M10010	Repair/replace striping	10.63911942
F20050	Drain cleaning	9.76223016
A20010	Overlay/leveling flex pavement	9.600893306
S31040	Rock scaling	9.155704642
M30010	Repair/replace pvmt. markers	8.73025525

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Activity	Description	Overall difficulty score
F40050	Snow hauling (stormwater)	8.577514446
R10000	Snow removal	8.434627132
C95040	Test/sample manhole	8.315715958
A21010	Profile grinding flex pavement	8.199461991
B10110	Crack seal rigid pavement	7.780948831
A10110	Crack seal flex pavement	7.695377916
F40030	Erosion/sed cntrl. supp purchase	7.580160299
F80002	Drainage contract	7.467093307
S40010	Major slide/slip remove/repair	7.350386207
F40060	Install new controls	7.325117155
F40210	Snow hauling (stormwater)	7.319371713
C11010	Lateral support - import matl.	7.058037548
F80003	Sampling and testing contract	7.041611606

Using the second overall difficulty score (without the effects of number in crew), the rank of each activity with respect to difficulty score can be evaluated. Using these ranks, an overall rank for each table of IMMS activities may be determined by averaging the ranks of activities within each table. Table 5.10 shows the top 20 IMMS table names that include the most difficult activities with respect to overall difficulty score without considering the effects of the number of crew. In Table 5.10, the lowest average rank for an IMMS table name corresponds to having the most difficult activities within that table.

Table 5.10: Top 20 IMMS table names with the highest overall difficulty score without considering the effects of number of crew.

IMMS table name	Average rank of activities within the table
Chain Control Activities	21
Lateral Support Activities	22
Ditches and Channels Activities	32.5
Storm Water Management, Administration	35.4
Flexible Pavement Activities	37.28571
Snow Activities	40
Sweeping Roadway Activities	41
Rigid Pavement Activities	44
Fixed Hardware Activities	45
Striping Activities	47.5
S Family Activities	47.55556
Curbs and Dikes Activities	54
Markings Activities	57.5
Storm Water Management, Drainage	59.33333

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IMMS table name	Average rank of activities within the table
Pavement Markers	60
Support Personnel Activities	60
Drainage Activities	65.33333
Roadside Vegetation Activities	69.33333
Cattleguard Activities	74
Sand and Salt Activities	75.66667
Roadside Delineators Activities	86

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Chapter 6: DEVELOPMENT OF COLLISION RISK INDEX

In this chapter, a classification methodology is developed for different work order activities with respect to risk of collision in roadside maintenance work zones. The data set developed in Chapter 3: describe a work order by numerous features extracted from various data sources. These features include, but are not limited to, activity codes, location (district, county, route, postmile), date (work date, month, day of week), lane closure features (length, duration, type, facility, cozeep/mazeep, detour), traffic volumes (AADT, truck AADT), route features (median type, barrier type, surface type, number of lanes, shoulder width), and collision data (severity, location type).

The SWITRS data set provides the response variables (the independent variables) of the classification model. The following analysis is set up to predict the chance of collision for maintenance work orders. Therefore, determining whether a work order corresponds with a collision report, which is available by matching SWITRS and LEMO_WorkOrder data set, is essential to the classification model. It is assumed that the response variable is binary, where 1 indicates that a work order matches a collision report and 0 indicates that the work order under consideration was not associated with any collisions. Using this binary response variable, one could develop a model that classifies each work order according to the probability of being in class 1 or 0 using the features described above.

However, before moving on to introducing the classification method implemented in this research study, one important feature of the final combined data set, the imbalance in data, is discussed.

Imbalanced Data Set

In finding the corresponding collision for each work order, it is assumed that the primary matching criteria are the location and date of a work order in a collision report for which road condition indicates a construction or repair zone. Since many work orders do not involve a situation resulting in a collision, the number of maintenance work orders that do not match a collision far exceeds the number of work orders for which a matching collision has been identified. Figure 6.1 demonstrates this imbalance in the data set. Notice from Figure 6.1 that only 1.7% of work orders in the LEMO_WorkOrder data set match a collision.

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This imbalance in the data set presents a challenging problem in developing a model whose accuracy should be more than 98%. Note that for a highly imbalanced data set, such as in this case, one could always predict no collision, i.e., class 0 or the majority class, and be right more than 98% of the time. This is called the no information rate (NI) and could be interpreted as a measure of imbalance in the data set. Moreover, such a highly imbalanced data set is not a good candidate for model fitting because the data set is heavily biased with respect to the majority class.

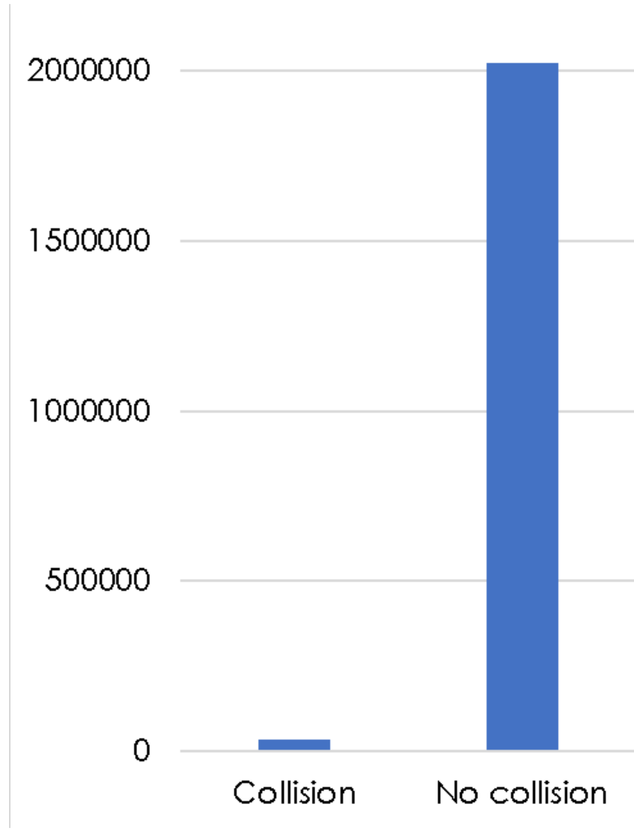

Figure 6.1: Collision imbalance in the final data set.

However, there are methods to artificially balance the initial data set for model training, such that the model has enough data from both classes to properly train itself such that it can predict the minority class as well as the majority class.

Synthetic Minority Over-Sampling Technique (SMOTE)

In this research study, Synthetic Minority Oversampling Technique (SMOTE) is used. SMOTE is a method that first implements a random basic under-sampling algorithm to thin the majority class. It then uses over-sampling to produce artificial

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data points 'close' to the minority class by measuring the distance between two data points of the minority class and randomly generating a new data point between them. It has been shown that the SMOTE algorithm performs better than under-sampling and over-sampling methods [18]. Using implementations of the SMOTE technique in R[2] libraries, the final data set used in this research study is balanced such that the number of minority class data points is approximately equal to that of the majority class.

Data balancing is only applied to the training set. For testing the performance of the proposed models, the final data set is divided into training and testing subsets where training set consists of 70% of the data and the remaining 30% are included in the testing subset. The testing subset is not balanced since testing the model should be performed over a data set that is representative of a real-world situation.

Initial Classification Model

A typical statistical model for classification of binary variables is the logistic regression model, which is typically used to model the probability of belonging to a class. Assume that the binary variable y is equal to one if a work order matched with a collision. Otherwise, y is assumed to be zero.

Equation 2: Logistic regression

$$\ln\left[\frac{P(y=1)}{1-P(y=1)}\right] = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n,$$

Therefore, where $P(y = 1)$ denotes the probability of work order belonging to class 1, let x_i denote the model predictors, i.e., data features, and β_i be the coefficients of model features. Using the balanced data set, one can solve for $\beta_i$using Maximum Likelihood Estimation (MLE) approach, which is available in most statistical packages.

In this research study, the primary response variable is considered to be binary, indicating whether a work order matches with a collision (this response can be extracted by matching the LEMO_WorkOrder data set and SWITRS data set using the process described in Chapter 3:). Table 6.1 identifies the entire set of model features, i.e., x_i, values, each of which belongs to one of the data sets described in Chapter 3.

[2] A statistical programming language

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Table 6.1: Model features.

Feature	Data set	Type
Day of week	Based on work date in LEMO	Categorical
Work month	Bases on work date in LEMO	Categorical
Activity codes	LEMO	Categorical
District	LEMO	Categorical
County	Work Order v5.2	Categorical
Route	Work Order v5.2	Categorical
Work duration (person-hour)	Work Order v5.2	Continuous
Work length (mile)	Work Order v5.2	Continuous
Lane closure (0, 1)	LCS	Categorical
Closure coverage (%)	Based on length of the closure in LCS	Continuous
Closure length (mile)	LCS	Continuous
Closure duration	LCS	Categorical
Closure type	LCS	Categorical
Closure detour (0, 1)	LCS	Categorical
Closure co(ma)zeep (0,1)	LCS	Categorical
Closed lanes	LCS	Continuous
Surface type	Clean Route File	Categorical
Median type	Clean Route File	Categorical
Barrier type	Clean Route File	Categorical
Road use type	Clean Route File	Categorical
Access type	Clean Route File	Categorical
Road division	Clean Route File	Categorical
Terrain type	Clean Route File	Categorical
Number of lanes	Clean Route File	Continuous
Road width	Clean Route File	Continuous
Shoulder width	Clean Route File	Continuous
Design speed	Clean Route File	Continuous
Road average daily traffic	Clean Route File	Continuous
AADT	AADT	Continuous
Truck AADT	Truck AADT	Continuous
Collision density	Based on LCS data set	Continuous

Data Pre-processing

Table 6.1 lists a mixture of continuous and categorical features. Most standard statistical methods cannot handle categorical data, and thus, categorical features of Table 5.1 must be converted to numerical values. This is done by generating a dummy binary variable for each level of the categorical variable. This process increases the number of features to more than 700, which translates

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to inefficient and computationally expensive model fitting. However, there are some statistical processes that can significantly reduce the dimension of data features. The following are the measures applied to the data features after generating dummy variables:

1. Remove near zero variance: Variables where values do not change significantly across different work orders are essentially constant and do not affect the model.
2. Remove linearly dependent features: Variables that are a linear combination of other features can be predicted by those features and do not need to be included in the model.
3. Remove highly correlated features: The effect of variables that are highly correlated can be captured by a smaller set of variables.

Some of these steps not only reduce the dimension of the data features but are also necessary for fitting some statistical models. For example, logistic regression cannot handle linearly dependent and highly correlated variables because linear dependency produces non-invertible matrices and highly correlated features prevent the regression solution algorithm from convergence.

Generating dummy variables produces binary variables with values that are either zero or one. However, continuous features, such as AADT, range from 0 to half a million. Therefore, the effect of continuous features will outweigh binary features and will result in model bias. To balance the effect of continuous and binary features, continuous features are scaled to a range between (0-1). This standardization has another positive effect and allows the decision-maker to interpret the magnitude of regression coefficients as feature importance.

Feature Selection Methods

After pre-processing data, the number of features reduces to 62. Fitting a logistic regression model with 62 features does not present a computational problem; however, it will make the fitting process susceptible to overfitting error. As a rule of thumb, more features result in more accurate models because larger sets of features allow the model to fine tune itself to small variations of data. However, a large set of features may allow the fitting process to fit the model to the noise in the data. An over-fitted model performs exceptionally well over the training set since it has already learned its noise but will perform poorly against new data with random noise.

In this research study, the extreme gradient boosting method is used and is described below.

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Extreme Gradient Boosting

The state-of-the-art algorithm for classification is extreme gradient boosting (xgBoost), which is an ensemble of boosted decision trees and thus does not hold the same level of interpretability as a regression model. However, since for binary classification extreme gradient boosting minimizes a logistic loss function to fit its decision trees, it might not be a bad idea to fit an extreme gradient boosting model and then use its features in a logistic regression analysis.

Cross-Validation

Recall that, in order to run a feature selection method over the data set, a training and a testing set are generated from the final data set. The training set is a balanced set and goes through the pre-processing steps. To run the feature selection methods, a 10-fold cross-validation set is created out of the training set, i.e., the training set is divided into 10 subsets, where each time one of the subsets is used for testing the performance of the feature selection method, the other nine are used for training the feature selection method. The overall accuracy of the feature selection method is a sample average of their accuracy over 10 testing subsets.

Model Fitting

In 0Matching SWITRS and LEMO_WorkOrder Data Sets in Chapter 3: two collision matching criteria were discussed:

1. Criterion 1 – collisions match work orders in location and date, and the collision road condition indicates a construction or repair work zone. This is considered to be the primary matching criterion.
2. Criteria 2 – Criteria 1 + collisions that match a lane closure in location, date and time of day and match a work order in location and date.

Table 6.2 shows the performance results of the different feature selection models. These methods are measured in terms of accuracy (Acc), which shows the proportion of correct predictions out of total predictions. For example, in the accuracy for recursive feature elimination method over a criterion, 1 is reported to be 0.82. To understand this proportion, consider the confusion matrix presented in Figure 6.2. Out of total 278,454 work orders in the data set where the work order did not correspond with a collision (class 0), the recursive feature elimination method resulted in a logistic regression model that predicted otherwise (class 1) for 46,857 work orders. An accuracy of 0.82 is determined by evaluating the proportion of true predictions (green cells in Figure 6.2) out of total predictions (green and red cells).

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Confusion matrix		Testing set	
		0	1
Model predictions	0	231597	1816
	1	46857	2721

Figure 6.2: Confusion matrix for RFE and collision matching criterion 1.

Table 6.2: Model selection results.

Collision matching criteria	Recursive feature elimination	Elastic net	Extreme gradient boosting with logistic loss objective function	Logistic regression via xgBoost
Criterion 1	Acc: 0.82, NI: 0.98	Acc: 0.82, NI: 0.98	**Acc: 0.97, NI: 0.98**	**Acc: 0.85, NI: 0.98**
Criterion 2	**Acc: 0.92, NI: 0.91**	Acc: 0.81, NI: 0.91	**Acc: 0.94, NI: 0.91**	**Acc: 0.89, NI: 0.91**

As can be seen in Table 6.2, the data imbalance, which is kept in the testing set, for some configurations results in accuracies that are less than the no information rate. This is not surprising for highly imbalanced data sets. There is no guarantee that the collected features should be able to accurately predict the chance of collision for maintenance work orders. For this reason, the driver's condition, speed, and driving characteristics, which may affect the chance of collision significantly, are not part of this study because they cannot be controlled for when planning and scheduling a maintenance work order.

However, even models that cannot beat the no information rate in accuracy may still be informative about the effects of certain features on the probability of collision if the underlying model achieves a reasonable accuracy. In Table 6.2, the configurations that can produce reasonable accuracies are identified by bold fonts.

Feature Selection Results

Interpreting the result of recursive feature elimination and elastic net methods is quite different than the extreme gradient boosting method. Both recursive feature elimination and elastic net methods are implemented in this research as different feature selection methods for a logistic regression model. However, the extreme gradient boosting method produces an ensemble of decision trees, which is not as easy to interpret.

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Logistic Regression Interpretation

Recursive feature elimination and elastic net method approach feature selection differently. In recursive feature elimination, the accuracy of the logistic regression model, with respect to different subsets of features, is evaluated. For example, Figure 6.3 plots the accuracy of the recursive feature elimination considering different subsets of features for collision matching criterion 1. The optimal subset of variables consists of 54 features, and the resulting model has a 91% accuracy in predicting the training data set. This model is then used to predict the test data set to investigate its performance with respect to an unbalanced data set, which represents real-world situations. The accuracies reported in Table 6.2 are evaluated against the testing set and show an accuracy of 82% in predicting the correct class for each work order.

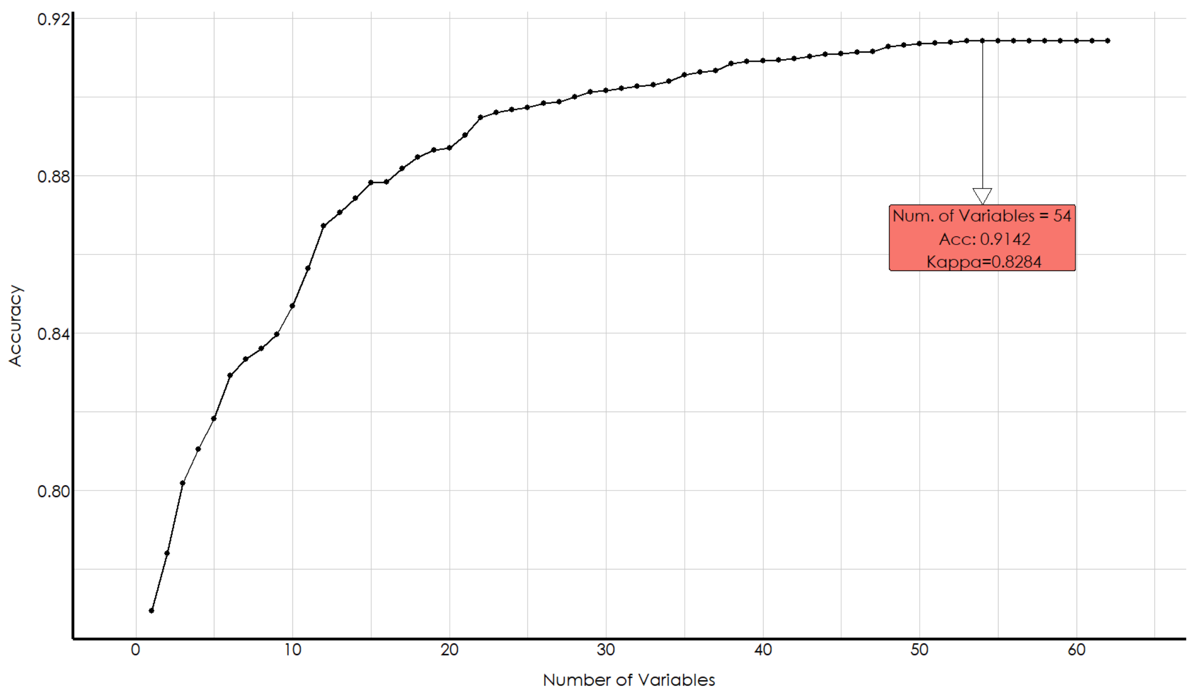

Figure 6.3: Accuracy of RFE for collision matching criterion 1.

In the elastic net method, the solution algorithm optimizes over different values of λ for a given α, e.g. $\alpha = 0.5$. Figure 6.4 shows the result of this optimization: where the top horizontal axis shows the number of features, the bottom horizontal axis denotes $\ln(\lambda)$, and the vertical axis shows the misclassification error, i.e., 1-accuracy. Most implementation of elastic net methods identifies two λ values. The left-hand dashed line identifies the minimum λ, which corresponds with a regression model of 60 features. The right-hand side dashed line identifies the most regularized (the least number of features) model such that the error is within one

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standard error of the minimum. In this case, the most regularized model must include 59 features to perform within one standard error of the minimum. The accuracy of the minimum error model is 94% when tested against the training data set. However, as shown in Table 6.2, this accuracy drops to 82% when assessed for the unbalanced testing set.

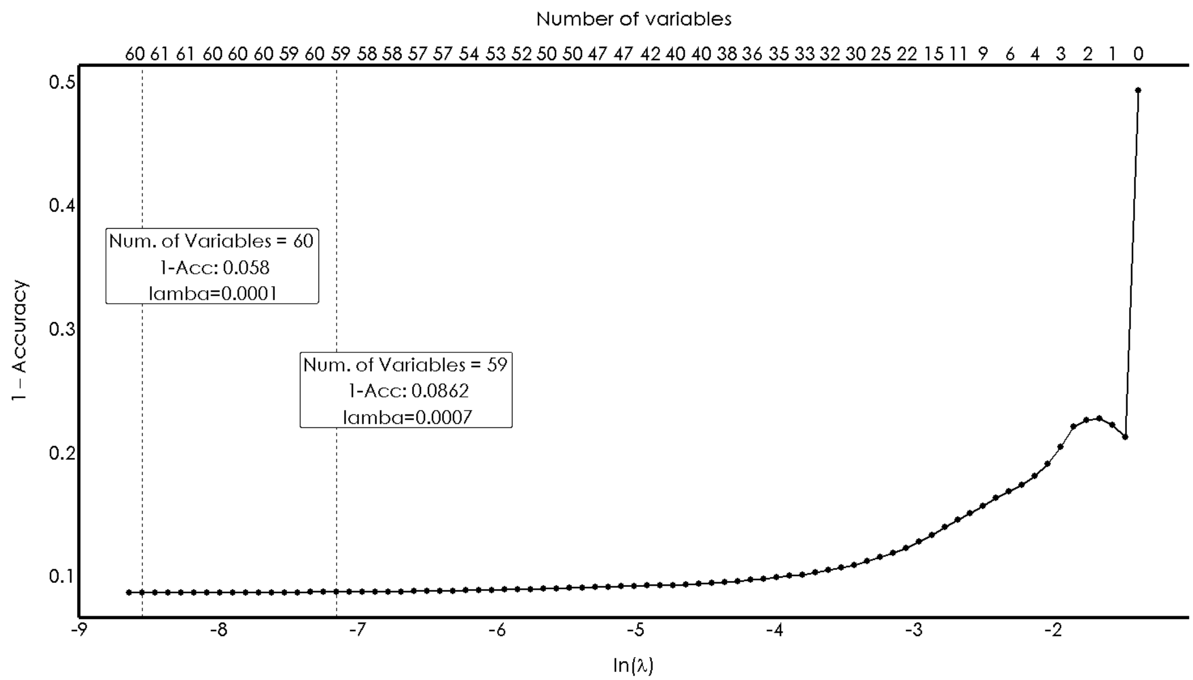

Figure 6.4: Accuracy of elastic net for collision matching criterion 1.

Extreme Gradient Boosting Interpretation

Since the extreme gradient boosting model is an ensemble of decision trees, the probability of belonging to a class comes from the portion of the fitted decision trees that classify a work order in a particular class. These decision trees do not limit the number of features, and in fact, the features used in each decision tree may be different. Instead, extreme gradient boosting provides a relative importance measure, which evaluates the relative contribution of each feature in optimization of the algorithm's objective function. For binary classification, the typical objective function of the extreme gradient boosting method is to minimize the logistic loss function. Therefore, the resulting relative importance scores may be used to construct a separate logistic regression model for easy interpretation.

To that end, Figure 6.5 plots the numeric scores for the top 30 important features. The extreme gradient boosting classification does not require a balanced data set to perform well, and instead relies on assigning more weight

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to the data points in the minority class. In addition, since the set of features under consideration for each decision tree may be different, this algorithm can also handle highly correlated features. Therefore, the training data set does not need to go through a balancing and preprocessing phase, and the xgboost algorithm is allowed to use more features to tune its fitting parameters. As can be seen in Table 6.2, this feature selection method performs significantly better. In Figure 6.5, a closure value of 1 denotes that a work order matched a lane closure. Surface type C and barrier type E show concrete surface and barrier types.

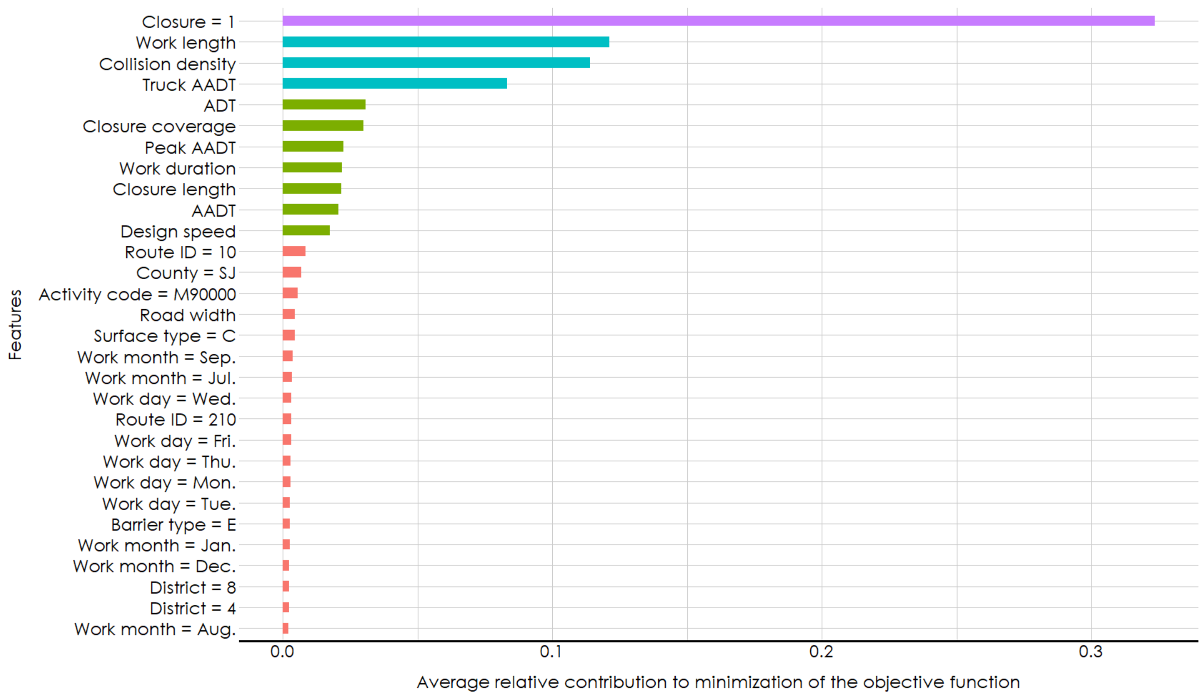

Figure 6.5: Feature importance for xgBoost and collision matching criterion 1.

Collision Risk Index

There exists an established stream of literature on developing indices for prediction purposes based on regression models. For example, [5] developed an index predicting the severity of injury given collision and maintenance work order characteristics. Reference [22] reviews a series of indices for the severity of crashes and injuries related to roadside features. Various regression models (e.g., logistic regression) may generate these indices. The indices may also be based on a set of features that are identified by other statistical methods.

It is clear from Figure 6.5 that the top four variables affecting the collision risk are existence or lack of lane closure, work length, collision density, and the truck percentage of the Annual Average Daily Traffic (truck AADT) volume. Using these four variables, the following Collision Risk Index (CRI) is developed:

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Equation 3: Collision Risk Index:

$$p = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \cdots + \beta_4 x_4)}}$$

In this Collision Risk equation, "p" is the probability of a collision that can lead to an injury, with values ranging between 1 (for a collision) and 0 for a no collision probability. The variables, $x_i's$ are defined as follows:

- $x_1 = 1$ if a work order requires lane closure and $x_1 = 0$ otherwise
- x_2 is the length of the scheduled work order in miles
- x_3 is the collision density i.e., the number of historical collisions per two-mile segments of the work order route
- x_4 is the truck percentage of the annual average daily traffic volume

The values of the coefficients β_i for i=1,…,4, can be determined for each work order, as described in detail in Chapter 3 of this report. As an example, if we consider a work order of activity type K10010 (repair/replace highway lighting) that is scheduled for Route 5 in San Diego County between postmile R10.0 and R27.0, assuming that this work order requires lane closure, the average truck AADT is 4695.848, and the average collision density is 89 accidents per mile, then the values of the β_i parameters are given by the following table:

Coefficient	Feature	Value
$\boldsymbol{\beta_1}$	Lane closure	1.731
$\boldsymbol{\beta_2}$	Work length	0.030
$\boldsymbol{\beta_3}$	Collision density	0.002
$\boldsymbol{\beta_4}$	Truck AADT	-3.77E-07

The Collision Risk Index is then calculated as:

$$p = \frac{1}{1 + e^{-(-5.262 + 1.731(1) + 0.3(17) + 0.002(89) - 0.000000377(4695.848))}} \cong 0.85,$$

The p-value of 0.85 means that there will be a reasonable probability of a roadside work zone collision in this situation with a probability of approximately 85%.

If one decides to use the entire 54 most important features identified by the extreme gradient boosting algorithm, then the same equation for the Collision Risk Index can be modified with more terms in the exponents corresponding to the 54 top features. This would require calculations of 54+1 $\beta_i's$ and assignment of values for 54 $x_i's$.

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Chapter 7: CONCLUSIONS AND RECOMMENDATIONS

This research study was performed in response to a need outlined by Caltrans related to evaluating the development of performance indices or metrics for difficulty or risk of performing maintenance operations associated with roadside features. It addressed the following research questions:

- Can using data available in different data sources and the literature provide a basis to develop a simple metric or metrics to assess the difficulty of maintenance operations associated with roadside features?
- Can risk indices be developed for such maintenance operations, which can assess the hazard risks to the operations and potentially to the workers performing such operations?

The work performed not only addresses the two research questions but also developed a Difficulty Index and a Collision Risk Index that can be computed for each work order based on parameters that were identified after considering a large data set as well as results of a survey from relevant Caltrans personnel.

The significant results of this research study include:

1. Classification of maintenance activities associated with roadside safety features.
2. Determination of factors that are most significant in the difficulty of performing these maintenance activities.
3. Determination of factors that are most significant in causing collisions in work zones.
4. Recommendations in the form of metrics or indices for assessing the level of difficulty and risk of hazards in performing maintenance or installation operations.

The result of this work enables Caltrans personnel to use objective data and measures for decision-making in planning and scheduling a maintenance operation. The results can also be used in allocating resources in terms of personnel and equipment, considering additional safety measures, and deciding what type of lane closure (if any) is necessary in order to reduce the risk of injury to its personnel and roadside workers.

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The relevant maintenance activities were classified according to five categories: lane closure requirements, crew size, site access difficulty, time duration, and mile length of operation. For each category, the top 10 activities were identified and are listed below in Table 7.1.

Table 7.1: Classification of relevant maintenance activities based on five categories.

Top 10 activities with the highest proportion of lane closure

Activity	Description
C95040	Test/sample manhole
F20050	Maintenance site corrective measure
F50003	Eval/develop de-icing criteria
F80201	Oversight drain clean contract
F80003	Sampling and testing contract
F80002	Drainage contract
B30010	Sub seal/jack slab rigid pavement
YD0000	Work for others d family
F30220	Construction compliance inspection
YA0000	Work for others a family

Top 10 activities with the largest crew size per work order

Activity	Description
W54083	Drug testing
W56038	Physical exmntns and licensing
W30059	(Student) meta
W51036	Special events/honor guard
W10058	(Instrctr)legally mandated trng
T41100	Receiving/issuing materials
W55038	Emrgncy trnsprtn empl. 1st aid
W40059	(Student) other training
W10059	(Student)legally mandated trng
W10049	Tailgate safety meeting

Top 10 activities with the highest access difficulty score

Activity	Description
C20010	Mechanical control
U80010	Fixed satcom - repair/replace
F80001	Oversight of construct contract
C93050	Clean cattleguard
F40150	Slide material hauling
F90103	Closure of existing site
S31010	Repair/replace rock fall protection
R91000	Avalanche control
R30110	Repair/replace fixed hardware
R10000	Snow removal

Top 10 activities with the longest average duration

Activity	Description
S31040	Rock scaling
F40050	Snow hauling (stormwater)
A30010	Dig out flex pavement
J70040	Maintenance toll plaza
F40210	Snow hauling (stormwater)
A21010	Profile grinding flex pavement
W52056	Legal tort cases – dscvry. rprt.
A20010	Overlay/leveling flex pavement
M30010	Repair/replace pvmt. markers
B31010	Slab replacement rigid pavement

Top 10 activities with the longest average mile-length

Activity	Description
F60030	Remove Acid/removal oversight
C20010	Mechanical control
F80002	Drainage contract
K20120	Night inspection sign lighting
F50005	Veg mgmt. & chem usage plans
C30020	Tree inspection
F10007	Employee specialized/training
M10120	Night inspection striping
K10120	Night inspection HWY lighting
M20120	Night inspection markings

Once the above classification was developed, and the five categories that are most relevant in terms of difficulty in performing a maintenance activity were identified, Caltrans conducted a survey of its maintenance crews to determine the importance of each of these categories. This research study then used this data and developed weight factors for each of these categories representing their relative importance in the maintenance activities. This research study then used the results and developed a simple equation as an Index of Difficulty (ID) that can be used to prioritize these maintenance activities. Using the Index of Difficulty, the top 10 maintenance activities from the group under consideration in descending order of ID scores are calculated and listed in Table 7.2.

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Table 7.2. Top 10 relevant maintenance activities with the highest ID scores (in descending order).

Activity	Description
A30010	Dig out flex pavement
A50010	Seal (all other) flex pavement
M10010	Repair/replace striping
F20050	Drain cleaning
A20010	Overlay/leveling flex pavement
S31040	Rock scaling
M30010	Repair/replace pvmt. markers
F40050	Snow hauling (stormwater)
R10000	Snow removal
C95040	Test/sample manhole

Another major result of this research study is a second classification of the relevant maintenance activities based on collision risks. Data from an Advanced Highway Maintenance and Construction Technology (AHMCT) injury database was matched with other data sources to develop a final data set. These data sources are depicted in Figure 7.1.

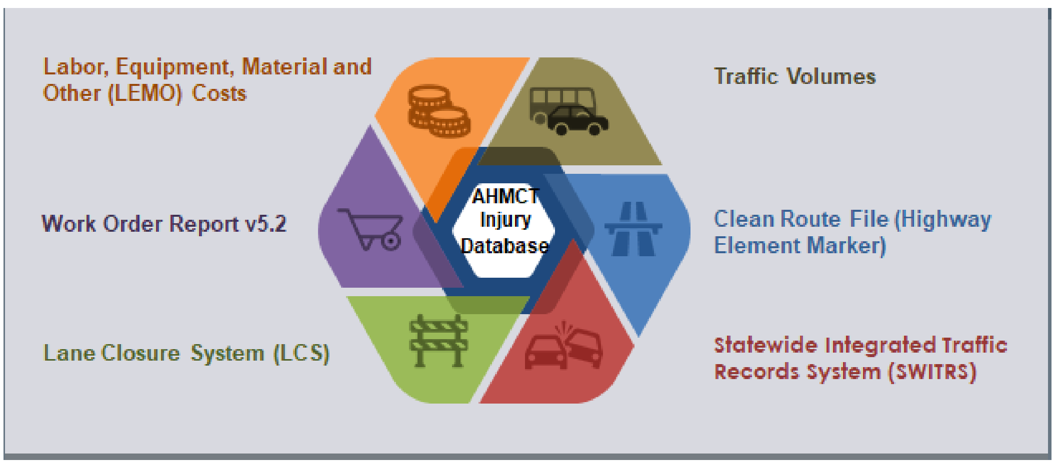

Figure 7.1: Data sources used to develop the collision risk index.

The results indicated that the top four variables affecting the collision risk are the existence of or lack of lane closure, work length, collision density, and the truck percentage of the Annual Average Daily Traffic (truck AADT) volume. Using these four variables, a Collision Risk Index (CRI) was developed that can be computed based on these four variables and from other information on the work orders.

One unexpected result of this aspect of the research was the importance and the effect of lane closure on the risk of collision for work orders. In Figure 6.5, having a lane closure is identified as the most important feature among all the 54 features

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in determining the level of risk. One might assume that a lane closure may lower the chance of a collision but the value of the coefficients β_i for lane closure is the highest in the work order example provided in the previous chapter. Figure 7.2 confirms this result since the number of work zone collisions that required a lane closure far exceeds the number of work zone collisions without a lane closure. However, it can be said that, in general, lane closures reduce the severity of injuries to highway workers. It should be made clear; however, that this does not mean a higher risk exist if lane closure is used when it is needed versus if it was not used. It only means that when maintenance or construction activities need lane closures there is a higher collision risk as compared to when such road operations do not require a lane closure. Many road construction and maintenance may involve working in the shoulders or on completely closed road sections and therefore do not need lane closures and therefore have a lower risk of collisions.

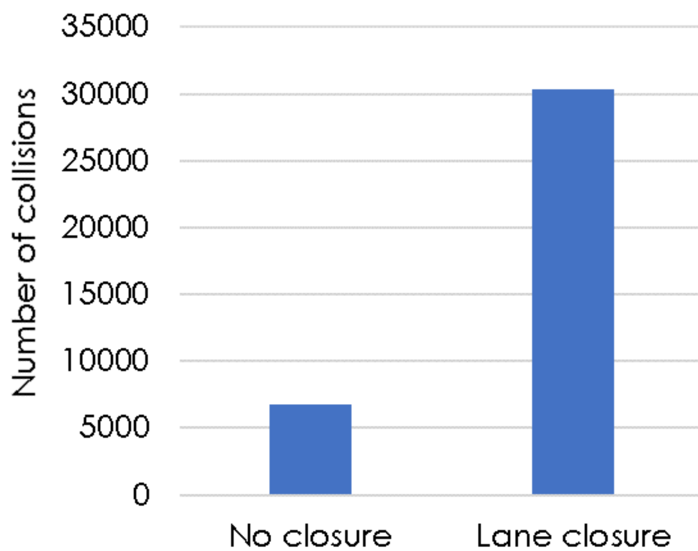

Figure 7.2: Proportion of collision with and without lane closure.

Figure 7.3 investigates the effect of the second most important factor in determining collision risk. Work orders with longer work length, in general, are exposed to higher risk of collisions. This is confirmed by data plotted in Figure 7.3, where the width of each violin is proportional to the percentage of work orders.

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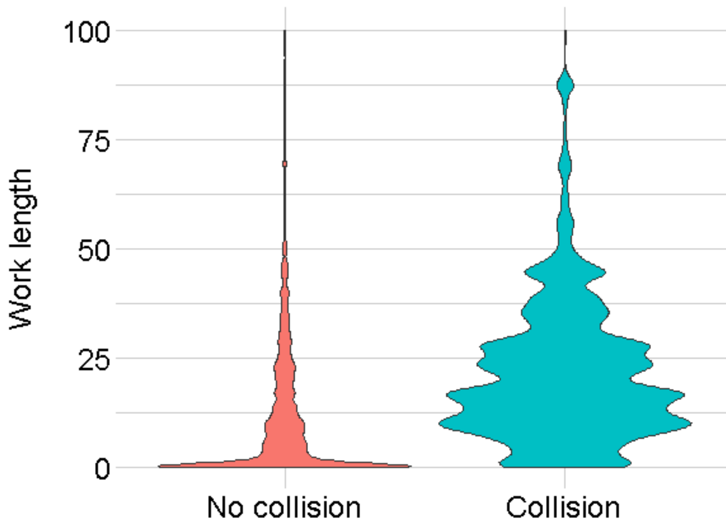

Figure 7.3: Distribution of work orders and collisions over work length.

A similar result is indicated for the effect of collision density on the risk of collisions. Figure 6.5 identifies collision density as the third most important factor in determining the level of collision risk. Figure 7.4 shows that a higher percentage of work orders match a collision where collision densities are higher.

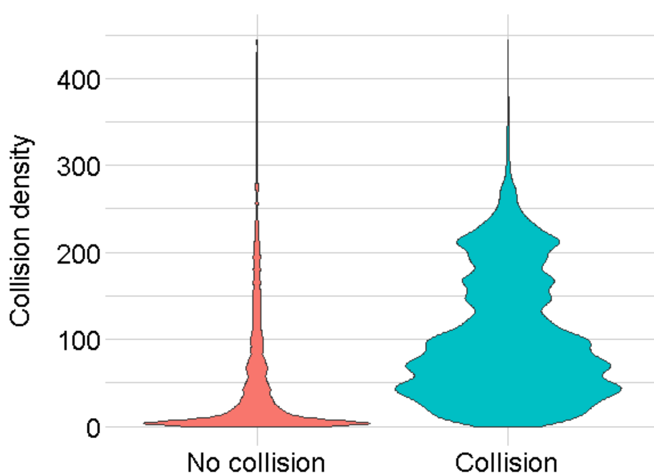

Figure 7.4: Distribution of work orders and collisions in terms of collision density.

The results of this research study may be adapted by Caltrans decision-makers in planning and scheduling maintenance work orders. For example, extra precautions and personal protective equipment may be considered for

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work orders where crews are exposed at a relatively long worksite, with a lane closure in place, where historical data shows a high density of collisions.

Recommendations

The following recommendations are made, based on the results obtained in this research study:

1. Consider including the use of the Index of Difficulty as part of the workflow in evaluating and prioritizing maintenance functions associated with maintaining roadside safety features.
2. Consider including the use of the Index of Difficulty in assignment of personnel, allocating appropriate equipment, and estimating the cost of relevant maintenance operations.
3. For maintenance functions with high values of Index of Difficulty, consider design or operational changes and/or policy modifications that can lead to improvement in the operation, thereby reducing the value of this index when appropriate.
4. Consider pilot studies that can be used to evaluate the efficacy of the Collision Risk Index developed in this research study.
5. Once the efficacy of the Collison Risk Index is established, then for maintenance operations with reasonable Collision Risk Index, consider additional safety precautions.
6. Consider follow-up research to develop a decision support tool with a dashboard that would allow ease of evaluation of Collision Risk Index and Index of Difficulty for field operations within Caltrans.

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APPENDIX A: BREAKDOWN OF AHMCT AND IMMS CLASSIFICATION

- Pavement repair (crack sealing, patching, and slab replacement, etc.): highway maintenance & bridge maintenance crews.

Table A0.1: Breakdown of pavement repair activities

IMMS family: IMMS table	Activity code	Description
A: Flexible pavement	A10110	Crack Seal
	A20010	Overlay/Leveling
	A21010	Profile Grinding
	A22010	Dist. 08 Unpaved Travel way Repairs
	A30010	Dig Out
	A40010	Patch Potholes
	A50010	Seal (All Other) Flex Pavement
B: Rigid pavement	B10110	Crack Seal Rigid Pavement
	B20010	Profile Grinding Rigid Pavement
	B21010	Overlay/Leveling Rigid Pavement
	B22010	Patch Spalls Rigid Pavement
	B30010	Sub Seal/Jack Slab Rigid Lane Pavement
	B31010	Slab Replacement Rigid Lane
C: Lateral support activities	C10010	Lateral Support-Native Material
	C11010	Lateral Support-Import Material
M: Out-of-control vehicle ramp activities	M93010	Repair/Replace
Y: Work for others	YA0000	Flexible Pavement
	YB0000	Rigid Pavement

- Guardrail repair, shoulder repair, sink hole repair, etc.: highway maintenance, functional & special crews.

Table A.2: Breakdown of guardrail & shoulder activities

IMMS family: IMMS table	Activity code	Description
M: Guardrail activities	M60010	Repair/Replace (Rail Only)
	M61010	Repair/Replace (End Treatment)
C: Fences activities	C40010	Repair/Replace

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C: Walls activities	C90010	Repair/Replace
C: Bike path activities	C91010	Repair/Replace
	C91050	Clean
C: Sidewalk activities	C92010	Repair/Replace
	C92050	Clean
C: Cattleguard activities	C93010	Repair/Replace
	C93050	Clean
C: Drywell activities	C94010	Repair/Replace
	C94040	Test/Sample
	C94050	Clean
C: Radiator water site activities	C96010	Repair/Replace
	C96050	Clean/Refill

- Litter, debris, and graffiti removal: highway maintenance, landscape maintenance, & special crews.

Table A.3; Breakdown of litter, debris, and graffiti removal activities

IMMS family: IMMS table	Activity code	Description
D: Litter and debris activities	D40050	Litter Control Roadway/Landscape
	D40150	Road Patrol/Debris Pickup
	D41000	Adopt-A-Hwy Safety Orientation
	D41001	Adopt-A-Hwy Administration
	D41050	Adopt-A-Hwy Litter Control
	D42050	Illegal Encampment Debris Removal
D: Graffiti activities	D60050	Graffiti Removal All Assets
Y: Work for others	YD0000	Litter/Debris/Graffiti

- Road sweeping: highway maintenance & sweeping crews.

Table A.4: Breakdown of road sweeping activities

IMMS family: IMMS table	Activity code	Description
D: Sweeping road	D30050	Sweeping Roadways
D: Carcass pickup, inspection & investigation	D10150	Carcass Pickup
	D20020	Supervisor Area Inspection

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- Sign installation and repair: special crews.

Table A.5: Breakdown of sign installation and repair activities

IMMS family: IMMS table	Activity code	Description
D: Illegal sign removal	D90000	Illegal Sign Removal
K: Highway lighting	K10000	Inventory Update
	K10010	Repair/Replace
	K10011	Third Party Damage
	K10120	Night Inspection
	K10 140	Group Relamp
K: Sign lighting	K20000	Inventory Update
	K20010	Repair/Replace
	K20011	Third Party Damage
	K20120	Night Inspection
	K20140	Group Relamp
	K20000	Inventory Update
K: Traffic signal	K40000	Inventory Update
	K40010	Repair/Replace
	K40011	Third Party Damage
	K40025	Pm Check
	K40026	Conflict Monitor Check
	K40140	Group Relamp
K: Flashing beacon	K50000	Inventory Update
	K50010	Repair/Replace
	K50011	Third Party Damage
	K50025	Pm Check
	K50140	Group Relamp
K: Freeway metering system	K60000	Inventory
	K60010	Repair/Replace
	K60011	Third Party Damage
	K60025	Pm Check
	K60140	Group Relamp
K: TMS field element	K70000	Inventory Update
	K70010	Repair/Replace
	K70011	Third Party Damage
	K70025	Pm Check
	K70140	Group Relamp
K: Traffic census system	K80000	Inventory Update

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	K80010	Repair/Replace
	K80011	Third Party Damage
	K80025	Pm Check
K: Miscellaneous activities	K90100	Test New Equip.
	K90110	Calibration Test Equip.
M: Sign activities	M40000	Sign Fabrication
	M40010	Repair/Replace
	M40120	Night Inspection Signs
M: Sign structure	M41000	Install/Remove Graffiti Deterrent
	M41010	Repair/Replace
M: Roadside Delineators	M50010	Repair/Replace
	M50120	Night Inspection Delineators
M: Out-of-control vehicle ramp activities	M92010	Electrical / Mechanical
Y: Work for others	Y91000	Illegal Sign Removal Outdoor Advertising
	YK0000	Electrical

- Pavement striping and marking: Special crews.

Table A.6: Breakdown of pavement marking and stripping activities

IMMS family: IMMS table	Activity code	Description
M: Stripping activities	M10010	Repair/Replace
	M10120	Night Inspection Striping
M: Marking activities	M20010	Repair/Replace
	M20120	Night Inspection Markings
M: Marker activities	M30010	Repair/Replace
	M30120	Night Inspection Markers

- Landscaping: Landscaping crews.

Table A.7: Breakdown of landscaping activities

IMMS family: IMMS table	Activity code	Description
E: Landscaping	E10040	Mechanical Control
	E11040	Manual Control
	E12040	Chemical Control
	E13040	Rodent Control
	E14040	All Other Control
	E21040	Pruning Groundcover
	E22040	Pruning Linear
	E23040	Replant Groundcover

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	E24040	Maintain Plantings
	E25040	Fertilizing Landscape
	E30010	Irrigation System Repair
	E31010	Irrigation Electrical
	E32020	Backflow Preventer
	E33040	Irrigating Landscape
	E34040	Truck Watering
Y: Work for others	YE0000	Landscaping

- Vegetation control: Landscape maintenance crews.

Table A.8: Breakdown of vegetation control activities

IMMS family: IMMS table	Activity code	Description
C: Roadside vegetation activities	C20040	Mechanical Control
	C21040	Chemical Control
	C22040	Manual Control
	C23040	Rodent Control
	C24040	All Other Weed Control Roadside
Y: Work for others	YC0000	Slopes/Drainage/Vegetation

- Tree pruning and tree removals: Tree crews.

Table A.9: Breakdown of tree control activities

IMMS family: IMMS table	Activity code	Description
C: Roadside vegetation control	C30020	Tree Inspection
	C30040	Tree Trimming
	C31040	Remove Tree

- Fire hazard reduction: Landscape maintenance & tree crews.

Table A.10: Breakdown of fire hazard reduction activities

IMMS family: IMMS table	Activity code	Description
C: Roadside vegetation control	C32040	Brush Control
	C20040	Mechanical Control
	C22040	Manual Control
	C24040	All Other Weed Control Roadside

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- Erosion protection: Highway maintenance & storm water crews.

Table A.11: Breakdown of erosion protection activities

IMMS family: IMMS table	Activity code	Description
C: Ditched and channels activities	C50010	Repair/Replace
	C50150	Clean
C: Curbs and dikes activities	C51010	Repair/Replace
	C51050	Clean
C & F: Drainage activities	C60010	Repair/Replace
	C60050	Clean
	C60220	Drainage Inspection
	F20005	Drain Stenciling
	F20020	Drainage Inlet Inspection
	F20030	Drain Stenciling Support Purchases
	F20050	Drainage Inlet Cleaning
C: Manholes activities	C95010	Repair/Replace
	C95040	Test/Sample
	C95050	Clean
F: Erosion & sediment control	F40030	Erosion/Sediment Control Support Purchases
	F40050	Snow Hauling (Storm water)
	F40060	Install New Controls
	F40120	SWMP Slope Inspection
	F40310	Repair/Replace Existing Controls
S family activities	S10000	Sand/Rock Patrol
	S30110	Minor Slide/Slip Remove/Repair
	S31010	Repair/Replace Rock Fall Protection
	S31040	Rock Scaling
	S40010	Major Slide/Slip Remove/Repair

- Avalanche control system: Highway maintenance crews.

Table A.12: Breakdown of avalanche control activities

IMMS family: IMMS table	Activity code	Description
R: Miscellaneous activities	R91000	Avalanche Control

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- Irrigation repair (irrigation valve, lateral line repair, controller wires, etc.): Landscape maintenance & electrical crews.

Table A.13: Breakdown of irrigation repair activities

IMMS family: IMMS table	Activity code	Description
E: Landscaping activities	E30010	Irrigation System Repair
	E31010	Irrigation Electrical
	E32020	Backflow Preventer
	E33040	Irrigating Landscape
	E34040	Truck Watering

- Snow removal and control: Highway maintenance crews.

Table A.14: Breakdown of snow control activities

IMMS family: IMMS table	Activity code	Description
R: Snow activities	R10000	Snow Removal
	R11000	Snow Hauling
R: Sand & salt activities	R20000	Cover Snow & Ice on Pavement
	R21000	Sand/Salt Material Handling
	R22000	Apply Anti-Icer
R: Chain control activities	R40000	Chain Control
R: Supported personnel activities	R50000	Support Personnel Snow/Ice
R: Miscellaneous activities	R90000	Miscellaneous Activities
F: Storm activities	F40050	Snow Hauling (Storm water)
Y: Work for others	Y90001	Snow Park Snow Removal
	Y90002	Snow Park Sign Maintenance
	YR0000	Snow/Ice Control

- Traffic control: Highway maintenance crews.

Table A.15: Breakdown of traffic control activities

IMMS family: IMMS table	Activity code	Description
M: Miscellaneous activities	M90000	Emergency Traffic Control
J: Tow services & bicycle shuttle	J50060	Tow Truck Operations
	J51060	Bicycle Shuttle
J: Toll plaza activities	J70010	Repair / Replace

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M: Barrier activities	M70010	Repair/Replace
Y: Work for others	YM0000	Traffic Guidance

- Rock blasting: Highway maintenance crews.

Table A.16: Breakdown of rock blasting activities

IMMS family: IMMS table	Activity code	Description
S family activities	S33000	Blasting

- Bridge repair, structural steel painting, bracing, and temporary bridge installation: Bridge maintenance crews.

Table A.17: Breakdown of bridge repair activities

IMMS family: IMMS table	Activity code	Description
H: Bridge activities	H10005	Bridge Id Stenciling
	H10020	Inspection H Family
	H10110	Bms Sub - Repair/Replace
	H10140	Bms Sub - Maintenance
	H20040	Bms Super - Maintenance
	H20110	Bms Super - Repair/Replace
	H30010	Bms Deck - Repair/Replace
	H30040	Bms Deck - Maintenance
	H40040	Bms Joints & Bearings - Maintenance
	H40110	Bms Joints & Bearings - Repair/Replace
	H50110	Bms Railing - Repair/Replace
	H60050	Bms Clean Pan, Gutter, Drainage Sys Bridges
	H70040	Rigging Containment - Paint
	H71040	Spot Removal & Spot Paint
	H72040	Spot Removal & Full Paint
	H73040	Full Removal & Full Paint
	H74040	Other Paint Activities
	H80040	Bms Mech/Electrical - Maintenance
	H80110	Bms Mech/Electrical - Repair/Replace
	H91110	Bms Seismic - Repair/Replace

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	H91140	Bms Seismic - Maintenance
	H92060	Bms Drawbridge - Operations
Y: Work for others	YH0000	Bridges
	YJ0000	Other Structures

- Culvert and drain cleaning: Highway maintenance & storm water crews.

Table A.18: Breakdown of culvert & drain cleaning activities

IMMS family: IMMS table	Activity code	Description
C: Ditched and channel activities	C50010	Repair/Replace
	C50150	Clean
C: Curbs and dikes activities	C51010	Repair/Replace
	C51050	Clean
C: Drainage activities	C60010	Repair/Replace
	C60050	Clean
	C60220	Drainage Inspection
	F20005	Drain Stenciling
	F20020	Drainage Inlet Inspection
	F20030	Drain Stenciling Support Purchases
	F20050	Drainage Inlet Cleaning
C: Manholes activities	C95010	Repair/Replace
	C95040	Test/Sample
	C95050	Clean

- Hazardous spill cleaning: Highway maintenance crews.

Table A.19: Breakdown of hazardous spill cleaning activities

IMMS family: IMMS table	Activity code	Description
D: Spill activities	D50050	Spills – Rdwy, Lane, Shldr, Appurtenance & Facility
D: Hazmat storage	D70050	Hazmat Storage and Disposal

- Storm damage and emergency incidents: Highway maintenance crews.

Table A.20: Breakdown of storm damage and emergency incident activities

IMMS family: IMMS table	Activity code	Description
F: Training activities	F10003	Employee Tailgate Meetings
	F10006	Employee Orientation/Training
	F10007	Employee Specialized Training

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	F10009	Prepare Storm Water Training Materials
	F10030	Storm Water Training Support Purchases
F: Drainage activities	F20005	Drain Stenciling
	F20020	Drainage Inlet Inspection
	F20030	Drain Stenciling Support Purchases
	F20050	Drainage Inlet Cleaning
F: Facilities & inspection activities	F30005	Maintenance Site Corrective Measure
	F30020	Maintenance Site Storm Water Inspections
	F30120	Maintenance Activity Inspections
	F30201	Water Treatment Plant
	F30220	Construction Compliance Inspection
	F30301	Equipment Wash Systems
F: Erosion & sediment control	F40030	Erosion/Sediment Control Support Purchases
	F40050	Snow Hauling (Storm water)
	F40060	Install New Controls
	F40120	SWMP Slope Inspection
	F40310	Repair/Replace Existing Controls
F: Administration activities	F50002	Snow and Ice Documents and Meetings
	F50103	MSWAT Meeting
F: Illicit discharges	F60020	ID/ID Investigation and Field Report
	F60050	Illicit Discharge Clean-up
	F60150	Remove Illegal Connection
F: Structural treatment activities	F70003	Treatment Bmp Database
	F70020	Treatment Bmp Inspection
	F70030	Bmp Support Purchases
	F70050	Clean/Mow Treatment Bmp
	F70101	Maintenance Field Activities Bmps
	F70103	Maintenance Site Bmps
	F70110	Repair/Replace of Treatment Bmp
	F70201	Treatment and Field Bmps Support Staff
F: Contract oversight	F80001	Construction Contract
	F80002	Drainage Contract
	F80003	Sampling and Testing Contract

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	F80004	Hauling And / Or Disposal Contract
	F80005	Water Treatment System Contract
	F80006	California Conservation Corps Contract
	F80007	Task Order Contract
F: Waste management	F90020	Local Enforcement Agency Inspections
	F90050	Transfer of Site Material
	F90101	New Waste And / Or Working Stock Site E
	F90103	Closure of Existing Site
	F90105	Site Fees
	F90120	Lea Documentation and Reporting
	F90150	Dispose of Site Material
	F90220	Waste And / Or Working Stock Sites Inventory
S family activities	S20000	Storm Patrol
	S21000	Flood Control
	S32050	Bench Cleaning
Y: Work for others	YF0000	Storm Water
	YS0000	Storm/Major Damage

- Public facilities maintenance (safety roadside rest areas, weigh stations, park, and ride lots, and vista points, etc.): Highway maintenance & landscape maintenance crews.

Table A.21: Breakdown of public facility maintenance activities

IMMS family: IMMS table	Activity code	Description
G: Safety roadside activities	G10010	Facility Repair/Replace
	G11040	Grounds Maintenance
	G12040	Chemical Control
	G13040	Rodent Control
	G14050	Janitorial
	G15040	Water Treatment Maint.
	G16000	Special Program
G: Vista point activities	G20010	Facility Repair/Replace
	G21040	Grounds Maintenance
	G22040	Chemical Control
	G23040	Rodent Control

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G: Inspection station activities	G30010	Facility Repair/Replace
	G31040	Grounds Maintenance
	G32040	Chemical Control
	G33040	Rodent Control
	G34040	Water Treatment Maint.
G: Park & ride activities	G40010	Facility Repair/Replace
	G41040	Grounds Maintenance
	G42040	Chemical Control
	G43040	Rodent Control
Y: Work for others	YG0000	Service Facilities

- Tunnels, tubes, and pumping plants maintenance: Tunnels and tubes crews.

Table A.22: Breakdown of tunnels, tubes, and pumping station maintenance activities

IMMS family: IMMS table	Activity code	Description
J: Pump plant activities	J10010	Repair/Replace
	J10020	Pm Check
	J10140	Maintenance
J: Tubes & tunnels activities	J20010	Repair/Replace
	J20040	Maintenance
	J21010	Control Room/Radio Repair
	J21060	Radio/Dispatch Activities
J: Channelizers activities	J60010	Repair/Replace
	J60040	Maintenance
	J60060	Scheduled Lane Change
J: Calibrate equipment	J90020	Calibrate/Repair Test
J: Ferryboat activities	J30040	Maintenance
	J30060	Operations
	J30110	Repair/Replace

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APPENDIX B: NUMBER OF EMPLOYEES FOR EACH ACTIVITY

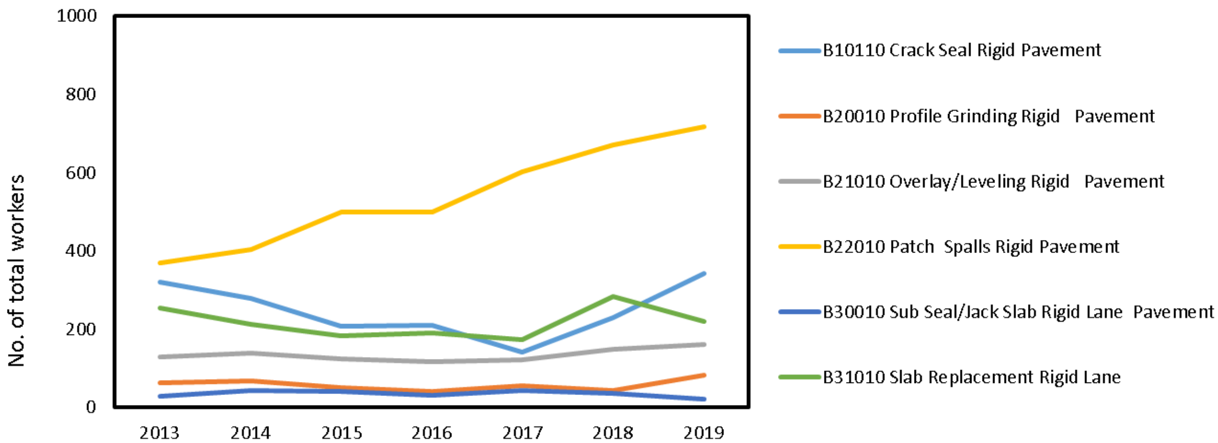

Figure B.1: B - Rigid pavements

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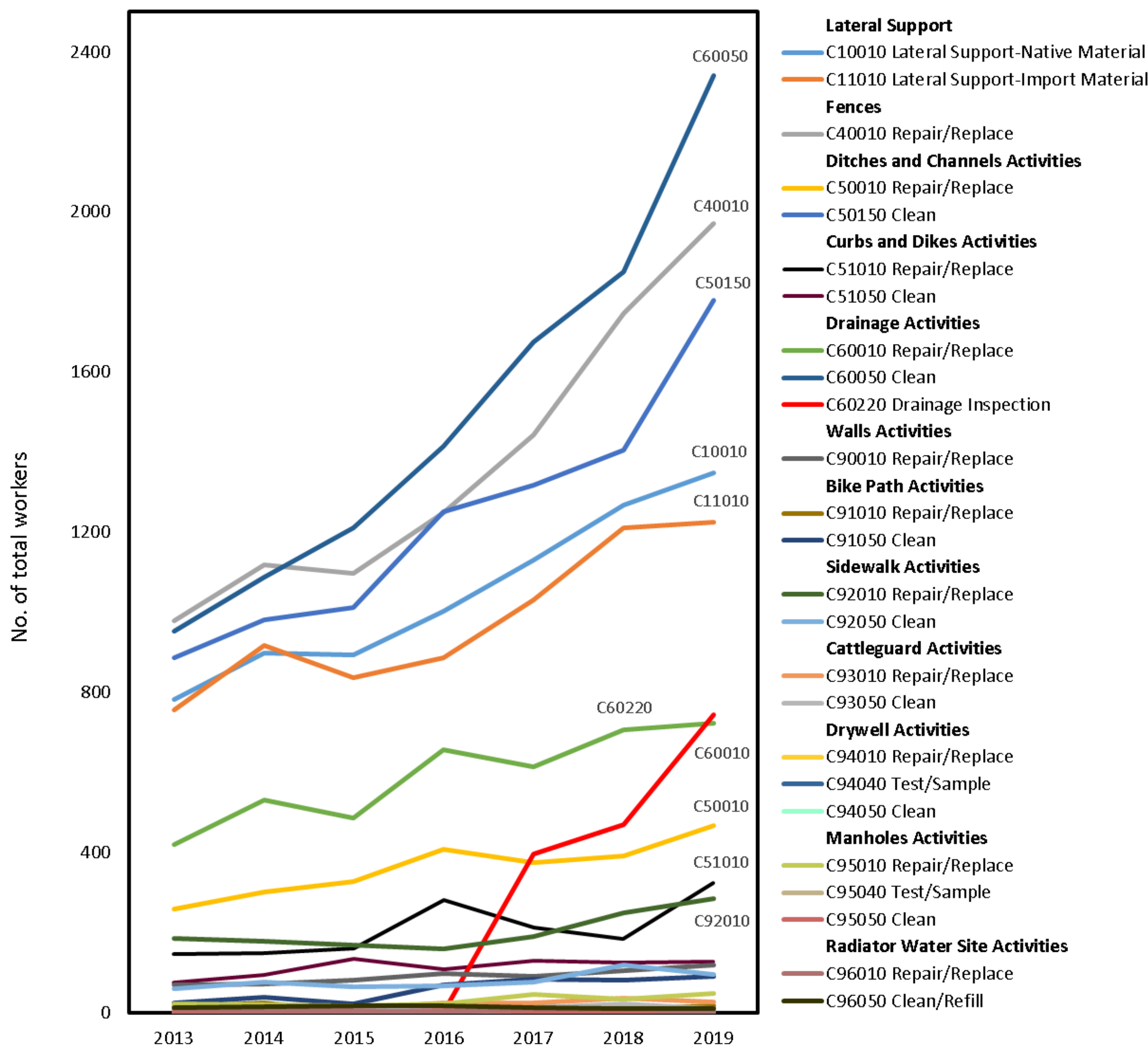

Figure B.2: C - Drainage, fences, and roadside appurtenances.

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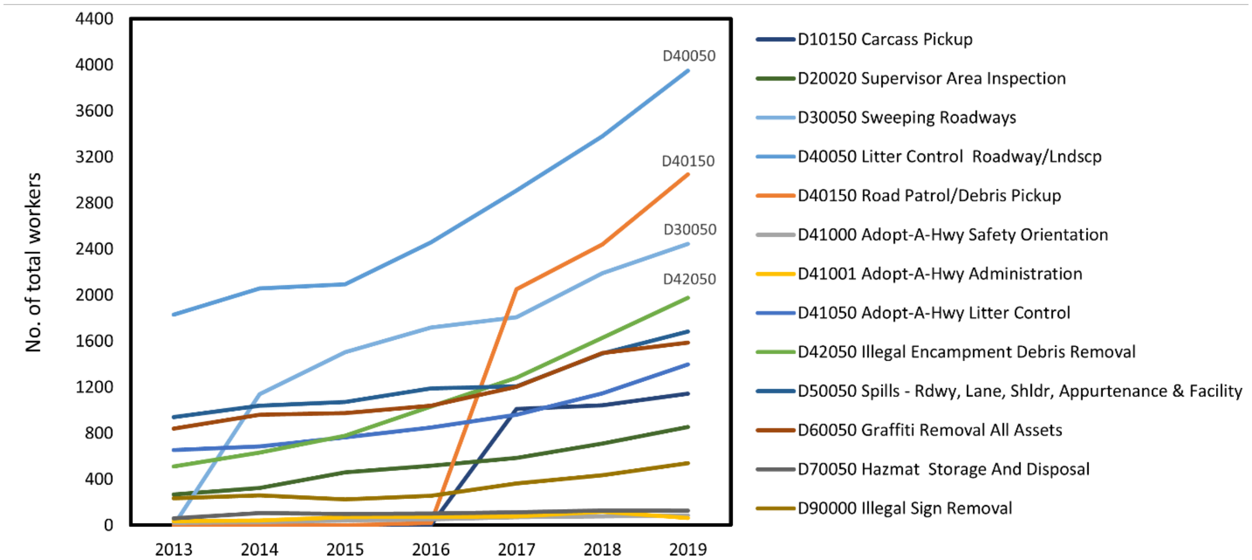

Figure B.3: D - Litter, debris, graffiti, and spills of substances on highway rights of way

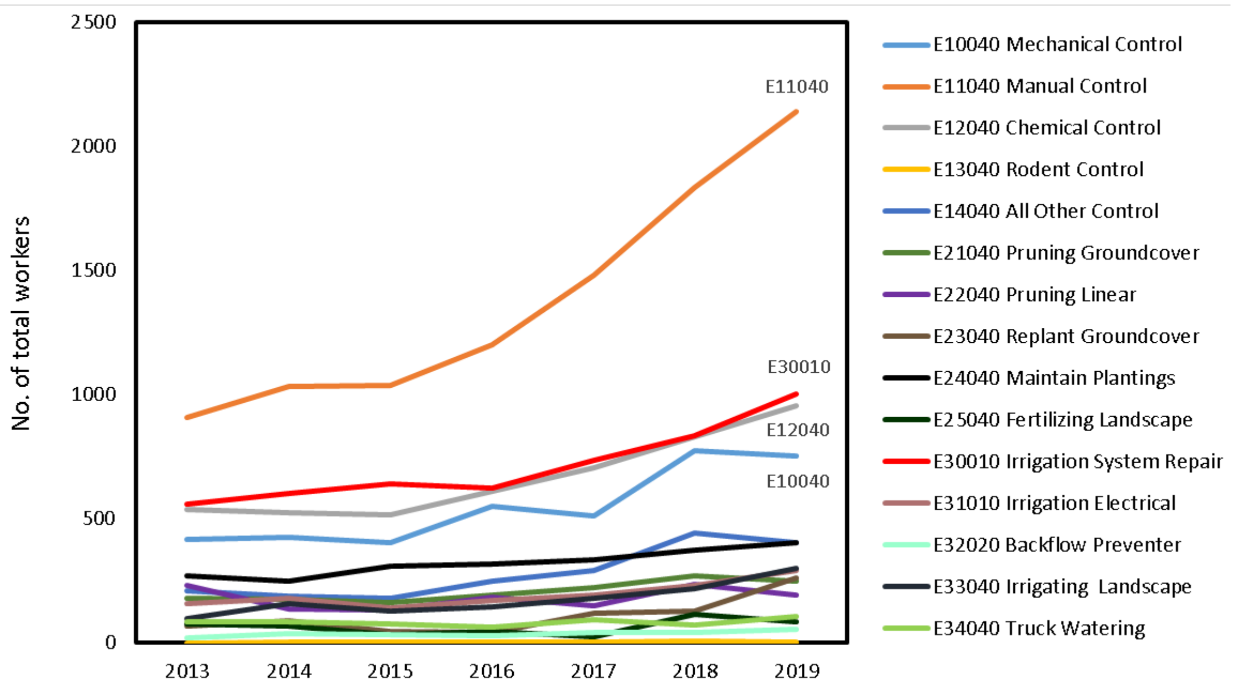

Figure B.4: E - Landscaping activities.

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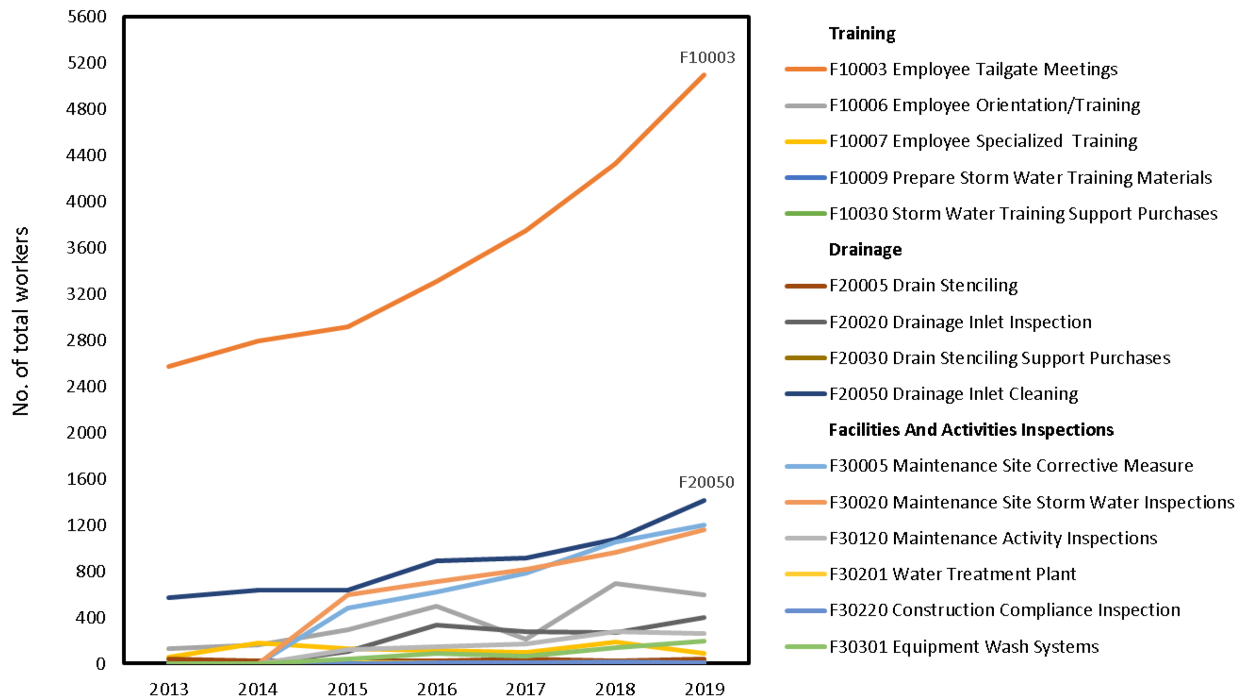

Figure B.5: F – Training, drainage, and facilities activities.

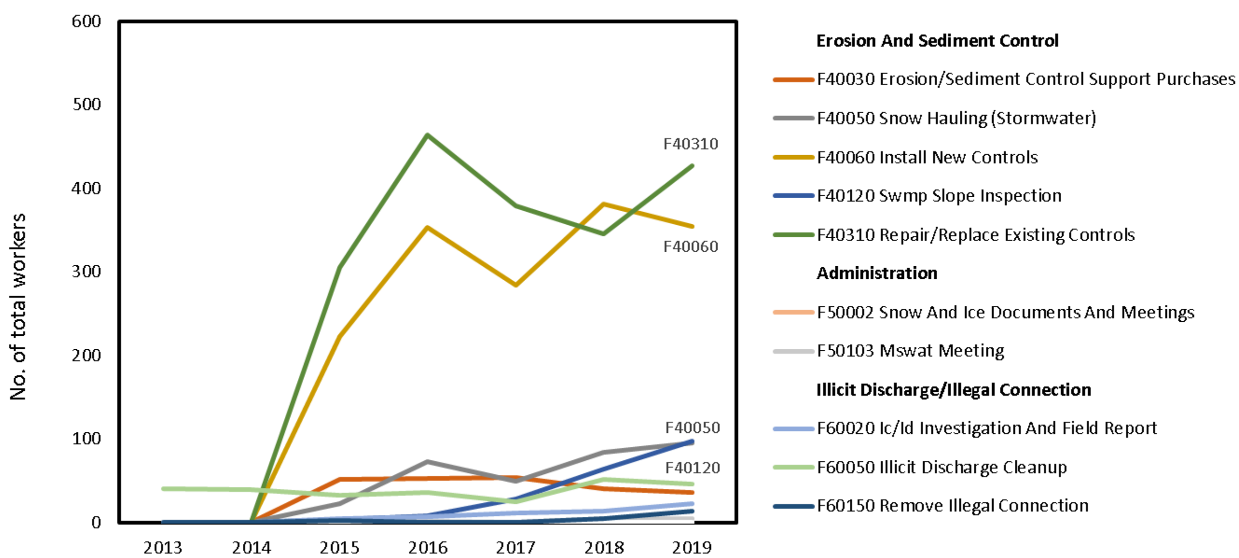

Figure B.6: F – Erosion control, administration, and illicit connection activities.

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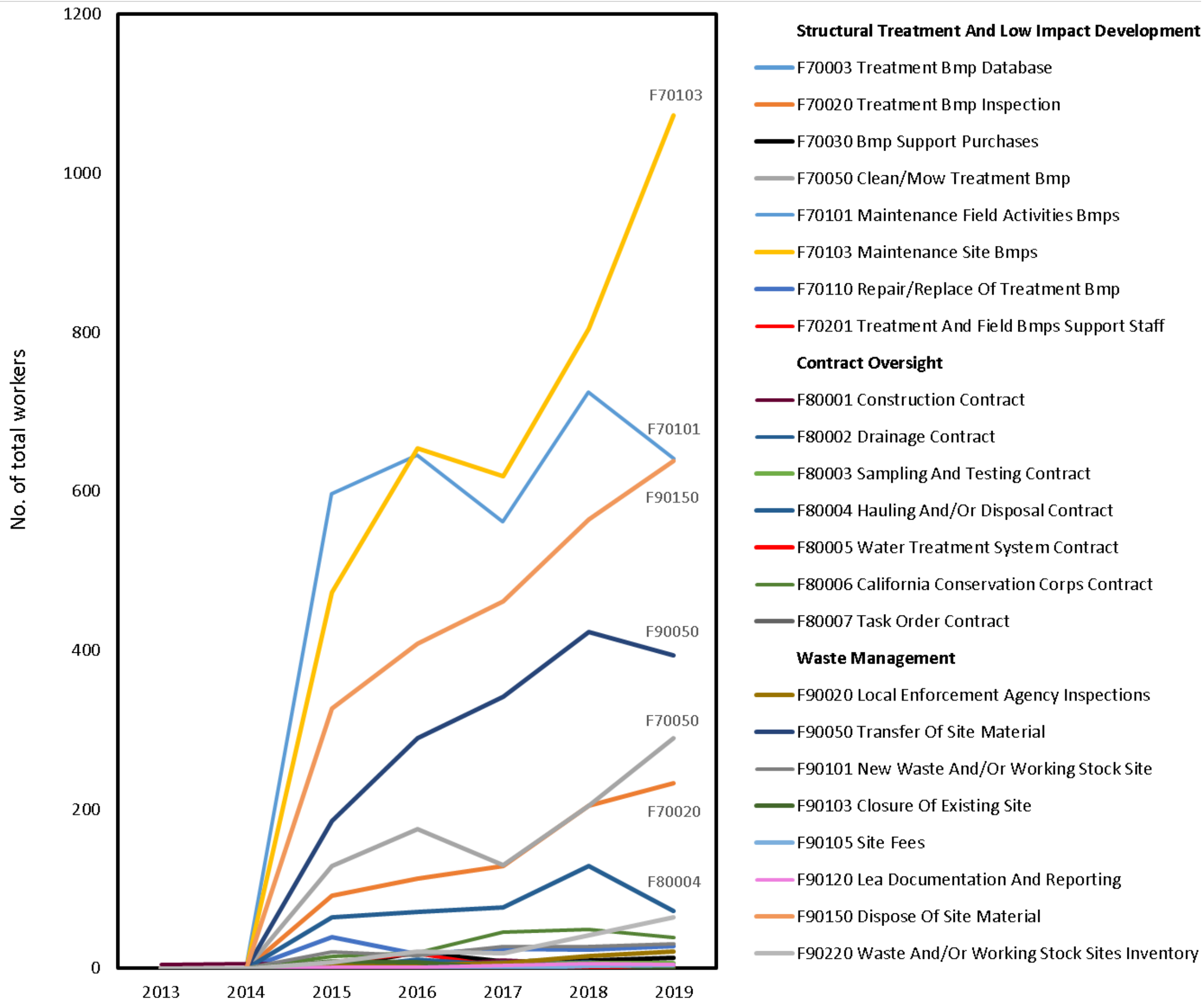

Figure B.7: F – Structural treatment, oversight, and waste management activities.

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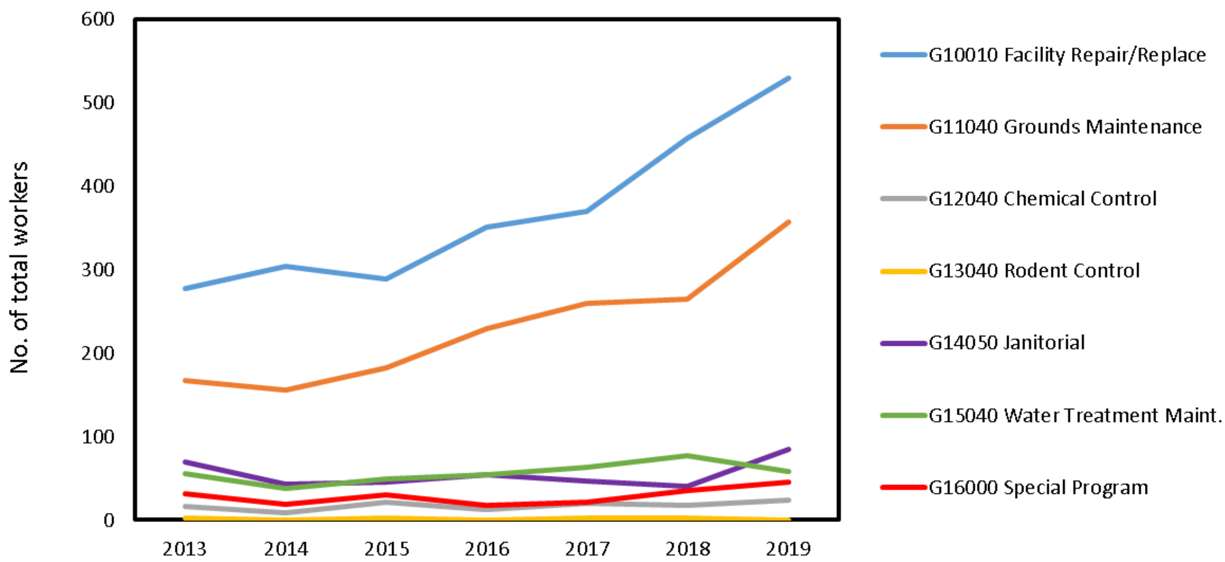

Figure B.8: G - Safety roadside rest area activities.

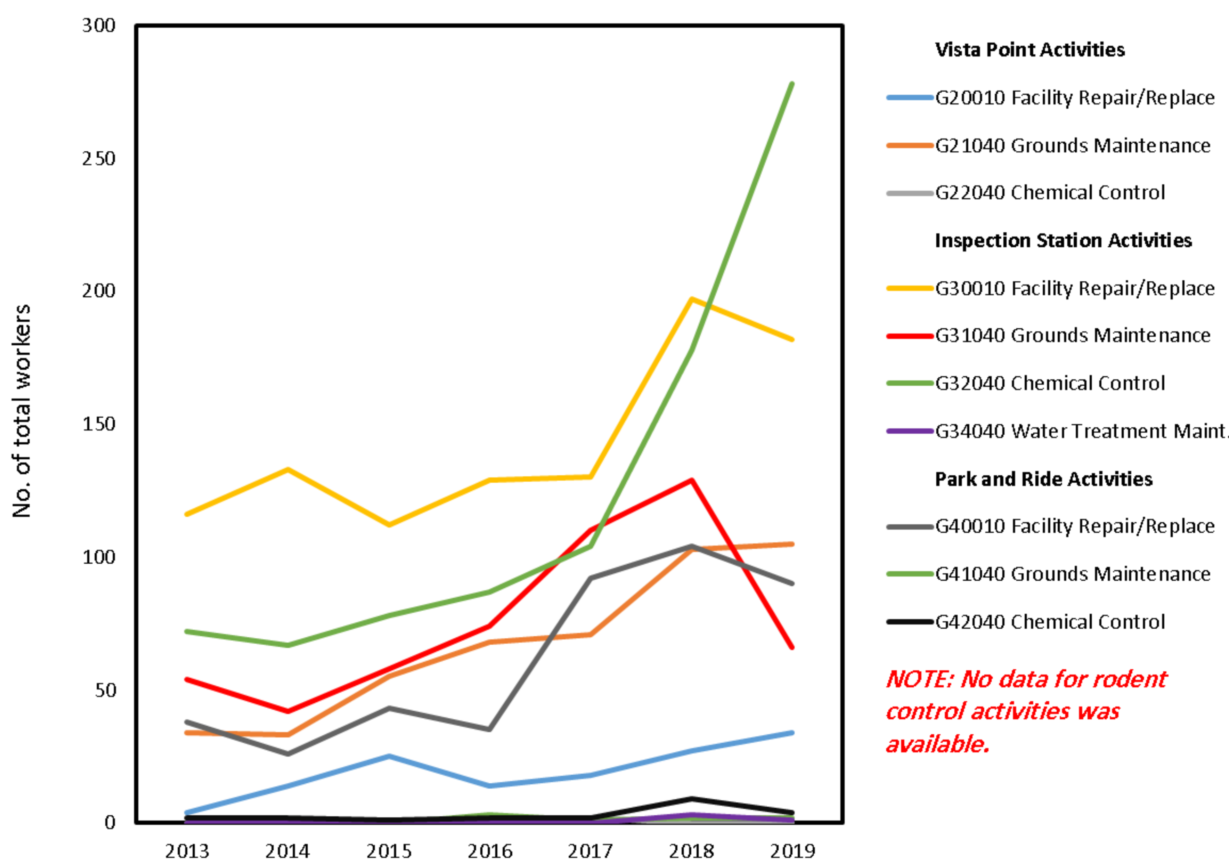

Figure B.9: G - Vista points, inspection, and park and ride activities.

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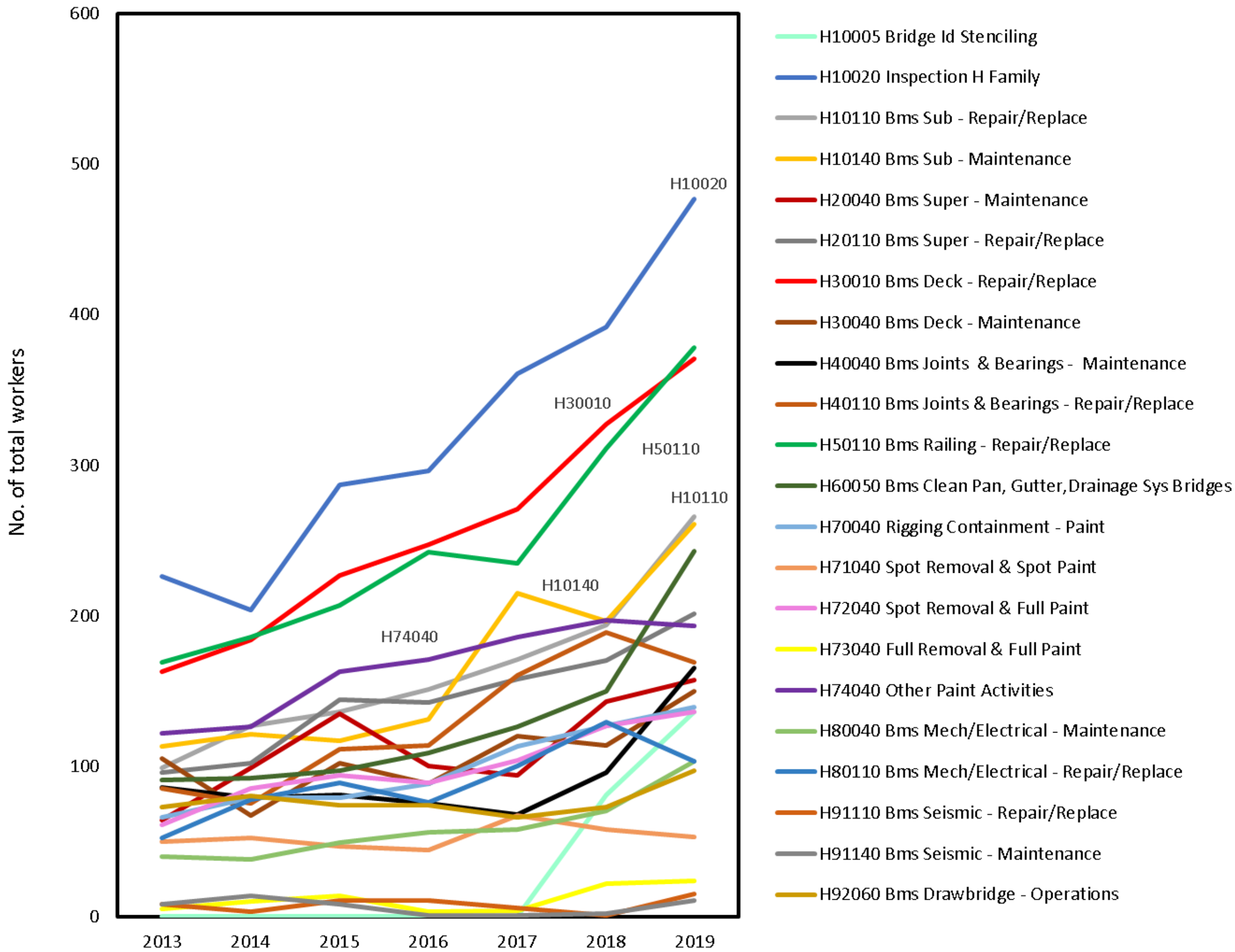

Figure B.10: H - Bridge activities.

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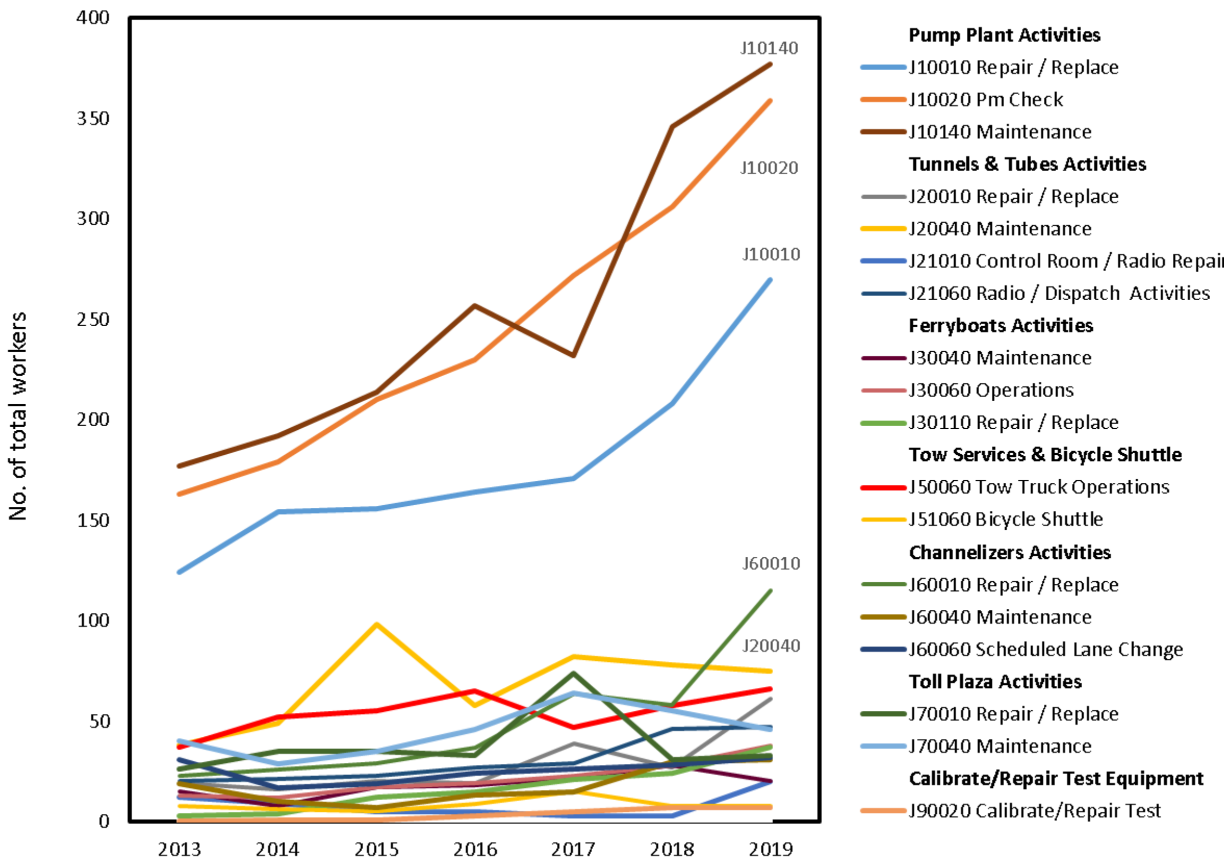

Figure B.11: J – Tunnels, tubes, pumps, and ferries operation activities.

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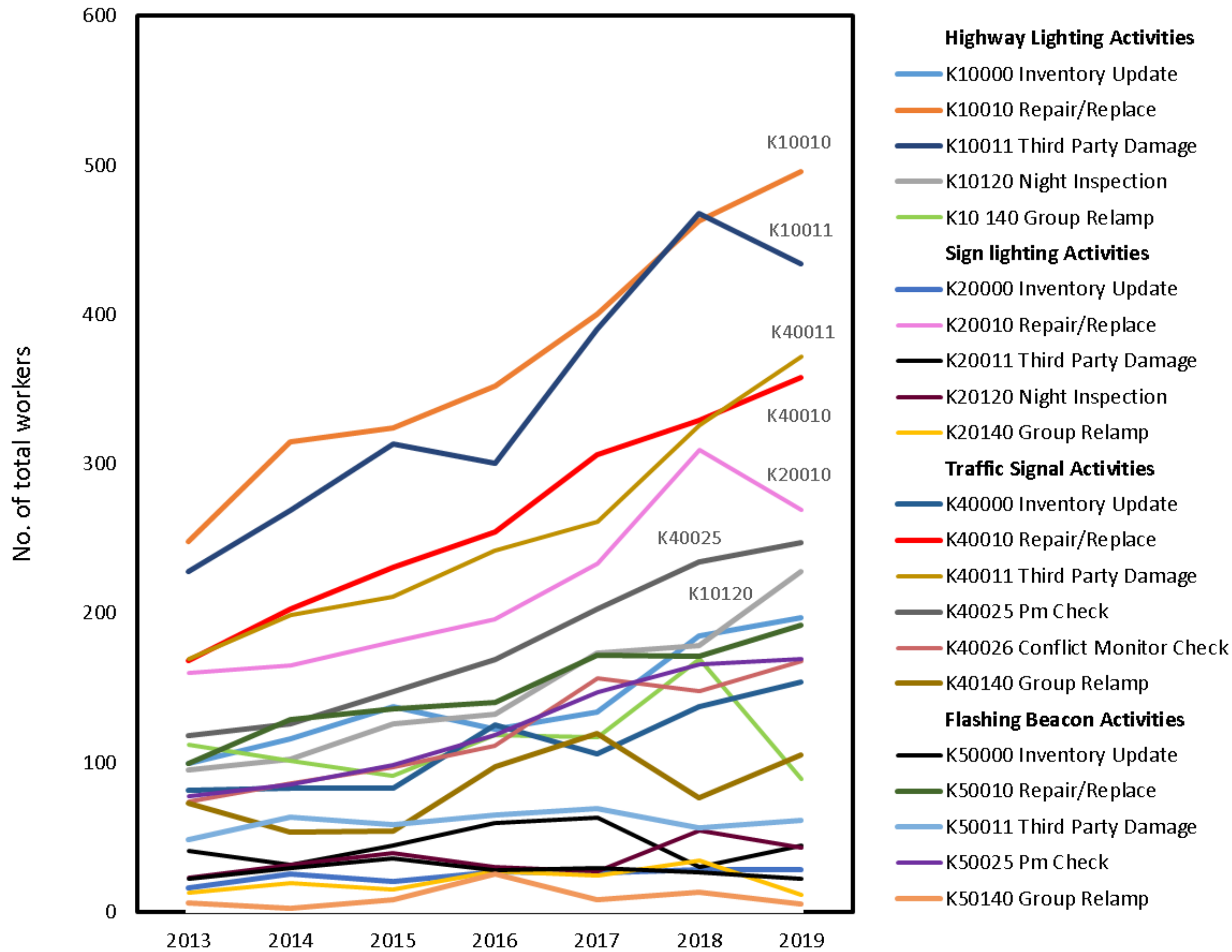

Figure B.12: K – Lighting, sign, beacon, and traffic signal activities.

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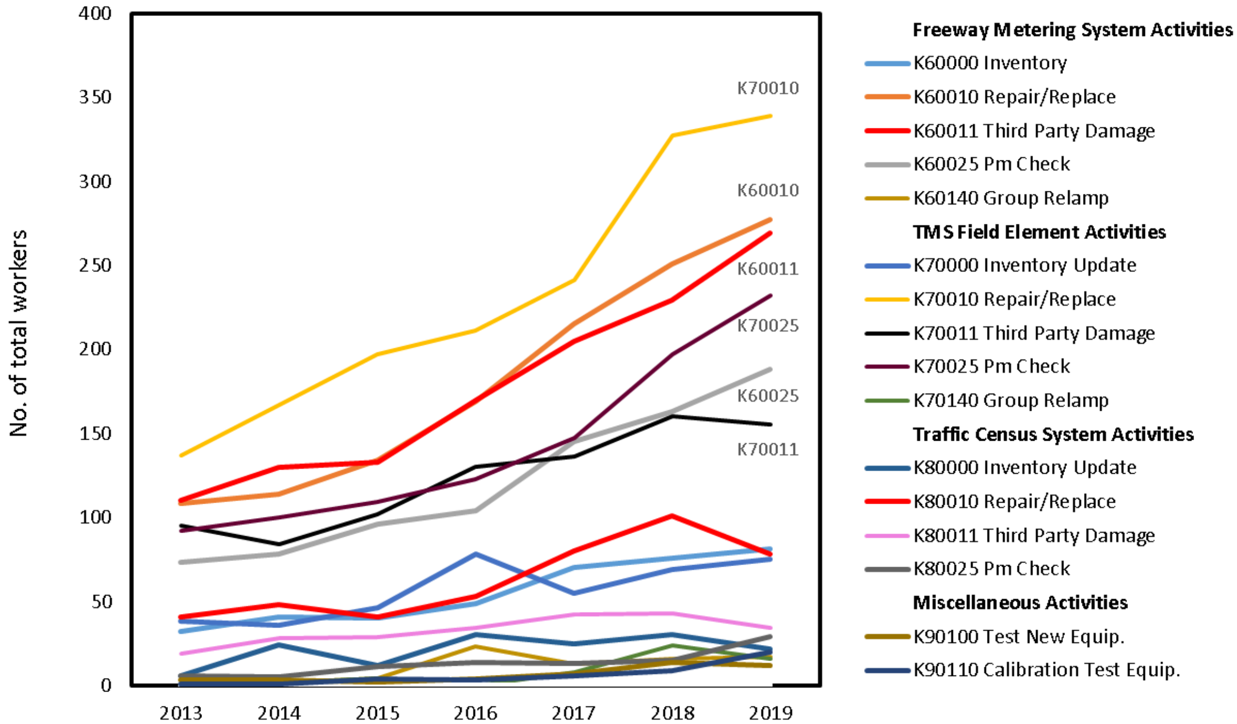

Figure B.13: K – Metering, census, and miscellaneous activities.

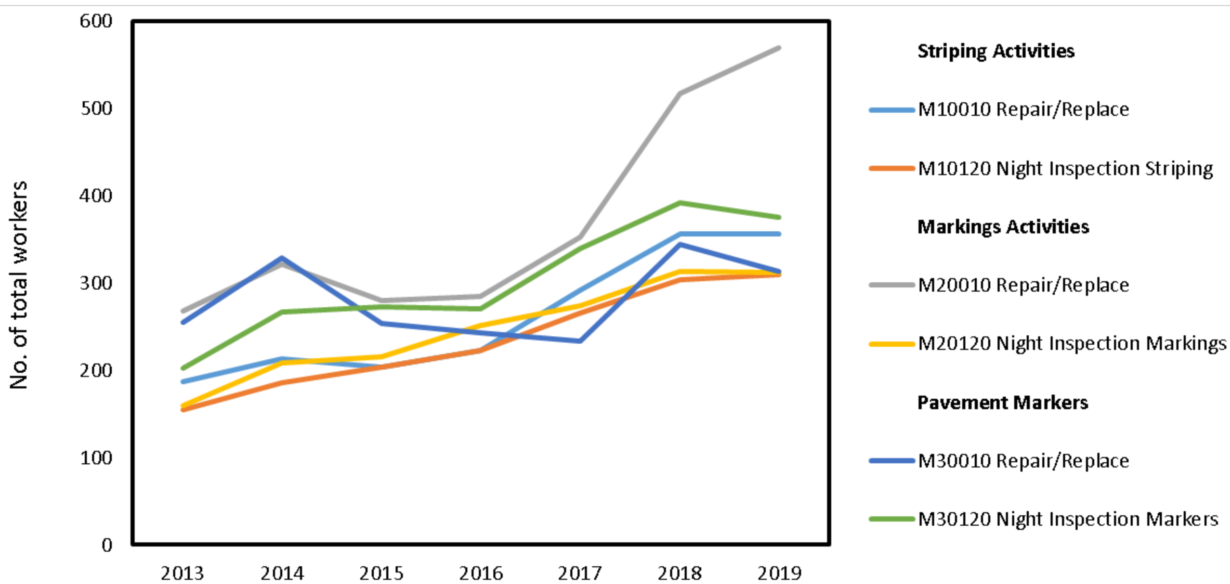

Figure B.14: M - Pavement delineation.

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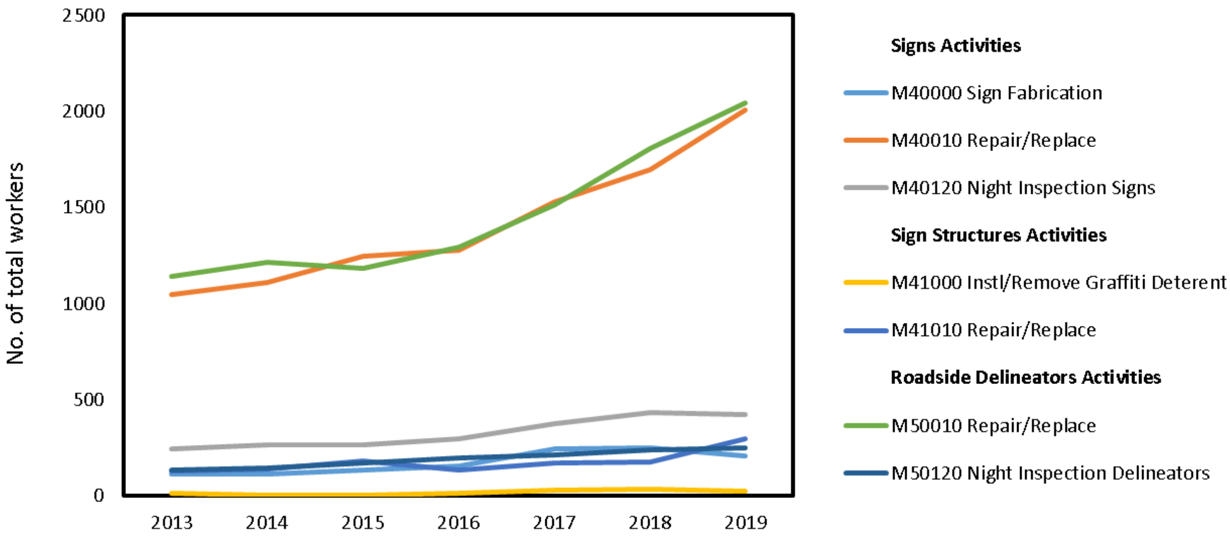

Figure B.15: M - Signs and delineators.

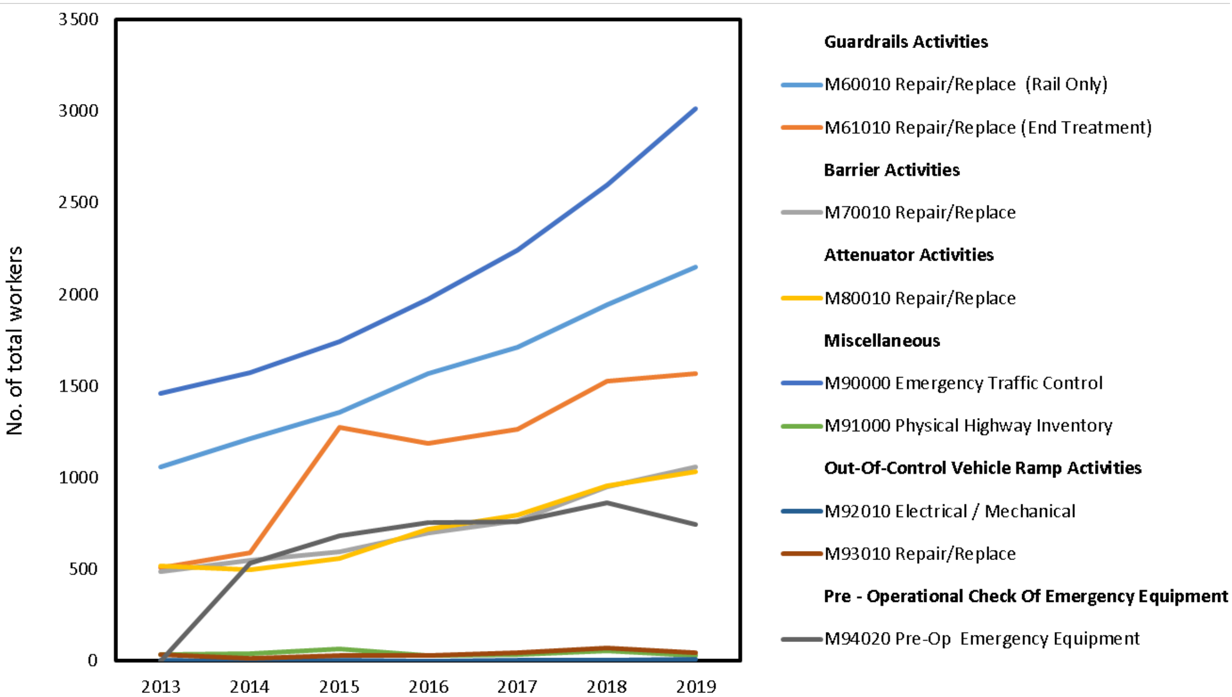

Figure B.16: M - Guardrails, barriers, attenuators, and miscellaneous activities.

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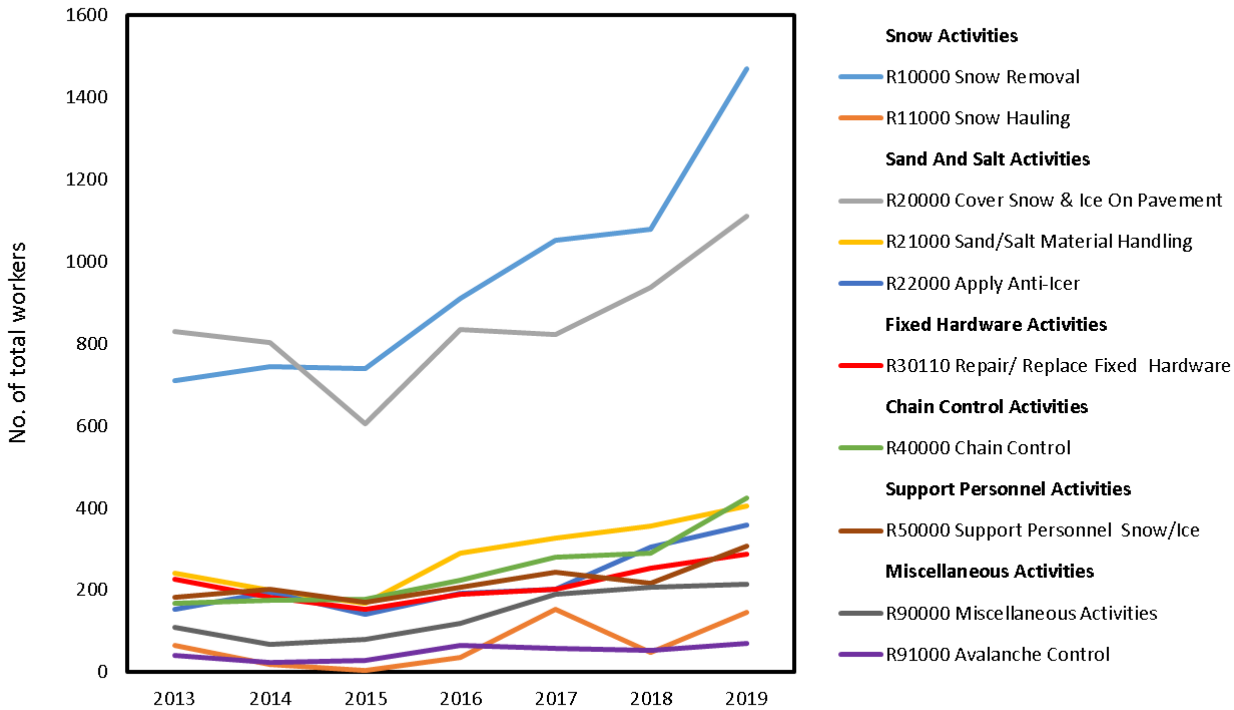

Figure B.17: R - Snow/ice control.

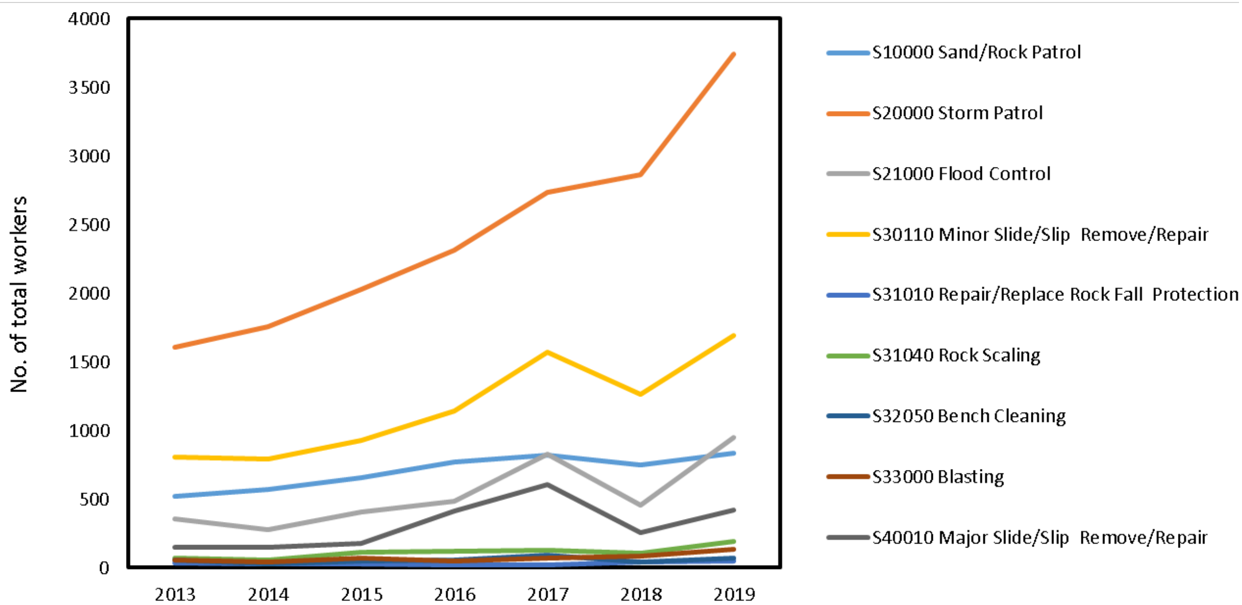

Figure B.18: S - Storm and damage control activities.

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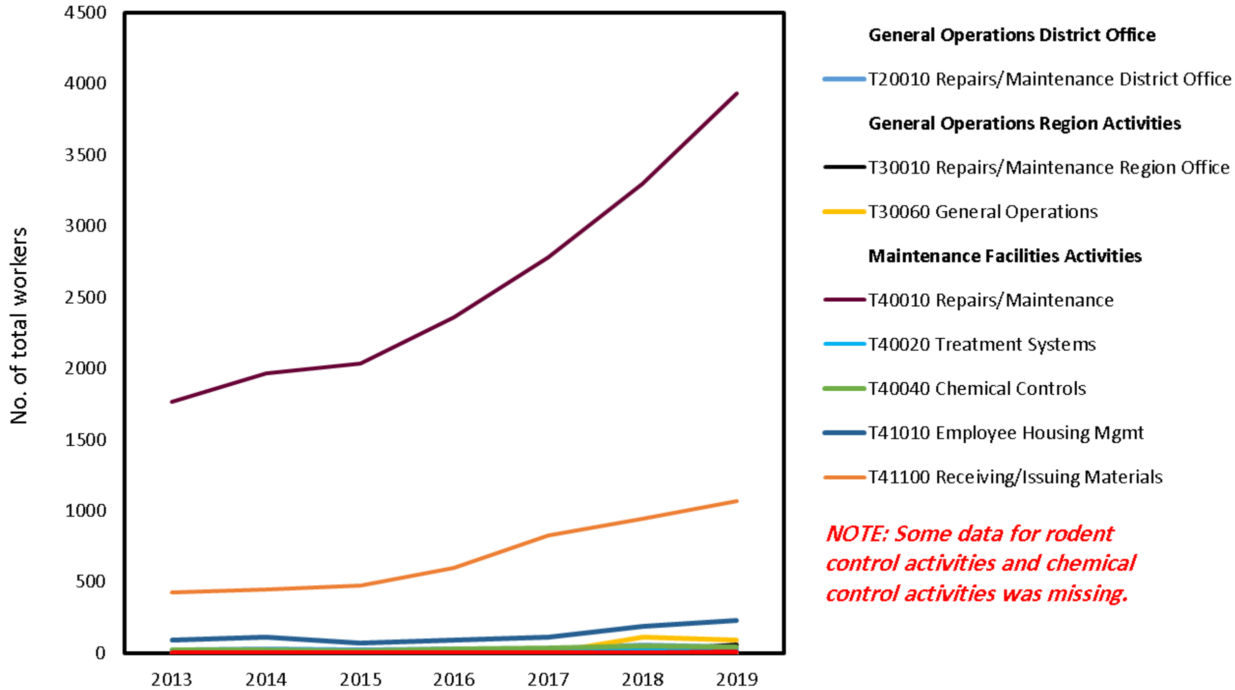

Figure B.19: T - Facilities and office activities.

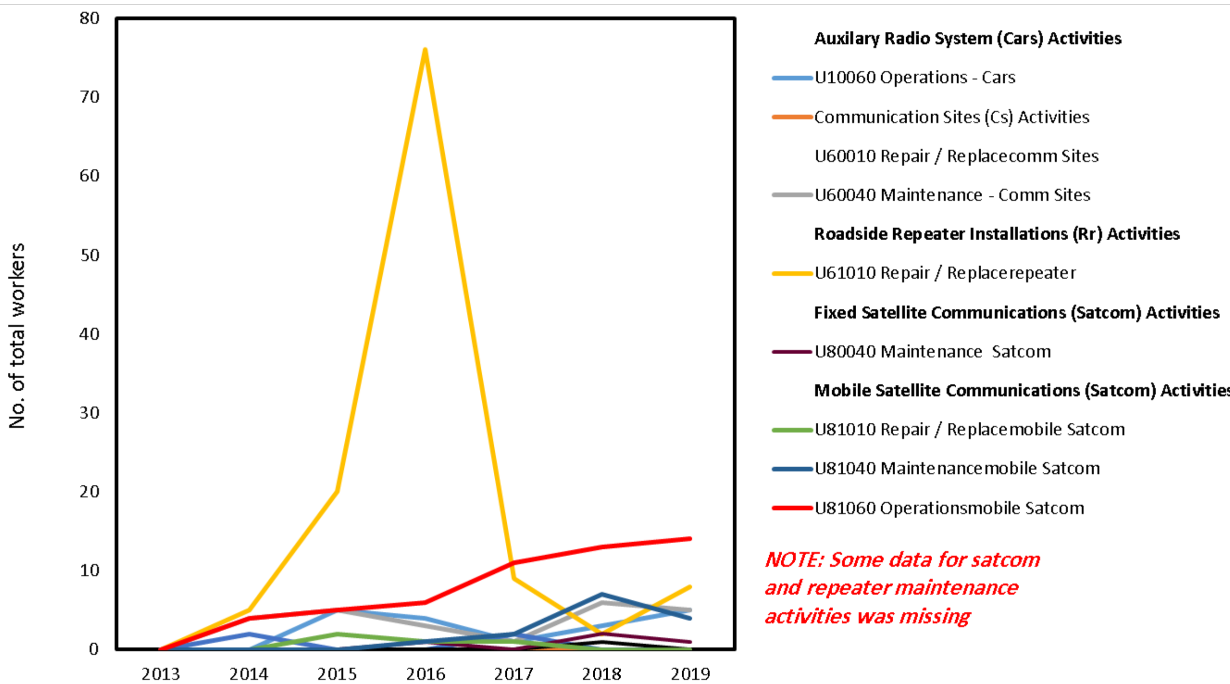

Figure B.20: U - Communication activities.

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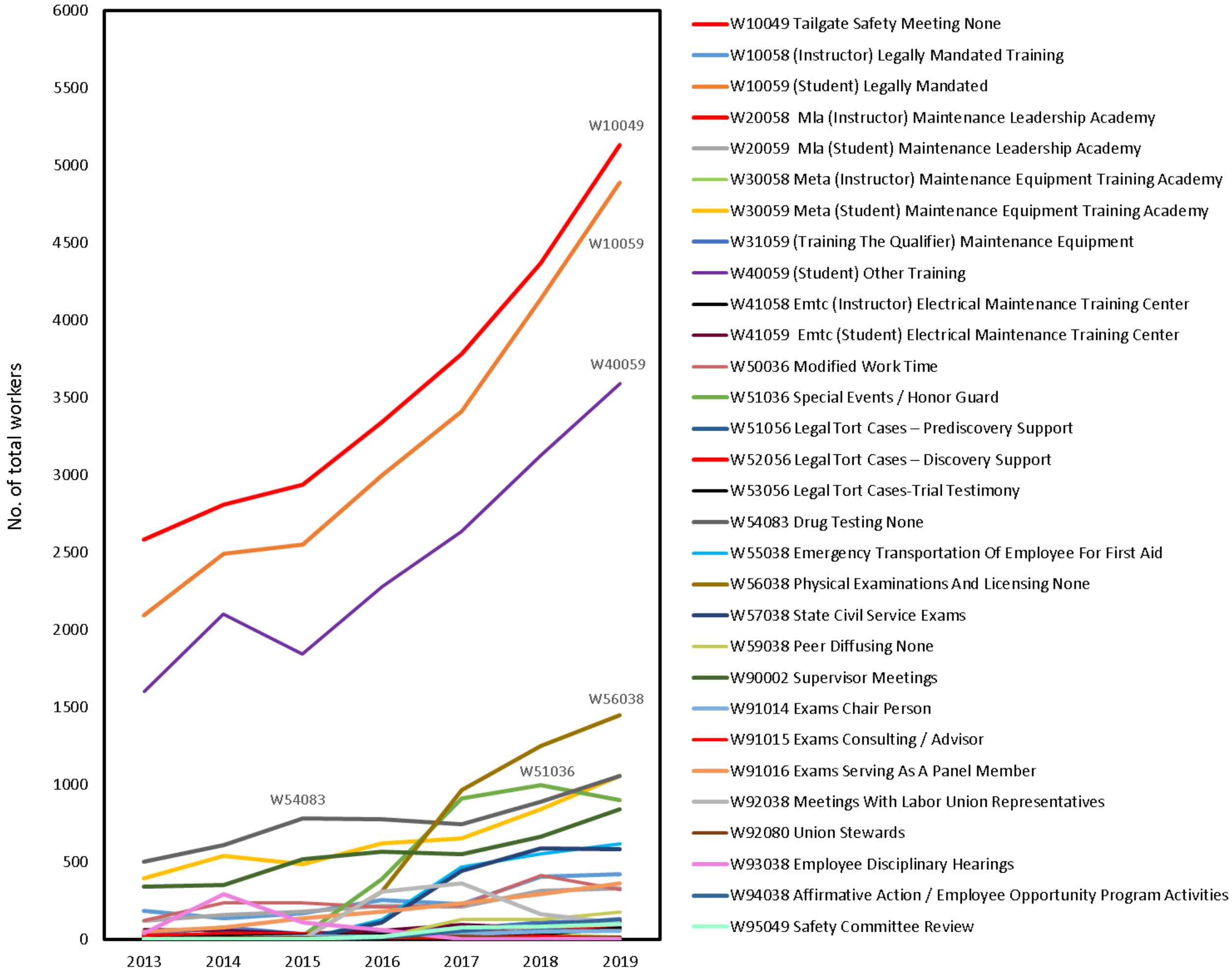

Figure B.21: W - Training and field auxiliary activities.

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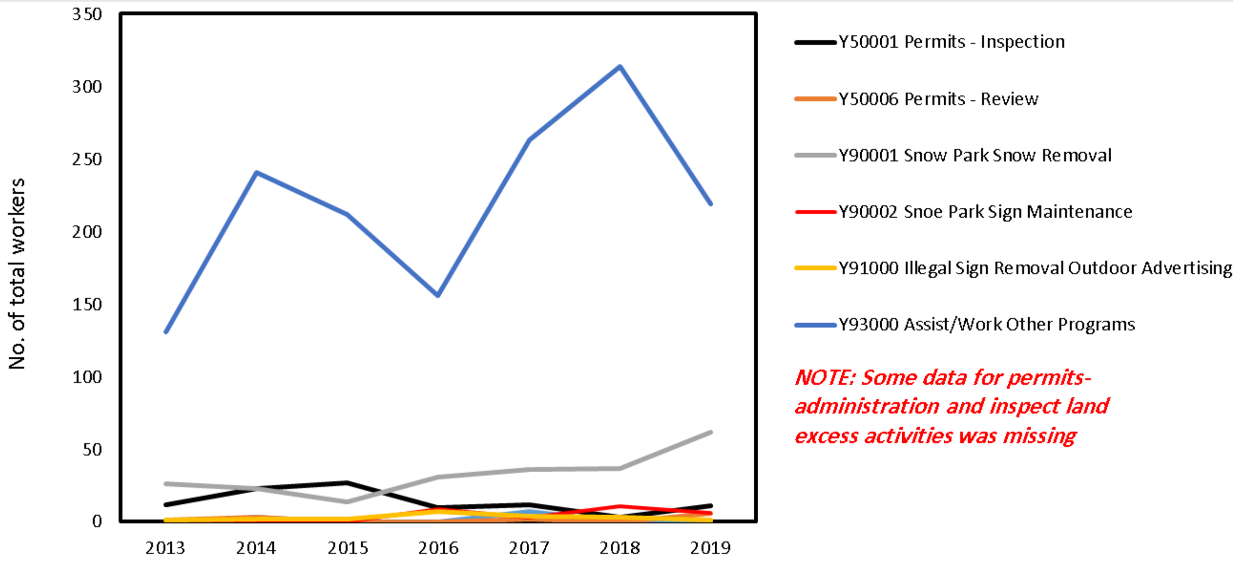

Figure B.22: Y - Work for others

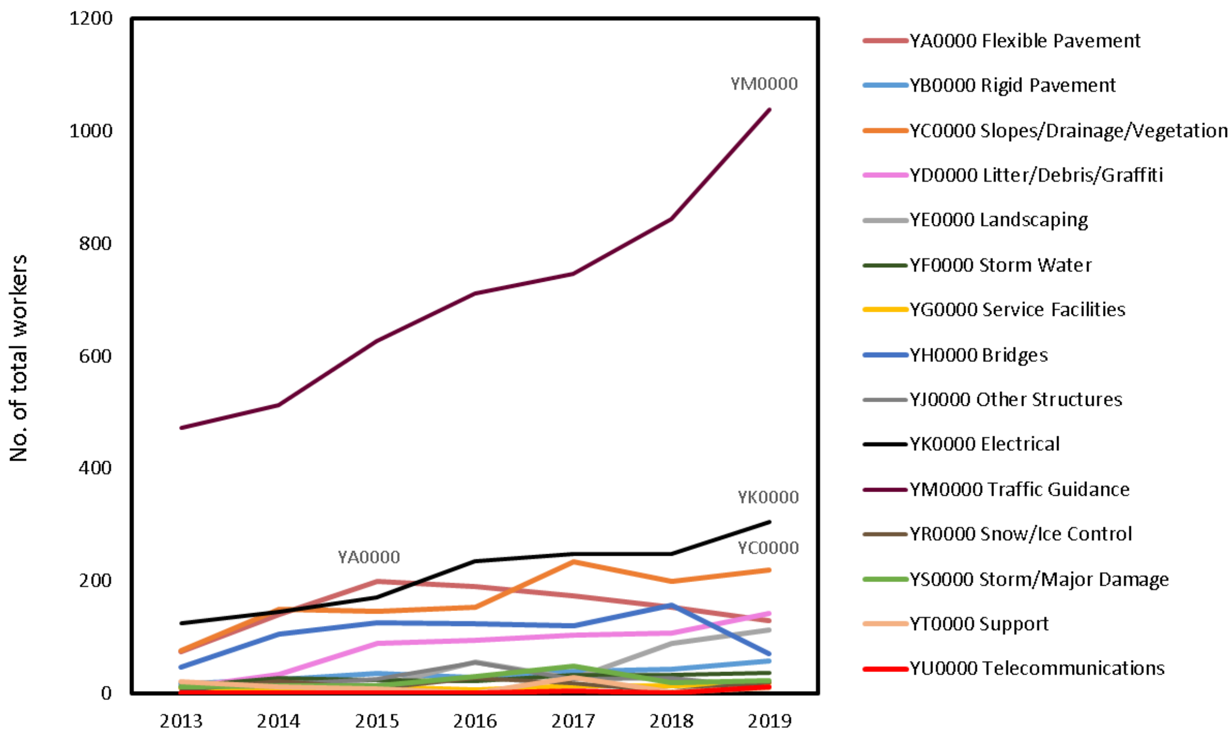

Figure B.23: Y - Maintenance activities for other departments

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APPENDIX C: PERFORMANCE MEASURES FOR ROADSIDE FEATURES QUESTIONNAIRE

Performance Measures for Roadside Maintenance Activities Questionnaire

In an effort to develop Performance Measures for Roadside Maintenance Activities, the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center is developing an analysis tool that can provide the needed data to aid in planning a Maintenance Activity. The following survey has been developed to collect input from Caltrans employees who have experience with the design, planning and/or execution of Caltrans maintenance operations.

This survey will ask for input on the following generalized activities:

- Guardrails, Barriers, and End Treatments
- Pavement Repair
- Landscaping and Irrigation
- Storm Water Mechanisms
- Signs and Poles
- Sweeping, Cleaning, and Litter pick-up
- Fencing and Electrical

Your experience and expertise are extremely valuable. Your time and effort are truly appreciated. We thank you in advance for your cooperation!

The PMRF Research Team at AHMCT

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A: General Characterizations of a Site on a Highway during Maintenance Activities

A1- Level of Difficulty

1- In your experience, does the number of people in a crew affect the level of difficulty to complete a typical maintenance task performed by your group? (Mark yes or no)

____ Yes ____ No

If yes, please indicate the level of importance:

Extremely important	Very important	Somewhat important	Not very important	Has no importance

2- We are considering the following components that can potentially indicate the difficulty of a maintenance activity. These are:

1. Duration of activity in terms of people-hours.
2. Lane closure requirements.
3. Mile-length of the maintenance activity.
4. Access to the work site.
5. LEMO (Labor, Equipment, Materials, and Other) cost – assuming that LEMO cost provides some indication of complexity and difficulty.

Please indicate how important these factors are when assessing difficulty:

Factor	Extremely important	Very important	Somewhat important	Not very important	Has no importance
Duration					
Lane closure					
Mile-length					
Access					
LEMO cost					

A2- Level of Risk

In order to develop a reliable model for Caltrans, we need your input to identify any missing factors that may correspond to "Risk of Injury" while working on roadside maintenance activities. The table below provides a list of factors, their description, and the associated data source, that we are currently considering.

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Data source abbreviations:

- Integrated Maintenance Management System (IMMS).
- Labor, Equipment, Materials, and Other (LEMO) costs obtained via IMMS.
- Statewide Integrated Traffic Records System (SWITRS).
- Lane Closure data via Performance Measurement System (PeMS).
- Traffic volume in terms of Annual Average Daily Traffic (AADT).

Risk Factor	Description	Data Source
Activity type	Activity codes	IMMS
Time of day	Peak hour, None-peak hour	SWITRS
Day of week	Mon., Tue., …	SWITRS
Duration of work	In person-hours	LEMO
Length of work	In mile	LEMO
Type of location	Freeway, Ramp, Intersection, …	SWITRS
Closure type	None, Moving, Lane, …	PeMS-Lane Closure
Closure length	In miles	PeMS-Lane Closure
Cozeep/Mazeep	Yes, No	PeMS-Lane Closure
Closure detour	Yes, No	PeMS-Lane Closure
Population	Less than 2500, 2500-10000, …	SWITRS
AADT	Average number of vehicles	PeMS-AADT
Truck AADT	Average number of vehicles	PeMS-AADT
Collision density	Average number of collisions	SWITRS
Lighting	Day, Dark, Dusk, …	SWITRS
Surface condition	Dry, Wet, …	SWITRS
Weather	Clear, Rainy, …	SWITRS
Control device	None, Functioning, …	SWITRS
Average speed	70, 60, 50, …	"Clean Road File"
Surface type	Concrete, Bridge deck, …	"Clean Road File"
Median type	Paved, Striped, Sawtooth, …	"Clean Road File"
Terrain	Flat, Rolling, …	"Clean Road File"
Roadway use	HOV, Bus lane, …	"Clean Road File"
Number of Lanes	1, 2, 3, 4, …	"Clean Road File"
Roadway division	Divided, Undivided, …	"Clean Road File"

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1- Do you see any factor that has NOT been listed that you feel plays a part in determining the Level of Risk in maintenance activities? Please list any missing Risk Factor and corresponding data source.

Comments:

B: Maintenance Operation Planning

Data provided in this section will be considered to see if a decision toolbox can be developed to assist Caltrans' decision maker in planning of maintenance operations based on injury risk and difficulty. The following sections have questions for each of the generalized maintenance activities that will be considered for the development of the decision toolbox.

B1- Barriers, Guardrails, and End Treatments

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When planning to repair or replace a Barrier, Guardrail, or an End Treatment, is the following information considered Needed, Useful, or Neither?

Information	Needed	Useful	Neither	Comment
Collision risk[1]				
Work order history[2]				
Collision history compared to other[3]				
Work order history compared to other[4]				

1- If "Needed" or "Useful", what Collision Risk information would you like to see:

- ◻ Collision attributes at the work site (head on, broad side, severity, number of fatalities, etc.).
- ◻ The risk level at the work site (5 highest, 1 lowest).
- ◻ Work zone collision history.
- ◻ Effect of a lane closure at the work site.
- ◻ Risk mitigation taken (cozeep/mazeep, extra signage, etc.).
- ◻ Other (please describe). ______________________________

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2- If "Needed" or "Useful", what Work Order History information would you like to see:

- ◻ Duration of the activity.
- ◻ Was there a lane closure?
- ◻ What were the LEMO costs?
- ◻ Other (please describe). ______________________________

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3- If "Needed" or "Useful", what Collision History Compared to Other information would you like to see:

- ◻ Compare work site location to other locations.
- ◻ Compare work site safety risk to other similar work sites.
- ◻ Local traffic volume at work site compared to other similar work site.
- ◻ Other (please describe). ____

____

4- If "Needed" or "Useful", what Work Order History Compared to Other information would you like to see:

- ◻ Retrievable similar work order parameters for other maintenance activities.
- ◻ Information about the maintenance activity for other work order parameters such as highway and postmile.
- ◻ Please include what other information related to work order history would you like see (If any). ____

____

B2- Pavement Repair

When planning to repair Pavement, is the following information considered Needed, Useful, or Neither?

Information	Needed	Useful	Neither	Comment
Collision risk[1]				
Work order history[2]				
Collision history compared to other[3]				
Work order history compared to other[4]				

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1- If “Needed” or “Useful”, what Collision Risk information would you like to see:

- □ Collision attributes at the work site (head on, broad side, severity, number of fatalities, etc.).
- □ The risk level at the work site (5 highest, 1 lowest).
- □ Work zone collision history.
- □ Effect of a lane closure at the work site.
- □ Risk mitigation taken (cozeep/mazeep, extra signage, etc.).
- □ Other (please describe). ____

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2- If “Needed” or “Useful”, what Work Order History information would you like to see:

- □ Duration of the activity.
- □ Was there a lane closure?
- □ What were the LEMO costs?
- □ Other (please describe). ____

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3- If “Needed” or “Useful”, what Collision History Compared to Other information would you like to see:

- □ Compare work site location to other locations.
- □ Compare work site safety risk to other similar work sites.
- □ Local traffic volume at work site compared to other similar work site.
- □ Other (please describe). ____

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4- If "Needed" or "Useful", what Work Order History Compared to Other information would you like to see:

- ☐ Retrievable similar work order parameters for other maintenance activities.
- ☐ Information about the maintenance activity for other work order parameters such as highway and postmile.
- ☐ Please include what other information related to work order history would you like see (If any).

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B3- Landscaping and Irrigation

When planning for Landscaping or Irrigation maintenance operations, is the following information considered Needed, Useful, or Neither?

Information	Needed	Useful	Neither	Comment
Collision risk[1]				
Work order history[2]				
Collision history compared to other[3]				
Work order history compared to other[4]				

1- If "Needed" or "Useful", what Collision Risk information would you like to see:

- ☐ Collision attributes at the work site (head on, broad side, severity, number of fatalities, etc.).
- ☐ The risk level at the work site (5 highest, 1 lowest).
- ☐ Work zone collision history.
- ☐ Effect of a lane closure at the work site.
- ☐ Risk mitigation taken (cozeep/mazeep, extra signage, etc.).
- ☐ Other (please describe). ____

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2- If "Needed" or "Useful", what Work Order History information would you like to see:

- □ Duration of the activity.
- □ Was there a lane closure?
- □ What were the LEMO costs?
- □ Other (please describe). ____

3- If "Needed" or "Useful", what Collision History Compared to Other information would you like to see:

- □ Compare work site location to other locations.
- □ Compare work site safety risk to other similar work sites.
- □ Local traffic volume at work site compared to other similar work site.
- □ Other (please describe). ____

4- If "Needed" or "Useful", what Work Order History Compared to Other information would you like to see:

- □ Retrievable similar work order parameters for other maintenance activities.
- □ Information about the maintenance activity for other work order parameters such as highway and postmile.
- □ Please include what other information related to work order history would you like see (If any).

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B4- Storm Water Mechanisms

When planning to repair or replace Storm Water Mechanisms, is the following information considered Needed, Useful, or Neither?

Information	Needed	Useful	Neither	Comment
Collision risk[1]				
Work order history[2]				
Collision history compared to other[3]				
Work order history compared to other[4]				

1- If "Needed" or "Useful", what Collision Risk information would you like to see:

□ Collision attributes at the work site (head on, broad side, severity, number of fatalities, etc.).

□ The risk level at the work site (5 highest, 1 lowest).

□ Work zone collision history.

□ Effect of a lane closure at the work site.

□ Risk mitigation taken (cozeep/mazeep, extra signage, etc.).

□ Other (please describe). ____

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2- If "Needed" or "Useful", what Work Order History information would you like to see:

□ Duration of the activity.

□ Was there a lane closure?

□ What were the LEMO costs?

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□ Other (please describe). ____

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3- If "Needed" or "Useful", what Collision History Compared to Other information would you like to see:

□ Compare work site location to other locations.

□ Compare work site safety risk to other similar work sites.

□ Local traffic volume at work site compared to other similar work site.

□ Other (please describe). ____

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4- If "Needed" or "Useful", what Work Order History Compared to Other information would you like to see:

□ Retrievable similar work order parameters for other maintenance activities.

□ Information about the maintenance activity for other work order parameters such as highway and postmile.

□ Please include what other information related to work order history would you like see (If any).

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B5- Signs and Poles

When planning to repair or replace Signs and Poles, is the following information considered Needed, Useful, or Neither?

Information	Needed	Useful	Neither	Comment
Collision risk[1]				
Work order history[2]				

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Collision history compared to other[3]				
Work order history compared to other[4]				

1- If "Needed" or "Useful", what Collision Risk information would you like to see:

- ◻ Collision attributes at the work site (head on, broad side, severity, number of fatalities, etc.).
- ◻ The risk level at the work site (5 highest, 1 lowest).
- ◻ Work zone collision history.
- ◻ Effect of a lane closure at the work site.
- ◻ Risk mitigation taken (cozeep/mazeep, extra signage, etc.).
- ◻ Other (please describe). ____

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2- If "Needed" or "Useful", what Work Order History information would you like to see:

- ◻ Duration of the activity.
- ◻ Was there a lane closure?
- ◻ What were the LEMO costs?
- ◻ Other (please describe). ____

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3- If "Needed" or "Useful", what Collision History Compared to Other information would you like to see:

- ◻ Compare work site location to other locations.
- ◻ Compare work site safety risk to other similar work sites.
- ◻ Local traffic volume at work site compared to other similar work site.
- ◻ Other (please describe). ____

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4- If "Needed" or "Useful", what Work Order History Compared to Other information would you like to see:

- □ Retrievable similar work order parameters for other maintenance activities.
- □ Information about the maintenance activity for other work order parameters such as highway and postmile.
- □ Please include what other information related to work order history would you like see (If any).

____

B6- Sweeping, Cleaning, and Litter Pick-Up

When planning for Sweeping, Cleaning, and Litter Pick-Up, is the following information considered Needed, Useful, or Neither?

Information	Needed	Useful	Neither	Comment
Collision risk[1]				
Work order history[2]				
Collision history compared to other[3]				
Work order history compared to other[4]				

1- If "Needed" or "Useful", what Collision Risk information would you like to see:

- □ Collision attributes at the work site (head on, broad side, severity, number of fatalities, etc.).
- □ The risk level at the work site (5 highest, 1 lowest).
- □ Work zone collision history.

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- □ Effect of a lane closure at the work site.
- □ Risk mitigation taken (cozeep/mazeep, extra signage, etc.).
- □ Other (please describe). ____

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2- If "Needed" or "Useful", what Work Order History information would you like to see:

- □ Duration of the activity.
- □ Was there a lane closure?
- □ What were the LEMO costs?
- □ Other (please describe). ____

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3- If "Needed" or "Useful", what Collision History Compared to Other information would you like to see:

- □ Compare work site location to other locations.
- □ Compare work site safety risk to other similar work sites.
- □ Local traffic volume at work site compared to other similar work site.
- □ Other (please describe). ____

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4- If "Needed" or "Useful", what Work Order History Compared to Other information would you like to see:

- □ Retrievable similar work order parameters for other maintenance activities.
- □ Information about the maintenance activity for other work order parameters such as highway and postmile.

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□ Please include what other information related to work order history would you like see (If any).

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B7- Fencing and Electrical

When planning for Fencing or Electrical maintenance operations, is the following information considered Needed, Useful, or Neither?

Information	Needed	Useful	Neither	Comment
Collision risk[1]				
Work order history[2]				
Collision history compared to other[3]				
Work order history compared to other[4]				

1- If "Needed" or "Useful", what Collision Risk information would you like to see:

□ Collision attributes at the work site (head on, broad side, severity, number of fatalities, etc.).

□ The risk level at the work site (5 highest, 1 lowest).

□ Work zone collision history.

□ Effect of a lane closure at the work site.

□ Risk mitigation taken (cozeep/mazeep, extra signage, etc.).

□ Other (please describe). _______________________________________

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2- If "Needed" or "Useful", what Work Order History information would you like to see:

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- □ Duration of the activity.
- □ Was there a lane closure?
- □ What were the LEMO costs?
- □ Other (please describe). ____

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3- If "Needed" or "Useful", what Collision History Compared to Other information would you like to see:

- □ Compare work site location to other locations.
- □ Compare work site safety risk to other similar work sites.
- □ Local traffic volume at work site compared to other similar work site.
- □ Other (please describe). ____

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4- If "Needed" or "Useful", what Work Order History Compared to Other information would you like to see:

- □ Retrievable similar work order parameters for other maintenance activities.
- □ Information about the maintenance activity for other work order parameters such as highway and postmile.
- □ Please include what other information related to work order history would you like see (If any). ____

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APPENDIX D: CLASSIFICATION OF MAINTENANCE ACTIVITIES WITH RESPECT TO DIFFICULTY

Error! Reference source not found. lists all activities with respect to their overall difficulty score as described by Equation 1: Index of difficulty. Higher difficulty scores correspond with more difficult roadside maintenance activities. Note that not all the IMMS activities are listed here since for some of them crew size data was not available.

Table D.1: Roadside maintenance activities by overall difficulty score

Activity	Description	Overall difficulty score
A30010	Dig out flex pavement	11.76758291
A50010	Seal (all other) flex pavement	10.70184479
M10010	Repair/replace striping	10.63860454
F20050	Drain cleaning	10.2101947
A20010	Overlay/leveling flex pavement	9.757010148
S31040	Rock scaling	9.591033229
M30010	Repair/replace pvmt. markers	9.153518021
F40050	Snow hauling (stormwater)	9.146972584
R10000	Snow removal	8.727143721
C95040	Test/sample manhole	8.574667441
A21010	Profile grinding flex pavement	8.425535308
B10110	Crack seal rigid pavement	8.407376691
A10110	Crack seal flex pavement	8.311323882
F40030	Erosion/sed control supp purchase	8.22245399
S40010	Major slide/slip remove/repair	8.187688761
F80002	Drainage contract	8.185839434
F40060	Install new controls	7.95378104
C11010	Lateral support - import matl.	7.776721221
F80003	Sampling and testing contract	7.736751453
R40000	Chain control	7.689041702
M20010	Repair/replace markings	7.579542783
B31010	Slab replacement rigid pavement	7.543851988
S33000	Blasting	7.45980243
C10010	Lateral support - native matl.	7.348039089
C50150	Clean ditch/channel	7.321065313

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S32050	Bench cleaning	7.310796443
F90103	Closure of existing site	7.13702339
C93050	Clean cattleguard	7.057258374
B21010	Overlay/leveling rigid pavement	7.030361417
S31010	Repair/replace rock fall protecting	7.027239637
S30110	Minor slide/slip remove/repair	7.006775089
F30301	Equipment wash systems	7.006618797
B20010	Profile grinding rigid pavement	6.935545564
YA0000	Work for others a family	6.919778508
C50010	Repair/replace ditch/channel	6.893153392
C32040	Brush control	6.885951367
D30050	Sweep hwy/shoulder	6.864360264
C51050	Clean curb/dike	6.835637244
K20120	Night inspection sign lighting	6.799226726
F40310	Repair/replace existing controls	6.752258363
R30110	Repair/replace fixed hardware	6.715003604
F80001	Oversight of construct contract	6.701179372
B30010	Sub seal/jack slab rigid pavement	6.675758621
M50010	Repair/replace delineators	6.644299364
C30040	Tree trimming	6.569375273
C20040	Mechanical control roadside	6.564563038
C60050	Clean drainage	6.50780991
R20000	Cover snow & ice on pavement	6.423944534
E14040	All other control landscape	6.357529026
C31040	Remove tree	6.356303373
YB0000	Work for others b family	6.32286525
S20000	Storm patrol	6.311023214
S10000	Sand/rock patrol	6.29368326
R50000	Support personnel - ice/snow	6.290665896
C60220	Drainage inspection	6.257016094
YD0000	Work for others d family	6.22428878
M91000	Physical hwy inventory update	6.202233967
E22040	Pruning - linear mechanical	6.177305698
C51010	Repair/replace curb/dike	6.161408408
C24040	All other weed control rdsd.	6.161006195
C30020	Tree inspection	6.107085602
F20005	Drain stenciling	6.071562164
R11000	Snow hauling	6.045163321
U61040	Repeater - maintenance	5.914689284
YS0000	Work for others s family	5.907950808
R91000	Avalanche control	5.893515434

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C22040	Manual control roadside	5.847558973
YF0000	Work for others f family	5.82208803
F90050	Transfer of site material	5.715772577
M40120	Night inspections signs	5.693277707
R21000	Sand/salt material handling	5.689800893
F10007	Employee specialized/training	5.682241833
C60010	Repair/replace drainage	5.66192328
D40050	Litter control	5.638208048
F80004	Hauling and/or disposal cont.	5.615924044
YE0000	Work for others e family	5.593911126
C21040	Chemical control roadside	5.578387874
R22000	Apply anti-icer	5.53341738
M10120	Night inspection striping	5.528169404
M20120	Night inspection markings	5.502513742
F40120	SWMP slope inspect/documentation	5.496953226
D20020	Supervisor area inspection	5.495345927
U60040	Comm site - maintenance	5.467963574
A22010	D08 unpaved travelway repairs	5.454523897
E11040	Manual control landscape	5.409089382
Y50001	Inspection - permits	5.395616389
F70201	Treat/field BMPS support staff	5.363823925
C92010	Repair/replace sidewalk	5.360541675
E21040	Pruning groundcover	5.324430674
F20020	Drain inlet inspection	5.321864063
Y93000	Assist/work other programs	5.309331388
K10120	Night inspection hwy lighting	5.306000858
C92050	Clean sidewalk	5.299482533
D40150	Road patrol / debris pickup	5.276143633
F70050	Clean/mow structural bmp	5.249243427
M30120	Night inspection pavement markers	5.198095281
F90150	Disposal of site material	5.187761309
J60060	Scheduled lane change channelizers	5.185671042
B22010	Patch spalls rigid pavement	5.046607587
YC0000	Work for others c family	5.045107637
C93010	Repair/replace cattleguard	5.037769177
R90000	Misc. activities	4.999580592
D90000	Illegal sign removal	4.993968571
E10040	Mechanical control landscape	4.9888824
F90101	New waste &/or work stock site	4.985393058
M50120	Night inspection delineators	4.976586577
M41000	Install/remove graffiti dtrnt. sgn. strc.	4.891426008

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K70010	Repair/replace TOS equipment	4.889813187
U80010	Fixed satcom - repair/replace	4.877154597
M41010	Repair/replace sign structures	4.828168318
D41001	Adopt-a-hwy administration	4.824436633
C23040	Rodent control roadside	4.824334958
A40010	Patch pot-holes flex pavement	4.822260852
Y91000	Illegal sign remove outdoor ad	4.81191037
J10140	Maintenance pumping plant	4.801990243
F70103	Maintenance site BMPS	4.703745086
E24040	Maintain plantings	4.66340744
YM0000	Work for others m family	4.658731716
F90105	Site fees	4.655098749
YJ0000	Work for others j family	4.621170145
C91010	Repair/replace bike path	4.608229347
K20000	Inventory update sign lighting	4.596221651
C96010	Repair/replace water site	4.580615269
F30220	Construction compliance inspect	4.536144971
E33040	Irrigating landscape	4.532917018
U60010	Comm site - repair/replace	4.486717608
F30120	Maint. Activity inspections	4.480854813
C91050	Clean bike path	4.447391632
K10000	Inventory update hwy lighting	4.418231965
E25040	Fertilizing landscape	4.408011516
F60050	Cleanup of illegal discharge	4.386286612
K20140	Group relamp sign lighting	4.367093465
F70020	Treatment bmp inspection	4.332960353
E23040	Replant groundcover landscape	4.332039809
E13040	Rodent control landscape	4.288003246
C90010	Repair/replace wall	4.271678946
M60010	Repair/replace guardrail	4.257331695
D60050	Graffiti removal all assets	4.247123943
K70000	Inventory update TOS equipment	4.222764713
YK0000	Work for others k family	4.213278438
K80000	Inventory update traffic counter	4.206110948
F30005	Maint. Site corrective measure	4.199888204
K60000	Inventory update ramp meters	4.160715207
F70101	Field activities BMPS	4.141091719
F80006	Calif conserve corps contract	4.134268203
E30010	Irrigation system repair landscape	4.105106793
M90000	Emergency traffic control	4.098729896
U61010	Repeater - repair/replace	4.048727429

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K40000	Inventory update traffic signal	4.034889169
M80010	Repair/replace attenuator	4.005943347
S21000	Flood control	3.962865659
M61010	Repair/replace end treatment gr	3.948283199
F70110	Repair of treatment BMP	3.9469277
E34040	Truck watering landscape	3.922228798
Y50005	Administration - permits	3.9132102
C94010	Repair/replace drywell	3.875747058
K50000	Inventory update flashing beacon	3.867176365
U81040	Mobile satcom - maintenance	3.840777542
YU0000	Work for others u family	3.83561513
E32020	Backflow preventer cert landscape	3.769641517
D41000	Adopt-a-hwy safety orientation	3.739720154
M40010	Repair/replace signs	3.725586166
J60010	Repair/replace channelizers	3.674033538
D10150	Carcass pickup	3.662416438
F70003	Treatment bmp database	3.615017545
D42050	Illegal encampment debris removal	3.590749946
E12040	Chemical control landscape	3.545874282
K10011	3rd party damage hwy lighting	3.535973347
F70030	Bmp support purchases	3.508196389
K10010	Repair/replace highway lighting	3.47974238
Y50101	Inspect/admin excess lands	3.474996489
K20010	Repair/replace sign lighting	3.45931067
E31010	Irregular electrical repair landscape	3.425134804
G30010	Facility repair inspect/weigh	3.402165859
F90220	Sites inventory	3.392227787
Y50006	Review - permits	3.351829878
M40000	Sign fabrication	3.348222056
C95050	Clean manhole	3.346531342
C95010	Repair/replace manhole	3.331771127
F60150	Remove illegal connection	3.330969041
C40010	Repair/replace fence	3.324225277
D50050	Spills rwy, lane, shldr & appurt.	3.302843334
F80007	Task order contract	3.273242126
U81060	Mobile satcom - operations	3.264335616
J10020	Pm check pumping plant	3.258331633
M70010	Repair/replace barrier	3.23747509
J50060	Tow truck operations	3.187331619
YR0000	Work for others r family	3.145200087
C96050	Clean radiator water site	3.100753067

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W50036	Modified work time	2.958533733
F10003	Bmp tailgate meetings	2.748536055
F30020	Maint. site SW inspections	2.696895593
G31040	Grounds maintenance inspect station	2.669896875
C94040	Test/sample drywell	2.616181062
J60040	Maintenance channelizers	2.543533277
YG0000	Work for others g family	2.481601416
F60020	IC/ID invest/field reports	2.431096042
U80040	Fixed satcom - maintenance	1.269153145
U81010	Mobile satcom - repair/replace	1.135519813
F30201	Water treatment plant	0.552770778

Table D.2 lists all activities with respect to their overall difficulty score without considering crew size.

Table D.2: Roadside maintenance activities by overall difficulty score without considering the effects of crew size.

Activity	Description	Overall difficulty score w/o considering the effects of crew size
A30010	Dig out flex pavement	11.76627849
A50010	Seal (all other) flex pavement	10.69994046
M10010	Repair/replace striping	10.63836264
F20050	Drain cleaning	10.20946961
A20010	Overlay/leveling flex pavement	9.755571568
S31040	Rock scaling	9.588414525
M30010	Repair/replace pvmt. markers	9.152850932
F40050	Snow hauling (stormwater)	9.140229589
R10000	Snow removal	8.726241398
C95040	Test/sample manhole	8.573832396
A21010	Profile grinding flex pavement	8.423111996
B10110	Crack seal rigid pavement	8.405216573
A10110	Crack seal flex pavement	8.310095875
F40030	Erosion/sed cntrl. supp purchase	8.219103622
F80002	Drainage contract	8.184753877
S40010	Major slide/slip remove/repair	8.184583479
F40060	Install new controls	7.9511601
F40210	Snow hauling (stormwater)	7.855981839
C11010	Lateral support - import matl.	7.77553504
F80003	Sampling and testing contract	7.731880351
R40000	Chain control	7.687319237

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Activity	Description	Overall difficulty score w/o considering the effects of crew size
M20010	Repair/replace markings	7.579274771
B31010	Slab replacement rigid pavement	7.541765061
S33000	Blasting	7.457837159
C10010	Lateral support - native matl	7.347331179
C50150	Clean ditch/channel	7.319923836
S32050	Bench cleaning	7.308504508
H74040	Other paint activities	7.303874572
F90103	Closure of existing site	7.130203851
C93050	Clean cattleguard	7.056949247
B21010	Overlay/leveling rigid pavement	7.027461866
S31010	Repr/replace rock fall protection	7.023473412
S30110	Minor slide/slip remove/repair	7.005846482
F40020	Install soil stab/sediment/rsp	6.996066002
B20010	Profile grinding rigid pavement	6.931401262
YA0000	Work for others a family	6.918015263
F20051	Sweep hwy/shoulder	6.908449385
F30301	Equipment wash systems	6.904130847
C50010	Repair/replace ditch/channel	6.890818219
C32040	Brush control	6.884956443
D30050	Sweep hwy/shoulder	6.864023155
C51050	Clean curb/dike	6.832732898
K20120	Night inspection sign lighting	6.799090762
F40310	Repair/replace existing cntrls	6.749782318
R30110	Repair/replace fixed hardware	6.713881464
F80001	Oversight of construct contract	6.697390739
B30010	Sub seal/jack slab rigid pvmnt	6.67344545
M50010	Repair/replace delineators	6.643563682
C30040	Tree trimming	6.568877409
C20040	Mechanical control roadside	6.56399327
C60050	Clean drainage	6.506954892
C60120	Culvert inspection program	6.481382757
R20000	Cover snow & ice on pavement	6.423086236
F40010	Repair/replace soil/sedmnt/rsp	6.376832891
E14040	All other control landscape	6.356373173
C31040	Remove tree	6.35572449
YB0000	Work for others b family	6.320173326
S20000	Storm patrol	6.310455139
S10000	Sand/rock patrol	6.293171575
R50000	Support personnel - ice/snow	6.288641142

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Activity	Description	Overall difficulty score w/o considering the effects of crew size
C60220	Drainage inspection	6.25564228
YD0000	Work for others d family	6.222823036
M91000	Physical hwy inventory update	6.201366917
E22040	Pruning - linear mechanical	6.176034886
C24040	All other weed control rdsd	6.158978009
C51010	Repair/replace curb/dike	6.158942309
Y20001	Work for communications	6.136483531
C30020	Tree inspection	6.106946153
F20005	Drain stenciling	6.070318002
F50005	Veg mgmt & chem usage plans	6.05086708
R11000	Snow hauling	6.040536187
H10020	Inspection - h family	6.022093623
U61040	Repeater - maintenance	5.908843963
YS0000	Work for others s family	5.9066445
R91000	Avalanche control	5.893043813
F50006	Npdes permit related activity	5.874744816
C22040	Manual control roadside	5.846938636
F40001	Inspect soil stab/sediment/rsp	5.824177196
YF0000	Work for others f family	5.820250931
F70010	Repair/replace structural bmp	5.740729935
F90050	Transfer of site material	5.712458197
M40120	Night inspections signs	5.692853475
R21000	Sand/salt material handling	5.683652484
C60010	Repair/replace drainage	5.660033918
F10007	Employee specialized/training	5.647925428
D40050	Litter control	5.637963411
F80004	Hauling and/or disposal cont.	5.612683616
YE0000	Work for others e family	5.592019494
C21040	Chemical control roadside	5.578204269
F40130	Disposal of surplus stockpiles	5.569673999
R22000	Apply anti-icer	5.532595638
M10120	Night inspection striping	5.527826383
M20120	Night inspection markings	5.502156395
F40120	Swmp slope inspect/documentation	5.495500972
D20020	Supervisor area inspection	5.495245321
F20001	Inspection drain inlet	5.490991022
U60040	Comm site - maintenance	5.465365655
A22010	D08 unpaved travelway repairs	5.451883347

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Activity	Description	Overall difficulty score w/o considering the effects of crew size
F80201	Oversight drain clean contract	5.437827477
E11040	Manual control landscape	5.408907607
Y50001	Inspection - permits	5.394928707
F70201	Treat/field bmps support staff	5.361670387
C92010	Repair/replace sidewalk	5.358710799
E21040	Pruning groundcover	5.322992483
F20020	Drain inlet inspection	5.320638742
Y93000	Assist/work other programs	5.308137134
K10120	Night inspection hwy lighting	5.305953492
C92050	Clean sidewalk	5.297420781
D40150	Road patrol / debris pickup	5.275736876
F70050	Clean/mow structural bmp	5.239642618
F30010	Repair/replc corrective measure	5.237585587
D10050	Debris/carcass pick-up	5.202136264
M30120	Night inspection pvmnt markers	5.197650007
F90150	Disposal of site material	5.18519194
J60060	Scheduled lane change chnlzers	5.184939343
B22010	Patch spalls rigid pavement	5.045663174
YC0000	Work for others c family	5.044036343
C93010	Repair/replace cattleguard	5.035789311
R90000	Misc activities	4.997973859
D90000	Illegal sign removal	4.993537243
F30003	Ovrsight/inspct field activity	4.991545217
E10040	Mechanical control landscape	4.988005189
F90101	New waste &/or work stock site	4.981735985
M50120	Night inspection delineators	4.975967084
M41000	Instl/rmv grfti dtrnt sgn strc	4.890375469
K70010	Repair/replace tos equipment	4.889403136
F50003	Eval/develop de-icing criteria	4.86529955
M41010	Repair/replace sign structures	4.826684868
D41001	Adopt-a-hwy administration	4.823528472
C23040	Rodent control roadside	4.822740781
A40010	Patch potholes flex pavement	4.821816741
J10140	Maintenance pumping plant	4.800175584
F70103	Maintenance site bmps	4.694991597
E24040	Maintain plantings	4.663017556
YM0000	Work for others m family	4.658188343
F80301	Oversight sample/test contract	4.652364854
YJ0000	Work for others j family	4.615116062

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Activity	Description	Overall difficulty score w/o considering the effects of crew size
C91010	Repair/replace bike path	4.604809636
K20000	Inventory update sign lighting	4.595622671
C96010	Repair/replace water site	4.579097002
F10004	General meetings (mgmt/supprt)	4.576472424
E33040	Irrigating landscape	4.53246814
F30220	Construction compliance inspec	4.53078676
F50007	Field activity/facility bmps	4.518764344
F40110	Perimeter control stockpiles	4.499678157
U60010	Comm site - repair/replace	4.483721881
K10140	Group relamp hwy lighting	4.480378006
F30120	Maint. Activity inspections	4.480015968
C91050	Clean bike path	4.446107432
K10000	Inventory update hwy lighting	4.418003596
E25040	Fertilizing landscape	4.406538494
F60050	Clean-up of illegal discharge	4.38468759
K20140	Group relamp. sign lighting	4.357142503
F70020	Treatment bmp inspection	4.330065885
E23040	Replant groundcover landscape	4.329422866
E13040	Rodent control landscape	4.287678506
C90010	Repair/replace wall	4.270214726
M60010	Repair/replace guardrail	4.257054989
D60050	Graffiti removal all assets	4.246904811
K70000	Inventory update TOS equipment	4.22229247
YK0000	Work for others k family	4.21289573
K80000	Inventory update trffc. counter	4.204801242
F30005	Maint. Site corrective measure	4.176725075
K60000	Inventory update ramp meters	4.160144325
F70001	Inspect structural bmp	4.144373878
F70101	Field activities BMPS	4.140862647
F80006	Calif. conserve corps contract	4.132712518
E30010	Irrigation system repair lndsc.	4.104925696
M90000	Emergency traffic control	4.098230392
U61010	Repeater - repair/replace	4.046639814
K40000	Inventory update traffic sgnl.	4.034412091
M80010	Repair/replace attenuator	4.005067026
S21000	Flood control	3.961514637
M61010	Repair/replace end treatment GR	3.94789009
F70110	Repair of treatment BMP	3.943393937
E34040	Truck watering landscape	3.921593414

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Activity	Description	Overall difficulty score w/o considering the effects of crew size
K50000	Inventory update flashn. beacon	3.866014563
U81040	Mobile satcom - maintenance	3.839888038
YU0000	Work for others u family	3.831161553
E32020	Backflow preventer cert lndscp.	3.769428154
D41000	Adopt-a-HWY safety orientation	3.736647185
M40010	Repair/replace signs	3.725497706
J60010	Repair/replace channelizers	3.672980004
D10150	Carcass pickup	3.661525357
F70003	Treatment bmp database	3.613190884
D42050	Illegal encampment debris rmvl.	3.59040218
E12040	Chemical control landscape	3.54574449
K10011	3rd party damage HWY lighting	3.534975446
F70030	Bmp support purchases	3.501182002
K10010	Repair/replace highway lighting	3.479568491
K20010	Repair/replace sign lighting	3.457648268
E31010	Irrig. electrical repair lndscp.	3.424552412
G30010	Facility repair inspct/weigh	3.391738226
F90220	Sites inventory	3.380975546
Y50006	Review - permits	3.350733879
M40000	Sign fabrication	3.346452521
C95050	Clean manhole	3.345000425
C95010	Repair/replace manhole	3.329958899
C40010	Repair/replace fence	3.324000479
F60150	Remove illegal connection	3.323175279
D50050	Spills rdwy, lane, shldr. & appurt.	3.301839953
F80007	Task order contract	3.271171908
U81060	Mobile satcom - operations	3.263941466
J10020	Pm check pumping plant	3.256578955
M70010	Repair/replace barrier	3.237070412
YR0000	Work for others r family	3.142128312
J50060	Tow truck operations	3.10800227
C96050	Clean radiator water site	3.099848433
W50036	Modified work time	2.929896575
F30001	Facility inspection stormwater	2.83767211
F40101	Inspect/monitor stockpiles	2.82457184
F30020	Maint. site SW inspections	2.694069078
G31040	Grounds maint. inspect station	2.667182977
F10003	Bmp tailgate meetings	2.547541347
J60040	Maintenance channelizers	2.542063125

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Activity	Description	Overall difficulty score w/o considering the effects of crew size
F60002	IC/ID investigation & report	2.461089626
F60020	IC/ID invest/field reports	2.429470759
U80040	Fixed satcom - maintenance	1.268814286
U81010	Mobile satcom - repair/replace	1.134963114

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