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Evaluate High Potential Areas for Overweight Trucks and Truck Accidents in California

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Authors

Huang, Jihua
Chan, Ching-Yao
Jang, Kitae

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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Evaluate High Potential Areas for Overweight Trucks and Truck Accidents in California

Jihua Huang, Ching-Yao Chan, and Kitae Jang

California PATH Research Report

UCB-ITS-PRR-2013-1

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May 2013

CALIFORNIA PARTNERS FOR ADVANCED TRANSPORTATION TECHNOLOGY

Evaluate High-Potential Areas for Overweight Trucks and Truck Accidents in California

Final Report

Jihua Huang, Ching-Yao Chan, and Kitae Jang[1]

UCB-ITS-PRR-2013-1

California Partners for Advanced Transportation Technology Program (PATH)
University of California at Berkeley

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[1] Currently a Professor with the Korea Advanced Institute of Science and Technology (KAIST), previously a Ph.D. student at UC Berkeley

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Executive Summary

To increase operational efficiency, reduce congestion, and meet federal requirements concerning truck size and weight limits, the California Department of Transportation (Caltrans) is exploring new plans and feasible projects designed to increase enforcement and reduce pavement damage due to overweight trucks. Installation of Weigh-in-motion (WIM) systems or Virtual Weigh Station (VWS) by Caltrans will provide information to the California Highway Patrol (CHP) that they can use to better enforce commercial vehicle laws in those areas. To support the effective deployment of WIM/VWIM facilities in California, this project is initiated to answer one basic question: where future WIM/VWS should be located to maximize their effectiveness in commercial truck weight enforcement.

To address the above concerns, this project aimed to pursue two issues. First, it evaluated high-risk areas for incidents of overweight trucks and truck-related crashes so as to identify locations most in need of better enforcement. These areas serve as candidate areas for Caltrans and CHP to determine which areas are most problematic, and to enhance enforcement activities. These locations may also be considered as candidate sites to be equipped with WIM systems and/or VWS or other types of enhanced enforcement. Second, since overweight trucks tend to bypass the facilities through alternative routes, this project developed techniques to identify possible bypass routes. These techniques can be applied to evaluating enforcement strategies for those problematic or high-risk areas.

Accordingly, the following six tasks were conducted in this project to provide a strategy for future WIM/VWS deployment:

1. The high-risk areas were identified by evaluating truck-related crashes,
2. The identified high-risk areas were then investigated to understand their attributes to help predict potential hazardous areas,
3. Areas that have high truck traffic volumes but little law enforcement, were identified based on truck traffic data and existing facility coverage. These areas, together with the high-risk areas, are the areas most in need of future WIM/VWS deployment.
4. Bypass route identification algorithms were developed to identify the alternative routes for bypassing Commercial Vehicle Enforcement Facilities (CVEFs).
5. Case studies were conducted to refine and verify the bypass route identification algorithms.
6. The deployment strategy for future WIM/VWS was developed based on the identified areas and the bypass route identification.

For Tasks 1-2, to identify the high-risk areas for truck-involved crashes, we analyzed three years (2006 through 2008) of crash data from Traffic Accidents Surveillance and Analysis System (TASAS). Our analysis used an approach as follows: 1) we partitioned the (continuous) state routes into 1-mile segments; 2) we counted the number of truck crashes within each segment; 3) the numbers of truck crashes were then color-coded and projected onto the geographical map. To understand the common attributes of the Truck Crash Concentration Locations (TCCLs), we evaluated the patterns of distribution and location shifts, as well as the relationship between overweight trucks and TCCLs. Our evaluation shows that (1) TCCLs are correlated with high truck traffic volumes and (2) TCCLs are often within the segments where merging/diverging truck movements are concentrated. Regarding the relationship between overweight trucks and TCCLs, we compared statistics of truck axle weights and total truck weights from WIM sites that are close to TCCLs with those from WIM sites that are far from TCCLs. Our analysis revealed that the WIM data does not indicate that larger numbers of overweight trucks cross WIM sites close to a TCCL or suggest that trucks at TCCLs are heavier.

For Task 3, areas with high truck traffic volumes but a low level of CVEF coverage are also in need of commercial truck weight enforcement. The truck traffic data from Caltrans Data Branch was examined to identify those areas with high truck traffic volumes. The locations of the CVEFs were then incorporated to map the existing CVEFs along state highways so as to evaluate existing CVEF coverage. Accordingly, all 242 state highways were categorized based on their truck traffic and CVEF coverage. Two-dimensional evaluation of truck traffic and CVEF coverage was conducted to reveal 15 high truck-traffic areas that lack CVEF coverage.

In Task 4, the bypass route identification algorithms were developed by formulating the identification of alternative routes as a route guidance problem, which selects a route between an origin to a destination based on certain criteria such as shortest distance, shortest travel time, and minimum number of traffic signals. Since the bypass routes are the alternative routes truck drivers use to bypass a weight station, the bypass route identification was then treated as a route guidance problem with an additional criterion that the optimum route should not include any road segment with a CVEF.

For Task 5, to verify the validity of the identified bypass routes, we selected three CVEF sites for case studies. The bypass route identification algorithms were applied to identify alternative routes for each selected CVEF. The identified routes were then verified through both a visual examination using Google Earth and a review by CHP officers. With the intention of further refining the algorithms, we conducted a focus group discussion with CHP officers and an interview with Caltrans Truck Service personnel to discuss factors that might influence the decisions of drivers of overweight trucks in selecting bypass routes. The discussions revealed that, other than freeway preferences and avoiding residential or narrow roads, there seem to be no consistent characteristics in truck drivers' passing behavior. Therefore, no new factors needed to be incorporated into the bypass route identification algorithms.

Based on the above results, in Task 6 we proposed a three-step strategy for future WIM/VWS deployment. First, the identified TCCLs and high truck-traffic areas that lack CVEF coverage serve as the candidate areas for future WIM/VWS deployment. Once an area has been chosen for consideration of WIM/VWS deployment, the second step is to identify/select candidate site locations in the area and apply the bypass route identification algorithm for each candidate location. The third step is to compare the effectiveness of the candidate locations based on the ease of their corresponding bypass routes. The candidate locations that result in longer bypass routes are the recommended locations from the perspective of mitigating bypassing behavior. This strategy provides a procedure for Caltrans to locate and deploy future WIM/VWS to maximize the enforcement effectiveness of a deployment site.

1 Introduction

There are a number of areas in California that have a high incidence of overweight trucks and accidents involving overweight trucks. It is likely that there are a significant number of additional areas that are at risk, but have not recently had a significant number of accidents associated with them. These areas need to be identified so Caltrans can determine which areas are most problematic and should be equipped with Weigh-in-motion (WIM) systems and/or Virtual Weigh Station (VWS).

Overweight trucks tend to bypass the existing Commercial Vehicle Enforcement Facilities (CVEFs) by using alternative routes. Identifying these locations and alternative routes would serve the following two purposes. First, it gives Caltrans the option to install WIM systems or VWS on those routes that are used by a significant number of overweight trucks. The information about these alternative routes can also be used by the California Highway Patrol (CHP) to better enforce commercial vehicle laws in those areas. Second, the bypass route identification would also provide a tool for evaluating the deployment of candidate WIM/VWS sites.

To support the effective deployment of WIM/VWIM facilities in California, this project aimed to identify locations most in need of future WIM/VWS and to develop techniques that identify possible bypass routes so as to locate future facilities, such that they cannot be easily bypassed. The overall goal was to provide a strategy for future WIM/VWS deployment.

1.1 Background

State roadway operating agencies and Metropolitan Planning Organizations (MPOs) are facing a broad array of challenges attributable to increasing truck traffic[2]. These include traffic congestion, transportation system deficiencies, safety, infrastructure deterioration, intermodal connections, environmental impacts, quality of life, economic development, and losses in productivity. The challenges that are most prevalent for state DOTs include congested urban highways, safety complications, and pavement deterioration.

Federal Highway Administration (FHWA) policy mandates that each state enforce vehicle size and weight laws to assure that violations are discouraged and that vehicles traversing the highway system do not exceed the legal limits. These size and weight limits are based upon design specifications and safety considerations, and enforcement shall be developed and maintained both to prevent premature deterioration of the highway pavement and structures, and provide a safe driving environment (23 CFR § 657.5).[3]

The increasing numbers of commercial motor vehicles traveling on the nation's roadways is the preeminent challenge faced by enforcement personnel[4]. At the same time, the enforcement workforce is not increasing to keep pace with the growing truck volumes; in many states, commercial vehicle enforcement personnel staffing levels are less than their full complement. This disparity between truck volumes and enforcement staffing – which is expected to widen – makes

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[2] NCHRP Synthesis 314, TRB, 2003.

[3] http://ops.fhwa.dot.gov/freight/sw/violation_report.htm

[4] http://www.ops.fhwa.dot.gov/publications/fhwahop09051/sec03.htm

it difficult for the involved agencies to ensure the safe, secure, and legal movement of commercial vehicles.[5]

In this environment, states require new ways to work "smart." States are looking for systems that:
- Automatically process large numbers of commercial vehicles while delaying only those that pose a safety risk or exceed weight regulations;
- Expand the enforcement net to reach roadways and areas not adequately covered by existing enforcement operations, while conserving enforcement resources; and
- Augment current enforcement processes to help mitigate the growth of unsafe commercial vehicle traffic.

1.1.1 Safety Concerns and Operation Needs in California

In the State of California, Caltrans is responsible to build and maintain CVEFs and CHP is responsible to operate them and enforce the laws and regulations governing movement of commercial vehicles on State Highways.

Most weigh station facilities were built between 1958 and 1968. Even the newest facilities were built prior to 1997. Most facilities are undersized and don't meet the current and/or future truck volumes on State Highways. There is significant backup and congestion in the vicinity of CVEFs. The existing facilities are in need of upgrades to increase operational efficiency, reduce congestion, and meet federal requirement concerning truck size and weight limits.

Construction of CVEF is generally cost prohibitive especially within metropolitan areas and have significant environmental impact. Caltrans needs to come up with new plans and feasible projects to increase enforcement and reduce pavement damage due overweight trucks.

1.1.2 Weigh-in-Motion (WIM) and Virtual Weigh Stations (VWS)

Weigh-In-Motion[6]

WIM scales measure approximate axle weights as a vehicle moves across sensors or scales and determine the gross vehicle weight and classification based on the axle weights and spacings. WIM systems have been used for commercial vehicle operations in the United States for many years. WIM is commonly deployed at weight enforcement facilities where static scales cannot handle truck traffic volumes. Traditionally, WIM has been used as a weight enforcement tool to sort trucks either on the approach ramp to a weigh station or on the mainline about a mile upstream of a weigh station. Mainline WIM uses variable message signs to call in trucks suspected of exceeding maximum allowable weight limits, which are directed to the static scale for compliance weighing.

Currently there are 106 data WIM collection sites in operation across California. Several of these sites are under construction, and further expansion of WIM systems are planned for the coming years.[7] All Caltrans WIM system sensors are either bending plates on frames embedded in concrete or piezo sensors epoxied into the pavement. Another alternative sensor is the load-cell.

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[5] http://www.ops.fhwa.dot.gov/publications/fhwahop09051/sec03.htm

[6] http://www.ops.fhwa.dot.gov/publications/fhwahop09050/sec02.htm

[7] http://www.dot.ca.gov/hq/traffops/trucks/datawim/index.html

Inductive loops are placed before and after the WIM sensor array. Loops measure vehicle speed and overall length. Caltrans WIM systems are configured to calculate GVW (gross vehicle weight), individual axle weights, weight violations, vehicle speed, overall length, axle spacing, and vehicle classification (such as passenger vehicle, bus, or truck-tractor/semitrailer).[8]

Virtual Weigh Stations[9]

A virtual weigh station is a roadside enforcement facility that does not require continuous staffing and is monitored from another location. Virtual weigh stations are established for a variety of purposes depending on the priorities and needs of each jurisdiction. Typical purposes include safety enforcement, data collection, security (e.g., homeland security, theft deterrence), and size and weight enforcement. These sites may use a variety of sensor components, such as a weigh-in-motion (WIM) installation, a camera system, and wireless communication, to collect data.

1.2 Project Goals and Approaches

The goal of this project was to develop a strategy for effectively deploying future WIM/VWS in California. The basic question that needed to be answered is where the future WIM/VWS should be located so as to maximize their effectiveness in commercial truck weight enforcement. This question involves two aspects: (1) where are the areas that are most in need of future WIM/VWS, and (2) where to locate the future WIM/VWS in those identified areas so as to minimize the possibility of overweight vehicles bypassing the facilities. As a result, our proposed approach aimed to purse these two main issues.

First, we identified areas that are most in need of future WIM/VWS. Such areas include locations that have a high concentration of truck-involved crashes, as well as locations that have high truck traffic volumes but currently lack commercial vehicle enforcement. With these areas identified, Caltrans can then determine which areas are most problematic and should be equipped with WIM systems and/or VWS.

Second, since overweight trucks tend to bypass the facilities through alternative routes, we developed bypass route identification algorithms to identify possible bypass routes. With the knowledge of the identified bypass routes, Caltrans may consider installing WIM/VWS on bypass routes that are used by a significant number of overweight trucks. CHP may also use the information of these alternative routes to better enforce commercial vehicle laws in those areas. Moreover, these bypass route identification algorithms could be applied to evaluate candidate WIM/VWS sites so that a site that results in longer bypass routes could be selected for WIM/VWS deployment.

Based on the proposed approach, the project then consisted of the following six tasks. The first task was to identify areas with a concentration of truck-involved crashes based on the crash data from the TASAS (Traffic Accident Surveillance and Analysis System) database. Instead of using the conventional regression analysis, we used an approach modified from the continuous risk

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[8] http://www.dot.ca.gov/hq/traffops/trucks/datawim/technical.htm

[9] http://www.fmcsa.dot.gov/facts-research/cvisn/expanded-CVISN.htm

profile method[10]: 1) we first partitioned the (continuous) state routes into 1-mile segments; 2) we then counted the number of truck crashes within each segment; 3) the number of truck crashes were color-coded and projected onto the geographical map. Based on this analysis, a truck crash density map for California was established and the high truck crash concentration locations (TCCLs) identified.

In the second task, the identified TCCLs were further evaluated to investigate their common attributes. These common attributes helped us understand what may contribute to the high risk areas and predict potentially hazardous areas. The analysis focused on (1) the patterns of distribution and recognizable location shifts over the years and (2) the relationship between TCCLs and overweight trucks.

The third task was to identify areas that have high truck traffic volume but lack commercial vehicle enforcement. In this task, truck traffic data from Caltrans Data Branch was analyzed to examine the distribution of truck traffic and to identify areas with high truck traffic volumes. Truck traffic along major corridors was also analyzed to evaluate traffic flow along the corridors. Also in this task, the CVEF location data was used to assess the coverage of the existing CVEFs. To facilitate the assessment, a mapping algorithm was developed to transfer the truck traffic count locations and the CVEF locations to a digital map of the California highway network.

In Task 4, bypass route identification algorithms were developed to identify the alternative routes for bypassing the existing CVEFs. The bypass route identification was formulated as an optimization problem that provides several paths between locations before and after a CVEF. In order to find the bypass routes, we chose a cost function that would be prohibitively large if a path were to go through the CVEF, and set up the optimization problem to minimize this cost function. As a result, the optimization yielded paths that would not go through the CVEF; that is, the resulting paths were the bypass routes. Route guidance techniques based on a labeled directed graph[11] were used to define the optimization problem and develop the bypass route identification algorithms.

In Task 5, three CVEF sites were selected for case studies to evaluate and compare the bypass route identification algorithms. The evaluation included manual examination of alternative routes around the CVEF sites based on the digital map and discussions with local CHP officers. To further refine the algorithms, we attempted to identify the factors that influence the decision of overweight trucks' operators in selecting bypass routes, so we could incorporate those factors into the bypass route identification algorithms. Therefore, in this task a focus group discussion with CHP officers was held and an interview with Caltrans Truck Service personnel was conducted to help identify those factors. The refined algorithms were then used in Task 6 to develop strategies for WIM/VWS deployment.

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[10] Truck crashes are rare events when compared to passenger vehicle crashes, and they have a tendency to be clustered (spatial autocorrelation). Such characteristics do not bode well with the assumptions underlying conventional regression analysis that is often used to model traffic crashes. The continuous risk profile method, however, does not require any assumption on crash occurring processes. Since truck crashes are too rare to use the continuous risk profile method directly, we made further modifications to the continuous risk profile method.

[11] Herbert, W. and Mili, F., *Route Guidance: State of the Art vs. State of the Practice*, Intelligent Vehicles Symposium, 2008 IEEE, Page(s): 1167 – 1174.

In the final task, the deployment strategies were developed to determine the optimum sites for deploying new WIM/VMS sites at areas with high safety risks or high truck traffic volume. The deployment strategies were built upon the bypass route identification algorithms developed in Task 4 and refined/verified in Task 5. The deployment strategies further included identifying highways in the area of interest, determining candidate sites for WIM/VMS deployment, evaluating each candidate site by applying the bypass route identification algorithms to find the corresponding bypass routes for each candidate site, and selecting the best site based on the evaluation. A candidate site that resulted in the highest cost function (and fewest bypass routes) was then selected as the optimum site for WIM/VWS deployment.

1.3 Report Organization

The remainder of the report is organized as follows: Section 2 describes the identification of truck-involved crash concentration locations; Section 3 presents the investigation of the common attributes of the identified TCCLs; Section 4 details the identification of areas with high truck traffic volumes but a low level of CVEF coverage; Section 5 presents the bypass route identification algorithms; Section 6 describes the case studies with an evaluation of the bypass route identification algorithms; Section 7 presents the proposed WIM/VWS deployment strategies; and Section 8 summarizes this report.

2 Identification of Truck-involved Crash Concentration Locations

To identify areas with a concentration of truck-involved crashes, we analyzed the historical truck crash data from the TASAS (Traffic Accident Surveillance and Analysis System) database[12]. This section first presents the general statistics of the truck-involved crashes over a three-year period (2006 through 2008), then describes, in detail, the truck-involved crash concentration locations (TCCL).

2.1 Truck-involved Crash Data

In this analysis, we extracted three years (2006 through 2008) of crash data from TASAS. We used data from this three-year period because the database was only updated to the end of 2008, when we acquired the data to conduct the study. We used three years of data to provide sufficient representation and ensure data stability. Since the TASAS data involve not only trucks but also other vehicles, such as passenger cars, we further queried crashes involving trucks for this study. The query results included a total of 47,288 truck-involved crashes (105,599 parties were involved in these crashes), accounting for 647 fatalities and 16,938 injuries.

Figure 2.1 shows the number of truck-involved crashes during this 36-month period. The blue bars represent the number of crashes per month (starting January, 2006) and the black curved line is the second-order best-fit line. As shown in Figure 2.1, the number of truck-involved crashes in California decreased during this 36-month period in a noticeable trend. This trend is consistent with the trend in total number of crashes in the same period.

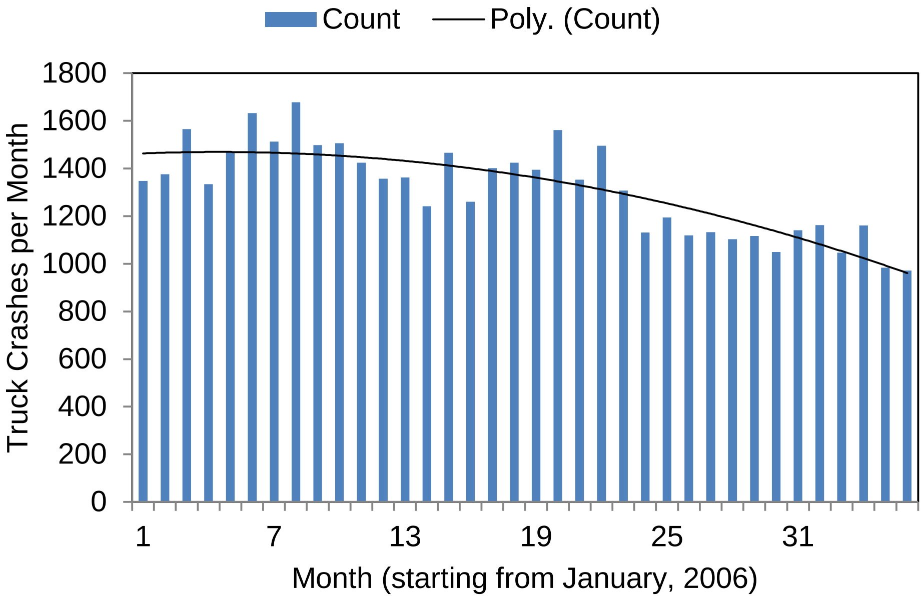

Figure 2.1 Number of truck-involved crashes in 36-month period (2006 – 2008)

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[12] TASAS is a computerized traffic crash database maintained by the California Department of Transportation (Caltrans).

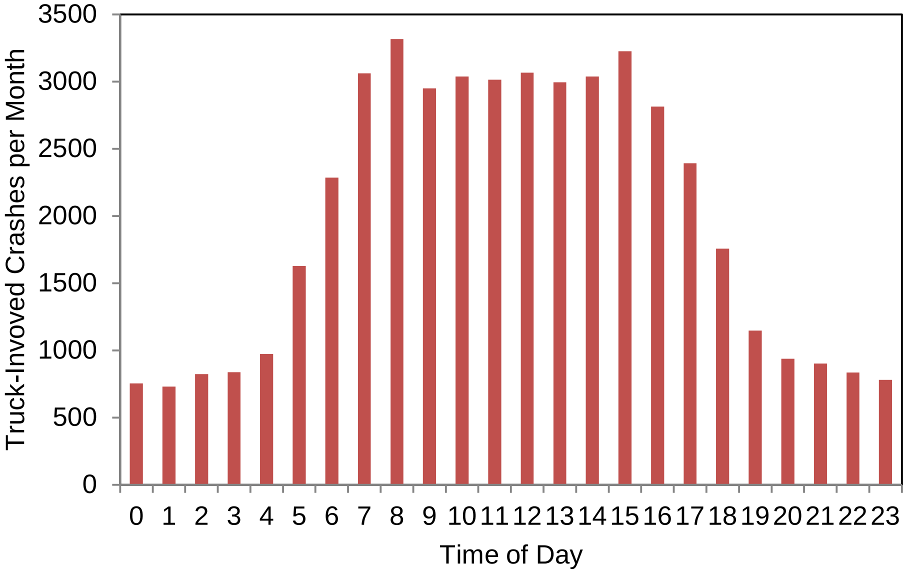

Figure 2.2 Time of day when truck-involved crashes occurred during data period (2006 to 2008)

Figure 2.2 shows the time truck-involved crashes occurred during the day. It shows that the majority of truck-involved crashes occurred during the day and higher numbers of crashes were observed during rush hours.

Figure 2.3 shows the distribution of the primary crash factors of truck-involved crashes. Unlike general traffic crashes, where speeding is the dominant primary crash factors, these truck-involved crashes had other violations as the leading cause. These contributed to more than 40 percent of truck-involved crashes.

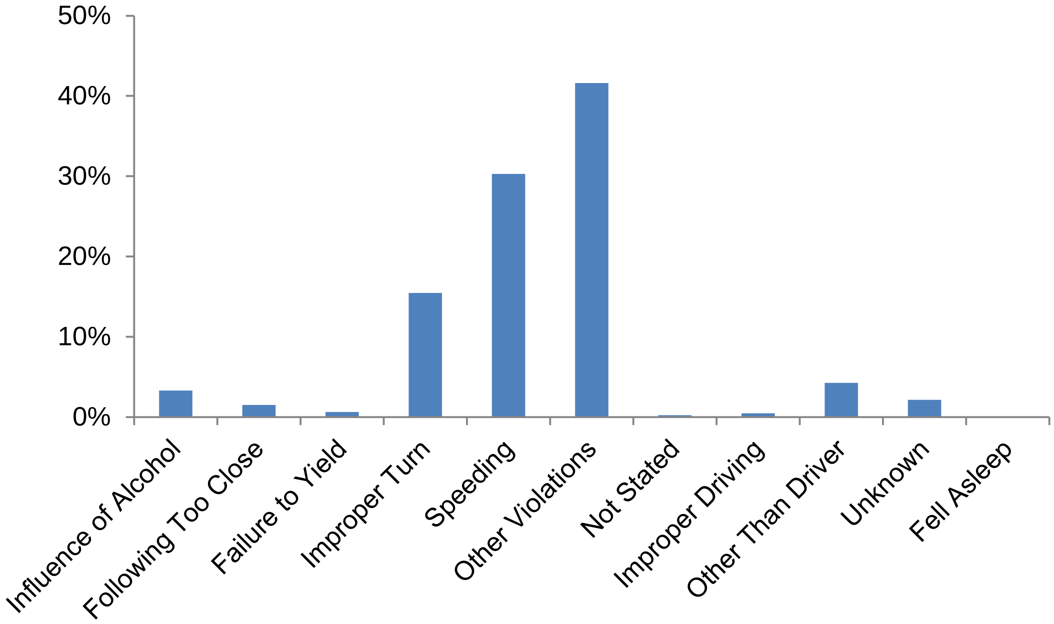

Figure 2.3 Primary crash factors of truck-involved crashes during data period (2006 to 2008)

Figure 2.4 shows the distribution of crash types for truck-involved crashes. Unlike general traffic crashes where rear-end crashes are the dominant crash type, sideswiping was the leading crash type in these truck-involved crashes.

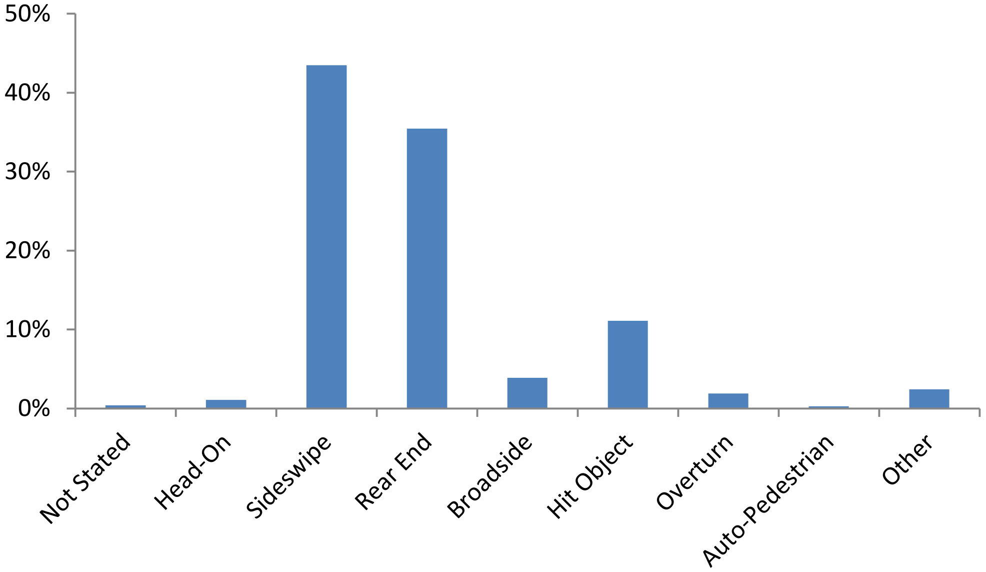

Figure 2.4 Type of truck-involved crashes (2006 to 2008)

2.2 Identification of Truck Crash Concentration Locations (TCCLs)

To help improve traffic safety, it is important to identify locations where truck crashes are concentrated and to understand the attributes of those locations. Although truck crashes occur more rarely than other traffic crashes, they have the tendency to be clustered (i.e., exhibiting spatial autocorrelation). Moreover, crashes are also spatially distributed across road networks. Therefore, spatial analysis is necessary to identify TCCLs.

In this study, we used a geographical information system and identification procedure as follows. First, since the crash data records use post mile information to indicate the crash location, a post mile map was established by incorporating post mile information into a roadway map database. Second, the crash locations corresponding to truck-involved crashes were calibrated and geocoded based on the post mile map. Third, all California State Routes were divided into one mile segments and the number of truck-involved crashes for each one-mile road segment was counted. Fourth, all of the segments were then ranked based on their count of truck-involved crashes. The top 20 TCCLs in California for the years 2006- 2008 are listed in Tables 2.1, 2.2, and 2.3 respectively.

Table 2.1 Top 20 truck crash concentration locations (2006)

District	County	Route	Begin PM	End PM	Direction	Prefix	Crash Count
8	RIVERSIDE	215	42.998	43.998	S		52
7	LOS ANGELES	57	3	4	N		37
7	LOS ANGELES	5	18	19	S		36
7	LOS ANGELES	5	17	18	S		33
4	ALAMEDA	80	2	3	W		31
7	LOS ANGELES	605	9	10	S		29
4	ALAMEDA	80	1	2	W		29
7	LOS ANGELES	60	24	25	W		28
7	LOS ANGELES	710	21.96	22.96	S		28
7	LOS ANGELES	57	2	3	N		28
7	LOS ANGELES	710	21.96	22.96	N		28
7	LOS ANGELES	60	12	13	W		27
7	LOS ANGELES	710	12.96	13.96	S		27
8	RIVERSIDE	215	41.998	42.998	N		27
7	LOS ANGELES	5	14	15	N		27
4	SACRAMENTO	5	23	24	S		26
12	ORANGE	91	6.996	7.996	W	R	25
7	LOS ANGELES	5	15	16	N		25
7	LOS ANGELES	60	24	25	E		25
7	LOS ANGELES	5	17	18	N		25

Table 2.2 Top 20 truck crash concentration locations (2007)

District	County	Route	Begin PM	End PM	Direction	Prefix	Crash Count
8	RIVERSIDE	215	42.998	43.998	S		53
8	RIVERSIDE	215	38.998	39.998	S		49
7	LOS ANGELES	60	24	25	W		44
7	LOS ANGELES	5	17	18	S		41
4	ALAMEDA	238	14	15	N		38
7	LOS ANGELES	60	24	25	E		37
7	LOS ANGELES	710	21.96	22.96	N		37
4	ALAMEDA	80	2	3	W		35
7	LOS ANGELES	57	3	4	N		35
7	LOS ANGELES	5	18	19	S		30
7	LOS ANGELES	5	17	18	N		30
12	ORANGE	5	43	44	S		29
7	LOS ANGELES	5	16	17	N		28
7	LOS ANGELES	57	3	4	S		25
7	LOS ANGELES	605	9	10	S		25
7	LOS ANGELES	710	12.96	13.96	S		25
7	LOS ANGELES	605	10	11	S		24
8	RIVERSIDE	215	39.998	40.998	N		24
7	LOS ANGELES	57	4	5	S		23
4	SAN FRANCISCO	80	3.951	4.951	E		23

Table 2.3 Top 20 truck crash concentration locations (2008)

District	County	Route	Begin PM	End PM	Direction	Prefix	Crash Count
7	LOS ANGELES	60	24	25	W		40
7	LOS ANGELES	5	17	18	S		32
7	LOS ANGELES	57	3	4	S		27
7	LOS ANGELES	605	9	10	S		27
7	LOS ANGELES	5	14	15	N		24
7	LOS ANGELES	5	18	19	S		22
7	LOS ANGELES	5	16	17	S		22
7	LOS ANGELES	710	21.96	22.96	N		22
7	LOS ANGELES	405	30	31	S		19
7	LOS ANGELES	710	21.96	22.96	S		19
12	ORANGE	91	15.999	16.999	E	R	19
7	LOS ANGELES	10	32.155	33.155	W		18
7	LOS ANGELES	57	4	5	S		18
4	ALAMEDA	880	16	17	S		18
7	LOS ANGELES	710	22.96	23.96	S		18
12	ORANGE	22	8	9	E		18
4	ALAMEDA	880	20	21	N		18
12	ORANGE	91	16	17	E		18
7	LOS ANGELES	10	17.155	18.155	W		17
7	LOS ANGELES	605	10	11	S		17

Figure 2.5 shows the crash density maps for truck-involved crashes in the year 2008. In this map, the density of truck-crash occurrences was shown for all roadway segments for one direction in the left chart and the other direction in the right chart. There is an observable concentration in the major truck corridors in both Northern and Southern metropolitan areas. Particularly noticeable is the greater concentration in the Los Angeles area. While we only show charts for 2008, the other years have similar patterns.

We used Alameda County in San Francisco as a case study to provide a detailed look at the clustering of truck crashes along specific segments. Figures 2.6 and Figure 2.7 show the detailed crash density map for truck-involved crashes in Alameda County with traveling direction in north/east and south/west directions, respectively. SR-238 in Hayward and I-880 near Oakland both have high-concentration segments.

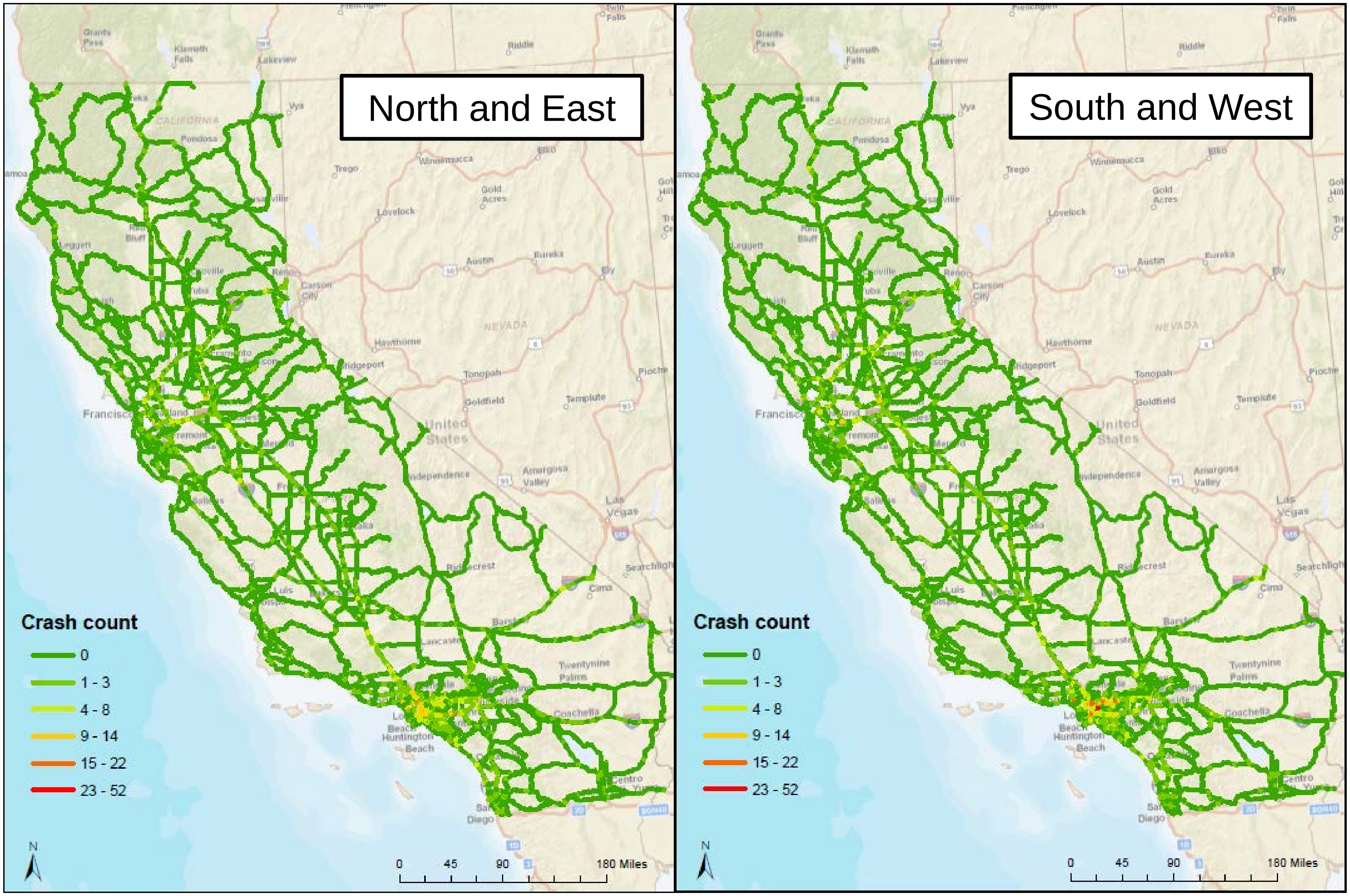

Figure 2.5 Crash density map for truck-involved crashes (California, 2008)

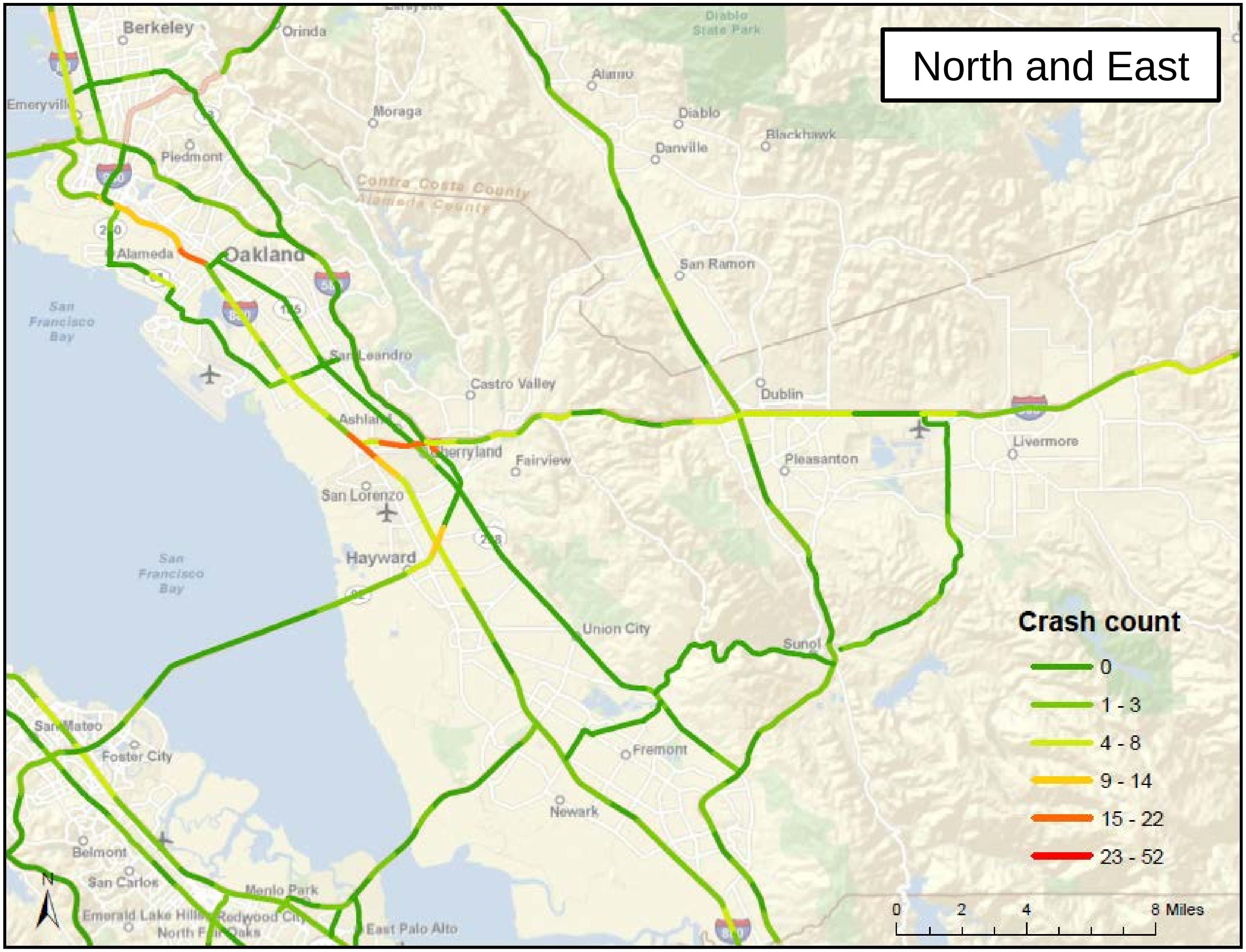

Figure 2.6 Crash density map (north/east direction, Alameda County, 2008)

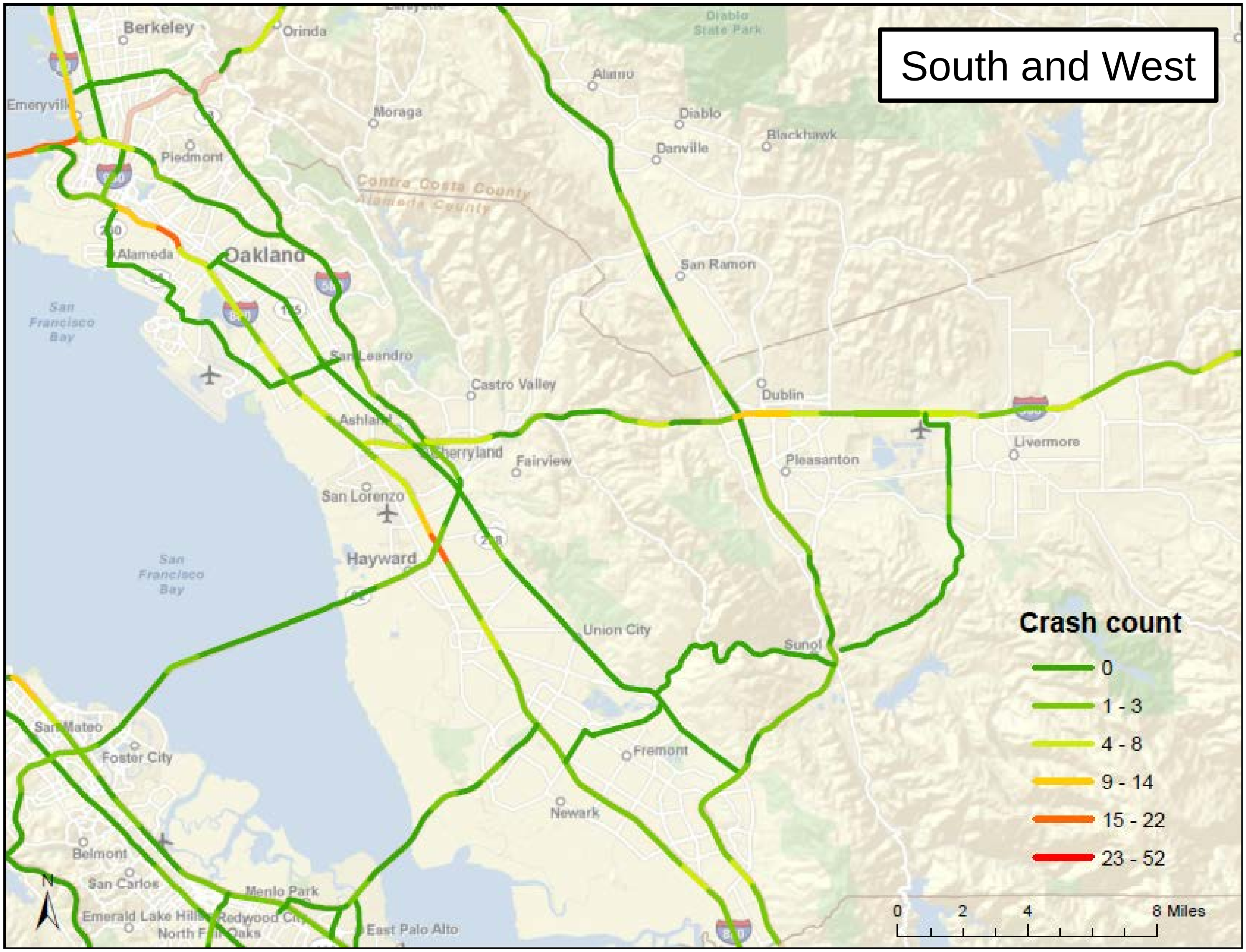

Figure 2.7 Crash density map (south/west direction, Alameda County, 2008)

3 Investigation of Attributes of TCCLs

To understand what may contribute to the high-risk areas and may also help predict potentially hazardous areas, we further evaluated the identified TCCLs to investigate their common attributes. The analysis focused on the following three aspects:

- patterns of distribution and recognizable location shifts over the years;
- the relationship between TCCLs and the overweight trucks.

This section describes the analysis and corresponding findings.

3.1 Patterns of distribution and recognizable location shifts of TCCLs

Although the top 20 TCCLs varied from year to year, some locations did show up among the top 20 TCCLs in each of the three years we studied. To analyze the location patterns and the variations in truck-involved crashes, we examined the truck-involved crashes at the top 20 TCCLs in each year. Figures 3.1, 3.2, and 3.3 show the numbers of crashes for the top 20 locations in 2006, 2007, and 2008, respectively. In each chart, the three-year truck-involved crashes at each TCCL are also given to allow an inspection of variations in those three years. In each figure, the top 20 TCCLs for a specific year are listed along the x axis; the three colored bars drawn at each TCCL represents the number of truck-involved crashes that occurred at that location in 2006 (blue bars), 2007 (red bars), and 2008 (green bars). In addition, the Top 20 locations ranked by the average number of truck crashes in those three years are shown in Figure 3.4. The corresponding truck traffic volume in AADT (Annual Average Daily Traffic) for those top TCCLs are provided in Figure 3.5.

The following observations can be made from a reading of these figures:

- On one hand, several TCCLs had relatively consistent numbers of truck-involved crashes over the three years, and are included in the top 20 TCCLs for each of the three years. Examples of such TCCLs include the road segment from post mile 18 to post mile 19 on south-bound Route 5 in Los Angeles (labeled as 5S-LOSANGELES-PM18, the 3rd TCCL in Figure 3.1), the road segment from post mile 17 to post mile 18 on south-bound Route 5 in Los Angeles (labeled as 5S-LOSANGELES-PM17, 4th TCCL in Figure 3.1), and the road segment from post mile 9 to post mile 10 on southbound Route 605 in Los Angeles (labeled as 605S-LOSANGELES-PM9, 6th TCCL in Figure 3.1). An inspection of several of these locations indicated that the TCCLs occurred at locations where significant truck traffic merging or diverging movements are involved.
- On the other hand, there could be significant variations in the number of truck-involved crashes from one year to another at some TCCLs. For example, the TCCL (labeled as "215S-RIVERSIDE-PM42.998" in Figure 3.1) that has the highest number of truck-involved crashes in 2006 and 2007, actually had less than 10 truck-involved crashes in 2008, and it is not included in the top 20 TCCLs for 2008. This type of short term change could be due to a short-term fluctuation or a temporary alteration of traffic patterns.
- The investigation of the causal factors of crashes and their concentration require more in-depth evaluation. It will be a topic worthy of further study, but is beyond the scope of this project, and thus will not be discussed further here.
- In Figure 3.4, where the top 20 locations are ranked for the three years, there are several clustered segments. For example,
  - I-710 Southbound, Los Angeles County, PM 21 and 22
  - I-5 Southbound, Los Angeles County, PM 17 and 18

  - I-5 Northbound, Los Angeles County, PM 14, 16, and 17
  - I-80, Westbound, Alameda County, PM 1 and 2
- In Figure 3.5, the AADT for the top 20 TCCLs are shown. A majority of these locations has significant high truck volume, so there is a degree of correlation between truck volume and TCCLs. However, the correlation of crash numbers and truck volume is not clear. This illustrates a typical problem with truck crash analysis, as they are relatively rare events and there is a data stability issue in the attempt to model their relationship with other variables.

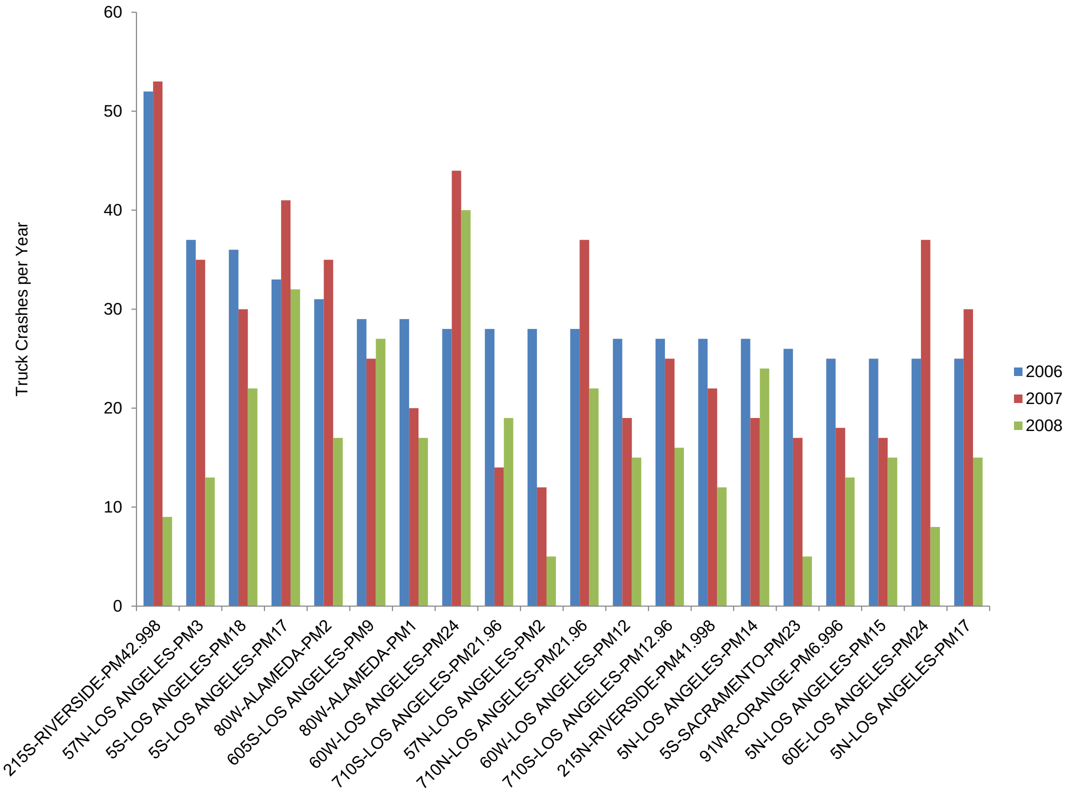

Figure 3.1 Number of truck-involved crashes at the top 20 TCCLs for 2006

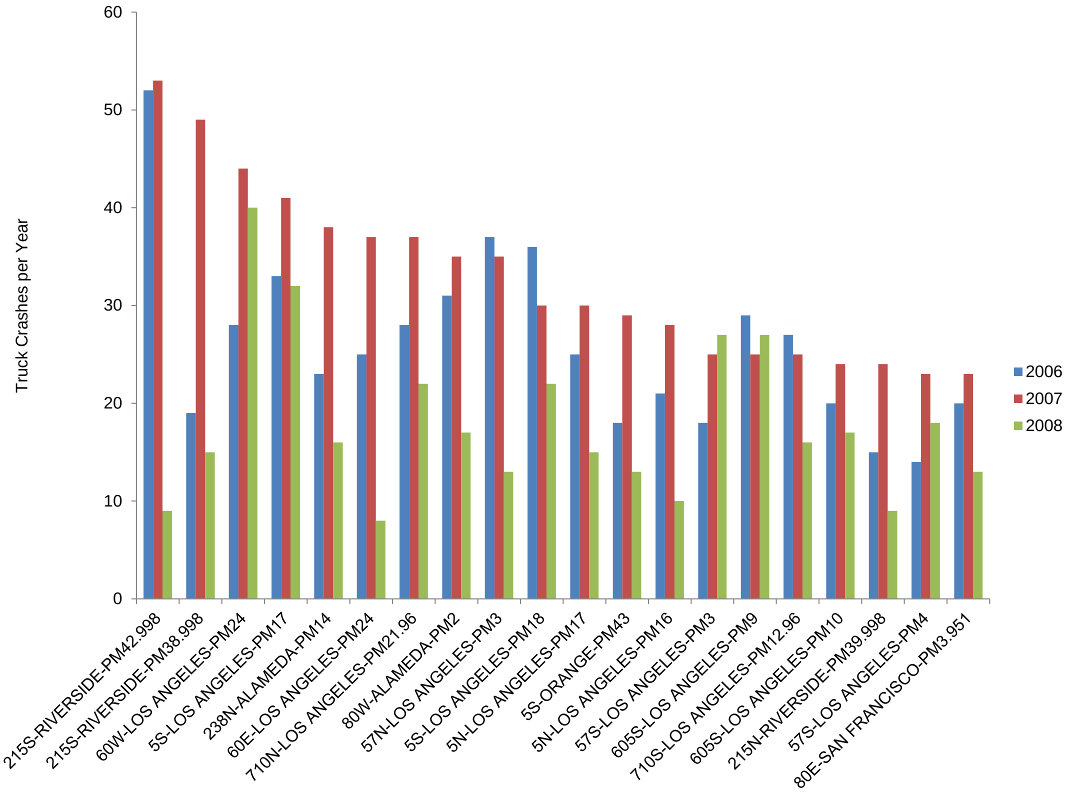

Figure 3.2 Number of truck-involved crashes at the top 20 TCCLs for 2007

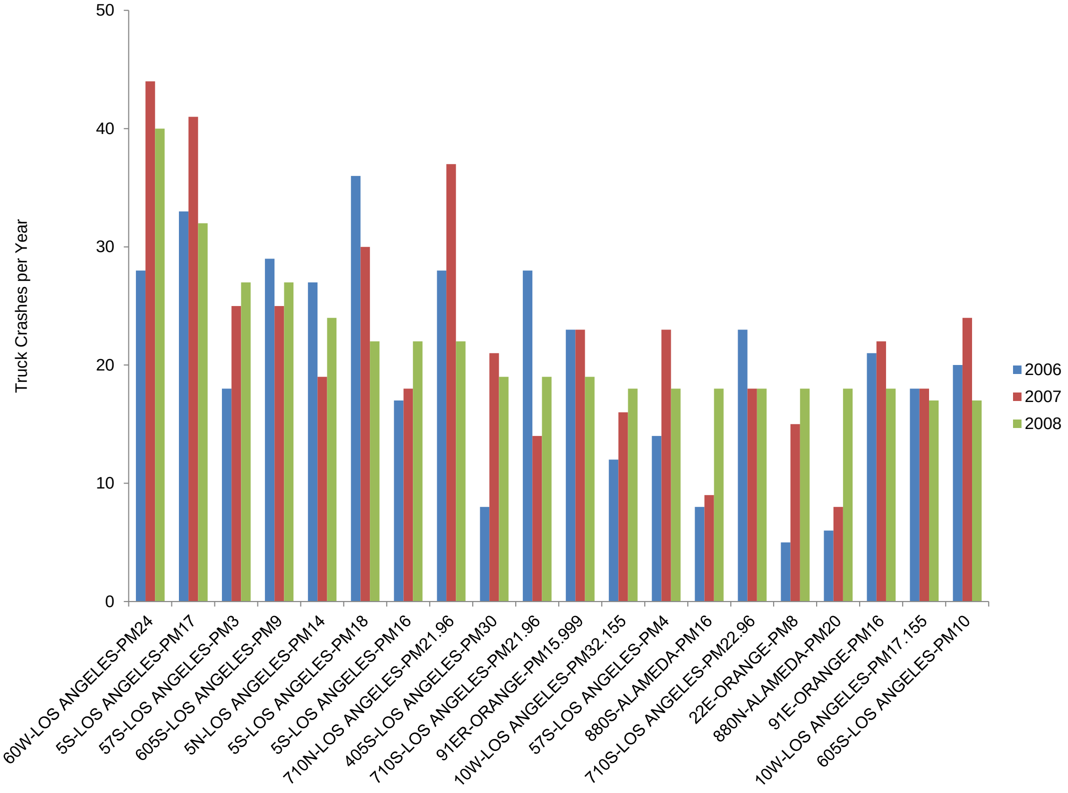

Figure 3.3 Number of truck-involved crashes at the top 20 TCCLs for 2008

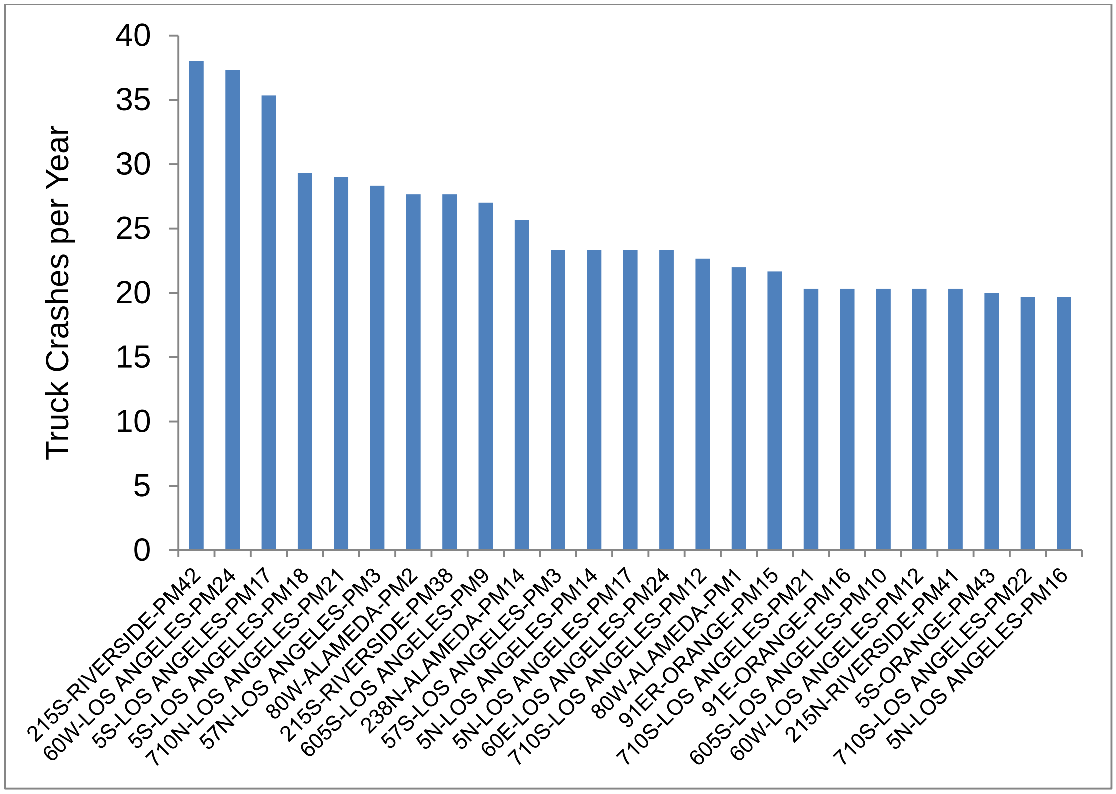

Figure 3.4 Top 20 TCCLs over the years 2006-2008 by average number of truck crashes

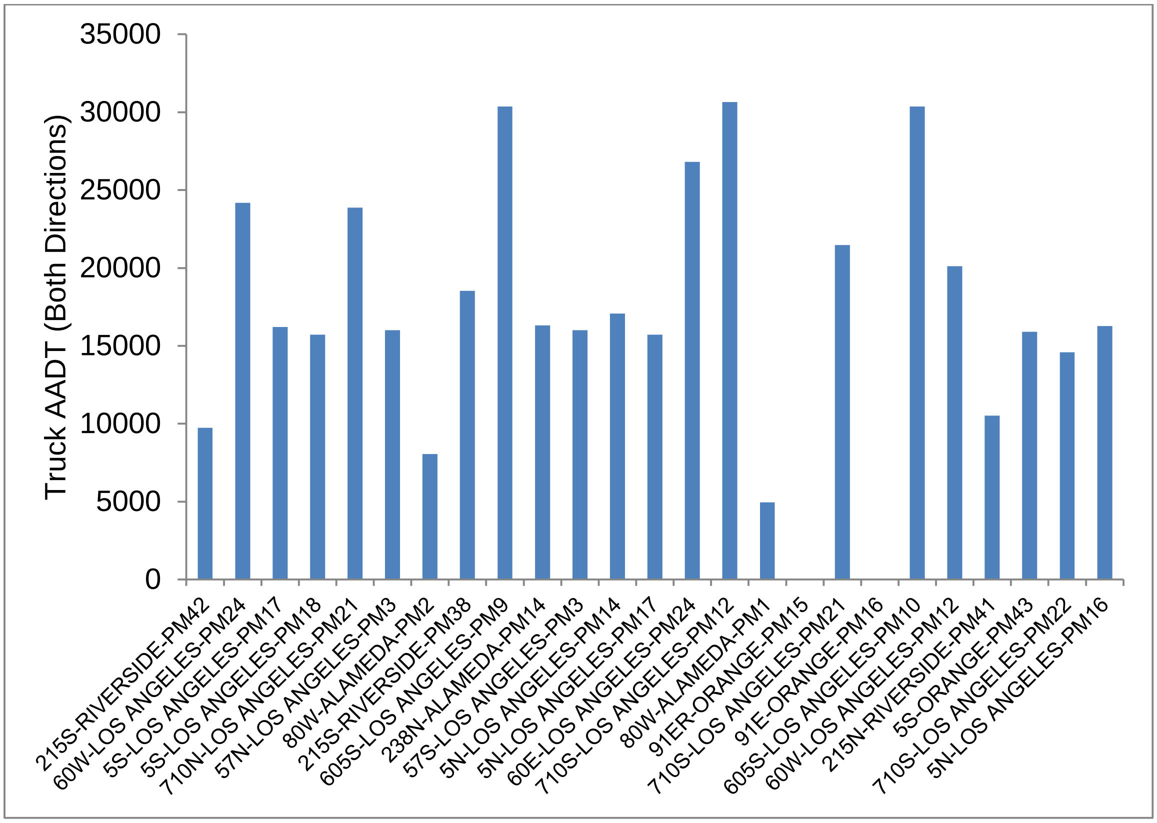

Figure 3.5 Corresponding Truck AADT for Top 20 TCCLs in Figure 3.4

3.2 Relationship between TCCLs and Overweight Trucks

Overweight trucks are perceived to be a traffic safety hazard; therefore, we further investigated whether overweight trucks are an attribute of the TCCLs. Since the crash data did not have truck weight information, we did not have access to the direct information on the total weight or axle weight of trucks involved in accidents. Instead, we compared the weight of trucks at or near TCCLs with that of trucks that were far away from any TCCLs, using data obtained from weigh stations. Our data analysis examined the statistics of truck axle weights, total truck weight, as well as truck lengths and speeds. Data collected in multiple months in 2010 were used in the analysis[13]. This section describes the analysis in detail.

To compare the statistics of the weight of trucks at or near TCCLs with those of trucks that are far away from any TCCLs, we first identified WIM sites that are at or near TCCLs; we treated the rest of the WIM sites as those that are far away from any TCCL. Table 3.1 lists the top 20 TCCLs for 2008, as well as the corresponding nearby WIM sites.

In Table 3.1, the left seven columns list the information of the 20 top TCCLs for 2008, with each row corresponding to one TCCL. For each TCCL, the information listed includes the district and county it resides in, the route and the corresponding segment defined by the post mile (PM) of its start and end locations, the travel direction, and the number of truck-involved crashes that occurred at the TCCL in 2008. For example, the TCCL listed in the second row is on Interstate 57 in Los Angeles County (LA), which is in District 7. This TCCL corresponds to the segment between post mile 3 and 4 on the northbound direction of Interstate 57. In 2008, a total of 37 truck-involved crashes occurred at this TCCL. The six columns to the right provide the information of the WIM sites that are closest to those TCCLs. The distances listed in the second column to the right are the distances from the closest WIM sites to the corresponding TCCLs. For example, the WIM site that is closest to the TCCL in the second row is WIM site #104, which is located at PM 21 on northbound Interstate 57 in Orange County (ORA). This WIM site is about 4 miles from the TCCL. All the identified nearby WIM sites except WIM site #111 are located on the same route with their corresponding TCCLs.

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[13] We used WIM data available from 2010 while TASAS data from 2008 due to limitations of data availability; therefore, this analysis is preliminary and only used to explore the linkage between the two data sets. Further analysis based on WIM data and crash data for the same years may be conducted following the approach and analysis described here.

Table 3.1 Top 20 TCCLs (2008) and the corresponding nearby WIM sites

District	County	Route	Begin PM	End PM	Direction	Crash Count	WIM #	County	Route	WIM PM	Distance	Direction
8	RIV	215	42.998	43.998	S	52	63	RIV	215	15	-28.498	Both
7	LA	57	3	4	N	37	104	ORA	57	21	4	N
7	LA	5	18	19	S	36	47	LA	5	56.1	37.6	S
7	LA	5	17	18	S	33	15	ORA	5	25.8	35	S
4	ALA	80	2	3	W	31	58	CC	80	7.5	8	W
7	LA	605	9	10	S	29	111	ORA	405	18.6	13	S
4	ALA	80	1	2	W	29	58	CC	80	7.5	9	W
7	LA	60	24	25	W	28	96	SBD	60	7.9	13.7	W
7	LA	710	21.96	22.96	S	28	59	LA	710	11.5	-10.96	S
7	LA	57	2	3	N	28	104	ORA	57	21	5	N
7	LA	710	21.96	22.96	N	28	60	LA	710	11.5	-10.96	N
7	LA	60	12	13	W	27	96	SBD	60	7.9	25	W
7	LA	710	12.96	13.96	S	27	59	LA	710	11.5	-1.96	S
8	RIV	215	41.998	42.998	N	27	63	RIV	215	15	-27.498	Both
7	LA	5	14	15	N	27	16	ORA	5	25.8	34	N
4	SAC	5	23	24	S	26	105	SAC	5	33.2	9.7	both
12	ORA	91	6.996	7.996	W	25	62	ORA	91	11.9	4.404	W
7	LA	5	15	16	N	25	16	ORA	5	25.8	35	N
7	LA	60	24	25	E	25	95	SBD	60	7.9	13.7	E
7	LA	5	17	18	N	25	48	ORA	5	56.1	38.6	N

In addition to the WIM data, there is also a monthly WIM site status document that describes the status (or quality) of the data at each WIM site. The status types are listed in Table 3.2. Only the data for sites with status "GOOD DATA" were used in our analysis. For example, six WIM sites (site #47, #48, #59, #60, #104, and #105) were excluded from the nearby WIM sites and 26 WIM sites were excluded from the distant WIM sites when we analyzed the January 2010 data.

Table 3.2 Types of WIM site status

NO DATA	🟥	XX		
PARTIAL BAD	🟥	P/B		SITE HAS ENOUGH GOOD DATA TO SUBMIT FOR REPORTING
GOOD DATA	⬛	G		DATA IS GOOD
NEEDS CALIBRATION	🟧	N/C		Weights no good - Do not use for the Truck Weight Study or SHRP until re-calibrated.
MARGINAL DATA	🟪	M		Data is slighty above defined error limits POSSIBLE CALIBRATION
BAD DATA	🟥	B		🟥
GOOD DATA ONE DIRECTION ONLY	🟦	G		🟦

The WIM data consist of, not only the axle weight of each truck, but also the total weight, the number of axles, the axle spacing, length of the vehicle, and vehicle speed. Some data elements are measured directly (axle weight left and right, times between axles crossing the loops); some are calculated (speed, length, axle spacing); and others come from a look-up table (truck classification and allowable weights).

For this analysis, we focused on the total weight and axle weight of the trucks. Table 3.3 is an excerpt of a spreadsheet that lists the statistics of both the total truck weight and the axle weight for each WIM Site based on January 2010 data[14]. The yellow shade highlights the WIM sites that are near a TCCL (as listed in Table 3.1). Note that two rows are allocated for each WIM site: the first row shows the percentage of trucks and truck axles in different weight bands, while the second row shows the exact number of trucks and truck axles in the corresponding weight bands.

For example, the first two rows show the statistics for WIM site #15, which is the closest WIM site to (about 35 miles away from) a TCCL that is located between post mile 17 and 18 on southbound Interstate 5 in Los Angeles County (as listed in Row 4 of Table 3.1). The first column in Table 3.3 shows that the number and percentage of trucks whose first axle had a weight between 4,000 pounds and 6,000 pounds. For WIM site #15, 54,069 trucks (i.e., 83 percent of the total number of trucks passing through this site in January 2010) had a first axle weighted between 4,000 pounds and 6,000 pounds. Columns 3 through 11 (i.e., columns under the caption “wpa statistics”) list the number and percentage of axles whose weight fell into specific ranges of weight per axle (wpa). For WIM site #15, 14,800 axles (about 4.54 percent of all the axles measured at that WIM site in January 2010) weighed less than 2,000 pounds, and 90,893 axles (about 27.9 percent of all the axles measured) weighed between 2,000 pounds and 4,000 pounds. No axle was detected to be over 20,000 pounds at WIM site #15, as shown in red in column 11. Columns 12 through 17 list the statistics of the total truck weight. For WIM site #15, 22,162 trucks (about 34 percent of all the trucks passing through this site) had a total weight less than 20,000 pounds, and 42,214 trucks (about 65 percent of all the trucks) had a total weight between 20,000 pounds and 40,000 pounds. Two trucks were detected to be over 80,000 pounds at this site in January 2010[15].

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[14] Such results can be obtained for each month, as well as for a whole year depending on the WIM data used.

[15] Since only two trucks out of 65,143 trucks had a total weight over 80,000 pounds, its corresponding percentage is therefore only 0.0000308, i.e., 3.08E-05 as shown in Column 16 of Row 2.

Table 3.3 Statistics of truck weight and axle weight at WIM Sites (based on January 2010 data)

		wpa statistics									truck total weight statistics					
WIM Site	wpa 4k-6klb	<2klb	2k-4klb	4k-6klb	6k-8klb	8k-10klb	10k-12.5klb	12.5k-17.5klb	17.5k-20klb	>20klb	<20klb	20k-40klb	40k-60klb	60k-80klb	80k-100klb	>100klb
15	54069	14800	90893	118489	76128	24599	814	34	0	0	22162	42214	589	5	2	0
15	0.832189	0.045433	0.279021	0.363734	0.233696	0.075513	0.002499	0.000104	0	0	0.341101	0.649726	0.009065	7.7E-05	3.08E-05	0
16	59356	32972	135277	111323	43417	12189	367	26	0	0	36628	28321	473	6	0	0
16	0.907196	0.098256	0.403125	0.331742	0.129382	0.036323	0.001094	7.75E-05	0	0	0.559821	0.432857	0.007229	9.17E-05	0	0
58	50366	24120	93131	87053	71158	35062	3098	110	0	0	26152	33195	3027	10	6	1
58	0.807264	0.076881	0.296849	0.277476	0.226811	0.111758	0.009875	0.000351	0	0	0.419163	0.532048	0.048517	0.00016	9.62E-05	1.6E-05
62	58734	10096	108150	110604	62962	46232	1982	50	2	0	26650	36561	4561	10	4	0
62	0.866462	0.029687	0.318015	0.325231	0.18514	0.135945	0.005828	0.000147	5.88E-06	0	0.393149	0.539359	0.067285	0.000148	5.9E-05	0
63	37143	26399	78307	72160	40361	12015	266	37	0	0	22940	22193	536	9	4	4
63	0.813006	0.115006	0.34114	0.314361	0.17583	0.052343	0.001159	0.000161	0	0	0.502123	0.485772	0.011732	0.000197	8.76E-05	8.76E-05
95	188298	32400	352259	399272	174624	46131	1187	80	2	0	85639	114124	827	14	4	3
95	0.938623	0.032208	0.350174	0.396908	0.17359	0.045858	0.00118	7.95E-05	1.99E-06	0	0.426891	0.568882	0.004122	6.98E-05	1.99E-05	1.5E-05
96	180067	26696	372760	324278	185165	68063	2422	126	2	0	93013	98566	3742	18	8	0
96	0.92178	0.027254	0.380557	0.331061	0.189038	0.069487	0.002473	0.000129	2.04E-06	0	0.476142	0.504569	0.019156	9.21E-05	4.1E-05	0
104	97056	15954	185897	217747	89178	42027	1769	71	1	0	44760	61538	3879	15	4	0
104	0.880758	0.028868	0.336377	0.39401	0.161366	0.076047	0.003201	0.000128	1.81E-06	0	0.406185	0.558441	0.035201	0.000136	3.63E-05	0
111	40354	4414	64284	82380	46676	19726	287	107	4	0	15258	27709	478	22	10	8
111	0.927998	0.020259	0.295046	0.378102	0.21423	0.090537	0.001317	0.000491	1.84E-05	0	0.35088	0.637208	0.010992	0.000506	0.00023	0.000184
1	187141	31651	232870	360691	280162	111680	1875	90	0	0	57499	142449	2952	45	45	5
1	0.9219	0.03106	0.228524	0.353959	0.274933	0.109596	0.00184	8.83E-05	0	0	0.283253	0.701736	0.014542	0.000222	0.000222	2.46E-05
2	122338	6352	83448	245491	273781	23259	197	21	0	0	16970	108478	276	26	7	0
2	0.972813	0.010042	0.131923	0.388098	0.432822	0.03677	0.000311	3.32E-05	0	0	0.134943	0.8626	0.002195	0.000207	5.57E-05	0
3	52954	25790	69015	102425	76749	17344	196	16	2	0	20155	37380	147	18	6	0
3	0.917652	0.088462	0.236728	0.351328	0.263256	0.059492	0.000672	5.49E-05	6.86E-06	0	0.34927	0.647766	0.002547	0.000312	0.000104	0
4	54172	6980	89018	109648	80004	39894	713	53	0	0	20919	41952	1965	14	5	4
4	0.835227	0.021391	0.272802	0.336024	0.245178	0.122258	0.002185	0.000162	0	0	0.32253	0.646818	0.030296	0.000216	7.71E-05	6.17E-05
5	190681	11476	170633	415123	328818	131469	2480	152	2	0	34917	169779	5621	46	54	12
5	0.906154	0.010825	0.160951	0.391569	0.310161	0.124009	0.002339	0.000143	1.89E-06	0	0.165932	0.806823	0.026712	0.000219	0.000257	5.7E-05
7	164691	46598	195107	325994	251862	59340	874	122	0	0	50594	123634	778	33	39	7
7	0.940635	0.052958	0.221738	0.370491	0.28624	0.06744	0.000993	0.000139	0	0	0.288968	0.706137	0.004444	0.000188	0.000223	4E-05
8	34730	41779	70160	65594	23926	1605	17	0	0	2	25421	15060	18	1	0	0
8	0.857531	0.205724	0.345475	0.322991	0.117814	0.007903	8.37E-05	0	0	9.85E-06	0.627679	0.371852	0.000444	2.47E-05	0	0
10	203800	27580	330578	372166	301044	67285	863	85	0	0	80840	136480	1819	13	3	1
10	0.929931	0.025082	0.300635	0.338455	0.273776	0.06119	0.000785	7.73E-05	0	0	0.36887	0.622753	0.0083	5.93E-05	1.37E-05	4.56E-06
12	24959	35343	72231	49706	34133	3165	72	5	0	0	22642	15526	61	10	1	0
12	0.652694	0.181567	0.371072	0.255354	0.175351	0.01626	0.00037	2.57E-05	0	0	0.592103	0.406015	0.001595	0.000262	2.62E-05	0
13	30359	15780	58918	58969	28783	19337	446	20	1	0	16094	18826	1168	14	1	1
13	0.840876	0.086582	0.323274	0.323554	0.157928	0.106099	0.002447	0.00011	5.49E-06	0	0.445768	0.521438	0.032351	0.000388	2.77E-05	2.77E-05

As shown in Table 3.3, none of the WIM sites that are close to TCCLs (shaded in yellow) detected any axle with weight over 20,000 pounds, while some WIM sites that are distant from TCCLs detected one or two axles with weights over 20,000 pounds. Both WIM sites close to TCCLs and WIM sites away from TCCLs typically detected some trucks with total weights over 80,000 pounds. Although Table 3.3 consists of relatively detailed and complete information regarding the statistics of axle weight and total weight of trucks, it does not provide a straight-forward overall view of the comparison. To facilitate the comparison, we generated figures to provide a different perspective of these statistics.

Figure 3.6 shows the number of trucks with total weights greater than 80,000 pounds (i.e., overweight trucks according to the total weight limit) at all WIM sites. The numbers labeled in the figure are the WIM site number for sites where more than 20 overweight trucks were detected (based on January 2010 data). For example, the WIM site that had the maximum number (i.e., 66) of trucks with a total weight over 80,000 pounds is WIM site #5, plotted on the left. The WIM sites that are near a TCCL are shown in blue and the WIM sites that are away from TCCLs are shown in black. The data quality is also shown: red marks sites with bad data or partially bad data (see Table 3.2 for details); magenta marks sites with marginal data. This figure shows that none of the WIM sites that are close to a TCCL (those corresponding to the blue stems) detected more than 20 overweight trucks, while 12 of the WIM sites that are away from TCCLs (those corresponding to black stems) had more than 20 overweight trucks. This figure clearly implies that WIM sites close to TCCLs did not have a larger number of overweight trucks than WIM sites that are away from TCCLs.

Figures 3.7 and 3.8 show the number of overweight trucks at all WIM sites, based on March and May 2010 data. As shown in Figure 3.7, 10 WIM sites that are away from TCCLs detected more than 20 overweight trucks, while one WIM site that is close to TCCLs detected 21 overweight trucks. In general, the numbers of overweight trucks at WIM sites that are close to TCCLs are not noticeably larger than those at WIM sites that are away from TCCLs. Similar observations can be made from Figure 3.8 which is based on May 2010 data. These figures consistently show that, among all WIM sites, WIM sites near a TCCL do not have a larger number of overweight trucks than WIM sites that are far away from a TCCL. Similar figures can be plotted to show the number of axles that are more than 20,000 pounds (i.e., the axle weight limit) at all WIM sites. Those figures also support the observation that WIM sites near a TCCL are not associated with large numbers of overweight trucks.

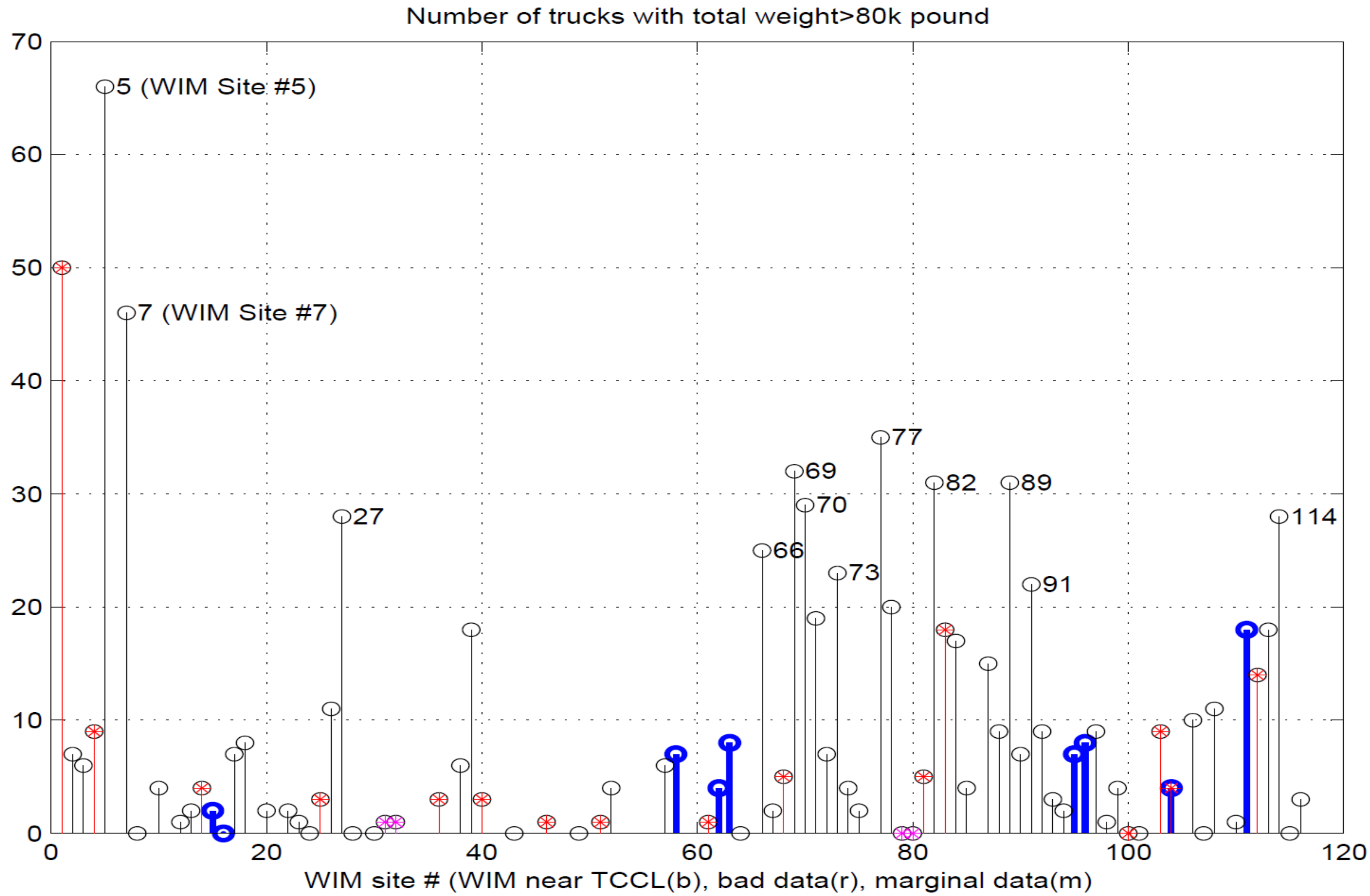

Figure 3.6 The number of overweight trucks at all WIM sites (based on January 2010 data)
(Numbers listed by the stem are the WIM site number; blue: WIM sites near a TCCL; black: WIM sites far away from TCCLs; red: WIM sites with bad or partially bad data; magenta: WIM sites with marginal data)

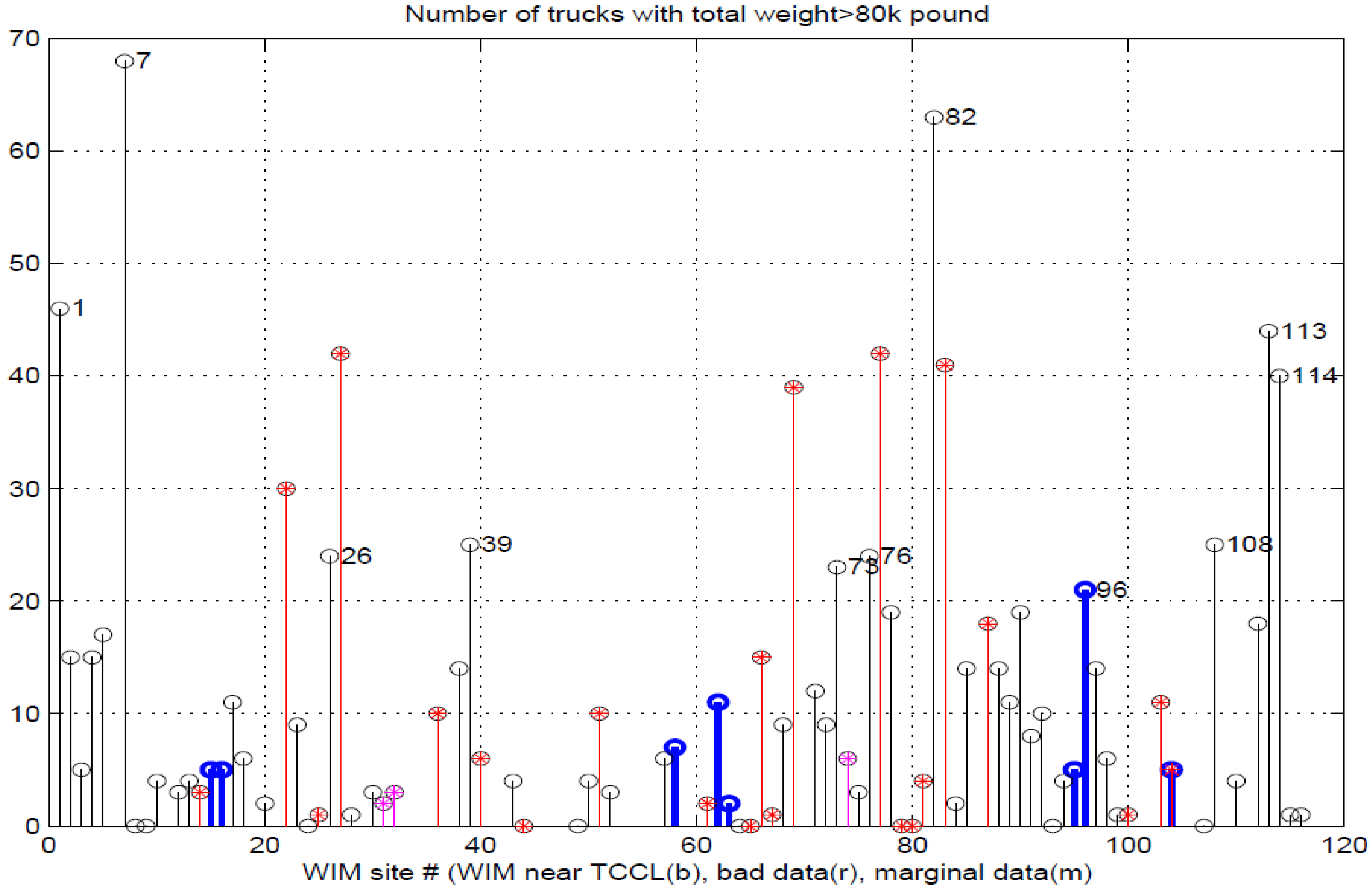

Figure 3.7 The number of overweight trucks at all WIM sites (based on March 2010 data)
(Numbers listed by the stem are the WIM site number; blue: WIM sites near a TCCL; black: WIM sites far away from TCCLs; red: WIM sites with bad or partially bad data; magenta: WIM sites with marginal data)

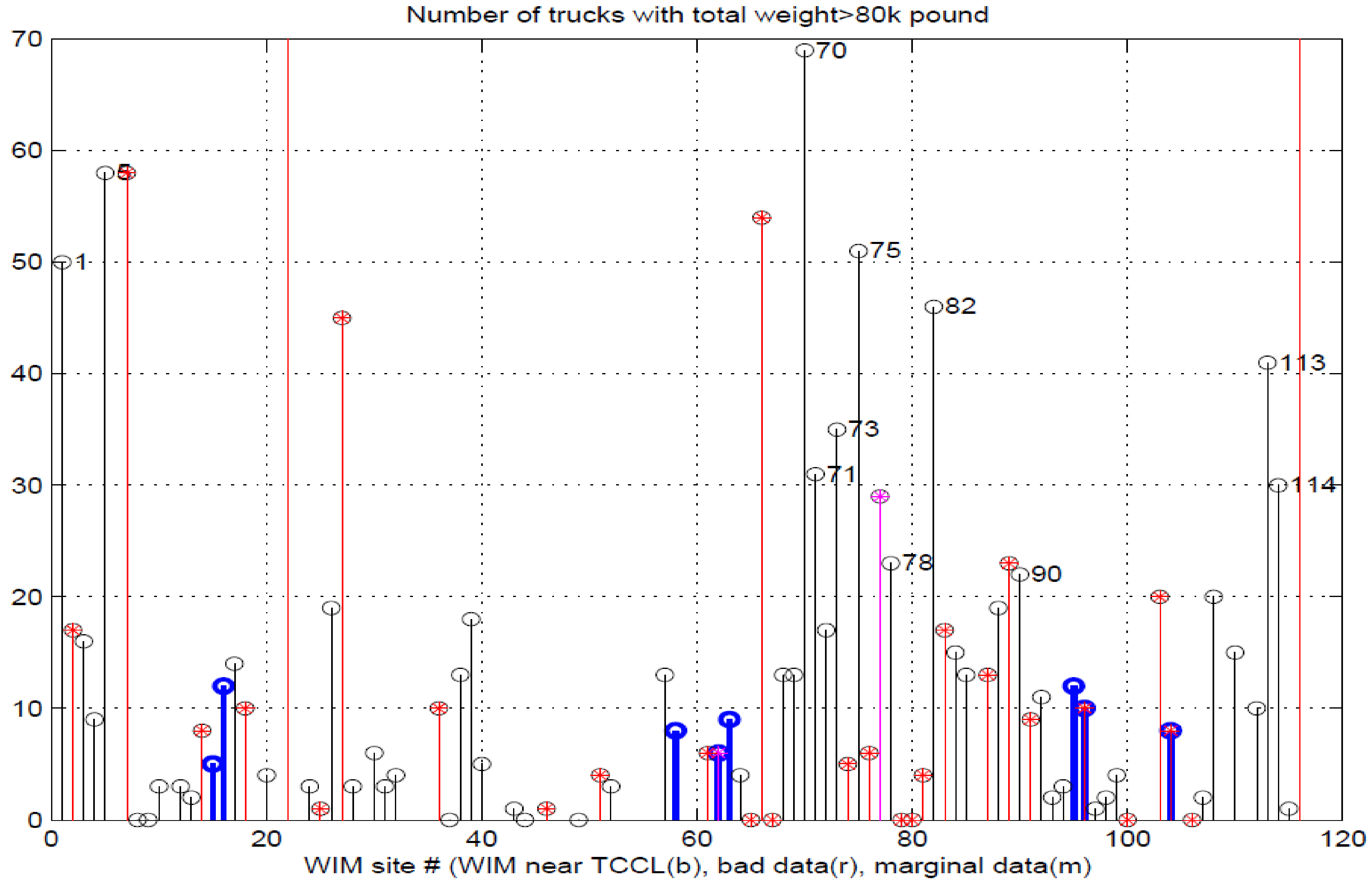

Figure 3.8 The number of overweight trucks at all WIM sites (based on May, 2010 data)
(Numbers listed by the stem are the WIM site number; blue: WIM sites near a TCCL; black: WIM sites far away from TCCLs; red: WIM sites with bad or partially bad data; magenta: WIM sites with marginal data)

In summary, overweight trucks were detected at both WIM sites near a TCCL and WIM sites far away from TCCLs. The WIM data does not suggest more overweight trucks at WIM sites near a TCCL. More detailed analysis of the distributions of truck weight and axle weight statistics indicates that trucks at WIM sites near a TCCL are not heavier than WIM sites far away from TCCLs[16].

It is worth noting that the above results do not necessarily suggest that truck overweight is not relevant to truck-involved crashes. On one hand, the data of a WIM site near a TCCL does not strictly reflect the truck weight at the TCCL: an overweight truck may bypass the WIM near the TCCL. On the other hand, overweight trucks may still be more likely to be involved in crashes because heavier trucks are harder to slow down or maneuver although this proposition is not supported by the WIM data. The statistics based on WIM data provide a general picture of truck weights at the WIM sites, which to some degree reflect truck weights in surrounding areas. With that in mind, the above results suggest that trucks at WIM sites near a TCCL are not heavier than those at WIM sites far from a TCCL[17].

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[16] There are variations from one WIM site to another, but when considering the WIM sites close to TCCLs as a group and the WIM sites away from TCCLs as another group, the data do not suggest that trucks at WIM sites close to TCCLs are heavier on average or have weights more concentrated in higher weight values, when compared to trucks at WIM sites away from TCCLs.

[17] Please note that this study is preliminary, since the WIM data used is 2010 data, while the TCCLs are identified based on the truck-crash data for 2006, 2007, and 2008 due to data availability at the time of the study. While some TCCLs have relatively consistent number of truck-involved crashes and are among the top 20 TCCLs in all three years, the mismatch in the duration of the data should not be ignored. Further analysis based on WIM data and crash data for the same years may be conducted using the approach and analysis described here.

4 Identification of Areas with High Truck Traffic Volumes but a Low Level of CVEF Coverage

To support the effective deployment of WIM/VWS, it is necessary to identify areas along highway corridors that are most in need of future WIM/VWS. These areas will then serve as candidate locations for deploying future WIM/VWS facilities, as well as a CHP presence.

4.1 Technical Approach

The areas that are most in need of future WIM/VWS usually have the following two characteristics: (1) they typically have relatively high truck traffic volumes; (2) and they typically lack CVEFs to support the weight enforcement.

The areas with high truck traffic volumes can be identified based on truck traffic data collected across California. In this project, we conducted a statistical analysis of the overall distribution of truck traffic, examining it along each state highway to identify high truck traffic areas.

To further examine whether those high truck-traffic areas have adequate coverage of existing CVEFs, we mapped the existing CVEFs along with truck traffic data for each state highway. Our examination then took two factors into consideration: the distance from high truck-traffic areas to the nearest CVEF; and the difference between truck traffic at the high truck-traffic areas and the truck traffic at the location of the nearest CVEF. The distance factor is straightforward: the closer the nearest CVEF, the better the coverage usually is. The difference in truck traffic, on the other hand, indicates changes in truck traffic from the high truck traffic areas to the nearest CVEF. A considerable decrease in truck traffic likely implies that trucks diverge to junction highways before reaching the nearest CVEF, or take alternative routes to bypass the nearest CVEF. In the former case, if there is inadequate CVEF coverage at the corresponding locations on the junction highways, such a decrease in truck traffic then indicates that the specific high truck traffic area lacks CVEF coverage.

However, obtaining truck traffic volumes at existing CVEFs is not straightforward. For conventional weigh stations as well as mini-site weigh stations, truck traffic at the location of the facilities is not readily available On the other hand, a WIM facility records every truck that passes through it every day, resulting in a huge amount of data. However, these data are only available at the WIM stations. Therefore, in this project, truck traffic at a CVEF is approximated by truck traffic through the nearest traffic count location[18].

Accordingly, the identification of areas that are most in need of future CVEFs involves three elements: 1) identification of areas with high truck traffic volumes based on truck traffic count data, 2) evaluation of CVEF coverage based on CVEF location data, and 3) identification of high truck-traffic areas that lack CVEF coverage. The next three sections present a detailed analysis and results for each of the three elements.

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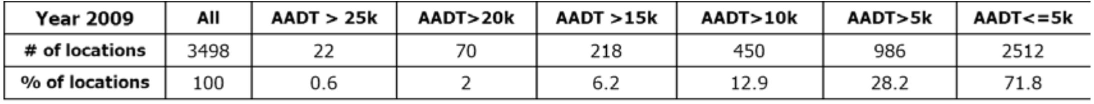
[18] Truck counting is done throughout the California in a program of continuous truck count sampling. The sampling includes a partial day, a 24-hour period, a 7-day cycle, and continuous vehicle classification counts. Traffic count locations occur at selected locations on the State Highway System. A more detailed description of count locations and CVEF locations is provided in Section 4.3 together with Figure 4.2.

4.2 Identification of Areas with High Truck Traffic Volumes

We used truck traffic data from the Traffic Data Branch of Caltrans[19] to identify areas with high truck traffic volumes. In this data, California State Highways are listed in the legislative route number order. Each traffic count location is identified by its post mile value, and the post mile values increase from the beginning of a route within a county to the next county line, then restart at each county line. Usually, post mile values increase from south to north or west to east depending on the general direction the routes follow within the state.

Table 4.1 summarizes the statistics of the 2009 truck traffic, which reveals that more than 70 percent of the count locations had an Annual Average Daily Traffic (AADT) smaller than 5,000. These statistics later served as a reference in determining what could be considered as high truck traffic volumes.

Table 4.1 Statistics of the 2009 Truck Traffic (AADT refers to truck AADT)



Year 2009	**All**	**AADT > 25k**	**AADT>20k**	**AADT >15k**	**AADT>10k**	**AADT>5k**	**AADT<=5k**
# of locations	3498	22	70	218	450	986	2512
% of locations	100	0.6	2	6.2	12.9	28.2	71.8

Since count locations are identified using post miles in each county and the post mile value restarts at each county line, we devised an aggregated post mile value to represent the post mile value of each count location from the beginning of the respective corridor. Without restarting at each county line, this aggregate post mile value can uniquely identify a count location along a corridor. As an example, Figure 4.1 shows the truck traffic flow along Interstate 5, where the aggregated post mile is on the x axis and each vertical stem represents the truck AADT at each count location.

By using the aggregate post mile to map count locations, we can conveniently examine the truck traffic flow along each route and identify areas with high truck traffic volumes. To give an example, the count locations with the two highest truck traffic volumes along Interstate 5 are labeled in Figure 4.1, specifying those two count locations.

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[19] Caltrans Traffic Data Branch, http://traffic-counts.dot.ca.gov/.

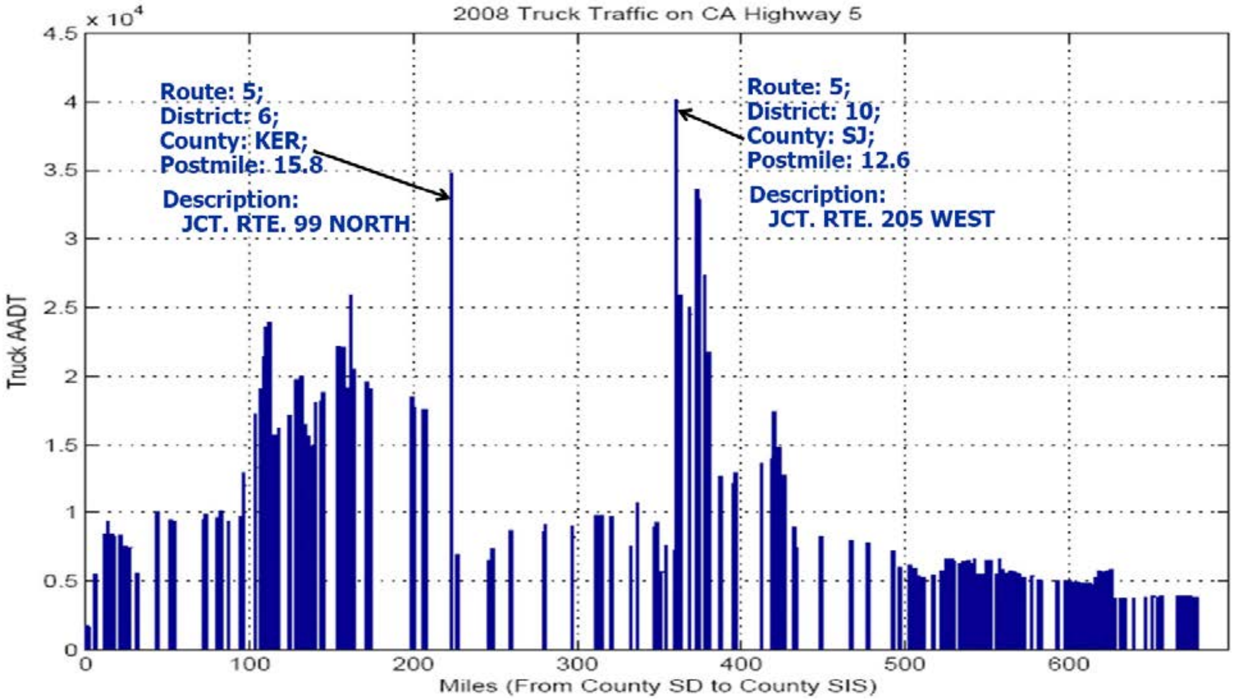

Figure 4.1 Truck traffic along Interstate 5

4.3 Evaluation of the Coverage of Existing CVEFs

In California, three types of CVEFs have been implemented for commercial vehicle weight enforcement: weigh stations, mini-site weigh stations, and WIM systems. Similar to the traffic count locations, the CVEF locations are also specified in post miles[20]. By computing the aggregate post mile from the beginning of the corresponding highway, we then located a CVEF along the highway in the same way we mapped the count locations. Figure 4.2 shows the locations of the CVEFs along Interstate 5 together with the truck traffic. The red dots represent the weigh stations while the black dots represent WIM sites (there are no mini-site weight stations on Interstate 5). The labels in Figure 4.2 provide detailed information (e.g., county, name, and facility type) of the corresponding CVEFs.

Plots like Figure 4.2 provided a great tool for us to evaluate CVEF coverage against truck traffic flow along corridors. In Figure 4.2, one area that stands out as a high truck traffic area that likely lacks CVEF coverage lies between WIM site #27 at Tracy (in San Joaquin County) and WIM site #1 at Lodi. The significantly low volume of truck traffic at these WIM sites in such close proximity to each other, indicates that most of the truck traffic in this area is not examined by these two WIM sites. Thus, this area appears to fit the category of a high truck traffic area that lacks CVEF coverage.

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[20] Caltrans' Office of Truck Service, http://www.dot.ca.gov/hq/traffops/trucks/#WSEF

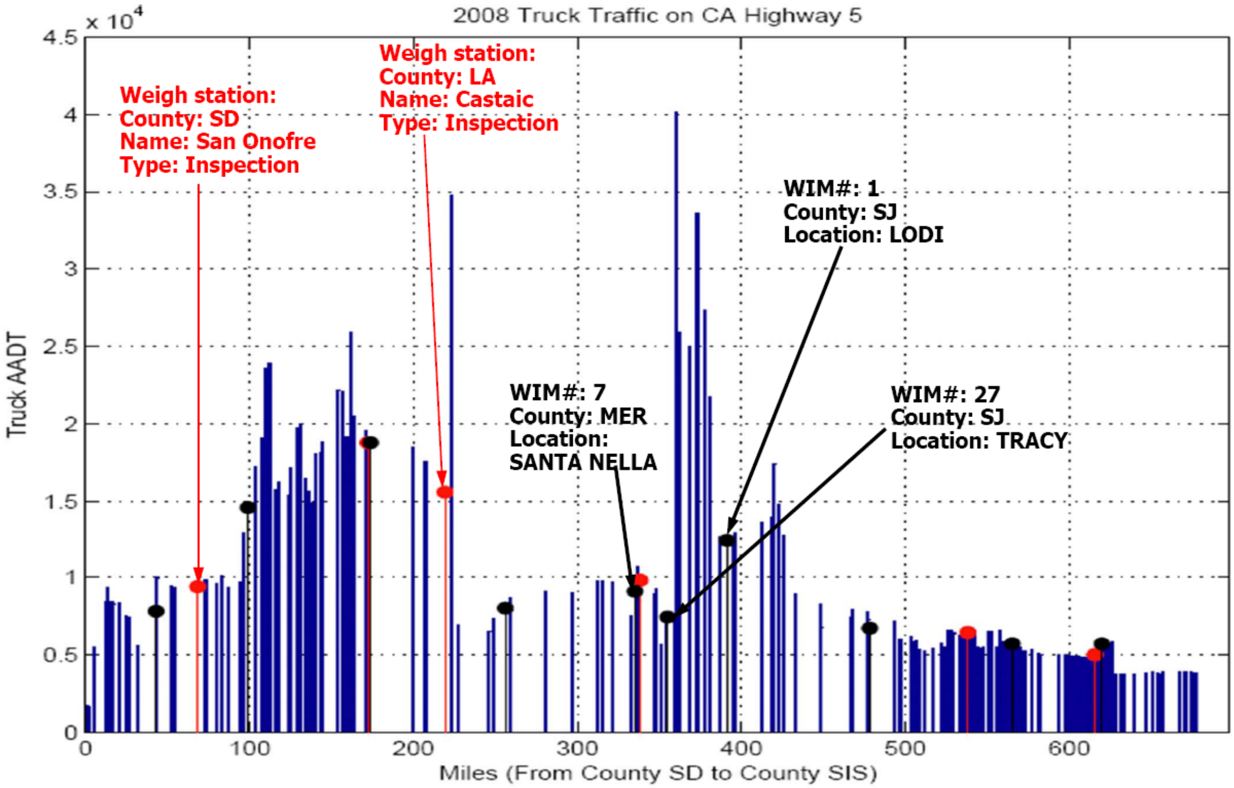

Figure 4.2 Truck Traffic and CVEFs along Interstate 5

However, it might be true that the majority of the truck traffic in that high truck traffic area could be examined by nearby CVEFs located at junction highways. Figure 4.3 shows the truck traffic and CVEFs around that high truck traffic area, together with the WIM location map of District 7. The map shows the junction routes include Interstates 205, 120, and 4. WIM site #44 on Interstate 205 is close to its junction with Interstate 5; it is possible that part of the truck traffic along that high truck traffic area on Interstate 5 comes from or exits to Interstate 205 and is examined by WIM site #44. Therefore, it is necessary to examine the CVEF coverage across different junction highways for a more accurate assessment.

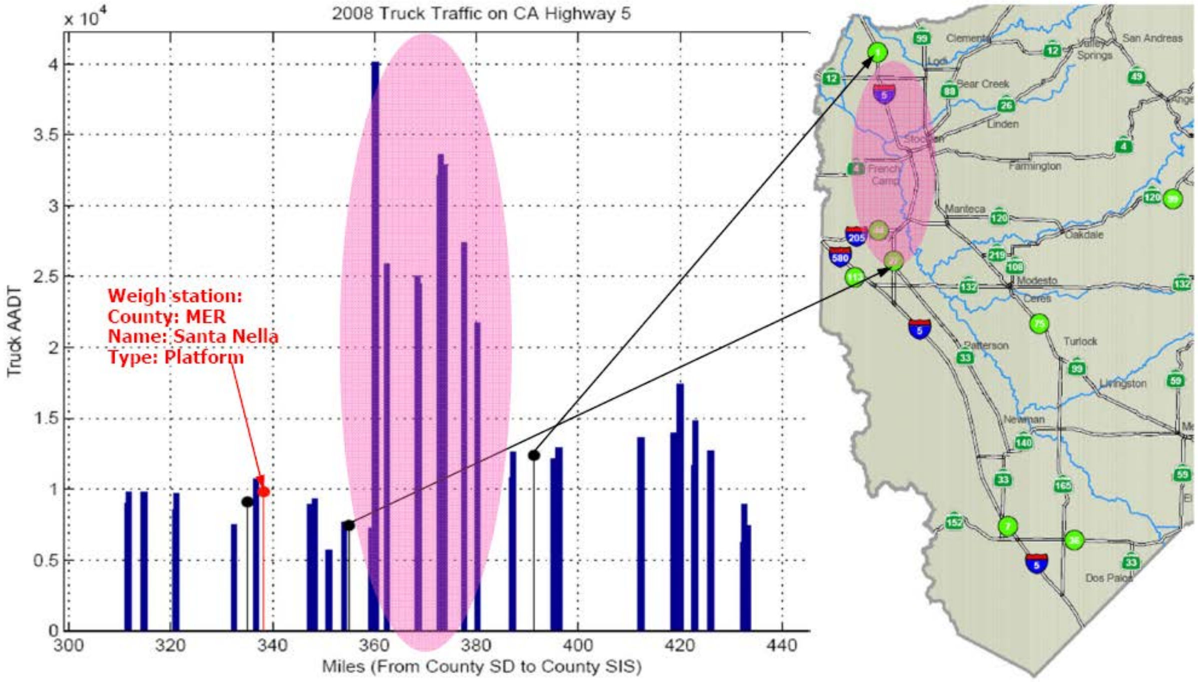

Figure 4.3 CVEFs and Truck AADT along Interstate 5 (details) with District 7 Map

4.4 Identification of High Truck Traffic Areas That Lack CVEF Coverage

Since there are a total of 242 state highways and 3,498 count locations in the 2009 truck traffic data, it would be time consuming to manually examine each state highway and its junction highways. Therefore, we adopted a two-step process as follows.

Step 1: Categorization of State highways. For each state highway, its truck traffic and CVEFs were examined to identify high truck traffic areas and evaluate CVEF coverage. Each state highway was then classified into one of six categories.

Step 2: Two-dimensional evaluation of truck traffic and CVEF coverage. For each of the state highways that fall into the most critical category, all of its junction routes around the high truck traffic areas were identified and included in the analysis. The truck traffic data as well as CVEF locations along both the highway of interest and the junction highways were imported into Google Earth for a 2-dimensional evaluation to provide a more accurate assessment of CVEF coverage.

4.4.1 Categorization of State Highways based on Truck Traffic and CVEF Coverage

The goal of the categorization is to provide a relatively complete picture of truck traffic and CVEF coverage along all the state highways. Based on the 2009 truck traffic statistics shown in Table 4.1, we chose two AADT thresholds, 5,000 and 10,000, to distinguish three levels of truck traffic:

- Low truck traffic if the truck AADT is smaller than 5,000,
- Medium truck traffic if the truck AADT is between 5,000 and 10,000,
- High truck traffic if the truck AADT is larger than 10,000.

As summarized in Table 4.1, among the 3,498 count locations, there are 2,512 (71.8%) count locations with low truck traffic, 536 (15.3%) count locations with medium truck traffic, and 450 (12.9%) count locations with high truck traffic.

With the above truck traffic levels, six categories were defined for the evaluation of the truck traffic and CVEF coverage along state highways:

A. State highways with low truck traffic[21] and at least one CVEF;
B. State highways with low truck traffic and no CVEF;
C. State highways with medium or high truck traffic and well-located CVEFs (which means that there are CVEFs located right at the areas with medium or high truck traffic);
D. State highways with medium truck traffic and at least one CVEF, however, the CVEFs are located away from the areas with medium truck traffic;
E. State highways with medium truck traffic but no CVEF;
F. State highways with high truck traffic and either no CVEF or CVEFs that are located away from areas with high truck traffic.

Generally speaking, among the six categories, Category A and C are most ideal in terms of CVEF coverage; Category B is not critical, due to its low truck traffic. Categories D and E are where the CVEF coverage could be improved, while Category F is the most critical; highways that fall into this category are most likely in need of future CVEFs[22]. As described with Figure 4.3, the highlighted segment of Interstate 5 falls into Category F.

Another example is provided here with Interstate 680. Figure 4.4 shows the truck traffic and the CVEF locations along Interstate 680; unlike the truck traffic figures shown in previous sections, truck traffic traveling in (OK? sentence is unclear) the two directions of I-680 is plotted separately, with the upper plot showing the truck traffic for the ahead leg[23], and the lower subplot showing the truck traffic for the back leg. Similarly, the CVEFs are also plotted into separate subplots, according to the highway leg on which they are located. If a CVEF covers both directions of the highway, it will be plotted in both the upper and the lower subplots.

The maximum truck AADT along Interstate 680 is over 10,000; therefore, Interstate 680 was considered a highway with high truck traffic. Two weigh stations and one WIM site are located along Interstate 680. The weigh station at Mission Grade (shown at the left in the upper plot) is about 10 miles away from the count locations with the two largest truck AADT. The fluctuation of the truck traffic between these two count locations are not dramatic. Therefore, we consider the weigh station at Mission Grade to be relatively well located. Similarly, the weigh station at Walnut Creek is also well located to monitor the medium level truck traffic at its corresponding segment of Interstate 680. Thus, Interstate 680 was classified as Category C: state highways with medium or high truck traffic and well-located CVEFs.

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[21] This means that the maximum truck AADT along the specific highway is smaller than 5,000.

[22] The categorization is based on analysis along each highway; the effects of CVEFs located at junction highways will be taken into consideration in Step 2 of this analysis.

[23] A leg is given for each count location and is denoted by an A (ahead leg), B (back leg), or O (equal volume both directions). Ahead leg corresponds to the route direction (from south to north or west to east). Back leg corresponds to the opposite of the route direction. The denotation O indicates that traffic volume is equal for both directions; in such cases the corresponding traffic volume is plotted in both the upper plot and the lower plots.

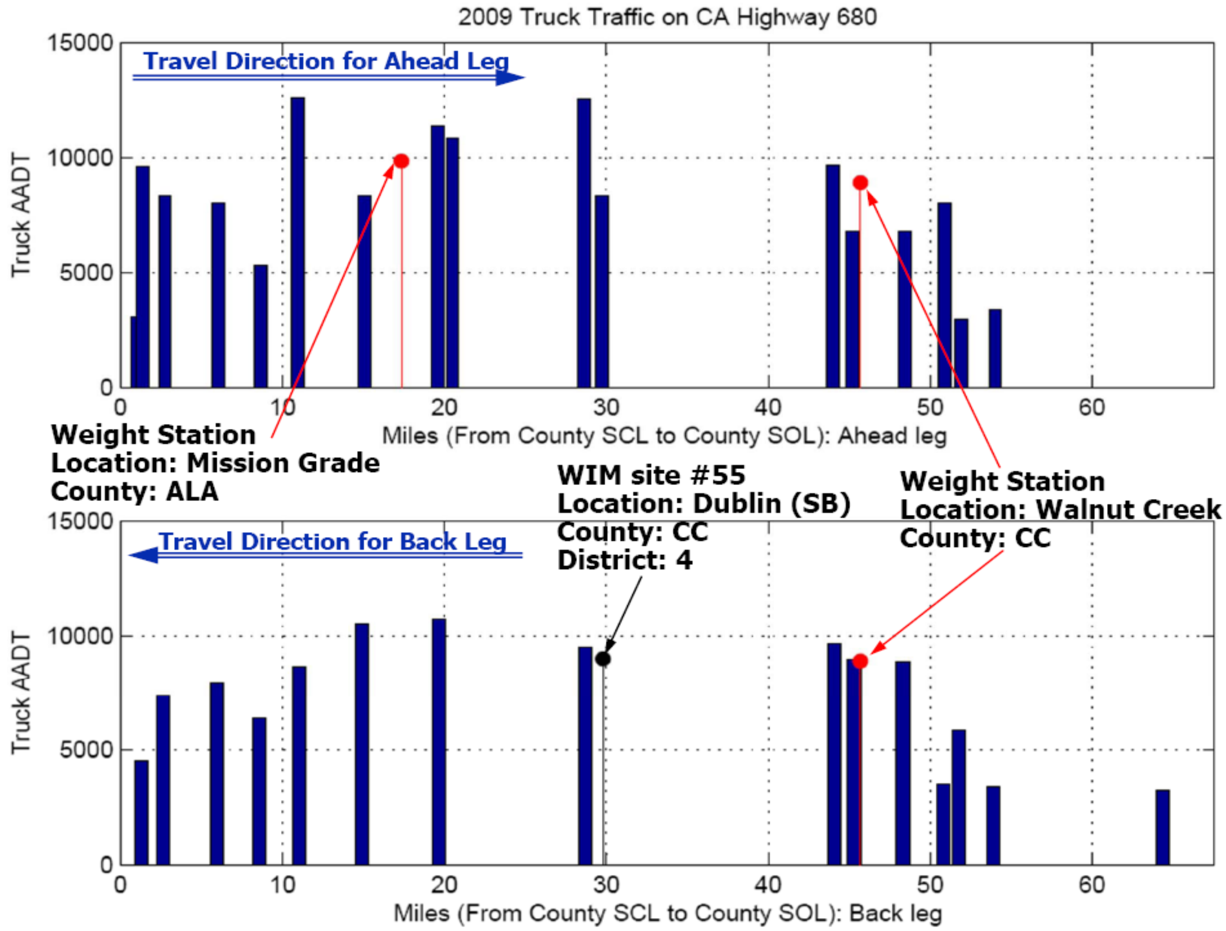

Figure 4.4 Truck traffic and CVEFs along Interstate 680 (Category C)

Following the same process, we classified each of the 242 highways from the 2009 truck traffic data into the six categories. Table 4.2 summarizes the classification results.

Table 4.2 Distribution of the Classification Results

Category	Description	Number of Highways
A	State highways with low truck AADT and at least one CVEF	17
B	State highways with low truck traffic and no CVEF	169
C	State highways with medium or high truck traffic and well-located CVEFs	21
D	State highways with medium truck traffic and at least one CVEF, however, the CVEFs are located away from the areas with medium truck traffic	10
E	State highways with medium truck traffic but no CVEFs	9
F	State highways with high truck traffic and either no CVEFs exists or CVEFs are located far away from the areas with high truck traffic	15

The 15 state highways that fall into Category F, the most critical category, include eight state highways (Interstates 22, 51, 105, 110 134 237, 238, and 605), which have no CVEFs and seven state highways (Interstates 5, 58, 65, 101, 120, 215, and 880) where CVEFs are located away from the locations with high truck traffic. These 15 highways are to be further examined together with truck traffic and CVEFs at junction routes in the next subsection.

4.4.2 Two-Dimensional Evaluation of Truck Traffic and CVEF Coverage

The two-dimensional evaluation was conducted by converting the post mile values of count locations and CVEF locations to GPS locations, then importing the truck traffic data and CVEF locations into Google Earth. Figure 4.5 shows the count locations and the CVEF locations along Interstate 5 in Google Earth. The blue and red drops represent count locations along the ahead and back legs[24], respectively. The magenta and red pins represent the locations of WIM and weigh stations, respectively (no mini-site weigh stations are located along Interstate 5).

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[24] When two count locations are at exactly the same location, Google Earth overlays them such that only one is visible from this distance. Thus, there appear to be more blue drops than red drops in Figure 5.5.

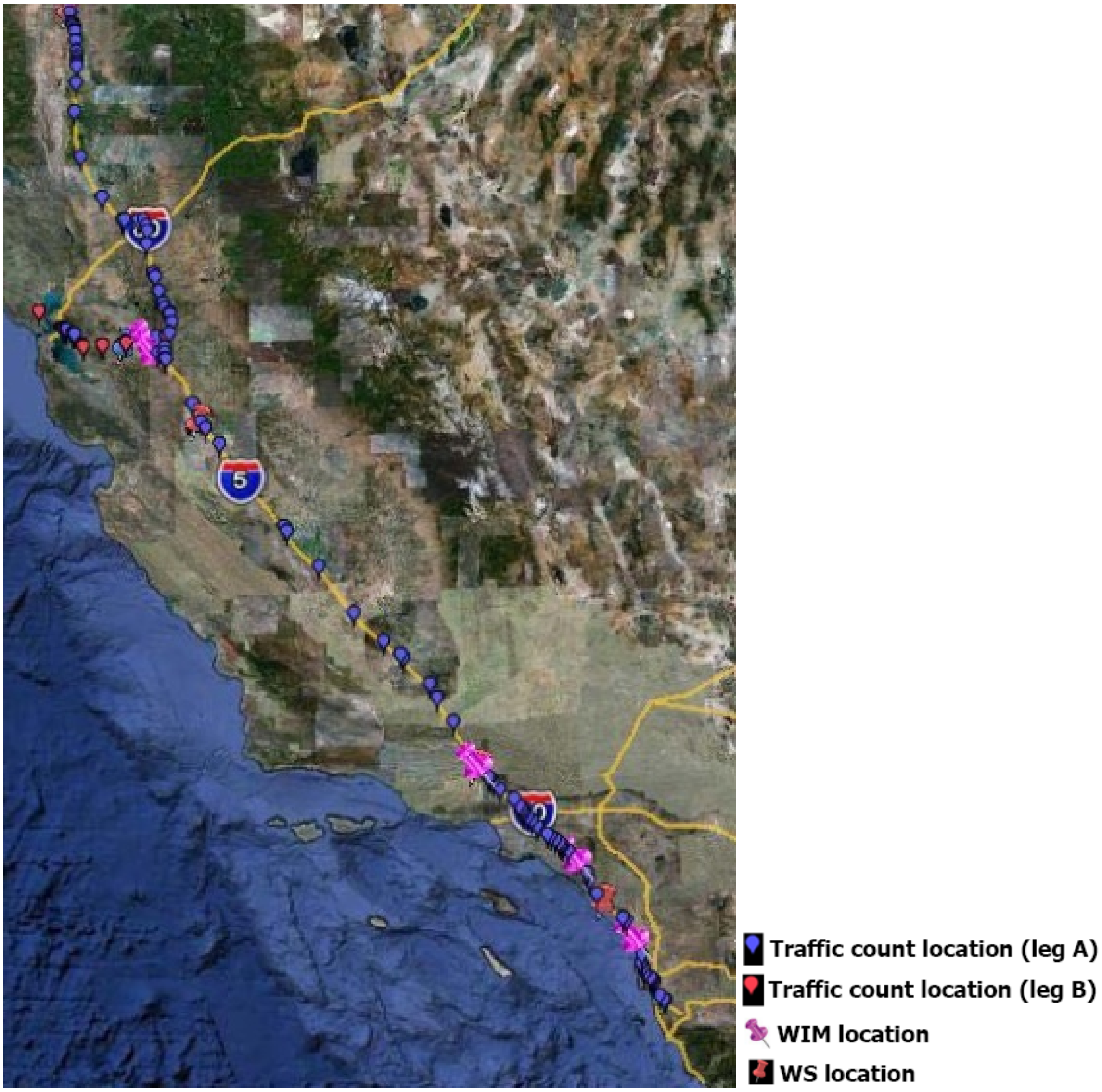


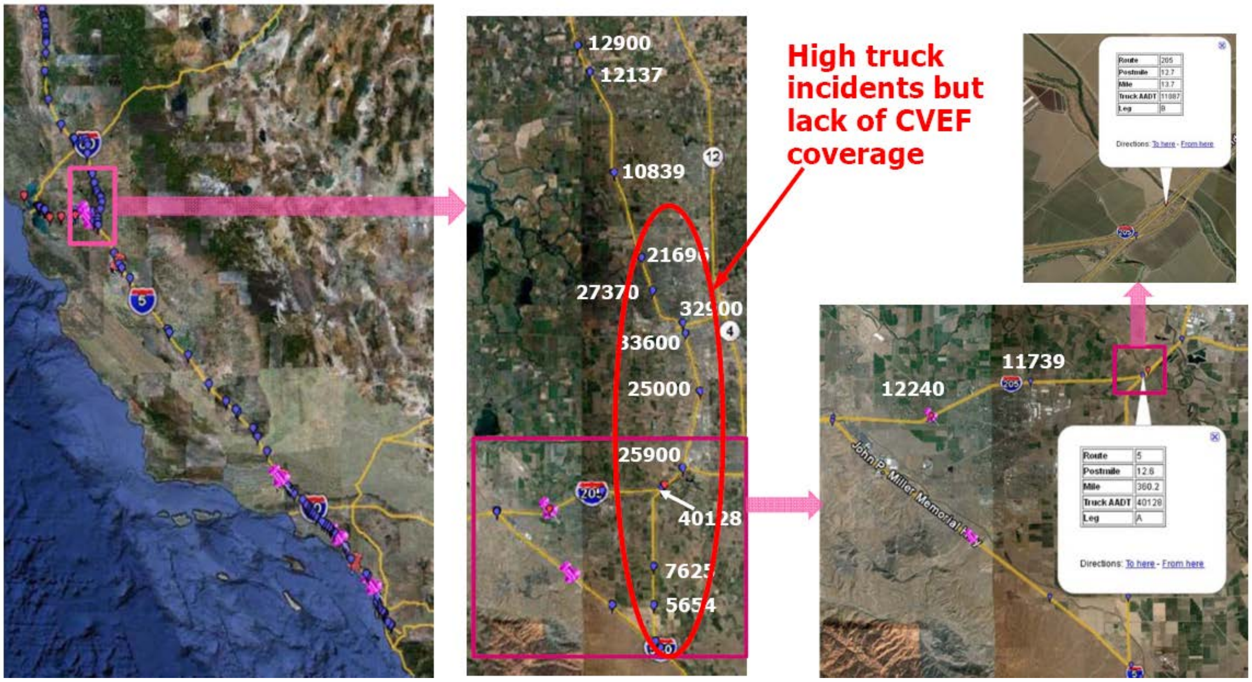
Figure 4.5 View of Truck traffic and CVEF locations along Interstate 5 in Google Earth

<u>Case Study #1: Interstate 5</u>

As described earlier with Figures 4.1 and 4.2, a high truck traffic area along the ahead leg (i.e., north-bound) of Interstate 5 between WIM sites # 27 and #1 is likely not covered by an existing CVEF . In Google Earth, we could locate this specific area (marked by a pink square in Figure 4.6a) and zoom into this area (shown in Figure 4.6b). Figure 4.6b shows that a long stretch of the segment along Interstate 5 (see the circled area) had truck AADT above 20,000 but no CVEF coverage. The maximum truck AADT was 40,128, right at the junction with Interstate 205. Figure 4.6c shows the zoom-in view of the triangle formed by Interstates 5, 205, and 580. Although there is a WIM site (#44) on Interstate 205, truck traffic through that WIM site is about 12,240, only one quarter of the maximum truck AADT on Interstate 5.

On the other hand, the truck AADT reduces from its maximum value of 40,128 to 25,900 at the next count location along the ahead leg of Interstate 5. Examination of truck traffic on Interstate 120 at this junction revealed that a truck AADT of 12,328 showed up at a count location on

Interstate 120, indicating that a quarter of the truck traffic left Interstate 5 and entered Interstate 120. The truck traffic at the next count location along Interstate 120 reduced to 2,073 and there are no CVEFs in between; therefore, those trucks were not examined by any CVEFs. As a result, we concluded that the high truck traffic area on Interstate 5 between WIM sites #27 and #1 (i.e., the area marked by the red circle in Figure 4.6b), indeed lacks CVEF coverage.



Route	205
Postmile	12.7
Mile	13.7
Truck AADT	11087
Leg	B

Directions: To here - From here

Route	5
Postmile	12.6
Mile	360.2
Truck AADT	40128
Leg	A

Directions: To here - From here

(a) (b) (c)

Figure 4.6 Two-dimensional analyses (Interstate 5) using Google Earth (The numbers shown are the truck AADT): (a) overall view of Interstate 5; (b) view of the high truck traffic area; (c) view of the junction highways

<u>Case study #2: Interstates 101 and 134</u>

Interstate 101 was also classified as Category F and Figures 4.7 and 4.8 depict the situation. Figure 4.7 shows the truck traffic and CVEFs along a segment of Interstate 101. The yellow and pink shaded areas highlight where the high truck traffic areas are, while the blue shaded area marks the nearest CVEFs. Around the nearest CVEFs, the truck AADT reduced by more than 15,000 from the maximum truck AADT value, suggesting that the majority of the trucks in the high truck traffic areas did not pass through those CVEFs. Figure 4.8 shows the same segment of Interstate 101 in Google Earth with the shaded areas corresponding to the shaded areas in Figure 4.7.

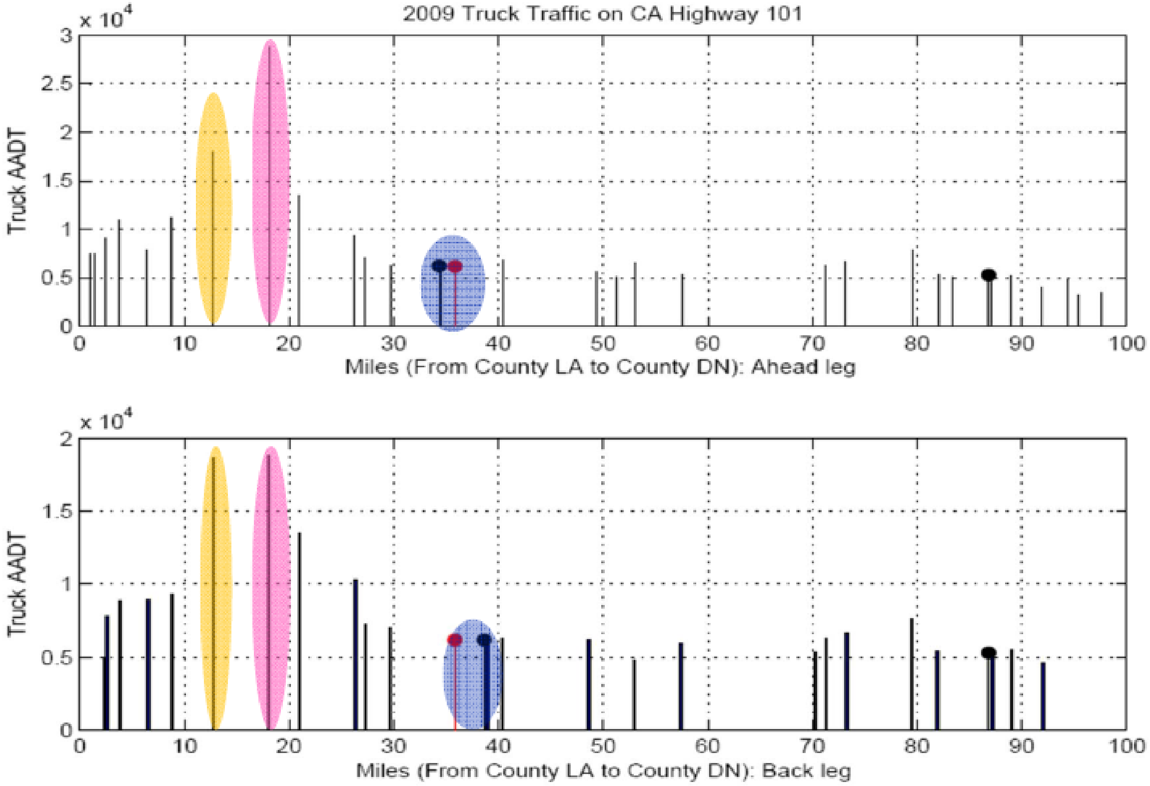


Figure 4.7 Truck traffic and CVEF locations along a segment of Interstate 101

Figure 4.8 View in Google Earth (The shaded areas correspond to those in Figure 4.7)

To facilitate the two-dimensional evaluation, the truck AADT along Interstate 101 and the junction highways (Interstates 405 and 134) is marked at the corresponding count locations as shown in Figure 4.8. At the junction between Interstates 101 and 134, a large number of trucks (approximately 14,546, based on the truck AADT on a count location on Interstate 134 before the junction) entered Interstate 101 from Interstate 134, leading the truck AADT on Interstate 101's ahead leg to increase from 1,7942 to 28,792. On the back leg of Interstate 101, the truck AADT increased from 10,283 to 18,860 where Interstate 101 meets Interstate 405, while the truck AADT decreased by about 3,000 on Interstate 405. These changes likely indicated that more trucks entered

Interstate 101's back leg from Interstate 405. Similarly, there was an approximately 9,000 decrease in truck AADT along the back leg of Interstate 101 when Interstate 101 and Interstate 134 diverge; this decrease likely indicated that a large number of trucks continued to Interstate 134 instead of staying on Interstate 101. However, there is no CVEF on Interstate 134; therefore, a large number of trucks (approximately 14,000 on each direction) were not covered by any CVEF. As a result, we concluded that the area marked by the red ellipse in Figure 4.9 is a high truck traffic area that lacks CVEF coverage.

Figure 4.9 Two-dimensional Analyses (Interstate 101) using Google Earth

By applying this analysis process to the 15 highways in Category F, we were able to verify that the high truck traffic areas identified along each of the 15 highways indeed lacked CVEF coverage. Table 4.3 summarizes those areas in terms of their corresponding count locations.

Table 4.3 High truck traffic areas that lack CVEF coverage

Interstate	Maximum Truck AADT	County	Post mile (A: ahead leg, B: back leg)
5	40128	SJ	12.623 ~ 32.9 (A), 20.951~25.365 (B)
22	12006	ORA	0.66~7.829(A), 7.829~10.478 (B)
51	15418	SAC	3.688 (B)
58	16250	KER	52.36~55.404 (A), 51.807 (B)
65	15855	PLA	4.863 (A)
101	28792	LA	11.747~19.99 (A and B)
105	17829	LA	2.106~17.823 (A and B)
110	20196	LA	4.061~25.751 (A and B)
120	12328	SJ	0.493 (A)
134	14546	LA	5.47 (A and B)
215	10085	RIV	23.537~38.339(A), 35.76~43.27 (B)
		SBD	0.402~9.364 (A), 4.052~8.603 (B)
237	9140	SCL	9.335 (B)
238	16625	ALA	14.469~14.951 (A)
605	25344	LA	5.046~20.189 (A and B)
880	24182	ALA	8.842~31.091 (A and B)

In summary, this section describes the identification of areas that have high truck traffic volumes but lack CVEF coverage. Our analysis involved three elements: the identification of areas with high truck traffic volumes based on truck traffic data, the evaluation of CVEF coverage based on CVEF location data, and the identification of high truck traffic areas that lack CVEF Coverage. The identification of areas with relatively high truck traffic volumes was based on truck traffic data collected across California, while the evaluation of CVEF coverage was conducted by locating the CVEFs along each corridor and examining their locations against the truck traffic. A high truck traffic area was considered well-covered if there was at least one CVEF nearby and the truck traffic did not decrease significantly at the CVEF. All of the 242 state highways were then classified into six categories, according to their truck traffic and the corresponding CVEF coverage. Among them, 15 state highways were classified into the most critical category: state highways with high truck traffic and either no CVEFs exist or CVEFs are located far away from the areas with high truck traffic. These 15 state highways were then further examined together with truck traffic and CVEFs at junction routes to obtain a more accurate assessment. Accordingly, the high truck traffic areas lacking CVEF coverage were identified and summarized in Table 4.3.