Developing Safety Management Tools for State Departments of Transportation

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Two safety management tools have recently been developed for the California Department of Transportation (Caltrans). One is the continuous risk profile (CRP) approach, which is a network screening procedure, and the other is the California Safety Analyst (CASA), a web-based application designed to assist state safety engineers in conducting safety investigations and in documenting their findings. This paper provides a qualitative description of the two tools and summarizes feedback from more than 100 Caltrans safety engineers who attended demonstrations of the web-based application. Findings from both empirical analysis and the survey indicate that CRP can significantly reduce the false positive rate and that CASA can greatly improve the efficiency of traffic safety investigations. However, misunderstandings remain about the relationship between the CRP approach, other methods explained in the *Highway Safety Manual*, and different safety management tools. The misunderstandings create challenges for the deployment of CRP and CASA in California.

The 2012–2013 California state budget asserts that the California Department of Transportation (Caltrans) is expected to receive about $11.2 billion for the fiscal year as the owner and operator of more than 50,000 highway and freeway lane miles in California. Once the funding is received by Caltrans, $2 billion is expected to be allocated to the State Highway Operation and Protection Program (SHOPP), which funds major capital improvement projects that are necessary for preserving, protecting, and improving the safety of the state highway system. SHOPP managers state that the program needs about $7.4 billion to construct all the projects it has identified as necessary but that it will receive only $2 billon. Such a shortfall in funding imposes additional challenges on SHOPP managers, who must divide the program's funding among nine subcategories. One of the subcategories, collision reduction, will receive $346 million, and locations with a high concentration of collisions (i.e., hot spots) that are detected by Caltrans will be investigated via this category.

Caltrans initiated its hot spot identification program in the early 1970s and has continuously monitored traffic collisions that occur on its roadways in an effort to identify sites that might require additional improvement. As a result of these efforts, many sites have been improved. However, Caltrans understands that the existing hot spot identification procedure has a high rate of false positives (i.e., the procedure requires safety investigation of sites for which improvements are not needed) (*1*). Caltrans initiated projects to improve its detection rate. This paper reports on two tools that have been developed to help Caltrans improve its hot spot detection rate and make the investigation procedure more efficient.

BACKGROUND

In addition to traffic collision data, safety performance functions (SPFs) (i.e., mathematical relationships observed between explanatory variables and traffic collision frequency) and network screening procedures play a critical role, not only in detecting hot spots but also in estimating the economic benefits of proposed countermeasures. Therefore, any errors that are introduced in estimating SPFs and that result in the application of an unsuitable network screening procedure will adversely affect the hot spot detection program. The subsection below discusses how errors can be introduced in the estimation of SPFs. The subsection after that explains various issues related to the network screening procedure.

SPFs and Performance Measurement

Most of the SPFs that are used by state agencies include only annual average daily traffic (AADT) as an explanatory variable. However, AADT is not the only explanatory variable that needs to be included in the SPF (*2*).

Other explanatory variables are omitted from the SPFs that state agencies use because of the lack of databases for monitoring those variables. For a state agency without a comprehensive database, the cost of building one can be prohibitive (*3*). The lack of complete data imposes challenges in estimating the true form of the SPF through the use of only a structural model: data are not available for explanatory variables that are believed to affect the SPF.

Even if the data are available, the estimation of a regression model for the SPF may result in standard errors so large that they may render many of the estimated coefficients insignificant and the standard errors of forecast unacceptably large. To make matters more challenging, the estimated value of the regression coefficients may depend on how the collision data are segmented. This topic is discussed later in the paper.

After SPFs are estimated, state agencies need to select a performance measure that will be used to detect and rank the sites for safety investigation. The *Highway Safety Manual* (HSM) (*4*) discusses 13 performance measures, as shown in Table 1 (see first column).

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TABLE 1 Data and Input Needs for Performance Measures (*4*)

	Data and Inputs				
Performance Measure	Crash Data	Roadway Information for Categorization	Traffic Volume	Calibrated Safety Performance Function and Overdispersion Parameter	Other
Average crash frequency	X	X	—	—	—
Crash rate	X	X	X	—	—
EPDO average crash frequency	X	X	—	—	EPDO weighting factors
Relative severity index	X	X	—	—	Relative severity indices
Critical rate	X	X	X	—	—
Excess predicted average crash frequency using method of moments	X	X	X	—	—
Level of service of safety	X	X	X	X	—
Excess predicted average crash frequency using SPFs	X	X	X	X	—
Probability of specific crash types exceeding threshold proportion	X	X	—	—	—
Excess proportion of specific crash types	X	X	—	—	—
Expected average crash frequency with EB adjustment	X	X	X	X	—
EPDO average crash frequency with EB adjustment	X	X	X	X	EPDO weighting factors
Excess expected average crash frequency with EB adjustment	X	X	X	X	—

NOTE: — = does not require that type of data and input. EPDO = equivalent property damage only, SPF = safety performance function, EB = empirical Bayes.

The second through fifth columns of Table 1 present the required data and input information (indicated by "X") to estimate the performance measure. Among the 13 performance measures, Caltrans has been using the critical rate. Previous studies (*5–7*) and the HSM recommend excess expected average crash frequency with empirical Bayes adjustment as the best performance measure. This can be explained with the help of Figure 1.

Suppose the white circle labeled O in Figure 1 is the observed collision frequency at a site. The observed value is readjusted by combining it with the SPF by using its overdispersion factor to estimate the site's long-term expected collision rate, as indicated by the black circle labeled E. The vertical distance between E and the SPF is considered the potential for safety improvement (PSI), which has been used as a performance measure in ranking sites for safety improvements and comparing the performance of different hot spot identification procedures (*8*). Note that PSI is an estimate obtained by combining the SPF and the observed collision frequency from a site. This indicates that the estimated value of PSI can be affected by how the site is segmented, as further discussed in the next section.

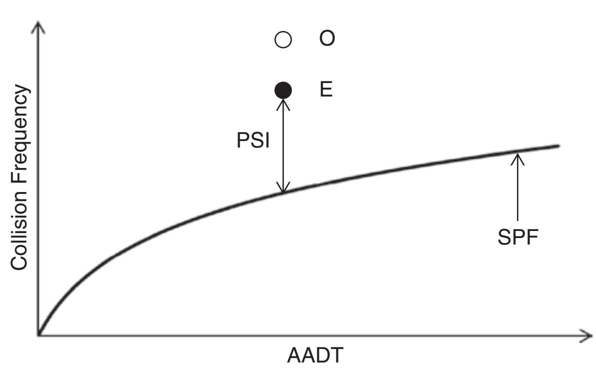

FIGURE 1 Empirical Bayes performance measure (*8*).

Site, Segment, and Roadway Group

More than one guideline for defining a roadway group exists (*1, 4*), and each roadway group that a state agency defines has an SPF associated with it. A roadway group can be subdivided into segments whose endpoints may be marked by changes in the values of the features that define the roadway group or in other values.

Suppose the roadway groups are classified only by the number of lanes. The endpoints of a segment can be designated to coincide with the locations where the number of lanes changes (i.e., a change in the feature that defines the roadway group). In addition, the endpoints of a segment can be marked by changes in AADT or high-occupancy-vehicle lane access points, depending on the agency's definition of a segment. The HSM discusses guidelines for segmenting roadways but does not explicitly state which procedure a state agency should follow in defining a segment (e.g., Figure 1).

After a segment is defined, the size of a site (i.e., the unit of a hot spot) needs to be determined by a network screening procedure. The HSM (*4*) introduces two network screening procedures: the sliding window method (SWM) and the peak searching method (PS). The challenge in using these approaches is that they require defining the size of a site before the data are analyzed, and the resulting hot spot list can vary significantly with the size of the site and the changes in SPFs (*8*). Hauer et al. (*9*) aptly described the challenges in choosing the size of a site and invite researchers to investigate other network screening methods with empirical data. To overcome the issues observed in estimating SPFs and the shortcomings of SWM and PS, Chung et al. proposed another network screening procedure, the continuous risk profile (CRP) approach (*10, 11*).

TWO TOOLS DEVELOPED FOR CALTRANS

The CRP method was identified as the most deployable research project under a Caltrans research project titled Promoting Research Results and New Technologies: Making the Case for Accelerated Deployment in 2009. The project received \$100,000 funding for the evaluation of its implementation. In 2010, an additional \$264,408 was received to compare the performance of the CRP method with that of the existing high collision concentration location identification method. As part of the research project, the research team also developed the California Safety Analyst (CASA) web-based application. Descriptions of CRP and CASA are presented in the following subsections.

Continuous Risk Profile

The CRP method first filters out the random noise in the data by using a weighted moving average technique and continuously plots the collision risk profile along a roadway segment, as shown by the bold line labeled CRP in Figure 2*b* (*8*). The predicted collision frequency based on the AADT for the segment is then obtained from the corresponding SPF (see F_1 and F_2 in Figure 2*a*). The unit of the value obtained from the SPF is converted into the unit comparable to CRP to be plotted together as shown by the dotted line labeled SPF in Figure 2*b*. The endpoints of a site are defined by locations where the CRP exceeds the dotted line (see locations labeled *s* and *e* in Figure 2*b*). Thus, the size of a site defined in the CRP method is not influenced by endpoints of segments.

The area between the horizontal dotted lines (i.e., SPFs) and CRP denotes the excess crash frequency (light gray area labeled *A* in Figure 2*b*). The area enclosed by s_i, e_i, and the dotted lines (dark gray area labeled *B* in Figure 2*b*) denotes the crash frequency of the SPFs. $A_i + B_i$ is the observed collision frequency (white circle in Figure 1), which is readjusted by using the empirical Bayes method (black circle in Figure 1) to estimate the PSI in the same manner to rank sites for safety investigation. The area $A_1 + B_1$ is the total number of collisions between s_1 and e_1 and is approximately the same as the actual number of collisions reported between s_1 and e_1.

The performance of the CRP approach has been empirically evaluated and compared with that of SWM and PS (*8*). The findings indicate that CRP produces a much lower rate of false positives and that the false negative rates (i.e., failure to identify sites that require improvement) of the three network screening procedures were comparable.

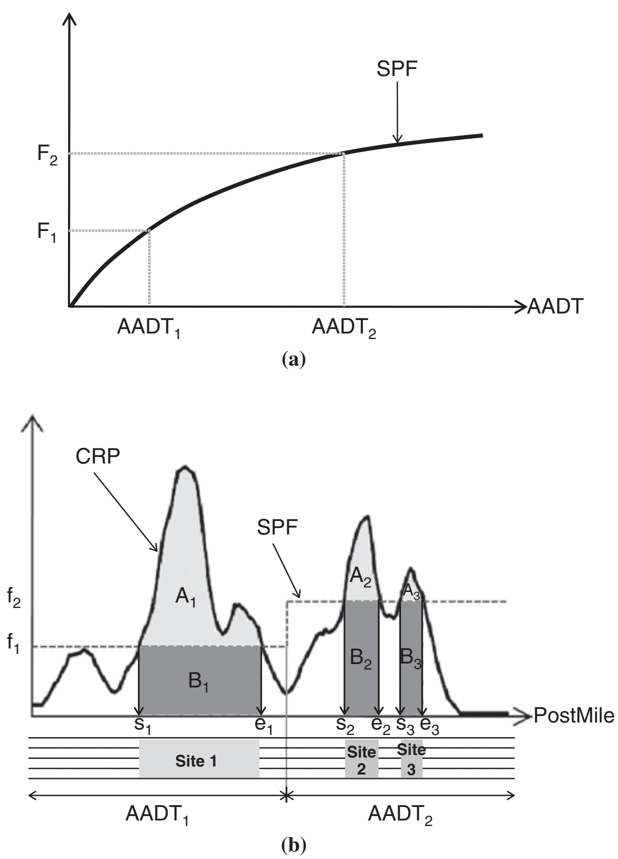

FIGURE 2 Continuous risk profile (CRP).

Traffic Investigation Report Tracking System and CASA

Caltrans uses the Traffic Investigation Report Tracking System (TIRTS) to document and track the findings from safety investigations. With TIRTS, safety engineers can retrieve traffic collision data in the vicinity of the site that they need to investigate. However, the system does not offer other relevant information (e.g., location of safety improvement projects in the vicinity, pictures previously taken at the site). As a result, safety engineers need to contact various functional units to obtain the necessary information—which prolongs the data-gathering process.

To expedite the gathering of required information, documentation, and improvement of the user interface, the research team developed a web-based application: CASA. Figure 3 shows a screenshot of CASA; the various modules of CASA are enclosed in the dotted box labeled A.

The information that is stored under the "my list" and "my report" tabs (inside the box labeled A in Figure 3) is unique to each user. There are currently three types of CASA accounts: administrator, supervisor, and safety engineer. The supervisors' and safety engineers' accounts are linked so that when a safety engineer submits a report under my list or my report, the report will be sent to the safety engineer's supervisors for approval. Once the report is approved, it can be accessed under "list" or "report" by anyone who has a CASA account with the appropriate permissions.

Under the "analysis" module (Figure 3), the user can enter location information by entering the post mile (see R 24.524 and R 38.642 in Figure 3) or simply by clicking two points on the map (see the balloons in the figure). After specifying the location, the user can select the time period by year, month, and date (see the boxes under time period in Figure 3). The options displayed next to "display options" enable users to access reports and to see the locations of the projects that are funded by different types of programs shown on a map. Note that in Figure 3, the box next to SHOPP has been checked. When this option is selected, the project location within the post miles (see the balloons in the figure) will be displayed on the map (see the circles in the figure). The detailed information related to these projects can be viewed by clicking the circles (see Figure 4).

FIGURE 3 CASA main page (*12*).

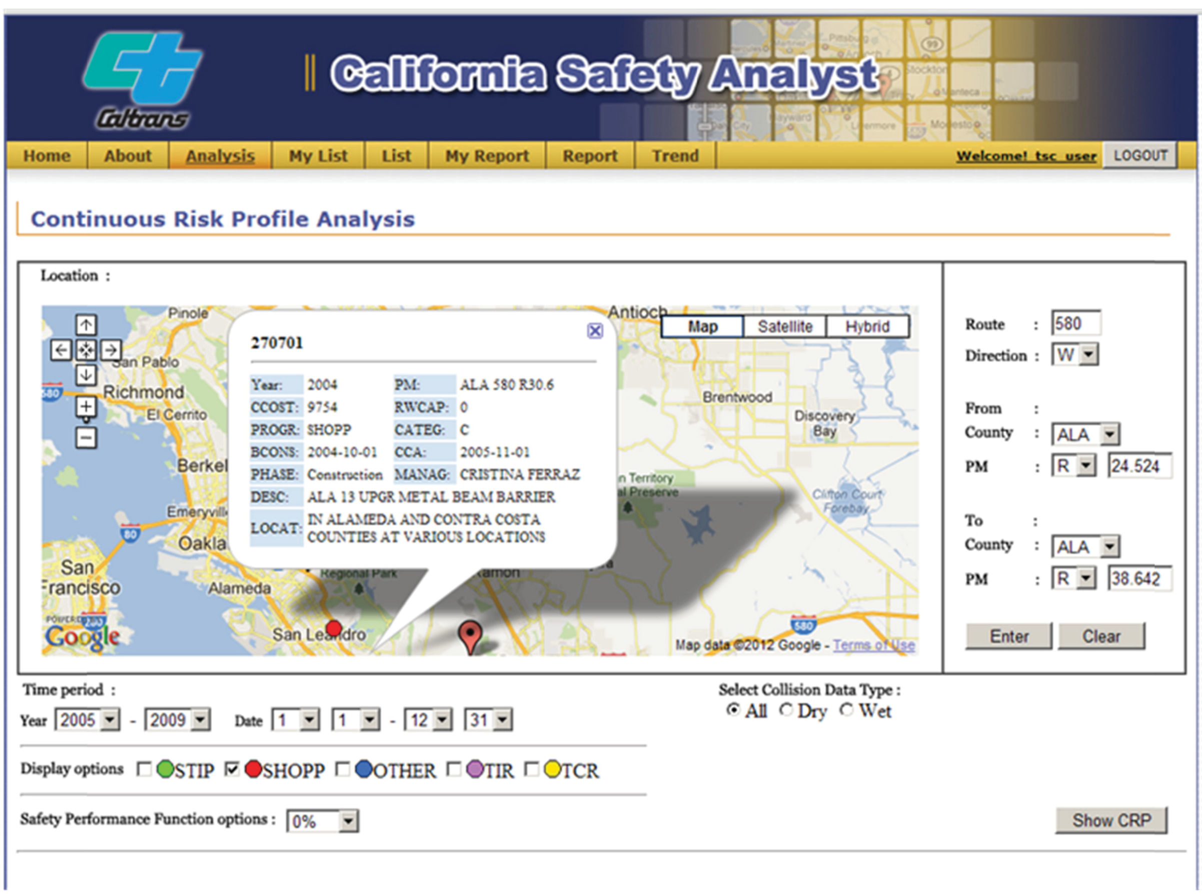

FIGURE 4 CASA analysis module (*12*).

Note that the dropdown box located next to "safety performance function options" is set to 0%. Changing this value to 70% or 90% and clicking the "show CRP" button will display the excess 30% or 10% CRP, respectively. In this example, 0% has been chosen so that the CRP plots presented in Figure 5 show the collision profile from 2005 to 2009.

The CRP from various years is displayed vertically for visual comparison across years, and the *x*-axis shows the corresponding absolute post mile (*13*) of the location information during the location selection step (see Figure 5*a*). Choosing the "select mode" button will display a vertical line (see Figure 5*b*). The user can conduct detailed analysis by placing those two vertical lines to select a subsegment (see Figure 5*c*) and clicking the "detailed analysis" button shown in Figure 5*a*. Similarly, the user can conduct before-and-after and proactive detection analysis by clicking "before & after report" and "proactive detection report," respectively.

The proactive detection report evaluates the subsegment to generate statistics showing whether the site is likely to become a hot spot within the next few years on the basis of the proactive detection procedure using CRP (*11*). The before-and-after report estimates the benefit–cost ratio of the project by considering the spillover benefit (*10*). "Detailed analysis" generates the report shown in Figure 6.

The subsection selected in Figure 5 is displayed on the map (Figure 6*a*). The route, time period, and location information are displayed for confirmation, and the data evaluated in the analysis can be downloaded in Excel format.

Figures 6*b* and 6*c* show some of the statistics that are produced under the "detailed analysis" module. Figure 6*b* shows the CRP during the most recent years (*10*) and shows collision distribution by time of day (see "time of day analysis"). The performance of the subsegment is also displayed together with the SPF (see "safety performance function analysis"). H62 (*1*) is the existing Caltrans highway rate group, and the figure shows the existing Caltrans SPF for this highway group. Note that the figure also shows that the safety level of the facility has been changing over time (see the circles in Figure 6*b* under "safety performance function analysis"). Moving the cursor on top of the circles will display the year.

Comparison of the subsection and the entire routes is also reported. Within this module, types of collision can be further selected to meet safety engineers' specific needs (see Figure 6*d*).

In developing CASA, the research team included all of the functions in TIRTS along with additional features that the safety engineers and their managers requested, such as display of additional relevant project information. With CASA, safety engineers can attach pictures taken at the investigation site as well as as-built plans, which can save a significant amount of time when safety engineers need to gather information to prepare for litigation. CASA provides flexibility in screening facilities to locate sites such as "hot spot locations based on traffic collisions that only occur in the median lane on rainy days during peak hours." Such flexibility was invaluable in comparing the safety levels of different types of high-occupancy-vehicle lanes (*14*) and in determining the proposed locations of variable speed limit signs along I-80 (*15*).

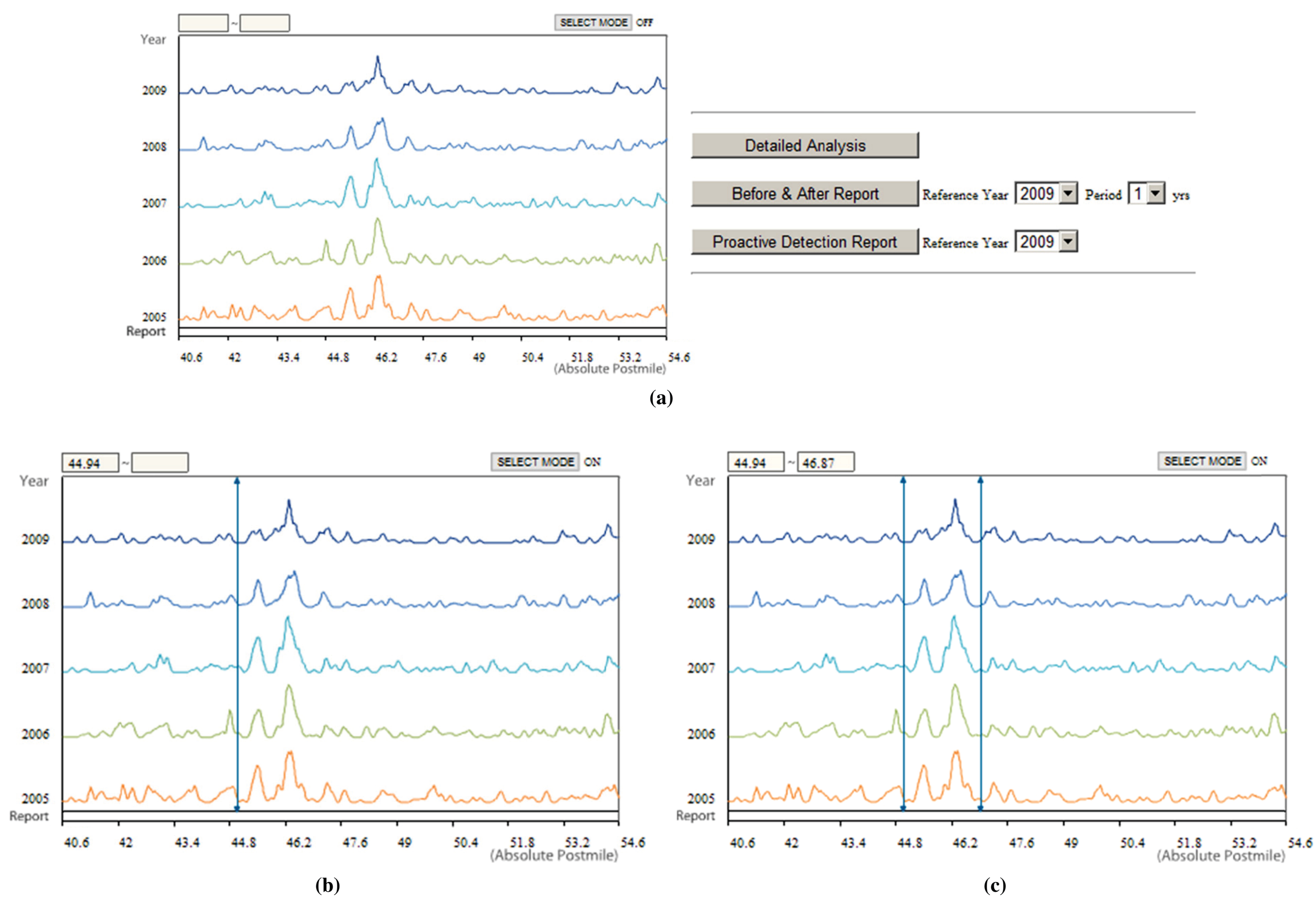

FIGURE 5 Collision profile from 2005 to 2009 (*12*).

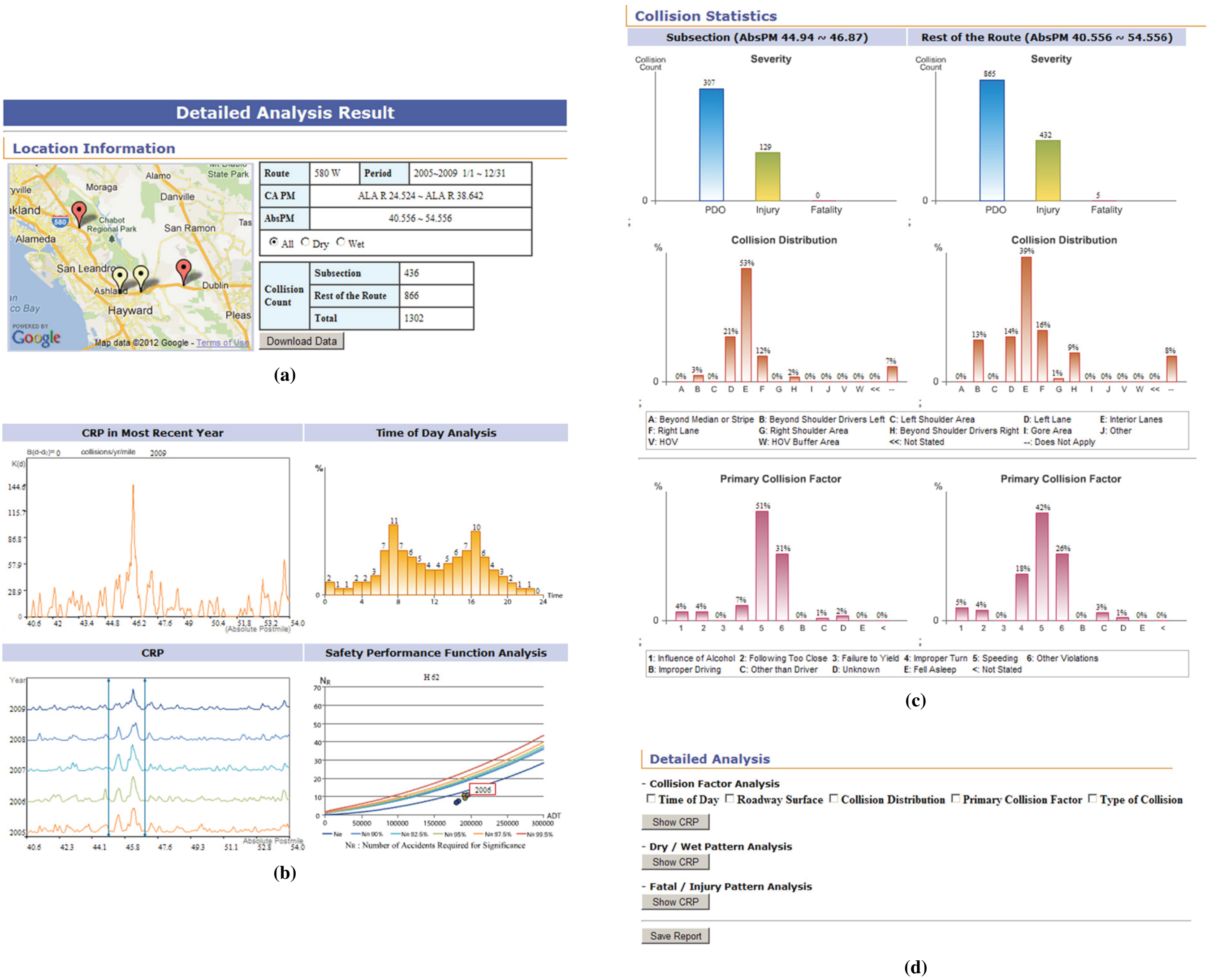

FIGURE 6 Detailed analysis report (*12*).

When CASA was first demonstrated in Caltrans District 4 (see Figure 7), the project team received an enthusiastic response from safety engineers. The research team was encouraged to demonstrate CASA to safety engineers in all 12 Caltrans districts, and all districts except District 8 were visited. After each of the demonstrations of CASA, the safety engineers and managers who attended the workshop were asked to complete a survey about their impressions of the two tools.

In total, 98 respondents (excluding safety engineers from District 4) from 10 districts participated in the survey. The participants are primarily professionals involved in road safety management in their jurisdictions and represent local stakeholders. Figure 8 summarizes the average responses to the five survey questions. The survey indicates that safety engineers strongly agree that the use of CASA and CRP will improve their efficiency in performing their daily duties and that implementation of these tools and techniques should be a high priority for the agency. Many of the safety engineers followed up with the research team to volunteer their involvement in enhancing CASA and to learn when they can start using the application.

CHALLENGES FOR CRP AND CASA DEPLOYMENT

Despite such a strong demand for CASA and the fact that the system is cost-free for Caltrans, there are still issues that need to be resolved before statewide deployment of CASA.

Misunderstandings About the Tools

FHWA developed the HSM in an effort to assist state departments of transportation in detecting high collision concentration locations (*4*). The core logic of the HSM uses SPFs, and the manual describes two network screening procedures: SWM and PS. Chung et al. (*10, 11*) proposed a new network screening procedure, the CRP approach, that can be used with current Caltrans SPFs and with SPFs developed by FHWA. However, even some of the researchers (*17*) misunderstood CRP as a method that does not use SPFs and is not consistent with the procedure described in the HSM. Although most Caltrans employees who attended workshops understood that CRP is a network screening procedure, such misunderstanding of

FIGURE 7 Map of Caltrans districts (*16*).

the method was frequently observed even within Caltrans. The procedure for using the CRP method is consistent with the procedure explained in the HSM.

Misunderstandings of CASA were also observed. CASA can be used with any method that a state department of transportation decides to implement. CASA assumes that hot spots will be identified at the headquarters level, only a few times a year by administrators via either SWM, PS, or CRP. Once the hot spots are generated, CASA can be used to compile and maintain the relevant information in one location. CASA is designed to save safety engineers time in gathering information needed for safety investigations, documenting findings, and making the findings available to other users. Most of the safety engineers and managers who attended the workshop immediately understood the advantages of using CASA, as shown in Figure 8. However, some still view CASA as an entirely new procedure for detecting hot spots that contradicts the procedure recommended by the HSM.

Misunderstandings About the HSM and SafetyAnalyst

The HSM does not shield state departments of transportation from lawsuits. According to 23 USC 409, the HSM does not establish a legal standard of care, set requirements or mandates, contain warrants or standards, or supersede other publications. However, many individuals within state departments of transportation erroneously consider that following procedures described in the HSM will protect them in cases of litigation. Although the HSM offers invaluable information to safety engineers, adherence to HSM-described procedures should not be driven by the misconception that this will provide a shield against any potential litigation.

SafetyAnalyst is a software tool that adopts the procedures described in the HSM. As explained earlier in this paper, the core logic of the HSM uses SPFs. SafetyAnalyst comes with default SPFs; however, its parameters need to be calibrated by using local conditions (*18*).

From the perspective of an agency that does not have any tools to investigate sites detected by its hot spot identification method, nor a procedure for detecting high collision concentration locations, SafetyAnalyst can be an attractive alternative. However, for agencies that are already using other tools, another option would be to allocate resources to development of relational databases, system integration, and the tailoring of the reporting capability of the tool to the agency's needs, such as CASA.

CONCLUSION

Two tools have recently been developed for Caltrans. One is a new network screening procedure, and the other is a web-based application designed to assist safety engineers in accessing information needed

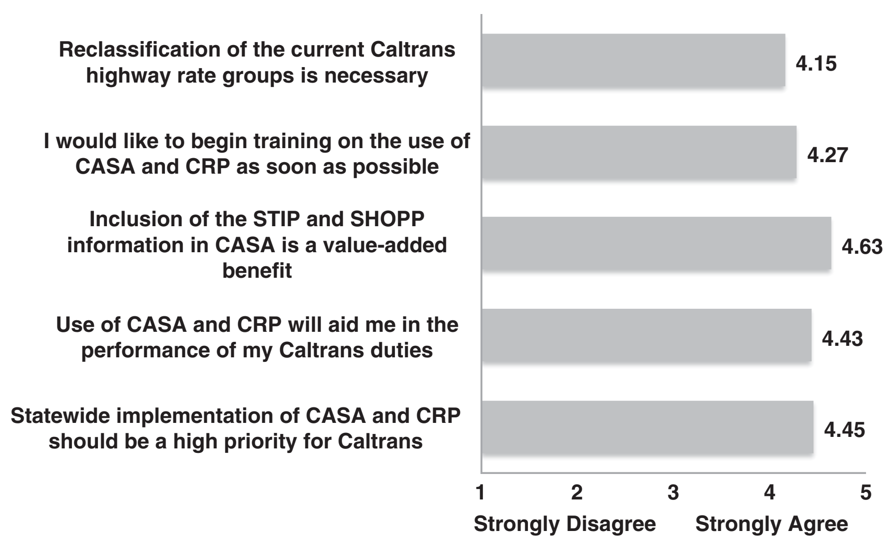

FIGURE 8 CASA survey responses across participating Caltrans districts (*n* = 98; STIP = State Transportation Improvement Program).

for safety investigation, documenting the findings, and sharing the information with other stakeholders.

The CRP approach is an innovative network screening procedure that allows SPF and traffic collision data to guide the selection of endpoints of sites for safety investigation. This approach can be implemented by any agency that uses either SWM or PS. The CRP approach can significantly reduce false positives and can be used as part of the hot spot identification that the HSM describes at the network screening level.

CASA is a prototype web-based tool that has been developed to meet the needs of Caltrans safety engineers. The advantage of CASA is that it was developed with research funding from Caltrans; therefore, Caltrans does not need to pay a license fee to use it. Since it is a web-based application, CASA's functions can easily be modified and tailored to meet the specific requirements of Caltrans and other government agencies.

Because of CASA's user-friendly interface, a number of safety engineers from various Caltrans districts have already requested this web-based tool and have even volunteered to be involved in beta version testing before statewide implementation. However, Caltrans has already committed to evaluating SafetyAnalyst, and further evaluation of CASA has been put on hold as of 2012.

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