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16. ABSTRACT

Accidents and injuries occur during maintenance activities that could be protected by the ArmorGuard or BalsiBeam mobile barrier systems. The main purpose of this study is to perform a scientific evaluation of the utility of the ArmorGuard system in Caltrans operations with the aim of providing a comparison of this system with the BalsiBeam system. The main research question involves determining the applicability and the cost benefit of using mobile barrier systems such as the ArmorGuard and the BalsiBeam in highway work zones and their comparative evaluation. Data from experimental evaluation and field demonstrations of the ArmorGuard system combined with comprehensive injury data collected in this research from work zone accidents provide the scientific basis for this study. The results include a product usage and deployment guidelines for the ArmorGuard mobile barrier system, a comparative cost benefit analysis of this system and the BalsiBeam system, and an operational comparison of the ArmorGuard system and other mobile barrier systems.

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Scientific Evaluation of the ArmorGuard Mobile Barrier System

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DISCLAIMER STATEMENT

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Accidents and injuries occur during maintenance activities that could be protected by the ArmorGuard or BalsiBeam mobile barrier systems. The main purpose of this study is to perform a scientific evaluation of the utility of the ArmorGuard system in Caltrans operations with the aim of providing a comparison of this system with the BalsiBeam system. The main research question involves determining the applicability and the cost benefit of using mobile barrier systems such as the ArmorGuard and the BalsiBeam in highway work zones and their comparative evaluation. Data from experimental evaluation and field demonstrations of the ArmorGuard system combined with comprehensive injury data collected in this research from work zone accidents provide the scientific basis for this study. The results include a product usage and deployment guidelines for the ArmorGuard mobile barrier system, a comparative cost benefit analysis of this system and the BalsiBeam system, and an operational comparison of the ArmorGuard system and other mobile barrier systems.

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DISCLAIMER/DISCLOSURE

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aerospace Engineering at the University of California – Davis, and the Division of Research and Innovation at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, State and Federal governments and universities.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California, the Federal Highway Administration, or the University of California. This report does not constitute a standard, specification, or regulation.

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Designation
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
AIS	Abbreviated Injury Scale
Caltrans	California Department of Transportation
CA 14	California 14
CHP	California Highway Patrol
DB	Database
DOT	Department of Transportation
DRI	Caltrans Division of Research and Innovation
M	Mobile
MAIS	Maximum Abbreviated Injury Scale
MBT-1	Mobile Barrier Trailer 1
SD	Short Duration
ST	Short Term
STS	Short Term Stationary
SHSP	Strategic Highway Safety Plan
TASAS	Traffic Accident Surveillance and Analysis System
US	United States
VSL	Value of Statistical Life

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EXECUTIVE SUMMARY

Accidents and injuries occur during maintenance activities that could be protected by the ArmorGuard or BalsiBeam mobile barrier systems. This research has involved experimental evaluations and cost-benefit analysis of ArmorGuard barrier and has compared it to the BalsiBeam barrier. This research has also provided support for the Challenge Area 14 of the California Strategic Highway Safety Plan in terms of developing a pilot database on highway work zone accidents demonstrating the usefulness of such information in addressing many work zone related questions and improving data collection, storage, and analysis for work zone crashes.

The significant findings are summarized below:

- The ArmorGuard barrier system can provide positive protection for workers over a long linear distance (224 feet using eight segments) with good visibility of work zone for the drivers. The BalsiBeam barrier, however, can provide only 30 feet of actual work area protection.

- At its full length of eight segments, the ArmorGuard barrier can deflect six feet in a moderate severity collision. Therefore, to avoid potential contact with the workers, it needs to be kept at least six feet away from the workers. This means that an additional half a lane of travel has to be blocked to provide the same working area for the workers. Furthermore, there are additional space requirements during deployment and takedown of this barrier bringing its lane closure requirements to 2 to 2.5 lanes. In comparison the BalsiBeam barrier has minimal (only up to 6 inches) deflection in a moderate severity collision and does not require closure of any lanes beyond those needed for the maintenance activity.

- ArmorGuard barriers, once deployed, can be easily maneuvered into position or moved around short distances by pulling or towing. They can also be rolled to a shoulder for overnight storage and then rolled out the next day. Their maneuverability can, however, be challenged in areas where the highway has high grades or cross slopes requiring more force to fight gravity in moving the barrier segments into position by the crew. A pickup truck can be used for towing in such situations or for movement over very short distances. The BalsiBeam system is fully movable for short and long distances without a need for an additional vehicle.

- At present, deployment of the ArmorGuard system requires approximately a minimum total time of 72 minutes to set and takedown eight barriers (9 minutes per barrier segment) using a crew of five people. The BalsiBeam barrier requires approximately 15 minutes for the same with no crew beyond the driver of the unit.

- Analysis of requirements of different maintenance tasks indicate that, in the most part, ArmorGuard barrier is more suitable for short term stationary operations and some very mobile operations (such as asphalt milling) while the BalsiBeam barrier is more suited for short duration as well as short term stationary operations. Both barriers can be used for bridge maintenance, with the ArmorGuard being applicable if there is enough room for deployment (allowing a closure of 2.5 lanes).

- Use of ArmorGuard barriers in their present form can put additional demands on the existing Caltrans infrastructure, in terms of operator requirements, training, and support equipment. For example, at present, few Caltrans yards have cranes and most do not have fork-lifts. Also, presently lean crew sizes would need to be increased for supporting effective ArmorGuard deployment which would require a crew of five people.

- Using data on work zone intrusion accidents involving injuries to roadway maintenance workers in California for a period of 10 years, the cost of all injuries (this includes fatalities at an estimated cost of $5.8 million for life based on national standards) is determined to be approximately a minimum of $4.2 million on a yearly basis.

- The same data when correlated with the maintenance applications involved indicates that the potential total injury costs (including fatalities) that can be averted by using ArmorGuard barriers can be up to $0.69 million while the same number for the BalsiBeam barriers can be up to $1.1 million.

- In supporting the Challenge Area 14 of the California Strategic Highway Safety Plan, a methodology has been developed for simple and effective data collection and reduction for California work zone accidents. A pilot database has been established with data on 2,389 accidents. This data (although limited at this time) indicates that the total cost of injuries and fatalities to all road users in work zone accidents can be close to $800 million per year. Furthermore, total such costs for the accidents in the activity area where the workers are present can amount to approximately 88% of these total costs.

INTRODUCTION

This research deals with a study of the ArmorGuard barrier, manufactured by Barrier Systems, Inc.[1], with the overall goal of performing a scientific and engineering evaluation of this system in terms of its deployment characteristics and its applicable uses in highway operations in California. In addition, this research is intended to provide a comparison of the utility and cost effectiveness of the ArmorGuard system with respect to the Balsi Beam mobile crash barrier system, developed by Caltrans.

The ArmorGuard system is a steel, highway barrier system consisting of 28 feet long sections each weighing approximately 3700 lb. These sections can be interlocked to form a 200-300 foot long barrier. They can be transported to a site by a truck or trailer, unloaded by a crane, and pushed or towed into position using self-contained retractable wheels. It can also be towed, once deployed, by a pickup truck over very short distances.

The BalsiBeam barrier system is a completely mobile barrier system developed by Caltrans. It consists of two rotatable telescoping steel beams configured and integrated to a semi-trailer with a tractor truck that can transport the barrier to a work zone at normal highway speeds. At a work zone, the semi-trailer would also be part of the barrier system. The two telescoping steel beams can retract to provide protection for a work area of up to 30 feet. They can also be rotated to provide protection on either side of the semi-trailer. Deployment can be performed from inside the cab of the tractor truck.

Both the BalsiBeam and the ArmorGuard system are like K-rails in terms of providing positive protection for the workers in a work zone as compared to traffic cones that do not provide for any positive protection. The K-rails consist of 20 feet long concrete sections each weighing approximately 8,000 lbs.

In terms of investigating usage and deployment characteristics, the focus of this research was on the ArmorGuard system; therefore, several experimental evaluations of the ArmorGuard system were performed while only one comparative experiment was performed for the BalsiBeam system. In performing the cost benefit analysis and making applicable usage recommendations both systems were equally evaluated. Since an important part of cost benefit analysis is the evaluation of injury costs due to improved safety in using a positive barrier, this research performed a comprehensive review of maintenance work zone accidents and injuries in California over a 10 year period. This data provided a scientific basis for cost benefit analysis in terms of (potential for) injuries and fatalities averted by the use of ArmorGuard and the BalsiBeam barriers.

EXPERIMENTAL AND FIELD EVALUATIONS OF THE ARMORGUARD BARRIER SYSTEM

Physical experimentation and demonstrations of the ArmorGuard steel barrier system played a critical role in evaluating this system's applicability for a highway work zone. The knowledge and data obtained from these were used to arrive at the conclusions reached in this report. The experimental evaluations provided detailed data on the requirements for deployment of the ArmorGuard system and its comparative evaluation with respect to the BalsiBeam system. The demonstrations were intended to expose Caltrans personnel to the ArmorGuard system and obtain feedback on potential applications and utility of the system in Caltrans field operations. The following nine research questions were considered during the experimentations and demonstrations:

- Setup & take down times — is the setup and take down time reasonable when compared to work time?
- Setup crew— how many workers are needed to deploy and take down the system?
- Specialized equipment — are there any specialized equipments or extra vehicles needed for deployment and take down?
- Transport Requirements — what are the types and number of vehicles needed for transporting the barrier to the work site?
- Work space — do the barriers provide sufficient space for the maintenance activity to be performed, including the space needed for workers, equipment, and support vehicles?
- Mobility — for mobile activities, can the barriers be towed safely at the necessary speed within the available space?
- Lane closure requirements — how many lane closures are needed to deploy and use ArmorGuard barriers?
- Safety in setup and take down — does setting and taking down the barriers expose workers to additional risks?
- Worker protection — for a given situation, task, setup time, work space, and worker exposure, is there an increase in worker protection that justifies the deployment?

Experimental Evaluations

The purpose of the experimental evaluations was to collect data on the deployment of the systems. Since the focus of this project was on the ArmorGuard system, several experiments were performed in a controlled environment on this system. In addition, an in-the-field experimentation of this system was performed side-by-side with a BalsiBeam system for comparative evaluation.

The experimental evaluations using the ArmorGuard system were intended to simulate realistic highway work zone conditions but performed in a controlled experimental environment so that data can be easily collected. Data was also obtained from an independent experimental evaluation of the ArmorGuard system by Caltrans from December of 2003. This data was combined with data from the controlled experimentations, and in-the-field experimentation to reach the final conclusions of this study.

Controlled Experimentations

For the controlled experimentations, an area of approximately five acres was painted with lane delineation marks that would allow simulation of three different highway work zone conditions with potential utility for the ArmorGuard. This area is shown in Figure 1 and consisted of two straight two lane sections of approximately 433 feet each and then a 25 feet wide Y intersection to allow simulation of a highway ramp. Three different work zone conditions were simulated using this facility. These are lane closure for bridge work with extended barriers as shown in

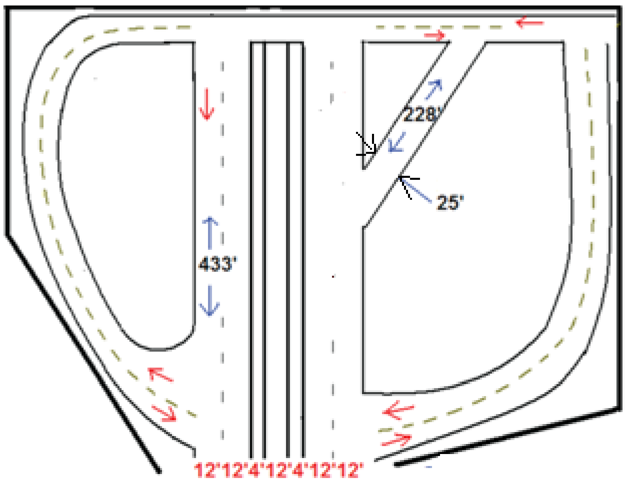


Figure 1. Test Layout for the Controlled Experiments.

the left lane in Figure 2, ramp closure as shown in the entrance to the y intersection, and two lanes contra-flow traffic management as shown in the right straight road section in Figure 2.

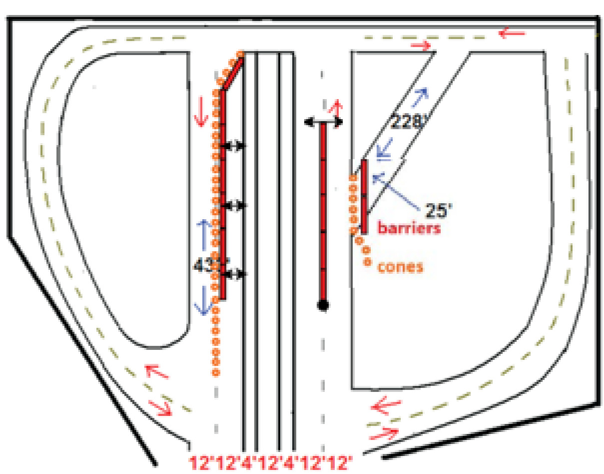


Figure 2. The three lane closures investigated.

The first work zone condition simulated was deployment and use of an extended barrier for multi-day tasks on a bridge. This condition can represent extreme maintenance projects, multi-shift and multi-day work on bridge decks, multi-day landscaping and culvert projects; overnight slab replacements, or long-length (100 feet or more) guardrail or median repairs. In this experiment, eight 28-foot sections of the ArmorGuard were used with proper end treatments.

The second work zone condition simulated was a ramp closure condition. It was evaluated to simulate conditions when there is a need for providing a visual barrier for traffic control such as in special events, rest areas, truck scales, parking lots, pedestrian control. This condition can also simulate incident management in quasi-emergency and reactive tasks such as main line break, minor slip outs, and slide protections.

The third work zone condition evaluated was to simulate contra-flow traffic management. This is a prevailing condition in accommodating known patterns of traffic flow. In simulating this condition, four to six segments of the ArmorGuard barrier were used.

In each of the three experimental evaluations the vendor did the deployment and take down of the system.

In-the-field Experimentation

An experiment was also performed in-the-field with the ArmorGuard system in conjunction with the BalsiBeam system, with both used for work zones on the opposite sides of a highway median for median wall repair. This was performed on Interstate 80 at post mile 33 in Colfax, California, about 50 miles east of downtown Sacramento. The ArmorGuard system was deployed on one direction of Highway 80 with the vendor for this system setting the system up and Caltrans crew setting up the BalsiBeam system in the opposing direction of Highway 80 for the same task on the same median wall. A schematic diagram of the set up for the ArmorGuard system is shown in Figure 3. In this setup, traffic cones are used to separate the traffic from the ArmorGuard system, work trucks are parked inside the protected zone and work is performed on the shoulder near the median wall.

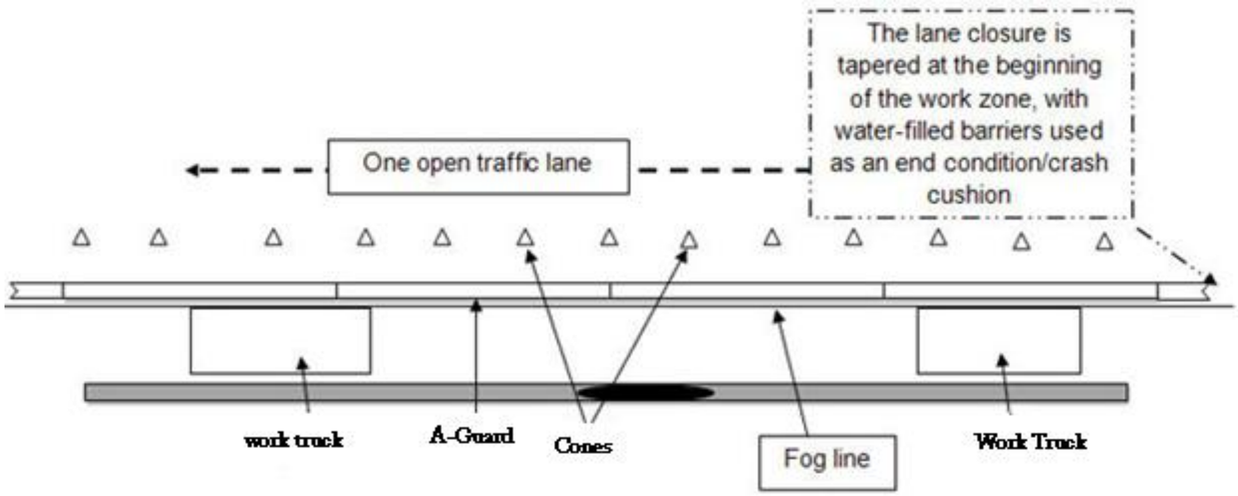


Figure 3. A schematic of the ArmorGuard Barrier Setup for in-the-field Experimentation.

In the case of the BalsiBeam system, the set up for comparative evaluation is shown in Figure 4. In this case, there is an attenuator truck behind the BalsiBeam system and the work truck referred to as tender truck in the diagram is within the working area.

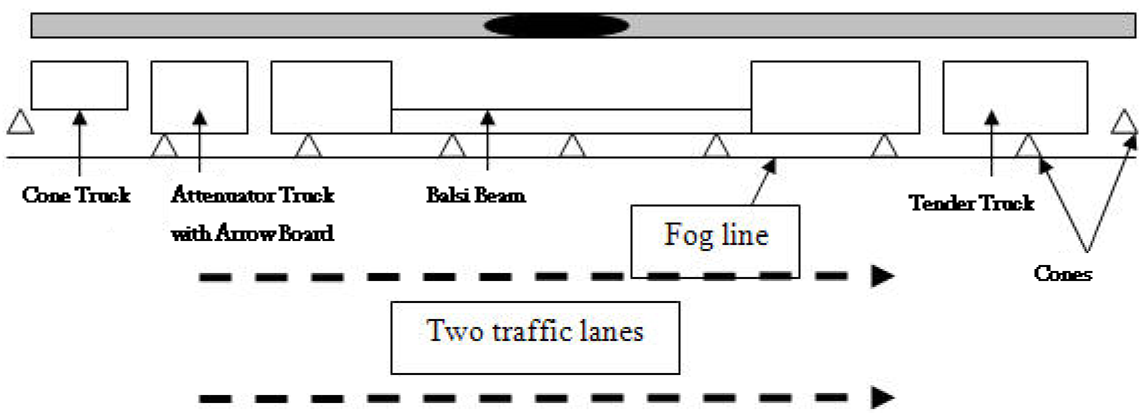


Figure 4. A schematic of the BalsiBeam Barrier Setup for in-the-field Experimentation.

In each of the experimental evaluations, time durations of deployment and take off were measured and other important parameters related to the research questions discussed earlier were noted. The details of experiments and the data collected are provided in Appendix A.

Field Demonstrations

In addition to the experimental evaluations, a total of eight field demonstrations of the ArmorGuard system were performed for Caltrans staff. The aim of the demonstrations was to obtain feedback from Caltrans participants on the utility and applicability of the system for California highways as would relate to the nine research questions discussed earlier.

In these demonstrations the basic deployment of the ArmorGuard barrier was illustrated. Each demonstration contained the complete ArmorGuard system, which consisted of eight 28 feet segments. More details about the demonstrations are provided in Appendix B. In these demonstrations a crew of five members was used for deployment and take down of the ArmorGuard system. It was pointed out, however, that the minimum required crew size would be a crew consisting of three workers. The time duration for deployment and takedown would, however, increase as the crew size would decrease. In all the demonstrations a crane was used to load and unload the barrier sections from the tractor-trailer. Three operators were used to unload (or load) the barrier sections from a tractor-trailer. Two additional crew members were used to roll each barrier section to its desired location and link the barrier sections together. It was also shown that one crew member was able to unlink two barrier sections.

COMPARATIVE ANALYSIS

The data and experience gained in the experimental evaluations and demonstrations of the ArmorGuard were combined to synthesize the following set of conclusions:

- At present, deployment of the ArmorGuard system requires closure of 2.0 to 2.5 lanes and approximately a minimum total time of 72 minutes to set and takedown eight barriers (9 minutes per barrier segment) using a crew of five people in a controlled environment. It should be noted that in the only one actual highway operation the total time for deployment and take down using three instead of five crew members was approximately 224 minutes or 28 minutes per barrier segment.

- Using all eight 28 feet segments of the ArmorGuard barriers, one can obtain 224 feet of barrier that would provide positive protection for the workers and good visibility of the work zone for the drivers. At their full length of eight segments, however, they can deflect six feet in a moderate severity collision requiring that workers be kept at least six feet away from the barrier. This means that approximately an additional half a lane of travel has to be blocked to provide the same working area for the workers. Furthermore, there are additional space requirements during deployment and takedown of this barrier increasing its lane closure requirements to a minimum of 2 to 2.5 lanes. The BalsiBeam barrier, however, can provide only 30 feet of actual work area protection but has minimal (only up to 6 inches) of deflection in a moderate severity collision and it can be just driven directly to the work site. Therefore, it does not require any lane closures.

- ArmorGuard barriers, once deployed, can be easily maneuvered into position or moved around. They can also be rolled to a shoulder for overnight storage and then rolled out the next day. Their maneuverability can, however, be challenged in areas where the highway has high grades or cross slopes requiring more force to fight gravity in moving the barrier segments into position by the crew. A pickup truck can be used for towing in such situations or for movement over very short distances. The BalsiBeam system is fully movable for short and long distances without a need for an additional vehicle.

- Use of ArmorGuard barriers in their present form can put additional demands on the existing Caltrans infrastructure, in terms of operator requirements, training, and support equipment. For example, at present, few Caltrans yards have cranes and most do not have fork-lifts. Also, presently lean crew sizes would need to be increased for supporting effective ArmorGuard deployment which would require a crew of five people.

In comparing the ArmorGuard barrier system to the BalsiBeam system it is clear that they each have their own unique features resulting in their applicability to different highway maintenance tasks. For example, the experimental evaluations have clearly demonstrated that the deployment and takedown times for the BalsiBeam system were much lower than the same for the ArmorGuard system. A side by side comparison of the two systems is provided in Table 1. This table also includes data on two other positive mobile barrier systems - the MBT-1 mobile barrier and the K-rails. The MBT-1 mobile barrier is a product of Mobile Barriers LLC [2] and has similarities to the BalsiBeam system. In Table 1, the information for the MBT-1 and K-rails are from product specifications and not from actual experimentation or demonstration.

It is clear from Table 1 that the ArmorGuard system can be viewed comparable to K-rails in terms of function and the ability to deploy, but with greater mobility and maneuverability once deployed. In terms of meeting needs for both protection and delineation, the BalsiBeam and MBT-1 offer greater value in ease and time duration of deployment and in minimizing the number of lane closures needed but lack in the total length of the protected area. In terms of the ArmorGuard and the BalsiBeam barrier systems, the main conclusion is that they both provide useful positive protection but have little overlap in their usage – each being applicable for different sets of highway maintenance tasks.

Different highway maintenance tasks were therefore evaluated as part of this study in terms of applicability of the ArmorGuard and the BalsiBeam barrier systems. This is described in the next section.

	ArmorGuard	Balsi Beam	MBT-1 Mobile Barrier	K-rails
Number of sections for Level 2 of NCHRP 350	8	1	1	8
Length of barrier, feet	224 for eight segments	50 incl tractor (30 actual)	42 to 104	100+
NCHRP 350, Level 3 Beneficial Length, feet	28	50	80	40
Minimum Total Time for deployment and takedown, minutes	For eight sections: with a crew of 5: 72 with a crew of 3 (based on only one real highway experiment): 224	15	0	64
Minimum crew size needed	3-5	0	0	2+
Specialized Deployment Equipment	crane or forklift	none	none	crane, forklift, or front loader
Support vehicles needed	Transport Vehicle for Cranes or forklifts, pickup truck for towing	none	none	Transport vehicle for cranes, or forklifts
Workspace: NCHRP 350, Level 3 Impact Deflection	6 ft	6 in	6 in	3 in (pegged) 6 ft (not pegged)
Mobility	Low speed and proximity by rolling or towing	Full	Full	None
Lane Closure: No. of lanes needed for deployment	2+	0	0	2+
Safety in set up and takedown	Exposes workers and tow vehicle	Full protection	Full protection	Exposes workers
Worker protection	Positive protection	Positive protection	Positive protection	Positive protection
Required end treatment	crash cushion required	normal shadow vehicle	normal shadow vehicle	crash cushion required

Table 1. Comparative Specifications and Deployment Characteristics of Mobile Barriers

MAPPING ARMORGUARD AND BALSIBEAM BARRIERS TO HIGHWAY MAINTENANCE TASKS

One of the main conclusions of the previous section was that the ArmorGuard and BalsiBeam barrier systems provide positive protection for work zones, but their differing characteristics make them suitable for different applications. In this section, different highway maintenance tasks are evaluated to determine the applicability of the ArmorGuard and the BalsiBeam barrier systems for each of such tasks. The following tasks are evaluated:

- Mobile Protection for Paving Operations — asphalt milling, asphalt overlay, litter pickup, pavement striping, raised pavement marker install / remove, sealcoat overlay.
- Bridge and Maintenance Tasks — bridge deck maintenance, landscaping, culverts, overnight slab replacements, long-length guard rail repair, median repairs, lighting installation / maintenance, sign installation / maintenance, traffic signal installation / maintenance.
- Landscaping, Culvert Maintenance and Debris Removal Operations — roadside landscaping, culvert maintenance operations, garbage bag pick up and litter removal.
- Snow and Ice Control— storm maintenance, snow removal operations with snow plows and blowers.
- Traffic Control — ramp closures, rest area closures, incident management, main line break, minor slip-outs, slide protection, flagging, contra-flow traffic management and channeling, temporary traffic management, gates in k-rail barrier.

Using published data (see, for example, [3]), the time duration for each of the above maintenance tasks can be estimated. This data can then be used to determine the time duration of the needed work zone. The following definition is used here for work zones based on their time duration:

- Short-Term Stationary - work zones that occupy a location for one hour or more during a single daylight period.
- Short Duration - work zones that occupy a location for less than one hour.
- Mobile - work zones that move intermittently or continuously along a roadway segment.

The ArmorGuard and BalsiBeam systems are then evaluated based on the time duration, work zone space requirements, and mobility requirements for each of the maintenance tasks stated earlier. The results are summarized in Table 2. The assumptions used in coming to the conclusions reached in Table 2 are as follows:

- Meeting the space requirement meant that the barrier would provide sufficient space for the maintenance activity to be performed including space needed for pedestrian workers and large equipment trucks.

- Meeting the time requirement meant that the deployment and takedown time for the barrier would not be greater than the time duration of the maintenance activity otherwise the barrier utility would be inefficient.
- Meeting the mobility requirements meant that the barrier needs to be towable at the necessary speed needed for the work to be performed.
- All parameters of space, time, and mobility had to be met for a barrier to be considered useful for a maintenance task.

		BalsiBeam				ArmorGuard			
Maintenance Activity	**WZ Duration**	**Space**	**Time**	**Mobility**	**Useful?**	**Space**	**Time**	**Mobility**	**Useful?**
Asphalt Milling	Mobile		X	X	No	X	X	X	Yes
Asphalt Overlay	Mobile		X	X	No		X		No
Bridge Maintenance	ST Stationary	X	X	N/A	Yes	X	X	N/A	Yes (if more than two lanes)
Guardrail Repair	ST Stationary	X	X	N/A	Yes	X	X	N/A	Yes
Culvert/Drain Work	ST Stationary		X	N/A	No	X	X	N/A	Yes
Landscape Work	ST Stationary		X	N/A	No		X	N/A	No
Litter Pickup	Mobile		X	X	No		X	X	No
Lighting Installation/ Maintenance	Short Duration	X	X	N/A	Yes			N/A	No
Pavement Striping	Mobile		X	X	No		X	X	No
Pothole Patching	Short Duration		X	N/A	No	X		N/A	No
Raised Pavement Marker Installation/Removal	Mobile		X	X	No		X	X	No
Sealcoat Overlay	Mobile		X	X	No		X		No
Sign Installation/ Maintenance	Short Duration	X	X	N/A	Yes	X		N/A	No
Snow and Ice Control	Mobile		X		No		X		No
Storm Maintenance	Mobile	X	X		No	X	X		No
Traffic Control (flagging, ramp closure, contra-flow))	ST Stationary		X	N/A	No	X	X	N/A	Yes
Traffic Signal Installation/Maintenance	Short Duration	X	X	N/A	Yes	X		N/A	No

Table 2. **Appropriateness of Maintenance Activities for ArmorGuard and the BalsiBeam systems (note: N/A: Not Applicable).**

In order to clarify how the appropriateness of the ArmorGuard and the BalsiBeam barriers were determined in Table 2, a sample of the maintenance tasks shown in Table 2 are described in more detail here. Starting with asphalt milling, this maintenance task consists of grinding the existing asphalt so that it can later be removed and replaced. This mobile activity moves at approximately three mph, requires the use of a large milling machine, and needs access to at least one travel lane. The milling machine cannot fit within the work zone created by the BalsiBeam barrier, so it cannot be used for this maintenance activity. The ArmorGuard meets the work zone requirements and is most useful when the work zone is established as being a short-term stationary. This occurs when extensive asphalt milling takes place, for example, when the milling machine is traveling forward and backward within the work zone. The ArmorGuard would not be used if the asphalt milling was mobile, because this would require additional personnel to move the barrier, which is not worth the effort and risk of having additional workers on the roadway, especially considering that there are not any pedestrian workers when asphalt milling is being performed.

Considering the asphalt overlay activity, the process moves at approximately five mph and consists of paving asphalt up to the edge of a travel lane. Large equipment and multiple work crews are required, and access to an entire travel lane is needed. Neither barrier meets the spatial requirements since the barriers take up lane width. Moving the barrier into the adjacent lane to make a sufficiently wide work zone for asphalt overlay work would further impede on traffic, potentially stopping traffic flow completely if the road only has two lanes.

Bridge maintenance and guardrail repair both require short-term stationary work zones that last more than one hour, and they can include a variety of activities. Examples of bridge maintenance activities are partial bridge deck replacement and concrete spall repair. Guardrail repair includes the removal and installation of rail posts, as well as the repair of end treatments on guardrails that have been damaged. Bridge maintenance and guardrail repair generally occur near the edge of the roadway or on the roadway shoulder and all equipment can fit within the confines of the BalsiBeam and the ArmorGuard work zones assuming more than two lanes of travel in direction of traffic flow. Both barriers can be used for these maintenance activities, with the BalsiBeam more likely to be used for activities over smaller areas and the ArmorGuard being more suitable for maintenance on larger bridge and guardrail sections that takes several hours to complete. If the number of travel lanes in each direction is limited to two lanes or less with shoulder width of less than half a lane, then the space requirements for deployment of the ArmorGuard cannot be satisfied since this barrier requires 2.5 lanes for proper deployment. In this situation only the BalsiBeam barrier is applicable for use.

Culvert and drain work often involves using large trucks to clean out drains, with the work occurring in front of the trucks. These trucks cannot fit within the BalsiBeam barrier work zone, so this barrier system cannot be used to protect this maintenance activity. The ArmorGuard barrier on the other hand meets the spatial requirements since it can create longer and wider work zones. This barrier system can therefore be used for extensive culvert and drain work that lasts several hours.

Landscape work and litter pickup both generally take place away from the roadway, and the large distance between the workers and traveling vehicles increases safety and reduce the level of need for positive work zone protection. It can be difficult to set up the barriers in the shoulder or off the roadway, especially with landscape or litter pickup crews that may not be trained to do so, and this factor combined with the low need for protection results in the ArmorGuard and BalsiBeam not being very useful for these maintenance activities.

Lighting installation and maintenance refers mostly to work on highway lights, and this is a short duration activity, meaning it lasts less than one hour. Therefore, the ArmorGuard does not meet the time requirements, because the deployment and take-down time for the barrier exceed the time needed to complete the work and therefore may not be an effective use of time. Instead, the BalsiBeam barrier can be used, because it meets the time and space requirements, with the 30 foot long work area fitting well around the light where work is being performed.

Pavement striping consists of painting the roadway lines between lanes. This is done using large trucks, which keep workers inside vehicles instead of walking on the roadway. This reduces the level of need for positive protection. Neither barrier meets the space requirements of this activity, because the road work takes place up to the edge of the travel lane. Both the ArmorGuard and BalsiBeam would intrude into an additional travel lane, further impeding on vehicle traffic.

Work for pothole patching generally lasts approximately five minutes at each site, making the BalsiBeam barrier the only potential option based on time requirements. Still, the BalsiBeam barrier cannot be used for this activity, because there is nowhere within the work zone to put the asphalt bin that holds the patching material.

Similar to pavement striping, raised pavement marker installation and removal work occurs between lanes, so neither barrier meets the space requirements.

A sealcoat overlay activity involves spraying oil from a large dispensing truck to the top of the pavement. The ArmorGuard and the BalsiBeam barriers cannot be used for this maintenance activity, because they would be in the way of the oil being sprayed from the dispensing truck. The oil would be sprayed onto the barriers themselves and would not reach the underlying pavement.

Sign installation and maintenance takes less than one hour at each location, so the ArmorGuard barrier does not meet the time requirements. The BalsiBeam barrier can be deployed and taken down in 15 minutes, and it provides enough space to work on a roadway sign. Therefore, it is useful for sign installation and maintenance.

Snow and ice control includes plowing snow and spreading sand or salt on the roadway. These usually involve using a snow plow or another large truck on the roadway, taking up travel lane space. The two mobile barriers would not be useful for this activity, because they would take up more roadway space, further intruding on traffic flow. The ArmorGuard and the BalsiBeam barriers also are not mobile at high enough speeds for some snow and ice control work. Storm maintenance generally consists of traveling to different locations to check for storm damage, and the ArmorGuard and BalsiBeam cannot travel fast enough to be helpful for this maintenance activity.

Traffic control includes flagging traffic, contra-flow traffic management, providing gates for traffic management and ramp closure. Typically the BalsiBeam barrier is either not large enough or maneuverable enough to be effective for this work. The ArmorGuard can be used as a visual and protective barrier and because it can be utilized in 28 feet segments, there are a variety of configurations that it can be used for.

Traffic signal installation and maintenance, specifically installing traffic loops in the ground, usually takes less than one hour at each location. The ArmorGuard does not meet this time requirement. The work zone width includes one travel lane. The BalsiBeam barrier can be used for this activity, because it meets the space and time requirements.

From the above analysis it is clear that bridge maintenance (when there are more than two lanes in each direction) and guardrail repair are the only two maintenance activities for which both the ArmorGuard and the BalsiBeam barriers are equal candidates. In all other activities listed in Table 2, either one or the other or none could be the only viable candidates. This clearly indicates that these two mobile barriers serve different purposes, in the most part, in highway maintenance tasks.

Using the experience gained in this part of the study, a usage and deployment guideline was developed for the ArmorGuard barrier system. This is provided in Appendix C.

COST BENEFIT ANALYSIS

For a work zone barrier system, an important part of cost benefit analysis is the evaluation of injury costs due to improved safety in using such a barrier. This research initiated a comprehensive review of data on work zone accidents and injuries in California and used the data as the scientific basis for evaluation of injury and fatality costs associated with such accidents and the potential benefits by using a positive barrier system such as the ArmorGuard and the BalsiBeam barrier system.

Performing a proper cost benefit analysis would require an evaluation of all costs associated with the use of a barrier system including unit cost, the cost of traffic congestion associated with the needed lane closures for deployment of the system, and so on. Bordman et al. [5] describe nine steps for a proper cost benefit analysis as follows:

1. Specify the set of alternative projects.
2. Decide whose benefits and costs count.
3. Catalogue the impacts and select measurement indicators.
4. Predict the impacts quantitatively over the life of the project.
5. Monetize all impacts.
6. Discount benefits and costs to obtain present values.
7. Compute the net present value of each alternative.
8. Perform sensitivity analysis.
9. Make a recommendation based on the net present value and sensitivity analysis.

In the case of this study, the emphasis was only on determining the potential cost of injuries and fatalities averted in work zone accidents by using a positive barrier and providing any comparative evaluation of the ArmorGuard and the BalsiBeam barrier systems in eliminating such costs.

The data used for such a cost-benefit analysis was extracted in redacted format (private information was eliminated) from reports of injuries and motor vehicle accidents in work zones involving roadway workers from the California Department of Transportation. Data for a period of 10 years from 1998-2007 was analyzed.

In order to establish potential costs of injuries and fatalities this research used guidelines established by United States Department of Transportation (US-DOT). In 1993 the US- DOT developed guidelines for valuing injury and fatality risk reductions, leading to what is known as the _Value of a Statistical Life'. These guidelines were based on the concept of willingness to pay, which refers to the observed willingness of people to pay modest amounts for small reductions in risk. As an example, if 10 million passengers on an already safe roadway are willing to pay an extra 20 cents in their fare to reduce the risk of accidental death per trip by 0.0000001, then over the 10 million trips, $2 million would be collected, and one less life would be lost. In this situation, the willingness to pay would be $2 million per life, even though no one has directly expressed a willingness to pay that amount to safe his or her life [6].

The Value of a Statistical Life (VSL) is a measure of the benefit of preventing a fatality, and it can be defined as the value of improvements in safety that reduce the number of expected fatalities by one. While estimates of VSL are based on the concept of individual willingness to pay, it is a subjective quantity that changes constantly and should be used with caution. In 2008, the US- DOT released a document [7] that updated the value of a statistical life to $5.8 million, and this value was chosen to appropriately reflect the conclusions of recent studies and the practices of other agencies. It was stated that $5.8 million should be used for DOT analyses that asses the benefit of preventing fatalities.

Nonfatal injuries are more common than fatalities, and these need monetary values assigned to them as well. It is not possible to determine detailed willingness to pay estimates for the wide range of potential nonfatal injuries, so a standardized method to interpolate values of expected outcomes scaled in proportion to VSL was established [8]. The relative value coefficients for preventing injuries of varying severity are based on the Abbreviated Injury Scale (AIS) [9]. The AIS is an anatomically-based injury severity scoring system that classifies each injury by body region according to its relative importance on a six-point ordinal scale. The maximum AIS (MAIS) is the highest, or most severe, AIS value in a person with multiple injuries. The cost of injuries for various severity levels are summarized in Table 3. In this table, the cost of injuries is calculated in terms of fractions of the VSL. To determine the injury cost for each severity level, the ‗Fraction of VSL' value was multiplied by the current VSL value of $5.8 million. These injury cost values as listed in Table 3 were used for the cost-benefit analysis to determine the monetary value of the benefits of injuries and fatalities averted with the use of the ArmorGuard and the BalsiBeam barrier systems.

Injury Severity	Injury Descriptor	Fraction of VSL	Injury Cost ($ Millions)
MAIS 1	Minor	0.0020	0.0116
MAIS 2	Moderate	0.0155	0.0899
MAIS 3	Serious	0.0575	0.3335
MAIS 4	Severe	0.1875	1.0875
MAIS 5	Critical	0.7625	4.4225
MAIS 6	Fatal	1.0000	5.8

Table 3. Cost of Injuries for Varying Severity Levels (MAIS = maximum abbreviated injury scale, VSL = value of a statistical life)

The motor vehicle accidents that can be prevented by positive protective barriers are intrusion accidents in which vehicles intrude into the work zone. The California work zone injury data used included all injuries experienced by employees, so the accidents in which work zone intrusions occurred were sorted from the rest of the data. From 1998-2007, there were a total of 323 work zone intrusion accidents that resulted in injuries of varying severity. These accidents were classified by the maintenance activity being performed at the time of the accident, the time duration of the work zone, and the maximum AIS value.

Classifications of the work zone intrusion accidents show trends in the data. The largest percentage of intrusion accidents resulting in roadside worker injuries occurred for maintenance activities involving litter, debris, or graffiti cleanup (19%), followed by traffic guidance (17%), which includes guardrail repair, traffic control, and sign installation and maintenance. Mobile work zones were involved in the largest percentage of work zone intrusion accidents (49%), and the majority (94%) of the injuries experienced by roadside workers was minor injuries with a maximum AIS value of one.

Knowledge of details of the maintenance activities, their respective work zone durations, and details of the activities for which the ArmorGuard and BalsiBeam barriers are most appropriate for were considered in determining which accidents could have been prevented with the two different barriers. The data set used included maintenance functions being performed when the accident happened. These maintenance functions are assigned codes to simplify later graphical representation as listed in Table 4. The distribution of the intrusion accidents from the data set based on these maintenance activity codes is shown in Figure 5.

A – Flexible Pavement	J – Other Structures
B – Rigid Pavement	K – Electrical
C – Slope/Drains/Vegetation	M – Traffic Guidance
D – Litter/Debris/Graffiti	R – Snow and Ice Control
E – Landscaping	S – Storm Maintenance
F – Environmental	T – Management and Support
G – Public Facilities	W – Training and Field Auxiliary Services
H – Bridges	Y – Work for Others

Table 4. **Maintenance Activity Codes for California Work Zone Injury Data.**

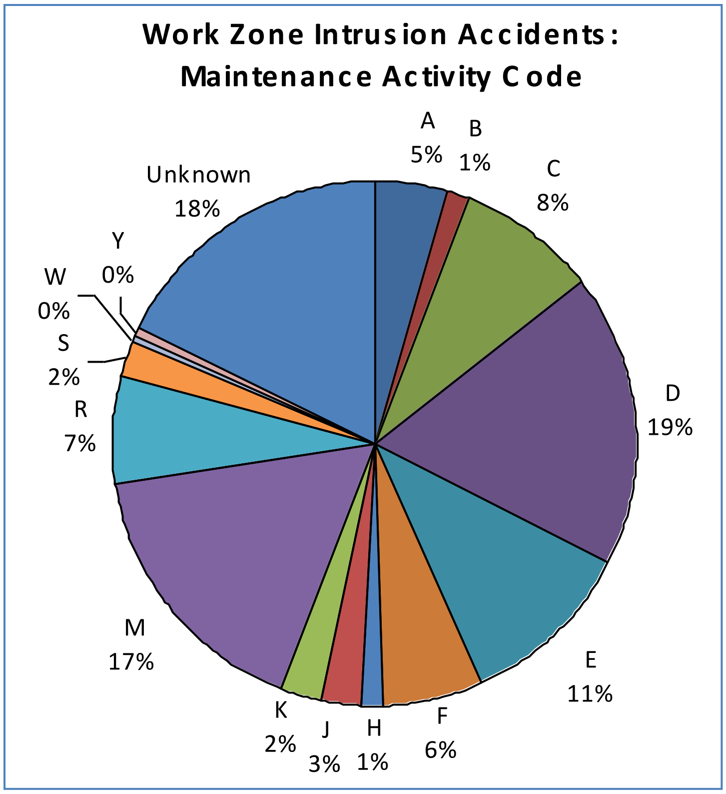


Figure 5. Distribution of Intrusion Accidents Based on Maintenance Activity.

The intrusion accidents in the data set were also classified based on work zone duration as defined in the previous section. The results are shown in Figure 6.

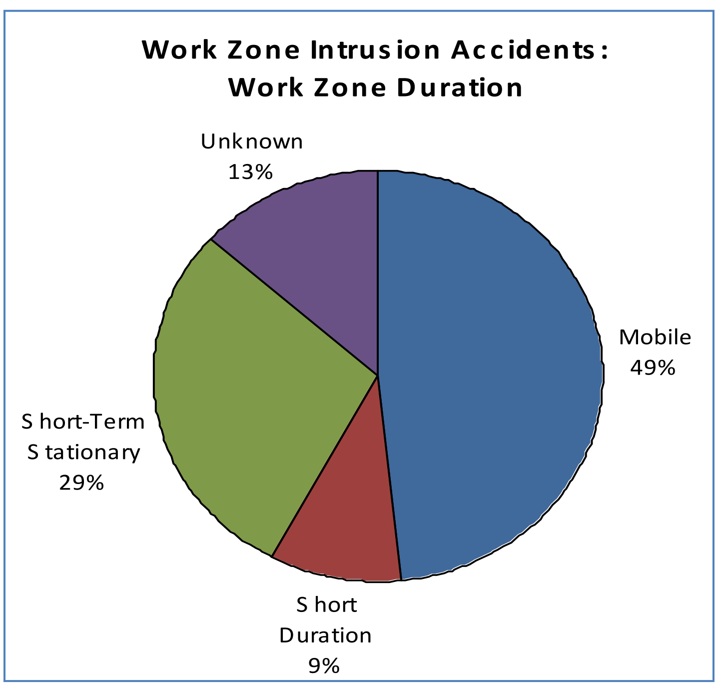


Figure 6. Distribution of Intrusion Accidents Based on Work Zone Duration.

Knowledge of details of the maintenance activities, their respective work zone durations, and matching of the ArmorGuard and the BalsiBeam barrier systems to the maintenance activity were considered in determining which accidents could have been prevented with the two different barriers. These were discussed in the previous sections and summarized in Table 2 in terms of mapping the applicability of the ArmorGuard and the BalsiBeam barrier systems to the maintenance activity. Data in Table 2 only included those maintenance activities for which there were reported accidents in the California work zone injury data. In this data set, intrusion accidents involving injuries to workers seated inside vehicles were also included. Mapping the maintenance activity codes from Table 4 to ArmorGuard and BalsiBeam maintenance applications from Table 2, the distribution of maintenance activities for which the ArmorGuard and the BalsiBeam barriers can provide protection is determined. This is shown in Figure 7 indicating that for some activities such as bridge and electrical works, the two barriers could have been effective for up to 50% of the accidents. The next category where the two barriers would have been effective is traffic guidance.

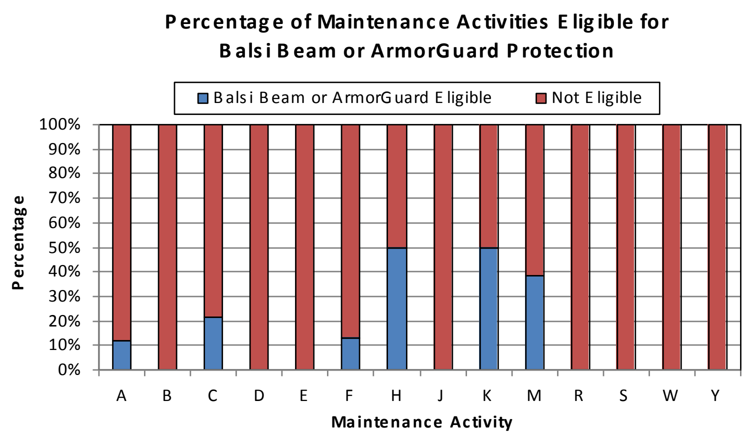


Figure 7. **Mapping of Maintenance Activities to Applicability of ArmorGuard and BalsiBeam Barrier Systems.**

Comparing the ArmorGuard and the BalsiBeam barriers, there are distinct differences due to the capabilities and limitations of the two barriers. The BalsiBeam barrier system is most eligible for use in short duration work zones, whereas the ArmorGuard barrier system is most eligible for use in short-term stationary work zones. Using work zone duration, the percentage eligibility of the two barriers to each type of work zone was calculated. This is shown in Figure 8 indicating approximately similar distribution in terms of applicability of the two barriers based on work zone duration. Mapping the injuries based on the maximum AIS levels (MAIS) to the two barriers under consideration is shown in Figure 9.

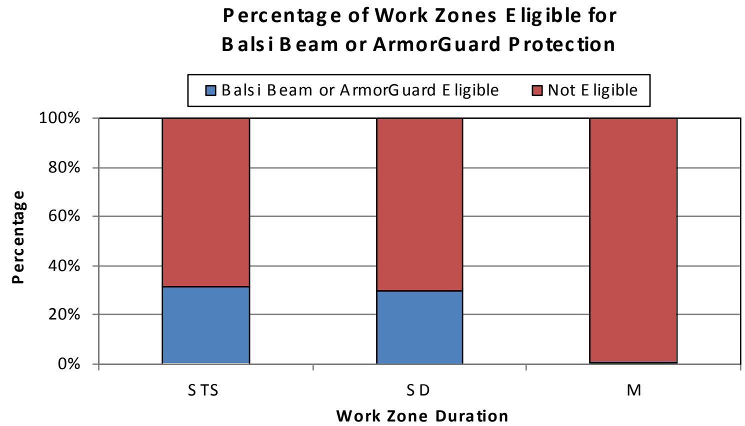


Figure 8. **Mobile Barrier Applicability Based on Work Zone Duration (Notes: STS: Short Term Stationary; SD: Short Duration; M: Mobile).**

Evaluating the data for each of the two barriers under consideration separately resulted in distributions bar graphs depicted in Figures 10 and 11. The data in these two figures indicate that the BalsiBeam barrier system would have been useful for a larger percentage of severe injury accidents in the data set considered and therefore would have resulted in larger monetary benefits. This affects the total benefits of injuries averted.

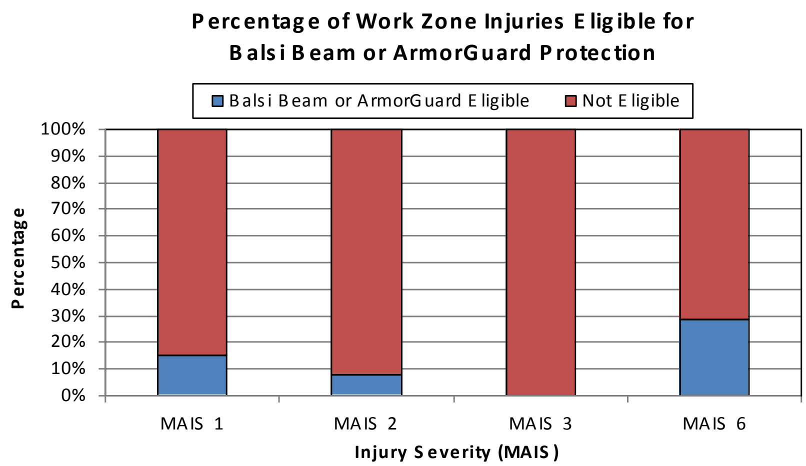


Figure 9. **Mapping of Injury Levels to the Two Mobile Barriers (note: MAIS: Maximum AIS values).**

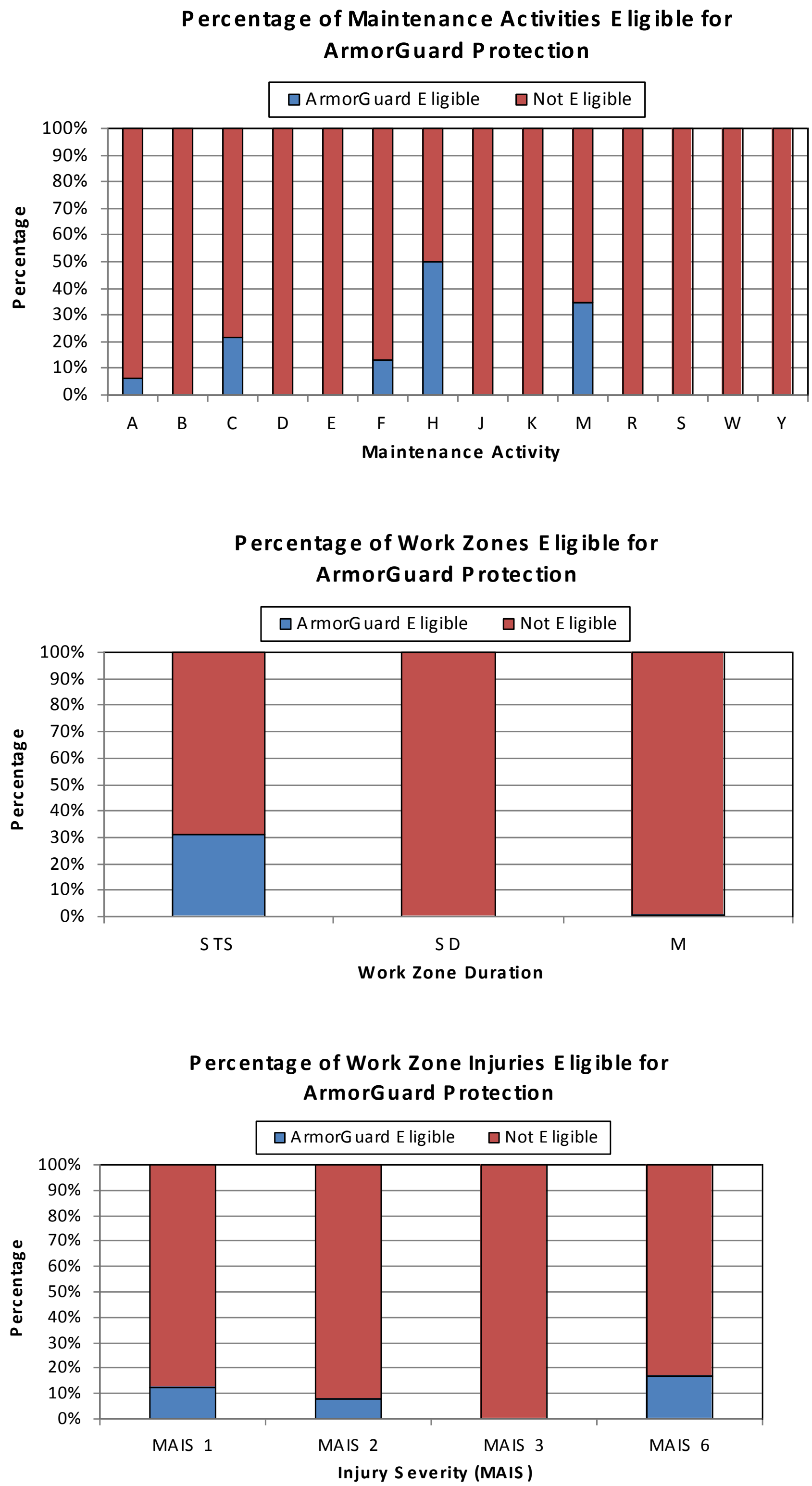
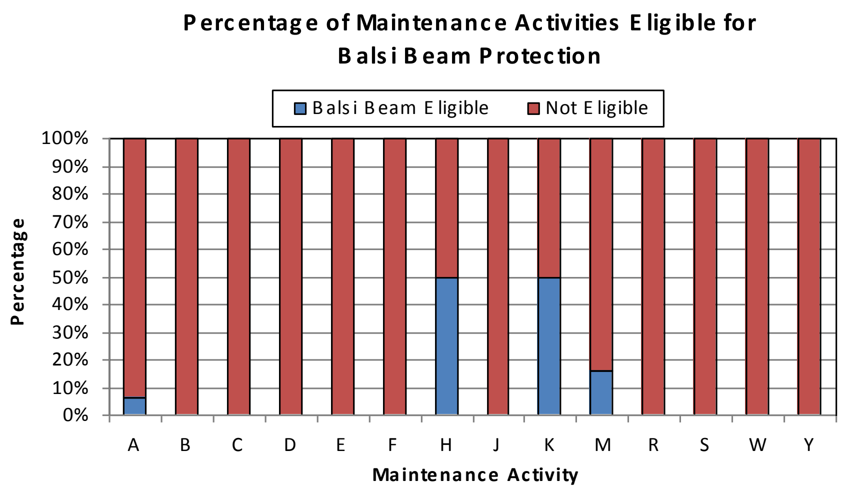
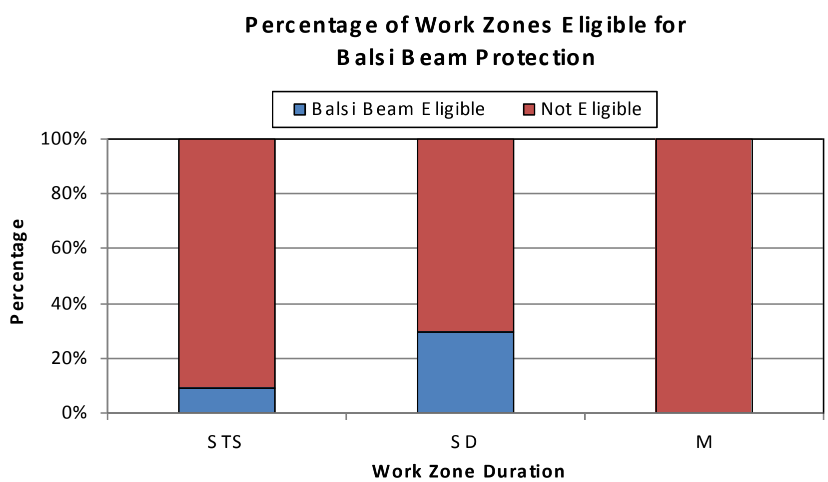


Figure 10. **Percentage of Work Zone Accidents Eligible for ArmorGuard Protection, sorted by maintenance activity, work zone duration, and MAIS (STS = short-term stationary, SD = short duration, M = mobile, MAIS = maximum AIS).**





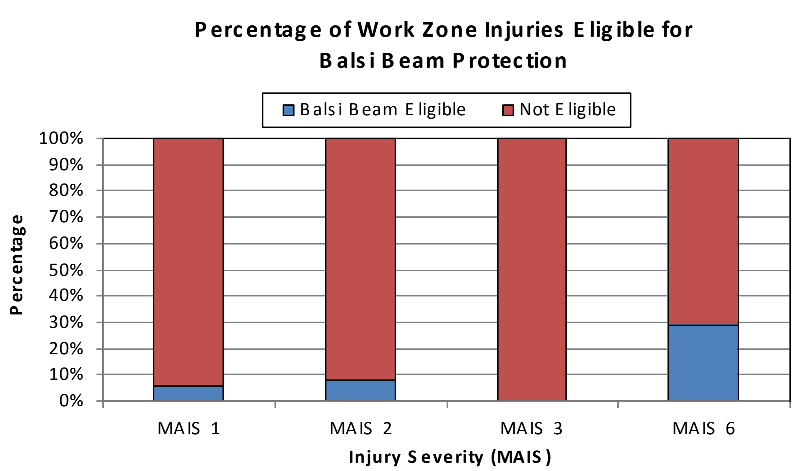


Figure 11. Percentage of Work Zone Accidents Eligible for BalsiBeam Protection, sorted by maintenance activity, work zone duration, and MAIS (STS = short-term stationary, SD = Short Duration, M = Mobile, MAIS = Maximum AIS).

It should be pointed out that California work zone injury accidents used in the assessment of the benefits of the barriers cannot be reenacted to determine if the barriers would have actually prevented the injuries. Instead, it has been assumed, based on knowledge of the work zones and the barriers, that particular injuries would have been averted.

Using the information regarding the maintenance activities, the applicability of the ArmorGuard and the BalsiBeam barrier systems to those activities, and the costs of injuries of varying severities based on the maximum AIS and the VSL, the benefits of the injuries and fatalities averted can be calculated. The details of this data are provided in table 5. The costs of accidents when standard work zone lane closures were used are the total injury costs in table 5 which come to a yearly average of approximately $4.2 million. The analysis indicates that based on the California work zone injury data for the years 1998-2007, up to approximately 27% of the total injury costs could have been averted with the use of a positive protective barrier. This means that using protective barriers potentially could have saved approximately $1.15 million each year in injury costs.

Injury Severity (MAIS)	Cost Basis by MAIS (Millions)	Total Injury Costs (Millions)	Costs Averted (Millions)
1	0.0116	3.5220	.0.5283
2	0.0899	1.1615	0.0928
3	0.3335	0	0
4	1.0875	0	0
5	4.4225	0	0
6	5.8	37.468	10.87
Total		42.152	11.49
Yearly Average		4.215 (approx. $4.2)	1.149 (approx. $1.15)

Table 5. Total Injury Costs and Injury Costs Averted (Note: MAIS = Maximum Abbreviated Injury Scale).

A breakdown of the costs that could have been averted if either the ArmorGuard or the BalsiBeam barrier system had been used for protection of the workers is shown in table 6. The costs averted for injuries that could have been prevented using either of the two barriers are the common costs averted for the barriers. These common costs are related to injuries that occurred during bridge maintenance and guardrail repair maintenance activities since these were the only activities with accidents for which both barriers are applicable. This information can be used to calculate the relative benefits of each of the two barriers. From the data in table 6, the average yearly cost averted from using the ArmorGuard barrier system is approximately $0.69 million, and the average yearly cost averted from using the BalsiBeam barrier is approximately $1.1 million. This suggests that if only the BalsiBeam barriers were used the potential injury costs averted would be approximately $0.41 million more each year than if only the ArmorGuard barriers were used. This cost difference comes from the greater costs averted by the BalsiBeam barrier for MAIS 6 injuries, which occurred in fatal accidents.

Injury Severity (MAIS)	Cost Basis (Millions)	ArmorGuard Costs Averted (Millions)	BalsiBeam Costs Averted (Millions)	Common ArmorGuard/BalsiBeam Costs Averted (Millions)
1	0.0116	0.4226	0.1761	0.0704
2	0.0899	0.0928	0.0928	0.0928
3	0.3335	0	0	0
4	1.0875	0	0	0
5	4.4225	0	0	0
6	5.8	6.369	10.866	6.365
Total		6.884	11.1349	6.528
Yearly Average		0.6884 (approx. 0.69)	1.11349 (approx. 1.1)	0.6528 (approx. 0.65)

Table 6. Distribution of the Costs Averted by Each and the Combination of the Two Barriers.

The last column in table 6 provides data on the combination of the costs averted using the ArmorGuard and the BalsiBeam, which is $0.65 million per year. This is the cost of injuries that occurred while performing maintenance activities that both barriers could have been used to potentially protect against. This common cost is also included in the costs averted separately by the ArmorGuard and the BalsiBeam barrier systems. Therefore, subtracting the common cost from each barrier‘s separate cost yields the cost that could have been averted by one barrier but not the other when both barriers are available to be used. For example, the cost averted by the ArmorGuard was $0.69 million minus the common costs averted ($0.65 million) is equal to $0.04 million, or $40,000. This suggests that $40,000 in injury costs could have been prevented each year by the ArmorGuard but not the BalsiBeam barrier. On the other hand, there were $0.59 million ($1.1 million minus $0.65 million), or $450,000, in injury costs that could have been potentially avoided each year by using the BalsiBeam barrier but not the ArmorGuard barrier system.

SUPPORT OF CHALLENGE AREA 14 OF CALIFORNIA STRATEGIC HIGHWAY SAFETY PLAN

The California Strategic Highway Safety Plan (SHSP) is a statewide, comprehensive, data-driven plan that provides a coordinated framework for reducing fatalities and serious injuries on California's public roads. The SHSP establishes statewide goals, objectives, and strategies to address California's safety needs. The SHSP identifies 152 key actions in 16 Challenge Areas to meet those needs. The SHSP involves over 300 safety stakeholders representing 80 different public and private agencies. The mission of Challenge Area 14 (CA 14) of the SHSP is "Improving Work Zone Safety". CA 14 has developed 14 Action Plans. This document reports progress on Action Plan 2: "Improve collection, storage, and evaluation of work zone crash data."

This research also provided support for the Challenge Area 14 of California SHSP in terms of initiating work on improving collection, storage and evaluation of work zone crash data. As part of this effort a pilot study was established to gather data and design a database that would allow access to the data for use in evaluating work zone accidents, resulting injuries and costs, and assessing mitigation measures. The motivation for this development is that standard databases provide little information on factors, injuries, traveling speed or where in the work zone traffic accidents occur.

This pilot study resulted in the AHMCT Injury Database (Injury DB) that presently includes data on 2,389 accidents for which their California Highway Patrol (CHP) traffic collision reports had indicated as having ongoing roadwork as a significant attribute. More details of this database and its data collection methodology are provided in Appendix D.
The database contains all of TASAS (Traffic Accident Surveillance and Analysis System) data plus detailed information on injuries, factors, outcomes, mitigation measures, where is the work zone, and traveling speed for the accidents in the database. The database can be used to query different information that can help decision making and develop mitigation techniques to improve work zone safety. For example, answers to the following questions can be obtained:

- What factor causes the highest number of work zone accidents?
- Is speeding a major factor in work zone accidents?
- What are the cost distributions for different accident outcomes?

The data to answer the first question is plotted in Figure 12 indicating that improper driving, inattention, and driving too fast and too close are the main causes of work zone accidents resulting in no or only minor injuries.

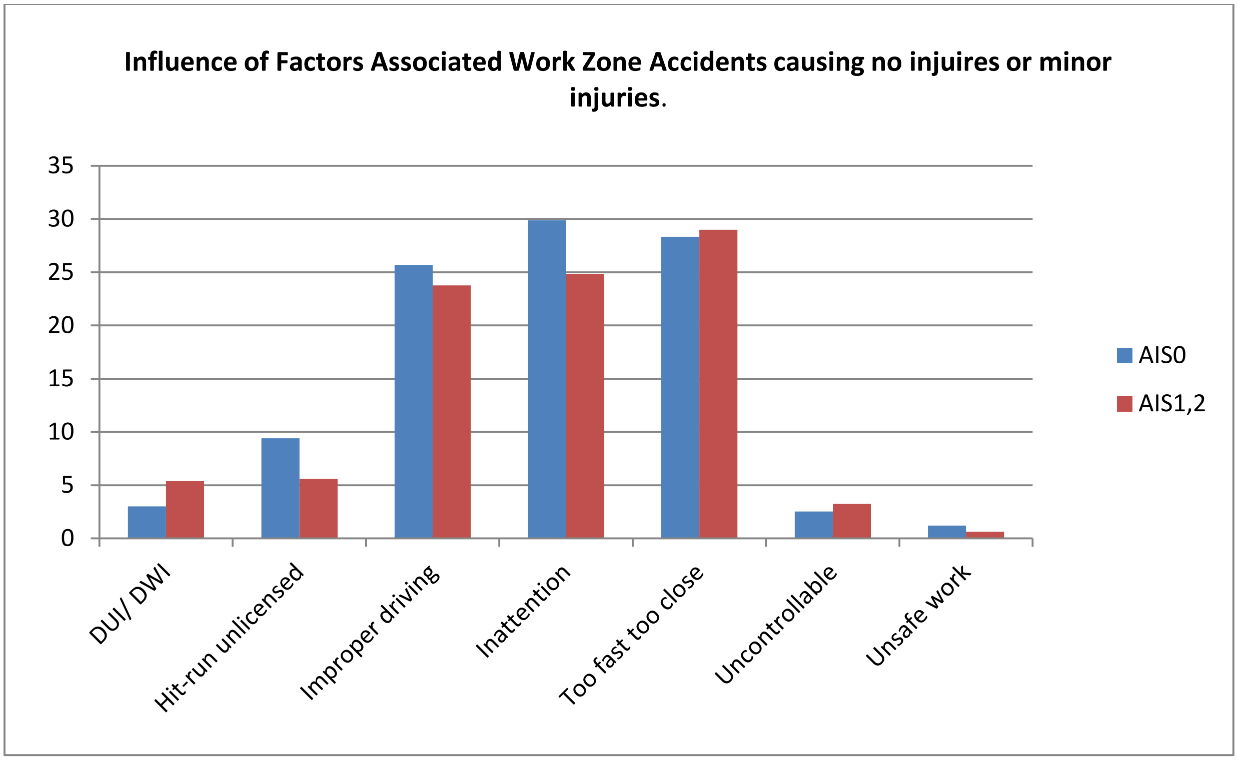


Figure 12. Distribution of Work Zone Accidents by Causative Factors Resulting in Minor or no Injuries.

In order to determine if speed is a factor in work zone accidents, the travel speed frequency for work zone accidents need to be evaluated. This is plotted for a sub-set of accident cases in the database (1375 counts) in Figure 13. Data in this figure indicate that only 28% of all such accidents occurred at speeds above 55 MPH. Therefore speeding does not seem to be a major factor for the cases considered.

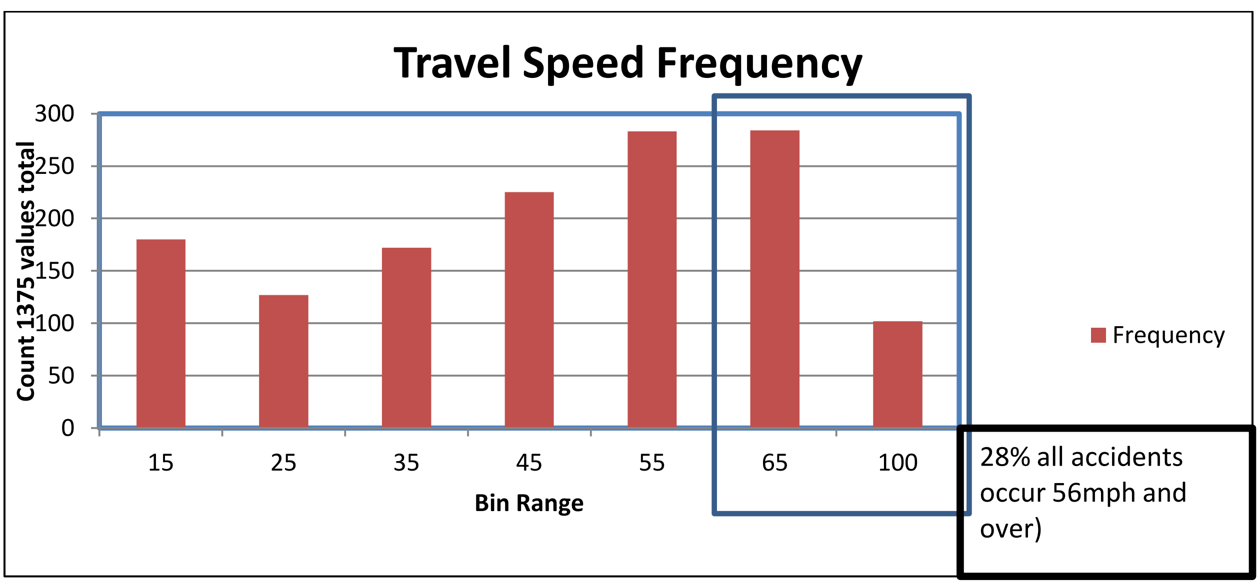


Figure 13. Travel Speed Distribution for Work Zone Accidents.

Finally the total yearly financial cost of injuries and fatalities in all work zone accidents in California (based on the existing data in the database) as a function of accident outcome in terms of location within the work zone and type of collision is shown in table 7. Data in this table indicates that the total yearly cost of injuries and fatalities in work zone can be close to $800 Million (actual value: $786 Million). Furthermore, in the activity area alone where the workers are present, such cost amount to approximately 88% (688 out of 786) of the total cost. It should be noted that this data includes all accidents both for maintenance as well as construction activities and the cost numbers are for all injured road users in the accident and not just the roadway workers.

work zone areas:	Collision Auto	Collision Barrier	Collision Object	Collision Rear End	Danger Ped / worker	Lost Control / rollover	Totals
advance, transition, activity, termination	$155.6	98.4	48.7	50.8	269.6	162.9	$786.0
activity only	$137.7	89.2	41.3	34.8	242.3	142.7	$688.0

Table 7. Costs of Injuries and Fatalities as a Function of Accident Outcome

CONCLUSIONS AND FUTURE WORK

This research has performed experimental evaluation of the ArmorGuard barrier system and has compared its deployment and utility to the BalsiBeam mobile barrier. The data and experience gained has identified the differential capabilities of these two systems. This data is then combined with data and knowledge of highway maintenance operations to map some of these operations to the two mobile barrier systems in terms of their applicability. As part of this research data was also collected on accidents in California involving highway workers. This data provided the basis for the cost benefit analysis in terms of injury and fatality costs potentially averted by the use of the ArmorGuard and the BalsiBeam barriers. This research has also supported the activities of the Challenge Area 14 of California Strategic Highway Safety Plan (SHSP) in terms of initiating work on improving collection, storage and evaluation of work zone crash data. In this effort a methodology was developed for data collection, storage and evaluation of work zone crashes in California. A pilot database was created which has proved the usefulness and versatility of this approach and has provided data and analysis to answer many questions related to work zone safety.

The research results have shown that ArmorGuard and BalsiBeam have different capabilities and applications for positive work zone protection. They have the potential to reduce injuries and save lives. The cost benefit analysis has shown the ArmorGuard barrier has the potential to reduce injury costs to roadway worker performing maintenance tasks by approximately $0.69 million annually and the BalsiBeam can recue injury costs by approximately $1.1 million on an annual basis. The cost benefit analysis performed did not consider other costs such as the cost of any potential congestion due to the differential in lane closure requirements for the two mobile barriers. The injury and fatality costs were also estimated based on initial costs and did not include other societal and potential long term costs. Estimating such costs and incorporating them into the cost benefit analysis can be considered as areas of future research.

In this research, it was recognized that if other methods of deployment are designed for the ArmorGuard that can reduce its time and space requirements for deployment and takedown, then the areas of applicability of this barrier system in highway maintenance tasks can increase. Developing designs for mechanized systems for better deployment and take down of this barrier system can also be a future area of research.

The data collection and reduction methodology developed in support of Challenge Area of 14 of California SHSP has shown the utility of such data in providing the basis for answering many work zone safety related questions. The database at the present time only has a record of 2,389 accidents for a limited geographic area in California over a limited number of years. This database should be expanded in the future to include data for at least 5 years and cover the entire California. Establishing a data repository on highway accidents in general and work zone accidents in particular can provide the data that can be the basis for many decisions in highway operations and maintenance.

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APPENDIX A

Experimental Evaluations

Controlled Experiments for Evaluation of the A-Guard Barrier System

The controlled experimental evaluations of the A-Guard systems were performed at the Caltrans Maintenance Equipment Training Academy (META) in McClellan, California. Three specific Work Zone tasks were evaluated experimentally: Extended Barrier for Bridge Work (set-up and takedown), Ramp Closure set-up, and Contra-flow Traffic Management operations. These controlled experiments took place on December 10, 2008. In each experiment the vendor performed the setup and take down of the barrier system using a crew consisting of five members. The process was evaluated step by step and time measurements were performed for each step. Feedback was then obtained from Caltrans observers, the AHMCT researchers present, and from the vendor personnel.

Extended 8-Segment Barrier for Bridge Work

A. Description of the Experiment

Goal	Demonstrate deployment and use of an extended barrier for multi-day tasks on a bridge. Show safe deployment in a simulated traffic situation with cars driving by. Show worker protection along an extended length. Show end-treatments/crash cushions. NOTE: most bridges have only a 2-foot shoulder.
Overview	Deploy 8 28-foot sections of A-Guard from a trailer using a crane; attach A-Guard to 9 ABSORB 350 crash cushion elements
Other related applications	Protection over several days for extreme maintenance projects, multi-shift and multi-day work on bridge decks, multi-day landscaping and culvert projects; overnight slab replacements, long-length (100 feet or more) guardrail or median repairs
Script	1. Set caution signs 750 feet to 1000 feet ahead. 2. Set cones with 25-foot spacing and taper to take lane 1. 3. Use a shadow vehicle to protect workers deploying barrier segments. 4. Drop barrier segments from trailer next to median. Assume a 2-foot shoulder. 5. Assemble barrier segments into an inked chain of barriers. 6. Deploy/push-out barriers using appropriate tools. Show work area. 7. Push-in barriers to simulate opening of roadway during rush hours. 8. Optional: show gate to allow vehicle access to area behind barriers. 9. Remove work zone

B. Time Measurements

	Setup Operations for Extended Barrier
Time (minutes)	Description of Task
00.00	Tractor-trailer with a crane and the A-Guard barrier sections on the trailer entered the work zone; pickup truck with ABSORB 350 crash cushions entered the work zone
03:00	9 ABSORB 350 crash cushion elements placed on ground at end of work zone (did not require heavy equipment, 2 people); removed straps holding barriers on trailer *NOTE: The ABSORB 350 crash cushions were not filled with water. It generally takes three minutes to fill each crash cushion element: approximately 27 minutes total to fill 9 elements. This was done at the same time that barrier sections were being removed from the trailer.
05:00	Hooked first barrier to crane
05:45	1st barrier section placed on the ground on the side of the trailer (3 people); 1st barrier section rolled on its wheels to the location of the crash cushions (2 people) *NOTE: There is no positive protection for the workers removing the barrier sections from the trailer. The barrier sections can be rolled from behind barrier protection, but this was often not the case during the demonstration. Usually one worker was protected while the other was not.
07:00	2nd barrier section placed on the ground
08:00	1st barrier section attached to the crash cushions (2 people)
09:00	2nd barrier section rolled to the 1st barrier section
	2nd barrier section attached to the 1st barrier section
09:30	3rd barrier section placed on the ground
11:00	3rd barrier section rolled to the first two barrier sections
	3rd barrier section attached to the 2nd barrier section
12:00	4th barrier section placed on the ground
13.00	4th barrier section rolled to the first three barrier sections
13:30	5th barrier section placed on the ground
14:15	4th barrier section attached to the 3rd barrier section *NOTE: Attaching two barrier sections involves putting a post through the two sections, which links the sections together. Then two cover plates (one on each side of the barriers) are placed over the joint between the two barriers, and each plate is held in place with two pins. The cover plates add the rigidity needed for the barrier to meet TL-3 requirements. For the attachment to occur, the two barrier sections

	must be aligned. Sometimes this was not the case, and adjustments to raise or lower the barrier sections were needed.
15:00	5th barrier section rolled to the first four barrier sections
15:30	6th barrier section placed on the ground
15:45	5th barrier section attached to the 4th barrier section
17:00	6th barrier section rolled to the first five barrier sections; 7th barrier section placed on the ground *NOTE: There were some problems getting the 6th barrier section to roll. It took less than one minute to make the adjustments to the barrier so it would roll properly.
17:30	6th barrier section attached to the 5th barrier section
18:20	7th barrier section rolled to the first six barrier sections
18:50	7th barrier section attached to the 6th barrier section
19:15	8th barrier section placed on the ground
	8th barrier section rolled to the first seven barrier sections
20:30	8th barrier section attached to the 7th barrier section
23:00	Cranks on all barrier sections adjusted (2 people)
27:00	Wheels added to the ABSORB 350 crash cushions (4 people)
29:00	Tractor-trailer with crane drove away
29:45	Cranks on all barrier sections adjusted
32:50	Barrier sections (8 linked together) pushed out to edge of work zone using a pickup truck with rollers on the right side; the rollers pushed against the middle panel of the A-Guard and moved the barrier horizontally
35:30	A-Guard barrier towed longitudinally at 3-5 miles per hour by pickup truck; barrier was attached to back of pickup truck *NOTE: Still need to lower A-Guard down from wheels to meet TL-3 requirements (takes ~2 minutes)
Total Time:	**35.5 minutes including towing** **32.5 minutes without towing**

	Takedown Operations for Extended Barrier
Time (minutes)	Description of Task
00.00	Tractor-trailer entered the work zone
00:45	Trailer positioned next to 8th barrier section

01:30	8th barrier section unlinked from 7th barrier section (1 person) *NOTE: This was done from behind the protection of the barriers. However, after the barrier sections were unlinked, the cover plates were placed back onto the barriers, and one worker was exposed to traffic while this was done.
02:40	Wheels removed from the crash cushions (2 people)
02:45	7th barrier section unlinked from 6th barrier section
03:20	6th barrier section unlinked from 5th barrier section
04: 10	5th barrier section unlinked from 4th barrier section
05.20	8th barrier section lifted off the ground
06.00	8th barrier section placed on the trailer; 7th barrier section rolled to the trailer
07.00	6th barrier section rolled to the trailer
07.05	7th barrier section placed on the trailer
08.25	5th barrier section rolled to the trailer
08.30	6th barrier section placed on the trailer
10.10	2nd barrier section unlinked from 1st barrier section
10.40	1st barrier section unlinked from crash cushions
11.30	Placed 6 wood pieces across first group of three barriers (6th-8th) on the trailer
13.00	5th barrier section placed on the trailer
13.05	1st barrier section rolled to the trailer
14.00	4th barrier section unlinked from 3rd barrier section
14.45	4th barrier section rolled to the trailer; 1st barrier section placed on the trailer
15.45	3rd barrier section unlinked from 2nd barrier section
16.40	3rd barrier section rolled to the trailer
16.45	4th barrier section placed on the trailer
	Placed 4 wood pieces across the second group of three barriers (5th, 1st, 4th) on the trailer
	Placed 4 straps across/over the first six barriers on the trailer
21.10	2nd barrier section rolled to the trailer *NOTE: A small tutorial on how to roll the barrier sections was provided to Caltrans workers, who then rolled the 2nd barrier section to the trailer themselves.
23.30	3rd barrier section placed on the trailer
25.30	ABSORB 350 crash cushion elements placed in pickup truck
26.15	2nd barrier section placed on the trailer

28.30	ABSORB 350 crash cushion elements strapped to pickup truck
32.45	Placed 2 straps across/over all barriers on the trailer
36.00	Tractor-trailer and pickup truck drove out of the work zone
Total Time:	**36 minutes**
Total Time for deployment and take down	**Without towing: 32.5+36 = 68.5 minutes (rounded off to approximately 72 minutes (using five crew members) or 9 minutes per segment)** **With towing: 35.5+35 = 70.5 minutes (rounded off to approximately 70 minutes (using five crew members) or 9 minutes per segment)**

C. Observations

- All time measurements are for a work crew of five for setup and takedown of the A-Guard system.
- Deployment time for eight segments of the ArmorGuard Barrier (without longitudinal rolling) was approximately 33 minutes and the take down until the truck left the work zone was approximately 36 minutes.
- Time to remove a barrier section from trailer to ground using a crane was 2 to 3 minutes.
- Time to link and unlink two segments together was approximately 0.5 to 1 minute.
- Time to link eight barrier sections together was approximately 20 minutes.
- Time to push the barrier sections to desired location and line up using a pickup truck with special wheel attachment was approximately 3 minutes.
- During the experiment a crew of five people was used. Three people were used to unload (or load) the barrier sections from the trailer. Two people were able to roll each barrier section to its desired location, and the same two people linked the barrier sections together. One person was demonstrated to be able to unlink two barrier sections. The total work force consisted of five people. It was stated in the post-demo meeting that the A-Guard could be deployed with only three people, but then more time will be required for deployment and takedown.
- The barrier sections can be rolled while the workers are behind the positive protection of the barrier being rolled. However, this was often not the method used during the experimentation. Typically, one of the two people rolling the barrier was outside protection near moving traffic. One person was also near traffic when placing the cover plates over the joints between barrier sections. There are two cover plates, one on each side, and the person working on the traffic side of the barrier was not protected. The workers also did not have protection near the trailer while the barrier sections were unloaded (or loaded), as well as when they were walking back and forth from the trailer to the linked barrier sections. The workers were also exposed to traffic while adding wheels to the ABSORB 350 crash cushions.

- With respect to the applicability to typical bridge work, it was felt that the two-foot shoulder restriction was not followed. The barriers were not pushed in, and it was determined during the experimentation that in order to do this, the pickup truck used to push the barriers would be outside barrier protection and next to moving traffic.

Ramp Closure Experiment

A. Description of the Experiment

Goal	Demonstrate convenient deployment and use of a visual barrier for example for ramp closure that would be more effective than cones and barrels. Show speed flexibility for ad hoc closures.
Overview	Ramp closure using 2 sections of A-Guard deployed from a flat bed truck with a forklift
Other related applications	Visual barrier for traffic control – special events, rest areas, truck scales, parking lots, pedestrian control; Incident management – quasi-emergency and reactive tasks such as main line break, minor slip outs, and slide protection
Script	[Set signs 750 feet to 1000 feet ahead.] Set cones with 25-foot spacing and taper to take area. Move 2 segments of 28-foot A-Guard barrier to off-roadway location using a tractor trailer system. Deploy barriers in place.

B. Time Measurements

Time (minutes)	Description of Task
Setup Operation for Two Barrier sections of the A-Guard Barrier (Ramp Closure)	
00:00	Tractor-trailer with a crane and the A-Guard barrier sections on the trailer entered the work zone; pickup truck with ABSORB 350 crash cushions entered the work zone
	Pickup truck parked at back of work zone to serve as a truck-mounted attenuator
00:50	Tractor-trailer parked on ramp
01:15	Removed the two straps that were across the top two barrier sections on the trailer
02:00	Forklift positioned under 1st barrier section on trailer (1 person driving forklift, 2 people directing driver for proper placement of forklift underneath barrier section)
04:30	1st barrier section placed on the ground *NOTE: The forklift lifted the barrier section from the middle and tilted the forklift

	so the barrier section would not fall off. The barrier section looked very unstable until the forklift was tilted. The forklift lowered the barrier section from the trailer and then drove the section close to the desired location (blocking off the ramp).
05:15	1st barrier section rolled into place (2 people)
05:30	1st barrier section lowered off wheels to ground (2 people); 2nd barrier section lowered from trailer by forklift
06:25	2nd barrier section placed on ground near 1st barrier section
06:45	2nd barrier section rolled into place
08:30	2nd barrier section attached to the 1st barrier section *NOTE: There were difficulties attaching the two barrier sections with the second cover plate. Several adjustments had to be made to the barriers so they were aligned properly.
Total Time	**8.5 minutes**

C. Observations

- The total time to deploy ramp closure was approximately 8.5 minutes with 2 to 3 minutes time required to move barrier sections from trailer to ground using a forklift.
- During the demonstration, three people were used to unload the barrier sections from the trailer. One person was driving the forklift, and two people were directing the driver on proper placement of the forklift underneath the barrier section. Two people were able to roll each barrier section to its desired location and link the barrier sections together. The total work force consisted of five people.
- The workers did not have any positive protection from moving traffic on the closed ramp until the first barrier section was in place. Even at this point, only half of the ramp was blocked with a barrier. Only after both barrier sections were in place was there complete positive barrier protection for the workers still on the ramp.
- Driving the barrier sections from the trailer to their placement as a ramp closure required a lot of space. The forklift swung around, requiring work space that exceeded the 28-foot length of the barrier sections. This may not be available at some work locations.

Contra-Flow Traffic Management Experiment

A. Description of the Experiment

Goal	Demonstrate fast daily management of contra-flow traffic to accommodate known patterns of traffic flow.
Overview	Setup to six 28' long sections of A-Guard and demonstrate contra-flow

	management by moving sections with truck mounted equipment.
Other related applications	Visual barrier for traffic separation and management
Script	1. Set barrier configuration assuming protected work area. 2. Move channel barriers to allow traffic to use a center lane in one direction. 3. Move channel barriers to allow traffic to use a center lane in other direction.

B. Time Measurements

The time measurements were similar to the ramp closure experiment except that it was extended due to using six rather than two barrier segments. The data is summarized in the table below.

Number of A-Guard barrier segments deployed in demonstrations	6
Deployment time without cone or message sign setting or movement of deployed barriers:	25 minutes or approximately 4 minutes per barrier section.
Take-down time without cone or message sign removal:	27 minutes or approximately 4.5 minutes per barrier section.

C. Observations

- The experimentation was performed under ideal road conditions – not all roadway areas are paved and flat. Barrier Systems staff indicated that A-Guard works on up to an 8% grade and can be towed on unpaved surfaces such as dirt.
- The crew consisted of five people and three lanes were needed for deployment and takedown.

In-the-field side by side Experimental Evaluation of A-Guard and B-B Barrier Systems

A. Description of the Experiment

Goal	Perform a Median Wall Repairs by setting up a work zone and then protect workers with A-Guard and B-B systems each on one side of the median.
Overview	Comparative evaluation using the A-Guard and the B-B systems. The B-B system was set on west-bound 80 (the down-hill side). The A-Guard

	system was set on east-bound 80.
Work and Observation Areas	Caltrans work rules forbid work on both sides of a roadway (such as both a shoulder and a median.) The rules do permit work on both sides of a median. This meant that the observation area had to be well off the roadway. However, the observation area was located immediately opposite the median repair site and allowed clear, unobstructed views of both demonstrations.
Weather & Traffic Conditions	Weather was clear and cold with no wind. The pavement was dry. Traffic was light in terms of count, but dangerous in terms of heavily loaded tractor-trailers traveling at high speed through the work zones. There was a constant, heavy, acrid smell of truck brakes.
Script	Set up a work zone, deploy barrier and protect workers. Signage and traffic cones for both zones were set by a Caltrans maintenance crew. The B-B was deployed by a Caltrans bridge maintenance crew. The A-Guard system was set by a Barrier Systems crew.
Notes/Observations	Per standard Caltrans procedures, an Attenuator vehicle protected each work zone. To perform the repair in the B-B work zone, a Tender truck for tools was also used. In the case of A-Guard system, an additional truck was used to carry the crash cushions. The setup times measured do not include the time required to implement signage and set warning cones, activities which occurred outside the viewing area. According to the District Superintendent, a full lane closure, as required by the A-Guard system, would typically require 15 to 20 minutes for set up. No estimate was available for closure preparation for the B-B zone, which was both shorter in length and which did not take a full lane closure for this median wall repair operation.

B. Time Measurements

Time	Description of Task
B-B system Set Up (one person one truck)	
10:07	Tender truck arrives.
10:09	B-B system arrives and immediately lowers rear attenuator.
10:11	B-B system lowers its legs and begins rotating its beam.
10:12	B-B system repeats rotation of beams for benefit of photographers.
10:13	B-B system barrier in place.
10:14	Work crew enters work area and begins work.
Total Lapsed	**7 Minutes**

Time:	

Time	Description of Task
B-B system Takedown (one person one truck)	
1:52	B-B system begins retraction process by swinging beam over to other side
1:53	B-B tractor moves forward to disengage ―V" support.
1:55	Truck Mounted Attenuator folds-up on trailer.
1:56	Backing truck to fold telescoping beams to locked position.
1:57	B-B tractor and tender truck leave workzone.
Total Lapsed Time:	**6 Minutes**
Total Time for Deployment and Takedown	**6+7=13 minutes (rounded off to approximately 15 minutes)**

Time	Description of Task
A-Guard Setup (three people, two trucks)	
10:19	Tractor-trailer arrives with barriers. There are 8 bundles, each 3700 lbs.
10:21	Truck arrives with crash cushions for end protection. There are 5 water-filled cushions, each 500 lbs.
10:29	Crane is ready. Crane begins lifting crash cushions into place.
10;32	Crash cushion 1 down.
10:45	Crash cushions 2-5 down.
10:50	Crane is secured and the truck moves 300 feet uphill.
11:02	Crane is setup, straps are undone. Barrier Section 1 on the ground.
11:08	Barrier Section 1 rolled into place.
11:20	Barrier Section 1 in place ad linked to crash cushions. (Note: Problems were encountered but resolved when lifting a 500 lb cushion in order to tuck Barrier Section 1 under it.)
11:53	Barrier Sections 2-8 moved into place and linked with one another.
11:57	Crane secure and setup completed.
Total Lapsed Time:	**98 Minutes**

Time	Description of Task
A-Guard Takedown (three people, two trucks)	
2:19	Tractor-trailer w/crane and flatbed trucks arrive.
2:25	Water cushions are disconnected from end barrier section and moved to center wall.
2:23	End barrier, barrier 1 rolling toward crane.
2:39	Barrier 1 lifted on truck.
2:50	Barrier 2 lifted on truck.
2:56	The truck moves 150 feet uphill and the last barrier in line, barrier eight is rolled to the crane.
2:57	Barrier 8 lifted on truck.
3:05	Barrier 7 lifted on truck.
3:10	Barrier 6 lifted on truck
3:18	Barrier 5 lifted on truck.
3:20	Barrier 4 freed and rolled to truck.
3:26	The load is strapped down with 6 barriers on the truck: 3 wide and 2 high.
3:40	Barrier 3 is lifted on the truck.
3:46	Barrier joint covers are collected and packed onto crane truck trailer.
4:00	With all 8 barriers on-board, 3 rows high, additional load straps are placed.
4:06	First water cushion is lifted onto flatbed truck.
4:15	All water cushions lifted onto flatbed truck.
4:17	Water cushions strapped down on flatbed truck.
4:25	Tractor-trailer w/crane and flatbed trucks leave.
Total Lapsed Time:	**126 Minutes**
Total Time for setup and take down	**98+126=224 (rounded off to approximately 225 minutes using a crew of three people)**

Time	Description of Task
Caltrans Removes Lane Closure (three people, two trucks)	
4:26	Beginning removal of lane closure: cones. Signs and arrow board trailer.
4:45	All lanes open.
Total Lapsed Time:	**19 Minutes**

C. Observations

- Both setup and takedown of the A-Guard system definitely required a minimum of three crew members while the B-B system only needed one.
- The total time for setup and take down for the B-B system was approximately only 5.8% of the total time for the A-Guard system. The time durations for A-Guard system used are based on using three crew members for setup and takedown.
- At each time the linear distance of protection provided by the B-B system was only 30 feet while with the A-Guard system it could be up to 140 feet.
- During setup and takedown of the A-Guard, there were many times when the crew members were not positively protected while moving the barriers from and to the trailer; the crew entered areas without positive protection in order to open and strap barrier bundles to the trailer; crew members loaded the trailer while not facing traffic; and a crew member had to climb to the top of the trailer to place stack spacers. The time duration for which the crew members were not positively protected was approximately 1/3 of the total time of deployment and retraction. The single crew of the B-B system however was not exposed to traffic without positive protection.
- During set up the A-Guard system required a shoulder plus a full lane closure because of the space requirements for the set up while the B-B system did not require any lane closures.
- Once the A-Guard system was packed and stowed, a temporary full road closure was put in place to allow the transport vehicle to get on the road. The B-B system did not require a lane closure in this situation.
- The A-Guard system required two transport vehicles for a crane, barrier sections, and crash cushions while the B-B system is installed on its own single transport vehicle.

APPENDIX B

ArmorGuard Barrier System Demonstrations

This study also involved performing eight demonstrations of the A-Guard system to Caltrans personnel. Each demonstration was executed by *Barrier Systems Inc.,* the developers of the A-Guard system. An equivalent “script” was followed for each demonstration with the aim of providing uniformity to obtain feedback in a controlled manner.
The main aim of the demonstrations was to expose the attendees to the A-Guard system for “real-time” operations on a simulated highway to evaluate the effectiveness, applicability, feasibility and usefulness of the A-Guard system for potential adaptation for their own work environments. In addition feedback was obtained from the participants on applicability of the A-Guard system for highway maintenance tasks in California.
The demonstrations took place at the same location where the experimental evaluations had been performed as described in Appendix A. The dates, main purpose, and type of attendees for each demonstration are summarized in the table B-1 below:

Demo Data	Main Purpose	Audience
10/12/08	Detailed A-Guard deployment and operation	Headquarter Directors and Managers
04/23/09	Vulcan vs. A-Guard demo	Deputy District Managers
07/31/09	A-Guard Typical Use Demonstration	Equipment Operators
08/04/09	A-Guard Typical Use Demonstration	Maintenance Leaders
08/14/09	A-Guard Typical Use Demonstration	Equipment Operators
08/18/09	A-Guard Typical Use Demonstration	Maintenance Leaders
08/28/09	A-Guard Typical Use Demonstration	Equipment Operators
09/01/09	A-Guard Typical Use Demonstration	Maintenance Leaders
09/18/09	A-Guard Typical Use Demonstration	Equipment Operators
09/22/09	A-Guard Typical Use Demonstration	Maintenance Leaders

Table B 1. List of Demonstrations of the ArmorGuard system.

In all the demonstrations, participation by Caltrans personnel was completely voluntary.
The following format was used at each demonstration:

1. Classroom briefing and discussion by AHMCT researchers on purpose and goals of the demonstration.
2. On-site briefing and during-demo commentary by A-Guard staff on product and usage.
3. Live demonstration of bridge work / paving scenario: moveable barrier using 8 sections deployed with crane.
4. Live demonstration of ramp closure scenario: close ramp using 2 sections deployed with fork lift.
5. Live demonstration of contra-flow traffic management: manual and pickup truck movement of 8 section interconnected string of A-Guard.

6. Voluntary feedback by the participants.

Each demonstration contained the complete A-Guard system, which consisted of eight 8.5m reinforced steel barrier segments illustrating the extended barrier type work used in controlled experimentations. An on-site crane and five crew members were used to load and unload the barrier sections from the tractor trailer and deploy them. The manufacturer, *Barrier Systems,* however, indicated that other deployment methods such as using a fork-lift, a wheel loader, or a winch and hoist could also be used.
The summary of the data on deployments and takedowns obtained during demonstrations is given in the following table:

Number of A-Guard barrier segments deployed in demonstrations	8
Deployment time without cone or message sign setting or movement of deployed barriers:	33 minutes (approximately 4 minutes per barrier)
Take-down time without cone or message sign removal:	36 minutes (approximately 4.5 minutes per barrier)
Number of lanes needed for deployment and takedown	3

Table B 2. Summary of the Data.

Observations

- During the demonstrations it was observed that the pickup truck used to move the barriers in place and pull them out was in the live traffic area.
- The process of loading and unloading the barrier sections was very unstable when using a forklift but was stable using a crane.
- The A-Guard can be one of the items available to Caltrans maintenance in a tool box; it has applications that do not necessarily overlap with B-B system. It can be used in some applications where the K-rails are used – the advantage is that A-Guard is that it can easily be maneuvered once on ground. The disadvantage is that it can have up to six feet of deflection in its fully extended configuration.
- Caltrans maintenance crew sizes are now typically down to three people that would make it difficult to handle the A-Guard system requiring a crew of five for time effective deployment.
- Concerns were raised on the equipment requirements for handling the A-Guard system such as use of large forklifts and cranes. There is limited if any accessibility to such equipment in Caltrans maintenance yards making it impractical at this time to consider using the A-Guard system.
- Pulling force requirements to move the barriers on slopes can require higher number of crew people to maneuver the system. It may therefore lose some of its advantages in high grade areas.

- Operator training, maintenance, and repair requirements should also be considered for systems such as A-Guard and B-B barrier systems before they can be fully adopted.
- Furthermore, there are concerns related to operator training for crane operators within the existing Caltrans maintenance work crew that need to be addressed for proper adaptation of the A-Guard system.
- Front end loaders are typically used by maintenance crew to handle K-rails the same need to be used to handle A-Guard barriers. Since there is limited accessibility to front-end loaders, the A-Guard system can be more appropriate for utilization by Caltrans for longer term closures.
- Concerns were also raised that as time and energy needed to setup and takedown the system increases such as for A-Guard barrier system, the desire to use it diminishes by the maintenance crew.
- Concerns were also raised for safety of the crew deploying and taking down the system since many times they were not protected during the demonstrations.
- An excellent application for the A-Guard system is in traffic control for long time duration work zones. They can also be used for guard rail repairs over long distances. Also for intersection work zones. It is not as useful for short time duration work.

Conclusions

The responses received in all the demonstrations were overall very similar. At each demonstration many of the observers liked the equipment and thought that if “re-worked” it might possibly become more useful for Caltrans operations. Some wanted the system to be able to curve more around a realistic roadside curve (15 degrees), some wanted a model that does not require as many people to deploy (3-5), and many wanted a system that does not need a crane for deployment due to the number of lanes it would require (a highway of 3 lanes or more). It was stated by many observers that the A-Guard system is best for long term work zones. In some situations for Caltrans type activities this was a major problem since they cannot maintain a long term lane closure due to cost and problems with congestion.

Practitioner Comments

During the deployment demonstrations, comments from approximately 150 practitioners were collected. Although a formal interview format and questionnaire were developed, it turned out that the people with the most direct field experience were the ones most resistant to formal questionnaires. All comments received were on volunteer basis and they were collected as participants felt that they would like to express it.
The following section provides a listing of individual comments and these comments are grouped by topics.

<u>Deployment</u>

Safety

- “I believe that A-Guard barriers are excellent equipment; however, I dislike the fact that a person has to lean over, in order to separate the two barriers from one another. This takes attention away from traffic.” — Mechanic.

- ”I consider anything that saves lives a good idea; however, I am concerned with the exposure required to deploy units”. — Supervisor.

Terrain

- ”When I suggested to one of the [Barrier Systems] workers that it would be very difficult to maneuver the barriers on a rough surface, he agreed. When I discussed this with a salesman, he claimed that it worked very well on rough surfaces, and he did not admit any limitations. He referenced a video on the site as proof. I do not believe it. ”— Operator.
- ”You would not typically have the large flat surfaces in our demo. I am concerned about the stability of the barriers on a typical roadway or roadside. ” — Supervisor.
- ”Keeping the barriers under control on an 8% slope would be a challenge. The nominal force pulling the barrier downhill is 240 lbs which is more than what it takes to get the barrier rolling. Would probably need 5 strong people on each barrier. ”— Observer.

<u>Infrastructure</u>

Equipment

- ”Where is the equipment to set it up going to come from? Where are the personnel going to come from? It would have to be handled by traffic control. Maintenance cannot do it. This would be a large addition to daily duties. Our maintenance crews are already down to 3. — Supervisor.
- ”We would have to use front loaders. We don't have cranes or fork lifts. ”— Supervisor.
- ”We tried the handling of barriers in a yard. The best way to handle them is by forklift. ” — Supervisor.
- I am concerned about the handling of the barriers with a forklift. Maintenance yards do not have the large forklift used in the demo. ”— Supervisor.
- ”We usually use a loader for lifting operations, and these barriers could be lifted with the loader the same way we now lift K-rails. The problem is that a yard only has one loader; it has to be taken by trailer out for the barrier setup. The loader is needed for other jobs. This barrier system would only be useful in longer term closures. ” — Supervisor.
- ”Loaders are limited in the height to which they can reach and would not be able to unload the truck shown in the demo.” — Observer.
- ”The A-Guard system is not practical since you need the truck and crane. This is not equipment that is available within Caltrans operations at the maintenance yard. There are no Caltrans crane operators. It is possible that the A-Guard system could become part of the pooled equipment where a system might be assigned to a district. ” — Supervisor.
- ”We tried handling the barriers in our yard. The best way to handle them is by forklift. ” — Supervisor.
- ”I think these barriers would need a lot of heavy duty equipment to move it around. I see this as a flaw.” — Supervisor.

Process

- ” I am concerned about the deployment system. Perhaps it would be better to unload directly from a big rig rather than using a crane.” — Operator.
- ”Crews will not use this unless the equipment for deployment is also provided. This system may work in longer term closures. ” — Manager.
- ”What about maintenance of the system, such as wheels and damaged panels? The usefulness comes down to set up and take down vs. energy and man power” — Operator.

People

- ”The demo included a large crew working diligently in a tight time sequence. The size of the crew is critical to what operations can occur in parallel. ” — Contractor.
- ”A big problem is that Caltrans is no longer certifying its own crane operators and therefore has none available. Caltrans could not load and unload the A-Guard system as demonstrated. ” — Supervisor.
- ”Believes it takes too many people to operate it. He doesn't like the fact that he would have to bring an extra truck. ”— Supervisor.
- ”Great system if you can train people properly, but realistically we are dealing with Caltrans people.” — Equipment Instructor.

<u>Usage</u>

Safety

- ”I like the idea of protecting the work zone. You cannot be aware of the traffic situation while working. You become focused on the work you are doing. ” — Operator.
- ”This is better than nothing.”— Supervisor.
- ”I am concerned about impacts. Accidents are random. I witnessed the end result of an event in which a semi blew through two K-rail barriers going across the median. Would these barriers be better than K-rails? Would they deflect the vehicles that drifted into the barrier at shallow angles? Sometimes when replacing slabs, we are two feet from live traffic. We are very exposed to traffic; I am interested in anything that can help keep a vehicle out. ” — Maintenance Worker.
- ”What would the end treatment of the barrier look like? Could the tail end of the barrier be angled inward to keep vehicles from entering the lane closure? Would a shadow vehicle be located at the entrance? ”— Supervisor.

Traffic Control

- ”I like the idea of placing gates in the median of roads like Hwy 5”. — Supervisor.
- ”The only effective solution to the work zone safety effort is to control the flow of traffic. We have to reduce the speed of the passing traffic by whatever means possible. ” — Supervisor.

- ”The system may be a useful in emergencies where we would normally use K-rail. The advantage being that the A-Guard is much lighter and can be maneuvered by hand once on the ground. A-Guard appears to be easier to install than K-rail. A typical event would be the case in which a length of guardrail has been destroyed and the repair work is not done by Caltrans crews. In this case the work is contracted out which takes time and therefore delays the repair. A temporary barrier of K-rail is then put in place by Caltrans to provide the protection originally provided by the guardrail. ” — Supervisor.
- Traffic will avoid the A-Guard system unlike cones. ” — Supervisor.
- ”It is a great system for traffic control. I have seen it operate in Coronado. ” — Equipment Operator.
- ”I believe this would work best for intersection work zones.” — Electrician.
- ”I think this would be great for closing bridges. Can the width be smaller? ” — Toll bridge, Supervisor.
- ”The open gate aspect of armor guard is not needed.” — Operator.

Maintenance

- ”It would be very unlikely that they we would set up a barrier as shown for most of our work zones. It is not applicable for maintenance operations. It requires too much manpower and time. Our crews typically consist of 3 people. We do not have enough people to get the work done let alone the barrier set up. This is ideal for a construction zone. Maintenance operations are too short in time to justify the added time and exposure. A typical maintenance crew might have one or two jobs a year in which this barrier system would potentially be used. Maintenance operations closures are too short in time. It would take a two day job to justify the use of the barrier. ” — Supervisor.
- ”A-Guard is too difficult to set up for most maintenance work. It may be useful in a place where maintenance workers have no escape such as working on bridges. One case in which the rolling feature may be useful is in taking a lane on an overpass. The A-Guard system could be assembled away from traffic in the area between the off-ramps and the main road. It would then be dragged into place on the bridge (overpass) to take the lane. The present operation involving K-rail and a loader takes a multiple lane closure on the bridge to set the barrier up. The A-Guard installation in this case is might be more efficient and have less impact on traffic”. — Supervisor.
- ”Due to the set up and take down effort, the A-Guard would not be considered in a closure of less than 8 hours. The ability to drag the A-Guard system may have an application when filling potholes or doing slab repairs. It would not work for crack sealing operations. The towing vehicle would have a modified hitch so it could pull from within the lane being protected. ” — Supervisor.
- ”I really like the way Armor Guard Barriers operate. However, they are not useful for short term operations. ” — Operator.
- I” believe that it is great equipment for construction, but not for maintenance operations. ” — Safety Advisor.
- ”I believe it would be good for long term operations.” — Contracts Manager.

- ”Los Angeles area cannot have permanent lane closures till 9 pm, and those must be shut down by 11. We can't have closures longer than 6 hours. So I am concerned about why this would be useful. I think this issue would also be a problem in San Diego”— Operator.
- ”I believe that A-Guard Barriers would work better than water barriers. I also like the fact that it is so easy to operate. ” — Supervisor.
- ”It is great equipment for long term operation.” — Operator.
- ”I am skeptical about the use of this system in my district”. — Operator.
- ”It is great equipment, and it's easy to use. However, it is not useful for our type of work (landscaping)” — Operator.
- ”The barrier system might be used for bridge work which often occurs over several days. It would be feasible to pull the barrier chain on and off the bridge at the beginning and end of the shifts. The barriers would be stored safely on the shoulder of the road off the bridge. ” — Supervisor.

Mobility

- ”I can imagine pulling the barrier to the jobsite from the yard. Are there other options for getting it to the job site (often our work is within a few miles of a yard)? I suggest a wheel configuration built into the barrier section that would allow the section to be towed at freeway speeds with a pickup to the jobsite. (He brought this up at the closing meeting later. The Vendor said Barrier Systems would not be able to develop that due to costs.) ” — Supervisor.
- ”I asked [the vendor] if the barrier can be pulled from the crash cushion end. No. This means it could only be pulled in the one direction with the crash cushion attached. ” — Observer.
- ”Could be have a barrier section attached to the forward corner of a vehicle that is shadowing the work area? This would help with intrusions into the work zone forward of the shadow vehicle. I am focused on exposure immediately in front of a barrier vehicle. ”— Supervisor.
- ”The Jersey barrier is very heavy and cannot be moved around as easily as the A-Guard which weighs less than 3500 lb. K-rail sections weigh 7000 lb (not sure) and they need to be pinned to the road. A loader is used to load and unload the K-rail. I have talked to a spec writer that told me that loaders have been damaged lifting the K-rail sections and that Caltrans may be restricted from using loaders with K-rails. The only option then would be to use their 7 ton forklifts which are not readily available. The lighter A-Guard would be a good substitute. ” — Supervisor.

Terrain

- ”The system looks good. I am concerned about how easy it is to deploy on a steep grade hill. I would like to see a system demonstration on a hill. ” — Supervisor.
- ”No, too many hills.” — Operator.
- ”We cannot use it in our area: we have mountains and lots of snow.” — Supervisor.
- ”It cannot be use for mountain area.” — Operator.

- ”I am concerned about how cold weather can affect the equipment; will it be as easy to use in cold weather? Towing might be practical if there are real sized tires for towing. If the system could move faster it would be useful for emergency response. ” — Operator.
- ”I am concerned about the test standards since I have seen an accident at more than 25 degrees.” — Equipment Instructor.
- ”Carrying the barriers with the forklift has to be done very carefully because the load (barrier) is not very stable. Irregularities on the road surface would easily cause the load to shift and become unstable. Steel structures on the steel forks have a very low coefficient of friction. I do not see any pockets or other feature that prevents the movement of the barrier on the fork. Note that you need a very wide work area to turn and move forward or back. I would not recommend it as a regular practice without further investigation”. — Observer.
- ”I am concerned about deploying in the mountains. It would be more useful to use a small dolly system for deployment. ” — Operator.

Safety

- ”I am concerned about when the barrier is hit: how far will it move and would it be safe for the workers? Is there a grabbing system for skidding? ” — Operator.
- ”I think that Armor Guard Barriers are a lot better than K-rails”. — Supervisor.
- ”I am concerned that there are not other systems to compare it to. Also I am concerned about costs. ” — Operator.
- ”I think this is a good system, but I would like to see a side by side comparison with K-Rail.” — Operator.

Vendor Comments

A summary of the comments from the Barrier System Inc. is provided in table B-3 below.

Subject	Vendor Comment
A-Guard vs. B-B system applications	"The applications for A-Guard and B-B systems do not overlap. They are very different products. A-Guard is not meant for worker protection."
Caltrans applications	_We have demonstrated the system. Caltrans is very creative and can figure out how to use the A-Guard system."
Gate Function	The vendor described the use of A-Guard as gating in median barriers. The A-Guard gating system is more versatile and does not require power to operate. It is ideal for gating that is not used regularly. Price of adapter plates to attach barrier as gate is $6,000-$10,000.
Deployment Time	*Setting the crash cushions would have increased deployment and take-down time by about half an hour each.*
Crew requirements	*A crew of 3 can install the barrier system* demonstrated today. The time to install will increase. A crew of 5 was used for all demos.
Slopes	*Barriers can handle 8% slopes* — Barrier Systems claims that the barrier can be set up on a road with 8% slope (longitudinal or lateral). Braking can be achieved by turning the wheel 90 degrees.

Table B 3. Vendor Comments.

APPENDIX C

Proposed Usage and Deployment Guidelines for the ArmorGuard Barrier System

This appendix describes the conditions and guidelines for utilization of the A-Guard barrier system in highway operations assuming availability of appropriate crew and equipment to deploy the system. ***This is a proposed and potential usage and deployment guideline. It should be carefully reviewed and updated by professionals in work zone safety and traffic operations before it can be considered for adaptation.*** In general, when utilizing mobile barriers, at least the following 14 factors should be considered. These factors should be weighted with a criticality rating from 1 to 5. The factors and their criticality are shown in table C-1 below. Projects receiving the highest aggregate scores can be given priority for deployment of mobile barriers.

Factor	**Criticality**
Lack of escape routes for on-foot personnel (bridge decks, etc.)	5
High volume traffic	4
High speed traffic	4
Night work (workers on foot in a stationary operations)	4
Median work (guardrail, median barrier, drainage)	3
Working on a gore point (e.g., attenuator replacement)	3
On-foot projects with extended duration in one location (more than 4 hours)	3
On-foot work adjacent to multi-lane freeways with narrow shoulders	3
Lane widths of less than 12 feet	2
High percentage of large vehicle (truck) traffic	2
High accident area (check recurrent accident data)	2
Multi-lane urban freeway	2
Two-lane rural highway	1
Rigid barrier that creates a vehicle "ricocheting" situation	1

Table C 1. Factors to Be Considered in Deciding Usage of ArmorGuard Barrier.

Considering the above factors and the experience gained from the experimental evaluations and field demonstrations, the use of the A-Guard system can be appropriate for the following situation:

- Visual barrier for traffic control: special events, ramp closures, rest area closures, parking lot control.
- Protection over several days: extreme maintenance projects, multi-shift and multi-day work on bridge decks, overnight slab replacements, minor slip outs and slide protection as replacement for K-rail.

- Multi-day culvert projects.
- Gate access in a K-rail section to allow vehicle access.
- Emergency roadway turn-around areas (as near the border with Mexico).
- Protection during reactive responses, such as a main line break.

Deployment Methods

- ArmorGuard barriers can be deployed in a variety of ways, using a crane, fork-lift, wheel loader, tilt-trailer, winch and hoist.
- Barriers may be able to be deployed by telescope and tow methods from a ramp, median, or shoulder.
- Once staged, manual push-back / push-out may be possible, but may require undue physical effort.

Deployment Guidelines for ArmorGuard Barrier

- Before deploying the barrier system to protect workers within a highway maintenance work zone, a multiple lane (3 lanes or two lanes and a shoulder) static lane closure must be placed to ensure the safety and minimize the hazards to deployment personnel.
- Since the deployment will require employees to be on foot in proximity to moving traffic and take approximately 15 minutes per section, the procedure is classified as a stationary operation. A Stationary Operation is defined in the Caltrans Maintenance Manual, Volume I, Chapter 8, and Section 8.10 [4]. All lane closures shall comply with Chapter 8, Section 8.23.
- Once the lane closure has been erected and the deployment process begins, the workers involved in the process must be protected by a shadow/barrier vehicle during the setup procedure (Chapter 8, Section 8.11). Due to the fact that there will be deployment personnel on foot in close proximity to moving traffic, it is further recommended that a person be assigned as a lookout (Chapter 8, Section 8.17) to warn employees of any errant vehicles within the immediate work zone.
- The services of a Maintenance Zone Enhanced Enforcement Program (MAZEEP) Officer should be enlisted to reduce traffic speeds and further protect workers on foot.
- A similar process should be considered for take down of the system which would also involve a static lane closure for the A-Guard transport vehicle.

APPENDIX D

AHMCT Injury Database

Introduction

In the state of California, approximately two Caltrans employees die in California highway work zones each year. An additional 70 fatalities per year occur to both motorists and non-Caltrans highway workers due to traffic accidents occurring within close proximity to a work zone. . 100 motorists die in California work zones each year. Also during the year, another 2800 people are injured in these same types of auto collisions. These events are both emotionally and financially costly to all residents. Conservative estimates suggest that work zone accidents and injuries have direct medical costs of about $800 million per year. Not to mention property damage, lost earnings, lost household production, travel delay, vocational rehabilitation, workplace costs, administrative costs, legal costs, pain, and lost quality of life.

Many efforts have been made to reduce and eliminate these fatalities and injuries. For example, workers are being kept in vehicles to provide them with positive protection, there are attempts to change driver behavior with publicity campaigns, use more full closures of highways, as well as working at night. All of these ideas have merit but a minimal amount of data exists to support their effectiveness. It was found to truly understand the causes of traffic accidents near or at highway work zones, it was determined that more ―in depth” information about each accident was needed.

Acting on the advice of Challenge Area 14: Work Zone Safety (CA14) of the Strategic Highway Safety Plan (SHSP), AHMCT has initiated the process of evaluating the full text of California Highway Patrol (CHP) Traffic Collision Reports also referred to as ―CHP 555” or ―555” reports. Approximately 2,389 Traffic Collision 555 reports have been read, evaluated in detail and synchronized with 18,100 Caltrans Traffic Accident Surveillance and Analysis System (TASAS) records. Each of these TASAS records referenced the traffic collision occurring within close proximity of a work zone.

Beginning the evaluation process, 40 causal factors and 19 collision outcomes were identified for the work zone collision incidents. The causal factors were grouped into six basic causes and outcomes. Injury descriptions were also evaluated and categorized in terms of the Abbreviated Injury Scale (AIS) developed by the Association for Advancement of Automotive Medicine. Creating a database which ties together the factors and outcomes of each traffic collision at a work zone begins the process of truly understanding the nature of work zone accidents involving the traveling public.

Methodology

The methodology used to develop the AHMCT database was ―requirements driven”. The following questions were kept in mind throughout the design and implementation of this project:

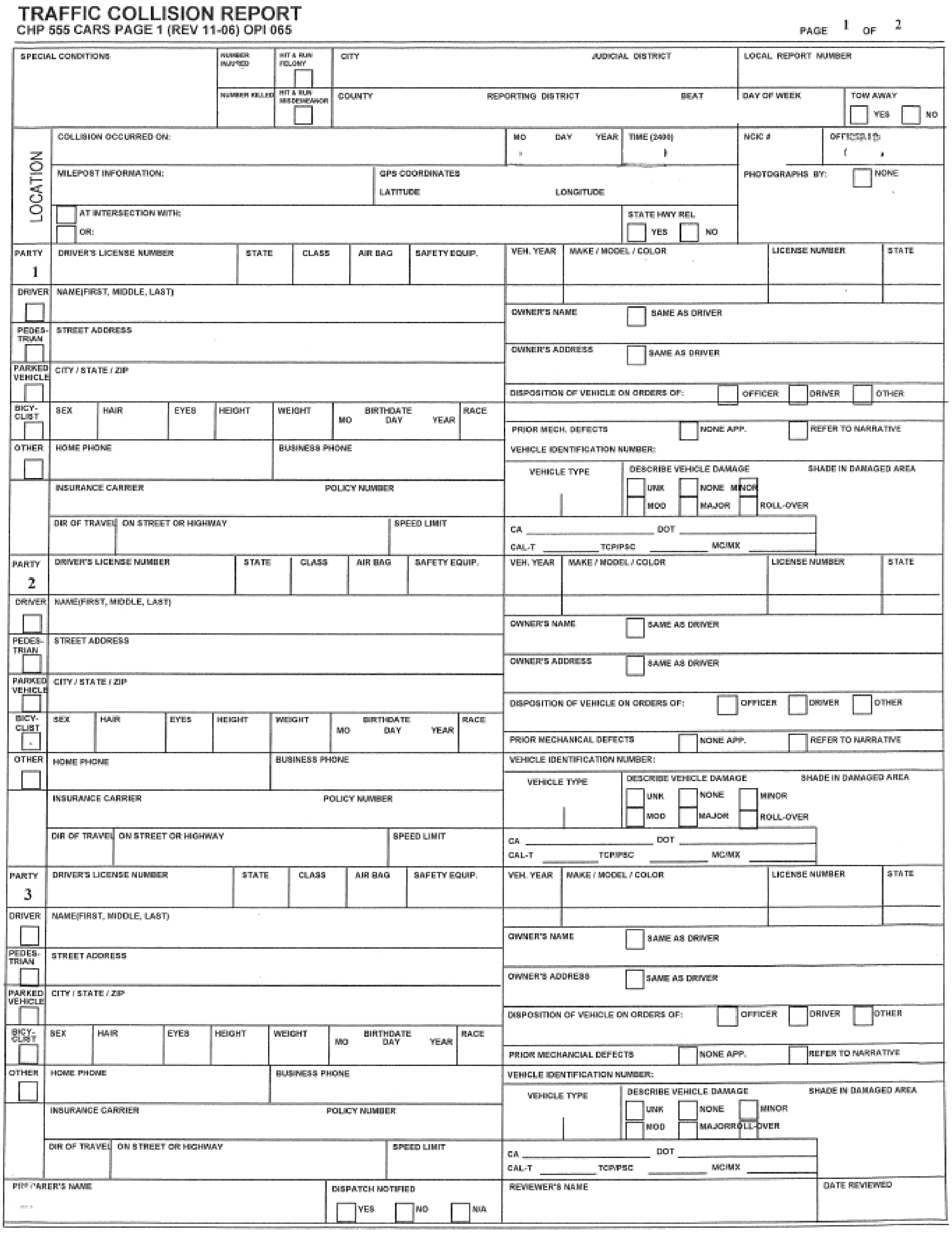
- What kinds of accidents occur in a work zone, what causes them, and can anything be done about them?
- Is it worth the cost to put up a barrier system (i.e. ArmorGuard)? If so, when and where?
- What factors, outcomes and attributes are important in terms of injuries and fatalities? Which ones of these can be affected through use of barrier systems?

To answer the above questions, four processes were developed. They are:

1. Gather individual CHP 555 reports as indicated by the TASAS information
2. Enter CHP 555 report information systematically into a database
3. Enter injury information (if any) and estimate associated cost due to the injuries
4. Analyze data and relationships between causes and factors.

California Highway Patrol (CHP) Traffic Collision Report Form

Figures D-1 and D-2 below show pages 1 and 2 respectfully, of the CHP 555 report form. The first page (Figure D-1) contains the majority of information such as drivers and vehicles involved and precise location of the incident. The second page (Figure D-2) provides additional information such as safety equipment in use and whether driver inattention was a factor in accident causation. After the first two pages any additional information is provided and differs depending on the collision. If pedestrians or witnesses were involved, that would be included in the report. Diagrams, statements, and descriptions of the accident scenes are prepared by the CHP officer on the scene. A typical CHP traffic collision report (555 reports) is five pages although they can be 40 pages in length as when a fatality is involved.


TRAFFIC COLLISION REPORT
CHP 555 CARS PAGE 1 (REV 11-06) OPI 065
PAGE 1 OF 2

SPECIAL CONDITIONS | NUMBER INJURED | HIT & RUN FELONY | CITY | JUDICIAL DISTRICT | LOCAL REPORT NUMBER
NUMBER KILLED | HIT & RUN MISDEMEANOR | COUNTY | REPORTING DISTRICT | BEAT | DAY OF WEEK | TOW AWAY YES NO

LOCATION
COLLISION OCCURRED ON: | MO DAY YEAR | TIME (2400) | NCIC # | OFFICER I.D.
MILEPOST INFORMATION: | GPS COORDINATES LATITUDE LONGITUDE | PHOTOGRAPHS BY: NONE
AT INTERSECTION WITH: | OR: | STATE HWY REL YES NO

PARTY 1
DRIVER'S LICENSE NUMBER | STATE | CLASS | AIR BAG | SAFETY EQUIP. | VEH. YEAR | MAKE / MODEL / COLOR | LICENSE NUMBER | STATE
DRIVER | NAME(FIRST, MIDDLE, LAST)
PEDESTRIAN | STREET ADDRESS | OWNER'S NAME SAME AS DRIVER
PARKED VEHICLE | CITY / STATE / ZIP | OWNER'S ADDRESS SAME AS DRIVER
BICYCLIST | SEX | HAIR | EYES | HEIGHT | WEIGHT | BIRTHDATE MO DAY YEAR | RACE | DISPOSITION OF VEHICLE ON ORDERS OF: OFFICER DRIVER OTHER
OTHER | HOME PHONE | BUSINESS PHONE | PRIOR MECH. DEFECTS NONE APP. REFER TO NARRATIVE
VEHICLE IDENTIFICATION NUMBER:
INSURANCE CARRIER | POLICY NUMBER | VEHICLE TYPE | DESCRIBE VEHICLE DAMAGE UNK NONE MINOR MOD MAJOR ROLL-OVER | SHADE IN DAMAGED AREA
DIR OF TRAVEL | ON STREET OR HIGHWAY | SPEED LIMIT | CA | DOT | CAL-T | TCP/PSC | MC/MX

PARTY 2
DRIVER'S LICENSE NUMBER | STATE | CLASS | AIR BAG | SAFETY EQUIP. | VEH. YEAR | MAKE / MODEL / COLOR | LICENSE NUMBER | STATE
DRIVER | NAME(FIRST, MIDDLE, LAST)
PEDESTRIAN | STREET ADDRESS | OWNER'S NAME SAME AS DRIVER
PARKED VEHICLE | CITY / STATE / ZIP | OWNER'S ADDRESS SAME AS DRIVER
BICYCLIST | SEX | HAIR | EYES | HEIGHT | WEIGHT | BIRTHDATE MO DAY YEAR | RACE | DISPOSITION OF VEHICLE ON ORDERS OF: OFFICER DRIVER OTHER
OTHER | HOME PHONE | BUSINESS PHONE | PRIOR MECHANICAL DEFECTS NONE APP. REFER TO NARRATIVE
VEHICLE IDENTIFICATION NUMBER:
INSURANCE CARRIER | POLICY NUMBER | VEHICLE TYPE | DESCRIBE VEHICLE DAMAGE UNK NONE MINOR MOD MAJOR ROLL-OVER | SHADE IN DAMAGED AREA
DIR OF TRAVEL | ON STREET OR HIGHWAY | SPEED LIMIT | CA | DOT | CAL-T | TCP/PSC | MC/MX

PARTY 3
DRIVER'S LICENSE NUMBER | STATE | CLASS | AIR BAG | SAFETY EQUIP. | VEH. YEAR | MAKE / MODEL / COLOR | LICENSE NUMBER | STATE
DRIVER | NAME(FIRST, MIDDLE, LAST)
PEDESTRIAN | STREET ADDRESS | OWNER'S NAME SAME AS DRIVER
PARKED VEHICLE | CITY / STATE / ZIP | OWNER'S ADDRESS SAME AS DRIVER
BICYCLIST | SEX | HAIR | EYES | HEIGHT | WEIGHT | BIRTHDATE MO DAY YEAR | RACE | DISPOSITION OF VEHICLE ON ORDERS OF: OFFICER DRIVER OTHER
PRIOR MECHANICAL DEFECTS NONE APP. REFER TO NARRATIVE
OTHER | HOME PHONE | BUSINESS PHONE | VEHICLE IDENTIFICATION NUMBER:
INSURANCE CARRIER | POLICY NUMBER | VEHICLE TYPE | DESCRIBE VEHICLE DAMAGE UNK NONE MINOR MOD MAJOR ROLL-OVER | SHADE IN DAMAGED AREA
DIR OF TRAVEL | ON STREET OR HIGHWAY | SPEED LIMIT | CA | DOT | CAL-T | TCP/PSC | MC/MX

PREPARER'S NAME | DISPATCH NOTIFIED YES NO N/A | REVIEWER'S NAME | DATE REVIEWED

Figure D 1. California **Highway Patrol Traffic Accident Report Form ("555"): Page 1.**

TRAFFIC COLLISION CODING

CHP 555 CARS PAGE2 (REV. 11-06) OPI 065

PAGE 2 OF 2

DATE OF COLLISION (MO. DAY YEAR)	TIME(2400)	NCIC #	OFFICER I.D.	NUMBER

PROPERTY DAMAGE	OWNER	OWNER ADDRESS	NOTIFIED ☐YES ☐NO
	DESCRIPTION OF DAMAGE		

SEATING POSITION

1 2 3
4 5 6
7

1 - DRIVER
2 TO 6 - PASSENGERS
7 - STA. WGN REAR
8 - RR. OCC TRK. OR VAN
9 - POSITION UNKNOWN
0 - OTHER

SAFETY EQUIPMENT

OCCUPANTS
A - NONE IN VEHICLE
B - UNKNOWN
C - LAP BELT USED
D - LAP BELT NOT USED
E - SHOULDER HARNESS USED
F - SHOULDER HARNESS NOT USED
G - LAP/SHOULDER HARNESS USED
H - LAP/SHOULDER HARNESS NOT USED
J - PASSIVE RESTRAINT USED
K - PASSIVE RESTRAINT NOT USED

L - AIR BAG DEPLOYED
M - AIR BAG NOT DEPLOYED
N - OTHER
P - NOT REQUIRED

CHILD RESTRAINT
Q - IN VEHICLE USED
R - IN VEHICLE NOT USED
S - IN VEHICLE USE UNKNOWN
T - IN VEHICLE IMPROPER USE
U - NONE IN VEHICLE

M/C BICYCLE - HELMET
DRIVER: V - NO, W - YES
PASSENGER: X - NO, Y - YES

EJECTED FROM VEHICLE
0 - NOT EJECTED
1 - FULLY EJECTED
2 - PARTIALLY EJECTED
3 - UNKNOWN

INATTENTION CODES

A - CELL PHONE HANDHELD
B - CELL PHONE HANDSFREE
C - ELECTRONIC EQUIPMENT
D - RADIO / CD
E - SMOKING
F - EATING
G - CHILDREN
H - ANIMALS
I - PERSONAL HYGIENE
J - READING
K - OTHER

ITEMS MARKED BELOW FOLLOWED BY AN ASTERISK (*) SHOULD BE EXPLAINED IN THE NARRATIVE.

PRIMARY COLLISION FACTOR
LIST NUMBER (#) OF PARTY AT FAULT
A VC SECTION VIOLATED: CITED ☐YES ☐NO
B OTHER IMPROPER DRIVING*
C OTHER THAN DRIVER*
D UNKNOWN*

WEATHER (MARK 1 TO 2 ITEMS)
A CLEAR
B CLOUDY
C RAINING
D SNOWING
E FOG / VISIBILITY FT.
F OTHER:*
G WIND

LIGHTING
A DAYLIGHT
B DUSK - DAWN
C DARK - STREET LIGHTS
D DARK - NO STREET LIGHTS
E DARK - STREET LIGHTS NOT FUNCTIONING*

ROADWAY SURFACE
A DRY
B WET
C SNOWY - ICY
D SLIPPERY (MUDDY, OILY, ETC.)

ROADWAY CONDITION(S) (MARK 1 TO 2 ITEMS)
A HOLES, DEEP RUT*
B LOOSE MATERIAL ON ROADWAY*
C OBSTRUCTION ON ROADWAY*
D CONSTRUCTION - REPAIR ZONE
E REDUCED ROADWAY WIDTH
F FLOODED*
G OTHER*:
H NO UNUSUAL CONDITIONS

TRAFFIC CONTROL DEVICES (1 2 3)
A CONTROLS FUNCTIONING
B CONTROLS NOT FUNCTIONING*
C CONTROLS OBSCURED
D NO CONTROLS PRESENT / FACTOR*

TYPE OF COLLISION
A HEAD - ON
B SIDE SWIPE
C REAR END
D BROADSIDE
E HIT OBJECT
F OVERTURNED
G VEHICLE / PEDESTRIAN
H OTHER*:

MOTOR VEHICLE INVOLVED WITH
A NON - COLLISION
B PEDESTRIAN
C OTHER MOTOR VEHICLE
D MOTOR VEHICLE ON OTHER ROADWAY
E PARKED MOTOR VEHICLE
F TRAIN
G BICYCLE
H ANIMAL:
I FIXED OBJECT:
J OTHER OBJECT:

PEDESTRIAN'S ACTIONS
A NO PEDESTRIANS INVOLVED
B CROSSING IN CROSSWALK AT INTERSECTION
C CROSSING IN CROSSWALK - NOT AT INTERSECTION
D CROSSING - NOT IN CROSSWALK
E IN ROAD - INCLUDES SHOULDER
F NOT IN ROAD
G APPROACHING / LEAVING SCHOOL BUS

SPECIAL INFORMATION (1 2 3)
A HAZARDOUS MATERIAL
B CELL PHONE HANDHELD IN USE
C CELL PHONE HANDSFREE IN USE
D CELL PHONE NOT IN USE
E SCHOOL BUS RELATED
F 75 FT MOTORTRUCK COMBO
G 32 FT TRAILER COMBO
H
I
J
K
L
M
N
O
P
Q

OTHER ASSOCIATED FACTORS (MARK 1 TO 2 ITEMS) (1 2 3)
A VC SECTION VIOLATED: CITED ☐YES ☐NO
B VC SECTION VIOLATED: CITED ☐YES ☐NO
C VC SECTION VIOLATED: CITED ☐YES ☐NO
D
E VISION OBSCUREMENT:
F INATTENTION*:
G STOP & GO TRAFFIC
H ENTERING / LEAVING RAMP
I PREVIOUS COLLISION
J UNFAMILIAR WITH ROAD
K DEFECTIVE VEH. EQUIP.: CITED ☐YES ☐NO
L UNINVOLVED VEHICLE
M OTHER*:
N NONE APPARENT
O RUNAWAY VEHICLE

MOVEMENT PRECEDING COLLISION
A STOPPED
B PROCEEDING STRAIGHT
C RAN OFF ROAD
D MAKING RIGHT TURN
E MAKING LEFT TURN
F MAKING U TURN
G BACKING
H SLOWING / STOPPING
I PASSING OTHER VEHICLE
J CHANGING LANES
K PARKING MANEUVER
L ENTERING TRAFFIC
M OTHER UNSAFE TURNING
N XING INTO OPPOSING LANE
O PARKED
P MERGING
Q TRAVELING WRONG WAY
R OTHER*:

SOBRIETY - DRUG PHYSICAL (MARK 1 TO 2 ITEMS) (1 2 3)
A HAD NOT BEEN DRINKING
B HBD - UNDER INFLUENCE
C HBD - NOT UNDER INFLUENCE*
D HBD - IMPAIRMENT UNKNOWN*
E UNDER DRUG INFLUENCE*
F IMPAIRMENT - PHYSICAL*
G IMPAIRMENT NOT KNOWN
H NOT APPLICABLE
I SLEEPY / FATIGUED

SKETCH

INDICATE NORTH

MISCELLANEOUS

Figure D 2. California **Highway Patrol Traffic Accident Report Form ("555"): Page 2.**

Collection of Individual CHP Traffic Collision Reports

The following steps were used to collect individual CHP 555 reports.

Obtain TASAS information for accidents in work zones.

Whenever a CHP 555 report is filled out it is sent to Caltrans headquarters where it is processed and non personal information about the collision is entered into the TASAS database. One parameter or –check box” in the report indicates whether the traffic collision occurred within close proximity of a work zone. All TASAS records with this condition were extracted from the database and stored in an Excel spreadsheet. As indicated previously, there were 18,100 records for the complete years 2006-2008. In other words, there were 18,100 accidents occurring in the state of California that were within close proximity of a work zone over a three year period. These collisions occurred amongst all twelve Caltrans districts.

The type of information that is provided in the TASAS database is shown in table D-1 below. As can be seen in this table, there is quite a bit of detailed information. What is not present; however, is (for example) any specific injury information or where within the work zone did the accident occur.

Year District Route County Post Mile Highway Group Access Control Median Type Barrier Type Number Of Lanes Left Number Of Lanes Right Population Code File Type Intersection / Ramp Accident Location	Side Of Highway Day Of Week Accident Date Accident Time Accident Number Primary Collision Factor Weather Lighting Roadway Surface Roadway Condition Right Of Way Control Type Of Collision Number Of Motor Vehicles Involved Party Type	Direction Of Travel Vehicle Highway Indicator Special Information Persons Killed Persons Injured Primary Object Struck Location A Other Object Struck Location B Other Object Struck Location C Other Object Struck Location Other Associated Factor Movement Preceding Collision Location Sobriety Drug Physical

Table D 1. List of Information Provided by a TASAS Report.

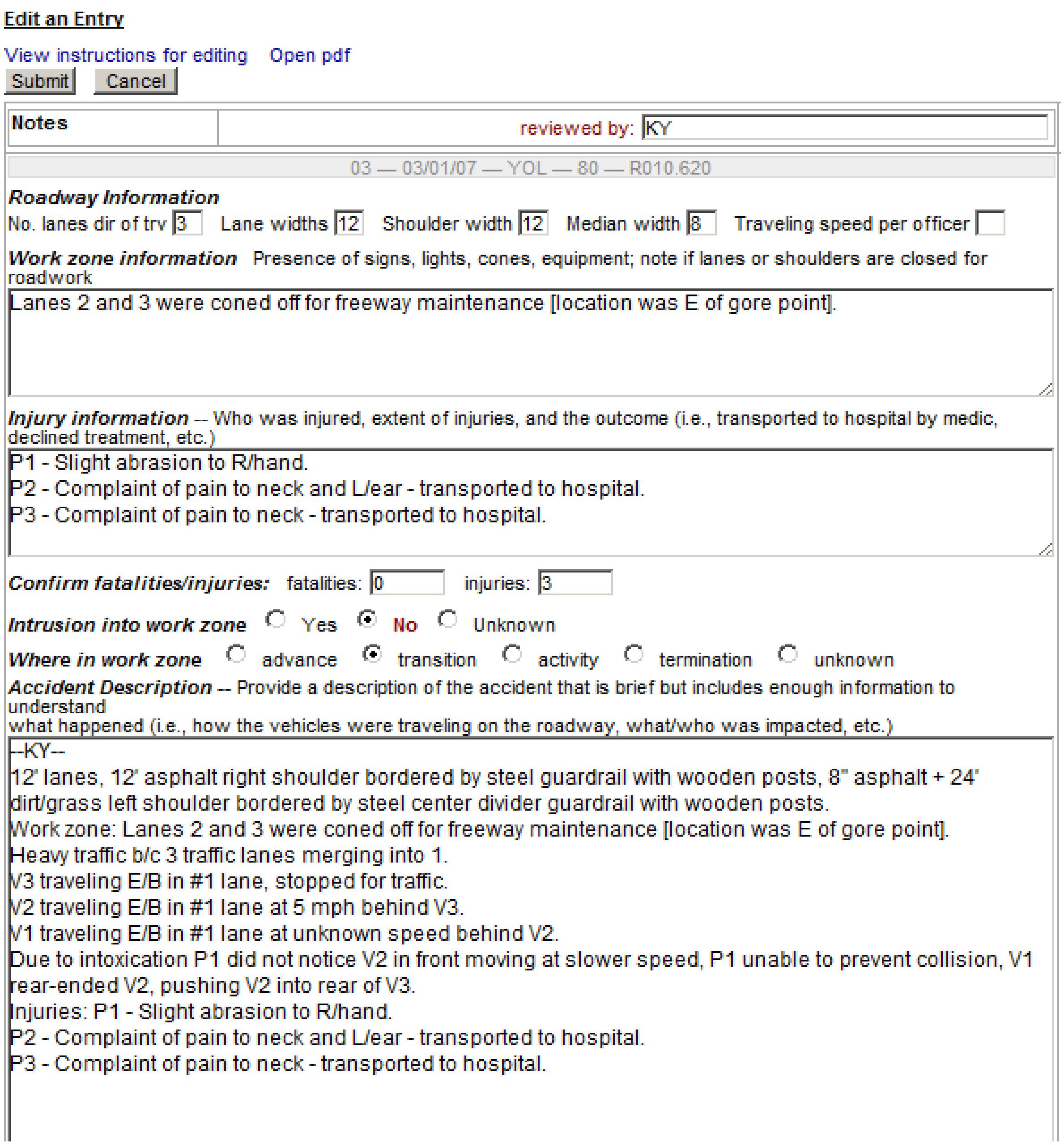
Collect the Individual CHP 555 Reports

Due to resource constraints, it was decided that a subset of the 18,100 traffic incidents of interest was to be collected. Each Caltrans district office retains an official hardcopy of each completed CHP 555 pertaining to that district. To obtain copies of these reports, AHMCT researchers visited three Caltrans district offices that were in northern California and within close proximity to UC Davis.

Using the County, Route, Post Mile, and Accident Date information from TASAS, physical reports were found and pulled from their filing system. Each report “pulled” was subsequently scanned and personal identification information redacted. The scanned documents resulted in Adobe Acrobat format (*.pdf) was then encrypted and ported to the AHMCT office.

Processing Collected CHP 555 Reports

To process each collected traffic collision report, a systematic approach was taken to obtain objective data from subjective information. To begin, basic information was entered into the database for each report (now in *.pdf format). Figure D-3 provides an example.



Edit an Entry

View instructions for editing Open pdf

Submit Cancel

Notes reviewed by: KY

03 — 03/01/07 — YOL — 80 — R010.620

Roadway Information

No. lanes dir of trv 3 Lane widths 12 Shoulder width 12 Median width 8 Traveling speed per officer

Work zone information Presence of signs, lights, cones, equipment; note if lanes or shoulders are closed for roadwork

Lanes 2 and 3 were coned off for freeway maintenance [location was E of gore point].

Injury information -- Who was injured, extent of injuries, and the outcome (i.e., transported to hospital by medic, declined treatment, etc.)

P1 - Slight abrasion to R/hand.
P2 - Complaint of pain to neck and L/ear - transported to hospital.
P3 - Complaint of pain to neck - transported to hospital.

Confirm fatalities/injuries: fatalities: 0 injuries: 3

Intrusion into work zone Yes No Unknown

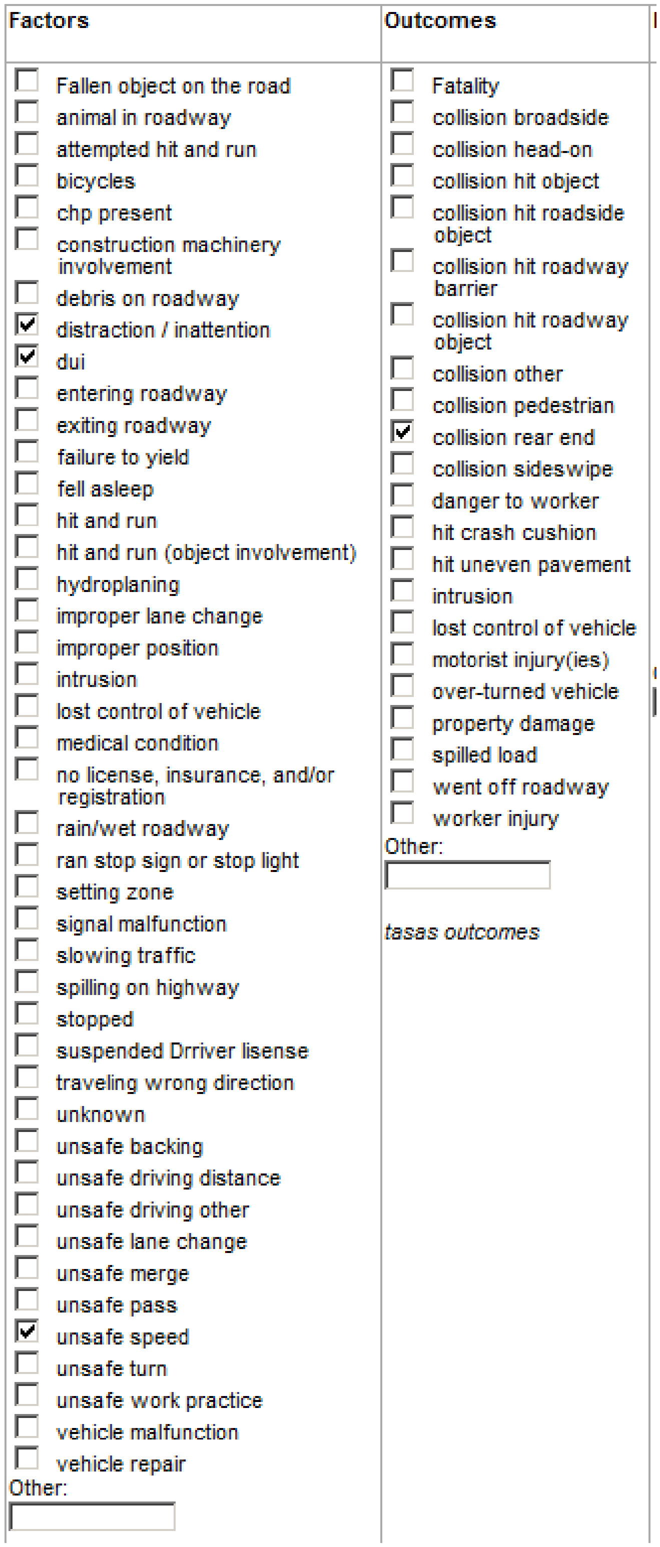
Where in work zone advance transition activity termination unknown

Accident Description -- Provide a description of the accident that is brief but includes enough information to understand
what happened (i.e., how the vehicles were traveling on the roadway, what/who was impacted, etc.)

--KY--
12' lanes, 12' asphalt right shoulder bordered by steel guardrail with wooden posts, 8" asphalt + 24' dirt/grass left shoulder bordered by steel center divider guardrail with wooden posts.
Work zone: Lanes 2 and 3 were coned off for freeway maintenance [location was E of gore point].
Heavy traffic b/c 3 traffic lanes merging into 1.
V3 traveling E/B in #1 lane, stopped for traffic.
V2 traveling E/B in #1 lane at 5 mph behind V3.
V1 traveling E/B in #1 lane at unknown speed behind V2.
Due to intoxication P1 did not notice V2 in front moving at slower speed, P1 unable to prevent collision, V1 rear-ended V2, pushing V2 into rear of V3.
Injuries: P1 - Slight abrasion to R/hand.
P2 - Complaint of pain to neck and L/ear - transported to hospital.
P3 - Complaint of pain to neck - transported to hospital.

Figure D 3. Example of Data Entry Screen When Entering Basic Collision Information into the Database.

The next step was to determine the factors and outcomes and enter these into the database. A protocol document was developed and referenced throughout the data entry process. A listing of the ―Factors and Outcomes" data entry screen can be seen in Figure D-4.



Factors

- [ ] Fallen object on the road
- [ ] animal in roadway
- [ ] attempted hit and run
- [ ] bicycles
- [ ] chp present
- [ ] construction machinery involvement
- [ ] debris on roadway
- [x] distraction / inattention
- [x] dui
- [ ] entering roadway
- [ ] exiting roadway
- [ ] failure to yield
- [ ] fell asleep
- [ ] hit and run
- [ ] hit and run (object involvement)
- [ ] hydroplaning
- [ ] improper lane change
- [ ] improper position
- [ ] intrusion
- [ ] lost control of vehicle
- [ ] medical condition
- [ ] no license, insurance, and/or registration
- [ ] rain/wet roadway
- [ ] ran stop sign or stop light
- [ ] setting zone
- [ ] signal malfunction
- [ ] slowing traffic
- [ ] spilling on highway
- [ ] stopped
- [ ] suspended Drriver lisense
- [ ] traveling wrong direction
- [ ] unknown
- [ ] unsafe backing
- [ ] unsafe driving distance
- [ ] unsafe driving other
- [ ] unsafe lane change
- [ ] unsafe merge
- [ ] unsafe pass
- [x] unsafe speed
- [ ] unsafe turn
- [ ] unsafe work practice
- [ ] vehicle malfunction
- [ ] vehicle repair

Other:

Outcomes

- [ ] Fatality
- [ ] collision broadside
- [ ] collision head-on
- [ ] collision hit object
- [ ] collision hit roadside object
- [ ] collision hit roadway barrier
- [ ] collision hit roadway object
- [ ] collision other
- [ ] collision pedestrian
- [x] collision rear end
- [ ] collision sideswipe
- [ ] danger to worker
- [ ] hit crash cushion
- [ ] hit uneven pavement
- [ ] intrusion
- [ ] lost control of vehicle
- [ ] motorist injury(ies)
- [ ] over-turned vehicle
- [ ] property damage
- [ ] spilled load
- [ ] went off roadway
- [ ] worker injury

Other:

tasas outcomes

Figure D 4. Screenshot of the "Factors and Outcomes" Selection Portion of the Data Entry Process for Each Collision.

To ensure high data integrity, a review process was performed. Three different reviewers were assigned to each data record. The same protocol was followed with each review as described in a subsequent section.

In a final pass, an injury expert categorized the injuries in terms of the Abbreviated Injuries Scale. To illustrate the process an example of resulting injury data from one particular collision is seen in Figure D-5. Figure D-6 shows the resulting injury data that was entered for that particular collision into the database.

P1 - Slight abrasion to R/hand. P2 - Complaint of pain to neck and L/ear - transported to hospital. P3 - Complaint of pain to neck - transported to hospital.

Figure D 5. Screenshot of the Injury Information.

arm: external, ais1
neck: pain, ais2
neck: pain, ais2
head: external, ais2

Figure D 6. Screenshot of the Resulting Injury Classifications.

CHP 555 Report Data Processing Protocol

Assigning factors and outcomes

The following guidelines were used in assigning factors and outcome.

General Notes:

- When adding notes, the following information was included:
  - Roadway information: lane widths, shoulder and center median widths/surface compositions, center divider barrier information (i.e., bushes, guardrail, etc.)
  - Work zone information: presence of signs, lights, cones, equipment, etc.; note if lanes or shoulders are closed for roadwork
  - Include the speed limit on the roadway (or in the work zone if it has been lowered for the work zone) – this can come from page 1 of the CHP report and/or from the accident descriptions
  - Include the traveling speeds of the vehicles if they are included in the CHP officer‘s summary (not if they are only in the driver/witness statements); also state if a vehicle was stopped when it was impacted and if a vehicle braked before the impact (because then the actual speed upon impact is unknown)
  - Provide a description of the accident that is brief but includes enough information to understand what happened (i.e., how the vehicles were traveling on the roadway, what/who was impacted, etc.)
  - Injury information: who was injured, extent of injuries, and the outcome (i.e., transported to hospital by medic, declined treatment, etc.)

- Use the following coding when referring to people involved in the accident: the driver of V1 is P1, the driver of V2 is P2, etc. – the passengers have to be referred to by different names (e.g., V1 front passenger)

- When reviewing the CHP reports, the following was verified:
  - Add the factors, outcomes, mitigation words, and where in the work zone the accident occurred – choose from the list of existing terms, and use the definitions below as guidance in assigning the correct terms to each accident. Tables D-2, D-3 and D-4 provide the lists.
  - Verify that if the accident is an intrusion, the "Intrusion" field/column has a "y" in it
  - Verify that the number of people injured is consistent between the database and the CHP reports ("PI" field/column)
  - Verify that the number of people killed is consistent between the database and the CHP reports ("PK" field/column)
  - Verify that the number of lanes in the direction of travel ("NLDT" field/column) is consistent between the database and the CHP report – the number of lanes can come from the accident diagrams and/or the accident descriptions

Term	Definition
alcohol	This factor should be replaced with "DUI" if it appears in the data.
bicycle	A bicyclist was at fault in the accident.
CHP present	CHP was present in the work zone at the time of the accident.
debris on roadway	There was debris on the roadway, which caused the accident.
distraction / inattention	The person at fault in the accident was distracted or inattentive, which is the reason the accident occurred.
drugs	This factor should be replaced with "DUI" if it appears in the data.
DUI	At least one person involved in the accident was under the influence of a substance (i.e., drugs or alcohol).
entering roadway	A vehicle was entering the roadway when the accident occurred.
failure to yield	The cause of the accident was a failure to yield.
hit and run	This was a hit and run accident. At least one person involved in the accident fled the scene, for example on foot or in a vehicle involved in the accident. The person who fled does not have to be the person at fault in the accident.
hit and run (object involvement)	An object from a vehicle (say V1) fell off and hit another vehicle, without the driver of V1 knowing anything had happened. The driver of V1 did not stop since he/she did not know of the accident caused by the dropped load, so it is a hit and run accident.
improper position	This should be replaced with "unsafe driving: Other" if it appears in the data.
lost control of vehicle	At least one person involved in the accident lost control of his/her vehicle.

merge	A vehicle was merging when the accident occurred. Be sure to fill in the field that describes "where" in the work zone the accident occurred.
no license and/or no insurance	This should be replaced with "no license no insurance and/or no registration" if it appears in the data.
no license no insurance and/or no registration	At least one person involved in the accident had no license, no insurance, and/or no registration with them at the time of the accident.
no registration for truck or trailer	This should be replaced with "no license no insurance and/or no registration" if it appears in the data.
ran stop sign	At least one vehicle involved in the accident ran a stop sign, which was the cause of the accident.
setting zone	The accident occurred while the work zone was being set up.
signal malfunction	The cause of the accident was a signal malfunction. This means the traffic signal(s) that mediates safe traffic flow was not working properly at the time of the accident.
taper area	This should be removed as a factor. Be sure to fill in the field that describes "where" in the work zone the accident occurred.
tire on roadway	This should be replaced with "debris on roadway" if it appears in the data.
unsafe driving: Other	The cause of the accident was a form of unsafe driving that has not been accounted for in other factors. This factor includes the factor "improper position" that is no longer being used for the data analysis.
unsafe lane change	The cause of the accident was an unsafe lane change.
unsafe speed	The cause of the accident was unsafe vehicle speed. This does not necessarily mean the vehicle(s) was traveling above the speed limit. It means that the vehicle(s) was traveling at a speed that was unsafe for the roadway and traffic conditions at the time of the accident.
unsafe turn	The cause of the accident was an unsafe turn.
unsafe work practice	This should be replaced with either "unsafe work practice: Highway workers" or "unsafe work practice: Motorists" depending on the situation.
unsafe work practice: Highway workers	The cause of the accident was an unsafe work practice by highway workers in the work zone. This can include an improper work zone setup that caused the accident or stepping outside the work zone boundaries.
unsafe work practice: Motorists	The cause of the accident was an unsafe work practice by a motorist. The person who caused the accident was working at the time. This can refer to, for example, truck (e.g., big rig) drivers, and can include unsafe driving of work vehicles or a failure to properly secure the truck load.

Table D 2. Factors used in Evaluating the Accident Reports.

Term	Definition
collision: Broadside	The accident was a broadside collision. This means the side of one vehicle was impacted by the front or rear of another vehicle. This is also known as a T-bone collision.
collision: Head-on	The accident was a head-on collision. This means the front of one vehicle was impacted by the front of another vehicle.
collision: Hit object	This should be replaced by either "collision: Hit roadside object" or "collision: Hit roadway object" depending on the situation.
collision: Hit roadside object	This collision involved vehicle impact with an object on the side of the road. This includes: trees, bushes, embankments, hillsides, drainage ditches, and fences on the side of the road.
collision: Hit roadway object	This collision involved vehicle impact with an object on the roadway. This includes: street signs, light posts, signboards, guardrails, cones, and other work zone equipment.
collision: Other	The accident was a collision of a type that is not one of the types of collisions included in the other outcomes. This can include, as an example, a collision with a tire or other debris on the roadway.
collision: Pedestrian	The accident was a collision between a vehicle and a pedestrian (person on foot).
collision: Rear end	The accident was a rear-end collision. This means the rear of one vehicle was impacted by the front of another vehicle.
collision: Sideswipe	The accident was a sideswipe collision. This means the side of one vehicle was impacted by the side of another vehicle.
danger to worker	This means the accident resulted in danger to a worker(s) in the work zone.
intrusion	At least one vehicle involved in the accident intruded into the work zone. In addition to vehicles that clearly intrude into the work zone, an accident is an intrusion accident if cones are knocked down by the vehicle(s) involved. The cones are considered a part of the work zone. The accident is also an intrusion if the accident occurs while the work zone is being set up, and the location in this case is the activity area. If "intrusion" is a factor, then "y" should be typed into the "Intrusion" column/field. For intrusion accidents, additional attention should be given to "where" in the work zone the accident occurred.
worker injury	The accident resulted in a worker injury.

Table D 3. Outcomes used in Evaluating the Accident Reports.

Assigning Where in Work Zone

An important piece of information concerning the traffic collision is ―where with respect to the work zone" did the traffic collision actually occurs. When this piece of information is available (sometimes it is not), it is described in the ―description" portion of the traffic collision report. The engineer reading the report must make a determination and choose from the following choices shown in table D-4.

Term	Definition
advance	This is the area of the roadway before the transition area and the area where work activity is being performed. There can be signs in this area warning of the work activity area ahead. There are not any cones or barriers here. (If vehicles are stopped/slowed for traffic and an approaching vehicle does not slow in time to avoid a collision, it is assumed that this is occurring in an advance area if there are no cones or barriers shown on the diagram of the roadway.
transition	This area of the roadway is where there is a transition into the activity area of the work zone. This includes the initial taper of cones or barriers showing that a work activity area is beginning. This also includes the area of the work zone leading up to a flagger - the area after the flagger is considered the activity area.
activity	This is the area where work is being performed, with cones or barriers marking off the area where the activity is occurring. If there is one flagger on each end of the work zone, the activity area is the area between the two flaggers.
termination	This area of the roadway is where there is a transition out of the activity area. This includes the final taper of cones or barriers showing that a work activity area is ending.
unknown	Based on the information and diagrams in the CHP reports, the location of the accident within the work zone cannot be determined.

Table D 4. Input Information Input on the Location of the Accident within the Work Zone.

Intrusions

Insert "y" if the accident is an intrusion into the work zone. Otherwise, we assume there was no intrusion at that time.

Evaluating Injury Information and Assigning Costs

When injury occurs during a traffic collision, there is an associated cost. Whether it is a sprained joint or a fatality, the cost of medical treatment is noteworthy. To obtain injury costs from collisions occurring in work zones, the injury description contained in the CHP 555 was critical. There is essentially no other objective method of estimating costs. As with other portions of the CHP 555, these were not always as complete as others. In particular when the injuries required EMS assistance, some CHP officers followed up if the injured person was admitted to the hospital or to specify the extent of injuries. Since injury costs are estimated based on specific information, there were instances where AIS values could not be determined so no cost was assigned even if the traffic collision report indicated an injured party.

The method to evaluate injury relies on the Abbreviated Injury Scale developed by the Association for Advancement of Automotive Medicine. There are more elaborate algorithms to calculate costs, but using them would be inconsistent with the accuracy of the data available. For example, in many accident reports there was only very minimal information on whether they were transported or not to a hospital.

Table D-5 shows the resulting associated costs for injuries based on AIS values. These values only consider short term medical care such as the costs due to an emergency room visit. These values are considered low since it does not include long term consequences due to injury. Take for example, a blue collar worker with a sprained ankle. This person is unable to work for a specified amount of time and thus has lost wages due to lost work which adds to the cost of injury. Another example is when neck and back pain is experienced. These types of injuries can lead to chronic pain or loss of work which also adds to the cost of injury.

BODY REGION: attribute, AIS value, cost

BODY REGION	ATTRIBUTE	AIS VALUE	COST
Arm/Shoulder	Pain	0	0
Back/Neck	Fx (Fracture or hard tissue damage)	1	1,000
Chest/Abdomen	Internal (soft tissue damage)	2	5,000
General	External (Skin)	3	20,000
Head/Face	None	4	80,000
Leg/Hip	Unknown	5	250,000
Fatality	Unknown	6	5,800,000

Table D 5. AIS level Attributes and Associated Injury Costs

The followings are the definitions for key terms used in our analysis.

BODY REGION

Leg — this includes hips, knees, and ankles

Back and Neck — Even though these are 2 separate entities, in car crashes they are usually lumped together, especially in frontal or rear end collisions

Arm — includes shoulders. A dislocated shoulder is defined as an AIS2 injury but sprains are assigned AIS1.

ATTRIBUTE

Pain — Indication directly taken from report

Fx — Fracture or injury to bone or joints

Internal — an internal injury to the chest region or bruising from the restraint system

External — Injury of the skin, including laceration, abrasion, contusion, and/or burns. The AIS value assigned would indicate the number and severity of the injuries.

Trauma — such as a punctured lung; the CHP 555 reports generally provide complete information in these cases.

AIS VALUE ASSIGNMENT
When detailed information is lacking, a minor injury is assumed (AIS1 or AIS2). If no information is given about transport to hospital, then it is assumed to be minor and assigned AIS1. If the injured party was transported to a hospital then an AIS value of 2 or higher was assigned.
Examples of AIS values:

- AIS 0 — No injury or minor pain
- AIS 1 — A doctor office visit or urgent care
- AIS 2 — a deep arm laceration, ais2 means transported to hospital so it must have needed some emergency room care.
- AIS 4 — broken hip.

COSTS

It is difficult to assess the actual cost of injuries compared to those causing fatalities. The monetary figure associated with a death also incorporates the entire impact on someone's life. Injury costs for this study only take into account the immediate medical cost with no consideration of lost income or future medical costs.

Analyzing the Data

We looked at the data in the AHMCT database in numerous ways. Here are some of them.

Basic Access

After one has logged onto the Accident Report Database, it is possible to restrict your search to District, year, county, route number, mile marker, fatalities, and injuries. Figure D-7 illustrates when this page is displayed.

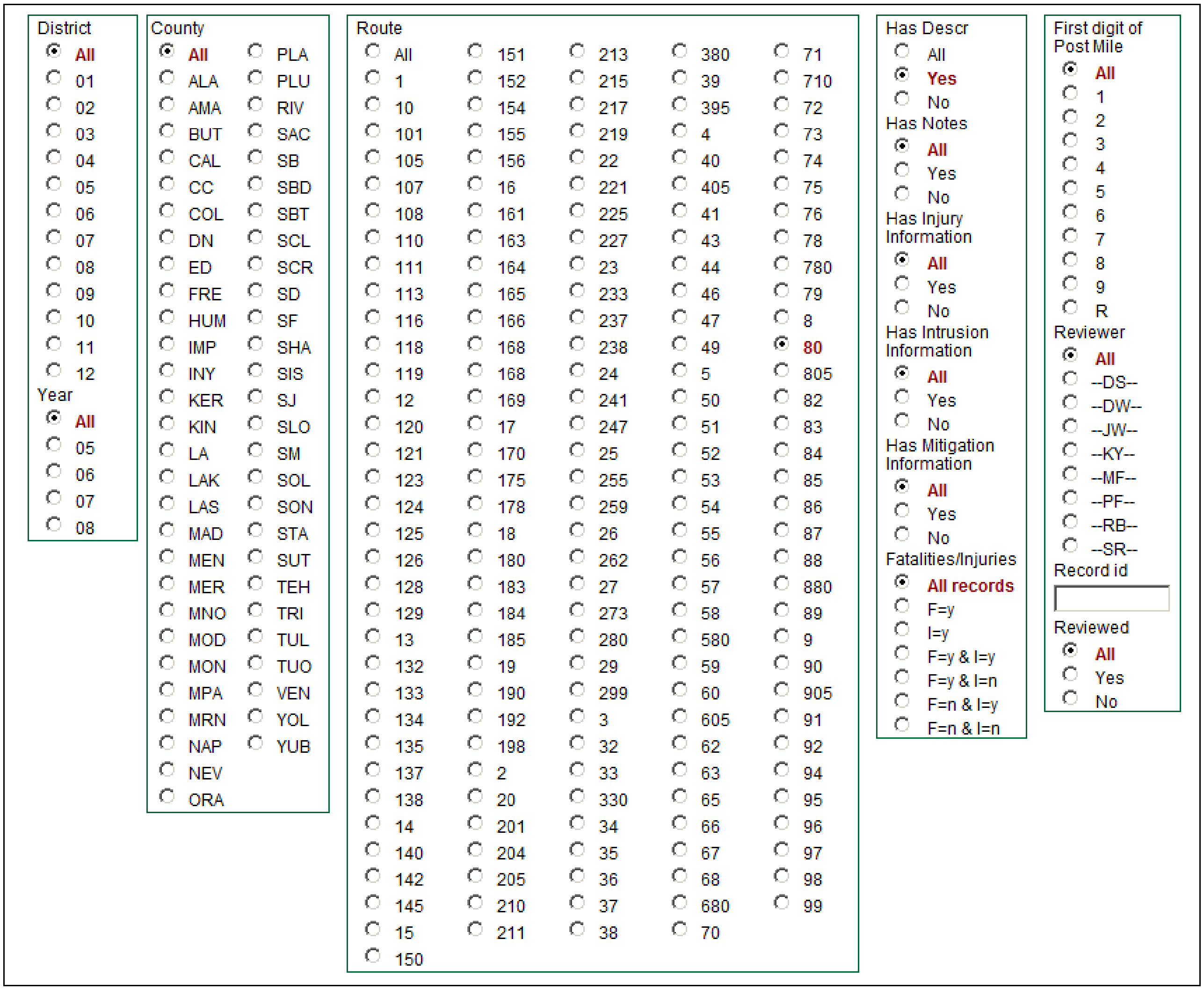


Figure D 7. First Page of the AHMCT Database for Selecting the Parameters.

Resulting associated reports or “records” are displayed in “Table Format” as seen in Figure D-8.

	get notes	DI	YR	RO	PM	CO	DTE	TME	Dscr	Notes	Pr Coll Factor	Ftl	Inj
1	2151	04	05	80	0.2	SOL	10/04/2005	0905	y	y	speeding		
2	2103	04	06	80	0.39	ALA	03/10/2006	1100	y	y	speeding		1
3	103	03	05	80	0.89	PLA	08/27/2005	1355	y	y	speeding		1
4	96	03	06	80	M001.162	SAC	03/05/2006	2042	y	y	failure to yield		1
5	2104	04	06	80	1.3	ALA	08/27/2006	2325	y	y			
6	104	03	05	80	1.58	PLA	10/05/2005	2020	y	y	other		1
7	2105	04	06	80	1.59	ALA	06/08/2006	0850	y	y	other		
8	105	03	05	80	1.814	PLA	08/10/2005	1320	y	y	speeding		
9	106	03	05	80	1.814	PLA	11/05/2005	1800	y	y	other		1

Figure D 8. Illustration of “Table View” of Traffic Collision Record Numbers (identified by “IDs”).

Figure D-9 shows the alternate format to view individual records. It is referred to as the “Notes” view since it reflects the notes taken while evaluating the traffic report.

Route = '80' and Description=yes found **176** rows.

edit dscr erw	Notes	Factors	Outcome	Where in WZ Intrusion	Roadway info WZ info Injury entry Injury analysis
1	--AL-- 3 12' lane EB freeway Work Zone: No information given. D1 was driving V1 in lane 1 at 15 mph. D2 was driving V2 in front of V1 in lane 1. Due to D1's unsafe speed and inattention (talking on the cell phone), D1 failed to see traffic slowing ahead and rear ended V2. No injuries reported 04 — 2005-10-04 — SOL — 80 — 0.2 — 0905 id=2151 reviewed by KY	distraction / inattention unsafe driving distance unsafe speed	collision rear end property damage	location unknown no intrusion	Lanes: 3 Lane widths: 12 No information given. None General: none, ais0
2	--DS-- Work zone: No information given. Bridge w/ 5 W/B lanes 11'6" each, bordered on either side by steel bridge rail with catwalk. V3 was traveling W/B in lane 4 at 10-20 mph in slowed traffic. V2 was traveling in lane 4 directly behind V3. V1 was traveling behind V2 in lane 4. P3 encountered slowed traffic and began to slow V3. P2 also began to slow down. P1 observed V2 slowing but was not able to stop in time and V1 collided with the rear of V2. The impact pushed V2 forward into V3. All vehicles were moved off the roadway following the collision. Injuries: P2 complained of pain to neck, back and right leg, will seek own medical assistance. 04 — 2006-03-10 — ALA — 80 — 0.39 — 1100 id=2103 reviewed by KY	distraction / inattention unsafe driving distance unsafe speed	collision rear end	location unknown no intrusion	Lanes: 5 Lane widths: 11'6 No information given. P2 complained of pain to neck, back and right leg, will seek own medical assistance. Neck: pain, ais1 Back: pain, ais1 Leg: pain, ais1

Figure D 9. Example of the “Notes View” when Evaluating Individual Traffic Reports.

Summary Counts

Figure D-10 shows a screenshot of the summary counts. All AHMCT entered data is associated with these results. No TASAS information is used.

name	number
Summary Factors	
dui	148
improper driving	1,140
improperdriving	6
inattention	633
too fast too close	1,829
uncontrollable	76
Summary Outcomes	
collision auto	279
collision barrier	438
collision object	1,984
collision rear end	1,064
danger ped/worker	52
lost control/rollover	102
Sobriety / Drug	
driver fatigue	29
hbd - impairment unknown	21
impairment unknown	208
hbd - under influence	436
under drug influence	23
other physical impairment	9
Highway group	
divided	14,986
divided highway	1,675
independent alignment - left	147
independent alignment - right	184
undivided	932
undivided highway	129
Access control	
1-way city st	9
conventional	1,713
expressway	443

Figure D 10. **Total Count Resulting from the AHMCT Entered Data.**

Relationships Among Variables

Functionality to evaluate relationships between factors, outcomes and costs was programmed into the web based interface of the AHMCT database. Figure D-11 shows how one can select the items they would like to see

AHMCT Criteria			TASAS Criteria					
no	**yes**	Summary Factors	no	**yes**	Summary Factors	no	yes	Nm vehicles involved
no	yes	Factors	no	yes	Factors	no	yes	Rural/Urban
no	yes	Summary Outcomes	no	yes	Summary Outcomes	no	yes	Vehicle type
no	yes	Outcomes	no	yes	Outcomes	no	yes	Roadway condition
no	yes	Intrusion	no	yes	Sobriety - Drug	no	yes	Right of way control
no	yes	Nm lanes	no	yes	Barrier type	no	yes	Roadway surface
no	yes	Lane width	no	yes	Access control	no	yes	Special information
no	yes	median width	no	yes	Day of week	no	yes	Vehicle Highway Indicator
no	yes	shoulder width	no	yes	File Type	no	yes	Weather
no	yes	Work zone where	no	yes	Highway Group			
			no	yes	Lighting			
			no	yes	Median type			
			no	yes	Nm lanes left			
			no	yes	Nm lanes right			

Figure D 11. Screenshot of a Typical Selection Panel.

When using the ―Compare” function, one can get comparison data from the piece of data of interest. Figure D-12 shows an example of summary factors for both AHMCT data and TASAS data. The costs are based on the extrapolation of percentages of factors between both AHMCT and TASAS data. It is assumed that the same percentage of factors, outcomes, and other information is equal within both databases (AHMCT and TASAS). Note that results are returned only for records that have been fully analyzed. Here one is looking for relationships, not absolute values.

These are results about which we have injury and injury cost information. Totals may vary due to incomplete information or because incidents may have multiple causes.
Categories are in the first column in normal black font. **Green numbers and bars** indicate the number of incidents for a category. The **black number** is the number of events for a category. **Blue numbers and bars** indicate injury costs based upon incidents.

	incidents	events	costs
Summary Factors -- ahmct	1,104	5,779	$351,893,045
DUI/ DWI	95	182	30,937,726
Hit-run unlicensed	196	351	36,805,769
Improper driving	605	2,032	198,087,046
Inattention	679	1,223	44,601,089
Too fast too close	695	1,842	40,867,725
Uncontrollable	68	111	451,998
Unsafe work	25	38	141,692
Summary Factors -- tasas	1,021	3,302	$113,598,890
dui	90	170	18,369,667
improper driving	461	930	73,008,926
improperdriving	6	12	48,991
inattention	342	561	1,412,982
too fast too close	652	1,582	20,634,666
uncontrollable	38	47	123,658

Figure D 12. Comparison of Frequency and Actual Weighted Presence of a Factor within the database (Note: Costs assume all 18,100 traffic collisions in TASAS are part of the resulting calculation).

Injury Relationships

Injury type and detailed information can be obtained for the entire database. When looking at —Summary Factors” as seen in Figure D-13, one can see that non-injury (—AIS=0”) and —minor injury (—AIS=1” and —AIS=2”) are the most frequent level of severity within traffic collisions.

These are incident results about which we have injury and injury cost information. Totals may vary because incidents may have multiple causes.

AIS / incidents	ais0	ais1	ais2	ais3	ais4	ais5	ais6	cost
Summary Factors -- ahmct	**660**	**315**	**251**	**33**	**6**	**2**	**5**	**$667,737,575**
DUI/ DWI	43	39	34	5	1	2	1	49,408,284
Hit-run unlicensed	134	39	39	7	3	1	2	78,440,307
Improper driving	366	159	142	26	6	2	5	367,462,919
Inattention	426	196	132	16	1	1	2	75,448,941
Too fast too close	404	223	164	12	3	1	2	96,011,205
Uncontrollable	35	18	20	4	0	0	0	719,967
Unsafe work	17	6	2	2	0	0	0	245,952
Intrusion -- ahmct	**661**	**313**	**250**	**32**	**6**	**2**	**5**	**$196,005,401**
no	542	243	177	18	3	1	5	192,018,568
yes	40	33	32	5	2	1	0	2,305,312

Parts / incidents	arm	back	chest	face	general	head	leg	neck
Summary Factors -- ahmct	**132**	**126**	**122**	**53**	**681**	**119**	**100**	**165**
DUI/ DWI	24	10	16	15	45	13	16	17
Hit-run unlicensed	19	17	20	14	136	15	18	22
Improper driving	87	57	79	38	382	61	68	58
Inattention	74	75	62	34	440	64	46	110
Too fast too close	82	88	71	30	416	82	63	131
Uncontrollable	11	8	11	7	37	7	8	8
Unsafe work	3	1	2	1	17	2	3	2
Intrusion -- ahmct	**131**	**125**	**121**	**54**	**682**	**118**	**100**	**163**
no	89	102	82	36	557	90	67	130
yes	20	10	18	10	43	10	19	17

Attributes / incidents	external	fx	internal	none	pain	trauma	unknown
Summary Factors -- ahmct	**138**	**107**	**34**	**656**	**323**	**5**	**5**
DUI/ DWI	32	18	2	42	28	1	1
Hit-run unlicensed	24	22	9	133	39	3	1
Improper driving	99	69	24	362	148	5	5
Inattention	76	49	14	426	195	1	1
Too fast too close	77	64	14	403	235	3	2
Uncontrollable	14	11	4	35	18	0	0
Unsafe work	3	4	0	17	4	0	0
Intrusion -- ahmct	**138**	**107**	**33**	**657**	**320**	**5**	**5**
no	93	67	26	539	257	2	4
yes	24	19	2	40	26	3	0

Figure D 13. Screenshot of Counts and Distribution for Types of Injuries.

Correlation of Factors and Outcomes

Displaying the relationships between factors and outcomes provides for useful information when trying to develop mitigation measures to reduce the number of collisions. Since the majority of collisions had multiple causes, displaying the correlation between factors provide further insights. Figure D-14 displays such information.

These results show the unweighted number of incidents for all pairs of summary variables. Each number in the grid is the sum of the number of incidents for the items at that point.

Totals for pairs of items may vary due to incomplete information or due to rounding of results.

AHMCT Summary Factors

	Too fast too close	Inattention	Improper driving	Hit-run unlicensed	DUI / DWI	Uncontrollable	Unsafe work
Too fast too close	1,005	667	310	172	64	43	2
Inattention	667	978	455	149	75	35	22
Improper driving	310	455	910	179	101	74	25
Hit-run unlicensed	172	149	179	301	30	16	4
DUI / DWI	64	75	101	30	132	10	
Uncontrollable	43	35	74	16	10	117	4
Unsafe work	2	22	25	4		4	33

AHMCT Summary Outcomes

	collision rear end	collision auto	prop damage	collision barrier	danger ped / worker	collision object	lost control / rollover
collision rear end	954	61	175	43	52	35	12
collision auto	61	424	69	67	59	37	18
prop damage	175	69	318	62	49	51	9
collision barrier	43	67	62	252	78	44	27
danger ped / worker	52	59	49	78	249	92	60
collision object	35	37	51	44	92	236	30
lost control / rollover	12	18	9	27	60	30	98

TASAS Summary Factors

	too fast too close	improper driving	inattention	dui	uncontrollable	improperdriving
too fast too close	10,154	1,316	5,011	649	455	23
improper driving	1,316	5,865	669	670	397	35
inattention	5,011	669	5,505	286	255	12
dui	649	670	286	1,333	36	
uncontrollable	455	397	255	36	869	2
improperdriving	23	35	12		2	52

TASAS Summary Outcomes

	collision rear end	collision object	collision barrier	collision auto	lost control / rollover	danger ped / worker
collision rear end	9,496	1,262	480	27	30	17
collision object	1,262	5,588	2,390	386	713	61
collision barrier	480	2,390	3,245	214	116	21
collision auto	27	386	214	1,050	41	14
lost control / rollover	30	713	116	41	744	2
danger ped / worker	17	61	21	14	2	105

Figure D 14. Screenshot of Correlations between Factors and Outcomes amongst both the AHMCT Database and the TASAS Database.

It is also possible to display correlations amongst individual factors. Figure D-15 displays such information.

ahmct factors ahmct outcomes tasas factors tasas outcomes Submit

AHMCT Factors

unsafe speed	942
unsafe driving distance	542
distraction / inattention	522
stopped	247
slowing traffic	198
hit and run	109
lost control of vehicle	104
unsafe turn	82
no license, insurance, and/or registration	65
unsafe lane change	63
dui	63
unsafe driving other	57
improper lane change	40
improper position	40
rain/wet roadway	29
unsafe merge	28
entering roadway	24
chp present	23
exiting roadway	18
distraction / inattention	817
unsafe speed	522
unsafe driving distance	345
unsafe lane change	172
stopped	162
unsafe turn	153
improper lane change	102
improper position	96
unsafe merge	93
lost control of vehicle	77
unsafe driving other	75
slowing traffic	73
dui	66

Figure D 15. Correlations amongst Individual Factors in AHMCT Database.

Correlation of Factors and Outcomes with Selected Variables

Factors and Outcomes can also be evaluated in terms of incident counts, fatalities and injuries, costs, where in work zone, number of lanes, geographical area, type of highway, and intrusions. Figure D-16 illustrates the correlation between Factors and Outcomes when evaluating intrusions.

The purpose of these numbers is to identify important relationships and not to report absolute values.
These numbers count incidents associated with an intrusion into a work zone. Since incidents can have multiple factors and outcomes, the numbers of incidents will not sum to the totals for their row or column. Also, since intrusions are based upon an analysis of accident records, only rows for which an intrusion value is known are returned.

AHMCT data

		collision auto	collision barrier	collision object	collision rear end	danger ped/ worker	lost control/ rollover	prop damage
no intrusion	**1,309**	337	147	121	838	126	54	267
dui/ dwi	61	12	18	12	32	9	4	18
hit-run unlicensed	238	80	30	13	141	19	8	53
improper driving	630	314	137	86	195	112	48	138
inattention	806	180	59	47	589	38	18	186
too fast too close	861	83	56	39	749	60	26	162
uncontrollable	81	17	15	32	23	23	6	20
unsafe work	18	7		6	5	3	1	11
yes intrusion	**126**	25	32	52	48	56	13	28
dui/ dwi	32	3	11	12	14	17	4	9
hit-run unlicensed	23	5	9	10	6	10	2	6
improper driving	106	23	29	46	35	50	12	26
inattention	79	12	17	31	38	38	6	18
too fast too close	55	10	12	18	25	29	8	11
uncontrollable	10	2	4	7	2	5	2	3
unsafe work	13		1	7	8	5		3

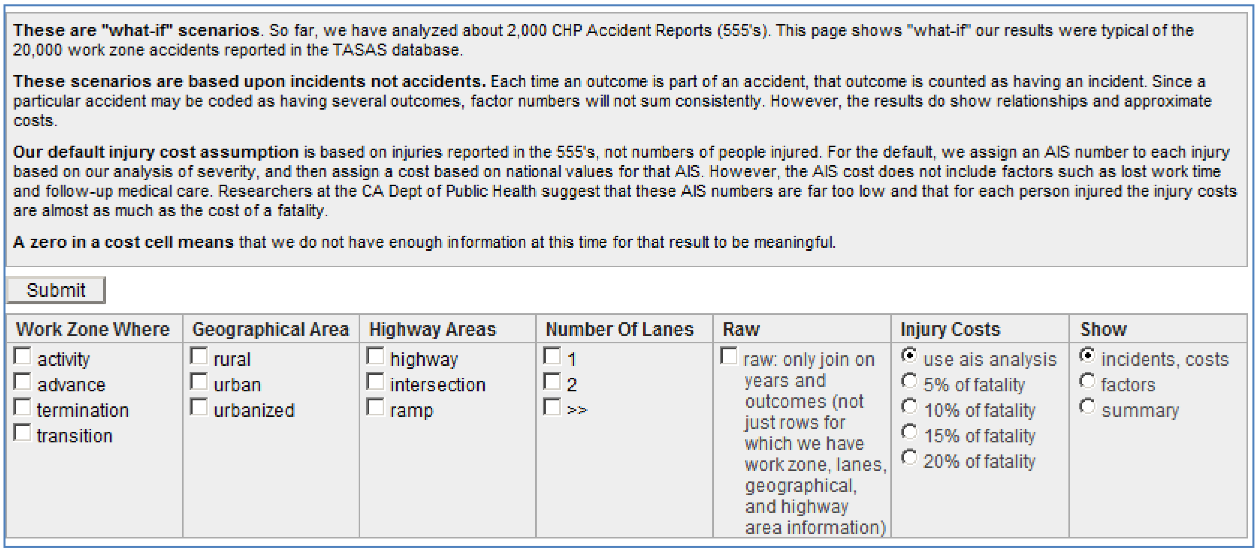
Figure D 16. Screenshot of correlation between Factors and Outcomes for Intrusions.

Mapping AHMCT sample to TASAS sample

The AHMCT data is consistent within its boundaries of about 2437 records. It was determined that a sufficient amount of traffic reports were processed to extrapolate results onto the TASAS database. Figures D-17 and D-18 show how the database might be used to determine costs associated with certain parameters that are pertinent.

Choose Variables and Output

The web based interface for the database has a functionality called ―Scenarios”. It allows the user to evaluate certain ―conditions”. Figure D-17 shows a screenshot of the selection panel for the Scenario capability.



These are "what-if" scenarios. So far, we have analyzed about 2,000 CHP Accident Reports (555's). This page shows "what-if" our results were typical of the 20,000 work zone accidents reported in the TASAS database.

These scenarios are based upon incidents not accidents. Each time an outcome is part of an accident, that outcome is counted as having an incident. Since a particular accident may be coded as having several outcomes, factor numbers will not sum consistently. However, the results do show relationships and approximate costs.

Our default injury cost assumption is based on injuries reported in the 555's, not numbers of people injured. For the default, we assign an AIS number to each injury based on our analysis of severity, and then assign a cost based on national values for that AIS. However, the AIS cost does not include factors such as lost work time and follow-up medical care. Researchers at the CA Dept of Public Health suggest that these AIS numbers are far too low and that for each person injured the injury costs are almost as much as the cost of a fatality.

A zero in a cost cell means that we do not have enough information at this time for that result to be meaningful.

Submit

Work Zone Where	Geographical Area	Highway Areas	Number Of Lanes	Raw	Injury Costs	Show
activity	rural	highway	1	raw: only join on years and outcomes (not just rows for which we have work zone, lanes, geographical, and highway area information)	use ais analysis	incidents, costs
advance	urban	intersection	2		5% of fatality	factors
termination	urbanized	ramp	>>		10% of fatality	summary
transition					15% of fatality	
					20% of fatality	

Figure D 17. A Screenshot of Selection Panel for the Scenario Capability (Note: results are returned only for records that have been fully analyzed. Here we are looking for relationships, not absolute values).

Figures D-18 and D-19 are screenshot of the results from the selection shown in Figure D-17. Figure D-18 shows the results correlated with Outcomes and Figure 19 shows the results for associated Factors. Figure D-20 is another output where the relationship between factors and outcomes is displayed. Note that results are returned only for records that have been fully analyzed. Here we are looking for relationships, not absolute values.

Work Zone Where	Geographical Area	Highway Areas	Number Of Lanes	Raw	Injury Costs	Show
☑ activity	☐ rural	☐ highway	☐ 1	☐ raw: only join on years and outcomes (not just rows for which we have work zone, lanes, geographical, and highway area information)	◉ use ais analysis	◉ incidents, costs
☐ advance	☐ urban	☐ intersection	☐ 2		○ 5% of fatality	○ factors
☐ termination	☐ urbanized	☐ ramp	☐ >>		○ 10% of fatality	○ summary
☐ transition					○ 15% of fatality	
					○ 20% of fatality	

TASAS rows = 18,075, AHMCT rows = 2,086

'what-if'		Collision Auto	Collision Barrier	Collision Object	Collision Rear End	Danger Ped / worker	Lost Control / rollover	Totals
incidents	**2005**	539	487	244	1,131	313	139	2,853
	2006	674	430	617	1,646	524	150	4,041
	2007	526	168	358	1,200	484	211	2,948
	2008	529	250	294	793	529	176	2,570
intrusions	**2005**	0	180	144	180	216	36	36
	2006	193	171	321	342	385	21	21
	2007	88	66	198	176	220	66	66
	2008	33	33	114	81	98	65	65
costs	**2006**	208,335,042	207,133,316	201,538,207	16,176,611	258,565,635	38,177,164	929,925,976
	2007	65,897,754	53,162,233	14,287,175	53,119,567	158,161,208	136,367,518	480,995,455
	2008	118,638,273	48,863,151	11,722,652	7,792,905	207,709,855	107,596,826	502,323,662

Figure D 18. A Screenshot of the Outcomes Output for Incidents in the Activity Zone (Note: cost estimates are also shown that are associated with traffic collision outcome types).

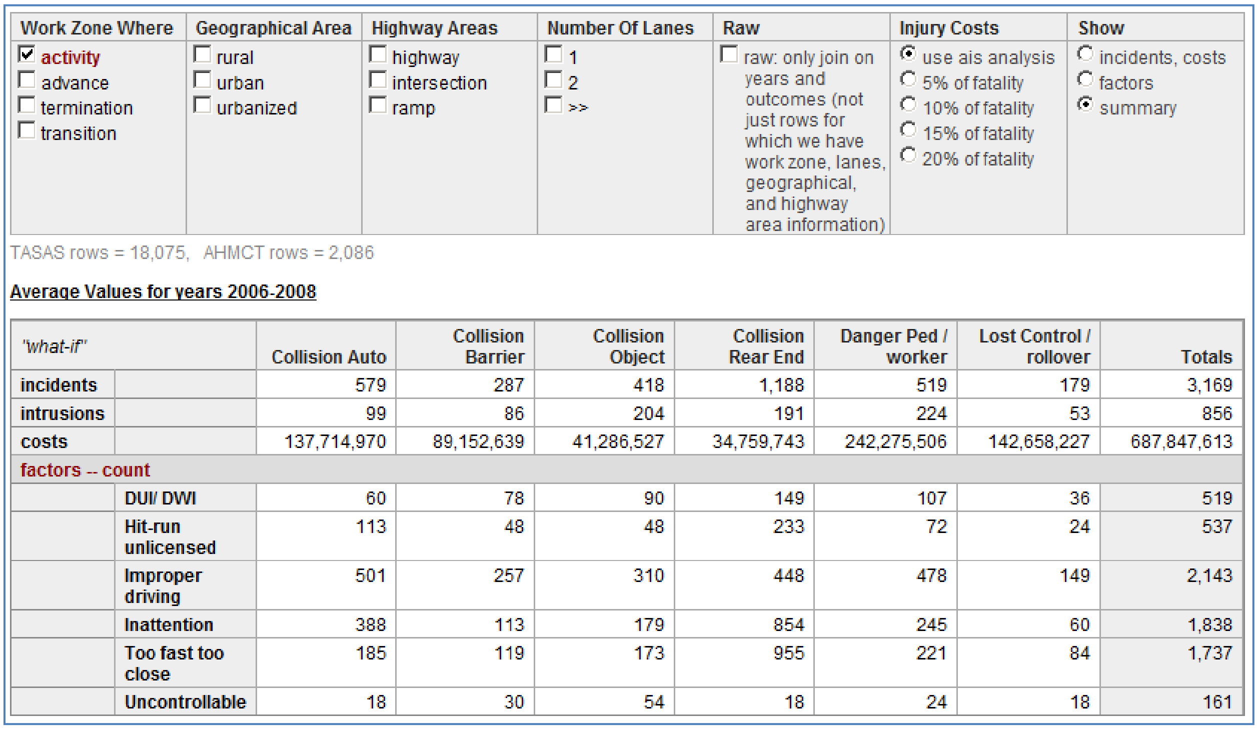
The following show sample factors output for incidents in the activity zone:

Work Zone Where	Geographical Area	Highway Areas	Number Of Lanes	Raw	Injury Costs	Show
☑ activity ☐ advance ☐ termination ☐ transition	☐ rural ☐ urban ☐ urbanized	☐ highway ☐ intersection ☐ ramp	☐ 1 ☐ 2 ☐ >>	☐ raw: only join on years and outcomes (not just rows for which we have work zone, lanes, geographical, and highway area information)	◉ use ais analysis ○ 5% of fatality ○ 10% of fatality ○ 15% of fatality ○ 20% of fatality	○ incidents, costs ◉ factors ○ summary

TASAS rows = 18,075, AHMCT rows = 2,086

'what-if'		Collision Auto	Collision Barrier	Collision Object	Collision Rear End	Danger Ped / worker	Lost Control / rollover	Totals
factors -- count								
2006	DUI/ DWI	94	131	112	355	150	56	898
	Hit-run unlicensed	112	37	75	337	37	19	617
	Improper driving	524	393	468	767	486	131	2,769
	Inattention	505	150	299	1,216	299	37	2,507
	Too fast too close	281	168	225	1,272	225	75	2,245
	Uncontrollable	0	75	94	56	56	19	299
2007	DUI/ DWI	63	84	84	42	84	42	400
	Hit-run unlicensed	147	63	42	295	105	42	695
	Improper driving	484	168	295	295	442	190	1,874
	Inattention	400	84	190	863	295	84	1,916
	Too fast too close	126	84	168	1,053	253	126	1,811
	Uncontrollable	0	0	0	0	0	0	0
2008	DUI/ DWI	29	29	73	59	88	15	294
	Hit-run unlicensed	88	44	29	103	73	15	352
	Improper driving	485	206	191	294	485	132	1,792
	Inattention	279	103	73	543	162	59	1,219
	Too fast too close	147	103	132	617	191	59	1,248
	Uncontrollable	44	15	59	0	15	29	162
factors -- costs								
2006	DUI/ DWI	336,758,220	7,544,624	1,581,081	4,640,110	287,773,973	7,017,108	645,315,116
	Hit-run unlicensed	978,358	59,880,337	1,215,754	177,429,495	175,663,995	242,648,032	657,815,971
	Improper							

Figure D 19. A Screenshot of the Factors Output for Incidents in the Activity Zone.



'what-if'		Collision Auto	Collision Barrier	Collision Object	Collision Rear End	Danger Ped / worker	Lost Control / rollover	Totals
incidents		579	287	418	1,188	519	179	3,169
intrusions		99	86	204	191	224	53	856
costs		137,714,970	89,152,639	41,286,527	34,759,743	242,275,506	142,658,227	687,847,613
factors -- count								
	DUI/ DWI	60	78	90	149	107	36	519
	Hit-run unlicensed	113	48	48	233	72	24	537
	Improper driving	501	257	310	448	478	149	2,143
	Inattention	388	113	179	854	245	60	1,838
	Too fast too close	185	119	173	955	221	84	1,737
	Uncontrollable	18	30	54	18	24	18	161

Figure D 20. A Screenshot of Third Output Type during the functionality Scenario.

Mapping Logic

The following describes the mapping logic that was used to derive the figures displayed in Figures D-18, D-19 and D-20. Roughly, since the amount of traffic reports that were processed was about 10% of the total possible candidates, each output value would be multiplied by 10 to get a sense for the results for all of California.

More accurately however, the following describes the procedure that was used for the calculations.

For Incident Counts:

For each year, do the following.

$$\frac{\text{Number of incidents in AHMCT per selection criteria}}{\text{Number of incidents in AHMCT sample}} = \frac{\text{Number of incidents in TASAS per selection criteria}}{\text{Number of incidents in TASAS sample}}$$

So

$$\text{Number of incidents in TASAS per selection criteria} = \text{Number of incidents in AHMCT per selection criteria} * \text{Number of incidents in TASAS sample}$$

Number of incidents in AHMCT sample

Fatality and Injury Costs using AIS data

For each year, do the following.

Fatality Costs

First, compute the number of fatalities.

$$\text{Number of fatalities in TASAS per selection criteria} = \frac{\text{Number of fatalities in AHMCT per selection criteria}}{\text{Number of fatalities in AHMCT sample}} * \text{Number of fatalities in TASAS sample}$$

Then, compute the cost of the fatalities.

$$\text{Cost of fatalities in TASAS per selection criteria} = \text{Number of fatalities in TASAS per selection criteria} * \text{Cost of a fatality}$$

AIS Injury Costs

First, compute the number of injuries.

$$\text{Number of injuries in TASAS per selection criteria} = \frac{\text{Number of injuries in AHMCT per selection criteria}}{\text{Number of injuries in AHMCT sample}} * \text{Number of injuries in TASAS sample}$$

Next, compute the average cost of an injury.

$$\text{Average injury cost in AHMCT sample} = \frac{\text{Sum AIS[0-5] costs in AHMCT}}{\text{Number AIS[0-5] events}}$$

Then, compute the cost of the injuries.

$$\text{Cost of injuries in TASAS per selection criteria} = \text{Number of injuries in TASAS per selection criteria} * \text{Average injury cost}$$

Fatality and Injury Costs using a Percent of Fatality cost for the Injury cost

Fatality Costs

First, compute the number of fatalities.

$$\text{Number of fatalities in TASAS per selection criteria} = \text{Number of fatalities in AHMCT per selection criteria} * \text{Number of fatalities in TASAS sample}$$

Number of fatalities in AHMCT sample

Then, compute the cost of the fatalities.

Cost of fatalities in TASAS per selection criteria	=	Number of fatalities in TASAS per selection criteria	*	Cost of a fatality

Injury Costs computed as Percent of Fatality Cost

First, compute the number of injuries.

$$\text{Number of injuries in TASAS per selection criteria} = \frac{\text{Number of injuries in AHMCT per selection criteria}}{\text{Number of injuries in AHMCT sample}} * \text{Number of injuries in TASAS sample}$$

Then, compute the cost of the injuries.

Cost of injuries in TASAS per selection criteria	=	Number of injuries in TASAS per selection criteria	*	Some percentage of the cost of a fatality