Site-Specific Issues: Application or Misapplication of Highway Safety Appurtenances

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The misapplication of safety appurtenances sometimes occurs because designers and specifiers do not have a thorough understanding of appurtenance characteristics or how they should be applied to hazards. The primary reasons include the following. First, highway appurtenance application and use guidelines are limited. Second, the background knowledge and experience of designers and specifiers is declining as a result of turnover and retirement. Third, appurtenance characteristics are not always published in a consistent and useful form. Fourth, the number of alternative appurtenances has increased. Fifth, the existing appurtenance approval procedures group devices into broad categories that do not adequately describe the intended use or limitations of any specific system. Providing better information and training to designers and specifiers can result in better application of safety appurtenances. Designers and specifiers should understand critical site considerations and system characteristics and have access to guidelines for selecting the appropriate system characteristics to address each specific site. Researchers, industry associations, manufacturers, FHWA, AASHTO, and others should work together to improve the information provided to designers and specifiers. A document could be published in which the testing, critical site considerations, system characterization, and application information are combined. Designers and specifiers need this information to make proper applications of safety appurtenances. This paper is focused on why safety appurtenances are misapplied, and steps to improve the overall situation are recommended. Detailed descriptions of key site considerations, system characteristics, and system testing and evaluation requirements are discussed.

The safety of the motoring public on the nation's highway system has significantly improved during the past 2 decades. The identification and removal of hazards and the development and application of safety appurtenances have been a major part of this improvement (*1*). However, even today, many serious injuries and fatalities could be avoided through continued focus on safety and the proper application of existing technology. The purpose of this paper is to address an element of the improvements that can be made to upgrade the level of safety for the motoring public.

Professionals in this industry can easily identify the problem by driving down the roadway and seeing a good safety appurtenance incorrectly applied (*2*). The appurtenance may be applied in such a way that it cannot work properly, or another system could have been applied that would have been less costly and would perform more acceptably for that specific site. In that case, an acceptable safety appurtenance, a valid system, has been misapplied.

The primary focus of this paper is on why safety appurtenances are not applied properly to hazardous sites and to suggest what can be done to improve the situation.

PROBLEM DEFINITION

The reasons that safety appurtenances are applied improperly must be identified before solutions can be formulated. It is suggested that the primary reason is that designers and specifiers do not have a thorough understanding of appurtenance characteristics or how they should be applied to hazards. Designers and specifiers work for departments of transportation, consultants, and contractors, and they should know what is being specified. The primary reasons for misapplication include the following.

First, guidelines for the proper application and use of highway appurtenances are significantly lacking.

Second, the background knowledge and experience of designers and specifiers is declining as a result of turnover and retirement. Many people who were involved in the field of highway safety in the 1950s, who started developing safety programs and hardware in the 1960s, and who started implementing these systems in the 1970s and 1980s are retiring. Their successors may know what products are available, but they do not always know the characteristics of the products and why one is preferred over the alternatives. Significant differences in products are often not well documented or understood.

Third, appurtenance characteristics are not always publicized in a consistent and useful form. It is confusing for designers and specifiers to try to evaluate and compare alternatives when the available information is not consistent. The people who design and specify highway appurtenances receive most of their information from product developers, manufactures, and promoters, and the product literature from various manufacturers is not consistent in characteristic descriptions.

Fourth, the number of alternative appurtenances has increased. In the past, a designer had only one or two solutions to choose from. New solutions have been developed over time to address specific sites. Each new solution has brought a new set of characteristics best suited to a particular application. Experience has shown that a single, generic solution is no longer the best choice for all sites.

Energy Absorption Systems, Inc., One East Wacker Drive, Suite 3000, Chicago, Ill. 60601.

Fifth, under existing appurtenance approval procedures, devices are grouped into broad categories that do not adequately describe the intended use or limitations of any specific system. Approvals are granted in such general categories as longitudinal barriers, crash cushions, end terminals, transitions, and truck-mounted attenuators. These categories may appear specific because they have differentiated between longitudinal barriers and crash cushions and between end terminals and crash cushions. The problem is that systems within the categories may be quite different. There is a significant difference between a cable guardrail and a concrete safety-shaped barrier in both performance and situations in which each should be used, but both are longitudinal barriers. Many types of longitudinal barriers have widely varying characteristics. Crash cushions are another example of specific devices that have different performance characteristics that affect application parameters. However, not enough descriptive information is included in the approval process. Approvals are granted in broad categories, and thus one cannot expect designers and specifiers to understand where and how specific devices should be used.

Regulating bodies are not filling the gap by supplying information that is technically descriptive enough to guide the designer or specifier. As an example, National Cooperative Highway Research Program Report 230 (*3*) describes how to test a crash cushion and how to evaluate its performance. Not explained, however, is where crash cushions should be applied. Guides published by AASHTO (*4,5*) describe the G-R-E-A-T system, Hex-Foam Sandwich System, Energite barriers, and other safety hardware as acceptable appurtenances, but do not provide sufficient information on how they should be used, the systems' strengths and limitations, or where they should be applied.

State specifications are another source of information, but they sometimes only identify the location (the mile marker) where a crash cushion is required. Specifiers refer to the AASHTO guides (*4,5*) or the state's approved list of highway hardware to select a product. The lists provide only limited system information or applications guidance, and thus the specifier makes a selection based on inadequate parameters.

GENERAL SOLUTION

The problems can be substantially resolved by providing better information and training for designers and specifiers (*6*). Critical site considerations that should be addressed by designers and specifiers to ensure that the hazard and the site conditions are properly identified should be developed.

In addition, approved systems could be described by characteristics that relate to the critical site considerations. An appurtenance that best meets the required site characteristics could then be applied. Specific recommendations include the following.

First, designers and specifiers should be trained to evaluate the hazard and describe it in terms that ensure that the hazard condition can be properly identified.

Second, testing, evaluating, and reporting procedures should be developed that describe safety appurtenances' performance characteristics and limitations relative to a comprehensive listing of critical site considerations. Broad categories (e.g., crash cushions) should be replaced with more specific classifications (e.g., redirective, bidirectional, nongating crash cushions with limited lateral deflection). This change would not require a whole series of new tests but rather a more thorough evaluation and description of existing tests. Information known from the testing being done on safety appurtenances should be made available to the people who design and specify their use.

Third, guidelines or recommendations matching each type of safety appurtenance (by specific characteristic category) to specific site conditions should be developed and published (*6*) to help designers and specifiers develop a better level of understanding of how appurtenance technology can be applied to the roadside to reduce injuries and fatalities.

The solution to the problem statement presented here is by no means the only way to solve the problem. Refinements would improve the suggested solution, and entirely different methods could be used to solve the problem. The solutions presented here are only one way to improve the siting and selection process for highway safety appurtenances.

RECOMMENDED APPROACH

The recommended approach is to develop a method to better ensure that highway safety appurtenances are properly applied to hazardous sites to improve motorist safety. The first step should always be to remove the hazard. However, if the hazard cannot be removed, it should be treated with the proper safety appurtenance (*4,5*).

The treatment of highway hazards should start with a description of the hazard and the key site considerations. Once this description is complete, safety appurtenances can be reviewed and the appropriate characteristics matched to the needs of the site (*6*). The recommendations must also include information on how to obtain the safety appurtenance characteristics. These issues are addressed in the following sections.

Key Site Considerations

The description of the hazard and key site considerations must be addressed by the designer or specifier. The following list is a starting point and is not all-inclusive. A group of experts in highway safety can add to and modify the list to ensure that the hazardous site characteristics are properly defined to facilitate the proper appurtenance selection.

The items on the list are not in order of relative importance. Although there may be general agreement that some of the factors consistently demand a higher value, the relative weight of other factors is specific to particular hazardous sites.

- *Available longitudinal space.* The available longitudinal space should be described. Longitudinal space is frequently limited when other site considerations must be addressed. Examples of these situations include bifurcations (gore areas) in which encroachment into the driver decision area cannot be allowed, longitudinal barrier ends near a crossover or turnaround area, and wherever geometric characteristics of

the site limit the available longitudinal space. The longitudinal space requirements of safety appurtenances vary significantly, so site constraints must be understood.

- *Hazard width and height.* The width and height of the hazard or the object that is being shielded should be identified. This information is valuable during consideration of attachments and transition options.
- *Available lateral space.* Restriction of available lateral space is a common site characteristic. Sharp drop-offs, drainage features, or other hazards may be located close to a hazard. If a solution is chosen that allows a vehicle trajectory behind the system, one problem has been solved but another created. There could be an object directly behind the guardrail that does not match the longitudinal barrier's deflection characteristics (e.g., a cable rail that may deflect up to 12 ft and a hazard that is only 2 ft behind the rail).
- *Hazard site width.* The overall site width should be described and considered. The available site width restricts potential solutions in the same way that limited longitudinal space does. The treatment options for a 30-ft-wide median are different from those for a 6-ft-wide median with a concrete median barrier (CMB) in the center.
- *Hazard proximity to traffic.* The distances from the lane line to the hazard and to opposing traffic lanes are additional restrictions on available lateral space that should be known for proper evaluation of a site.
- *Available maintenance space.* The available maintenance space affects overall site safety and system maintenance costs. If the available space is restricted, maintenance personnel will be subjected to personal risk, costly traffic controls will have to be applied to maintain the system, and traffic congestion will become an issue. Since there are significant differences between appurtenance maintenance characteristics, the available maintenance space should be described.
- *Surface conditions and anchoring options.* The surface conditions in the area around the hazard should be described such that the various anchoring options for appurtenances can be properly applied. The soil characteristics, type of subbase, thickness and strength of portland cement concrete or asphaltic concrete, and cross-slopes should be included in the description. The presence and location of drainage features, expansion joints, and other surface features should also be described.
- *Anticipated impact speed.* The anticipated impact speed should be defined to ensure that the appurtenance selected has sufficient capacity. Guidelines (*4,5*) and other information is available (*7*) to help designers and specifiers estimate the anticipated impact speed for a specific site. This estimate can be improved by consulting local traffic engineering professionals.
- *Average traffic volume.* The average traffic volume at a site, along with the various site geometry factors, has a significant influence on impact frequency and maintenance requirements. This factor should be described and taken into account during appurtenance selection.
- *Impact frequency.* The impact frequency is not always known for new installations, but a prediction can be made based on similar sites. Existing sites that are being renovated should have an accident history. Whatever information is available should be described and used during selection of the appurtenance.
- *Unidirectional or bidirectional traffic.* The direction of traffic in the vicinity of the hazard should be described. If the site has unidirectional or bidirectional traffic in the vicinity of the hazard, the appurtenance characteristics should match the site conditions. This factor, along with other site geometry issues, will help determine such key system requirements as redirection and gating characteristics.

The key considerations for the site can now be defined in terms that pertain to a specific hazard that is to be protected. The next step is to describe safety appurtenance system characteristics such that the proper system can be selected for that hazard.

Definitions of System Characteristics

The system characteristics for each approved safety appurtenance should be described in terms that give the designer or specifier enough information to determine if the appurtenance is applicable to a specific site. Those system characteristics are discussed in this section (*5,6*).

Redirection Capability

The basic definition of a redirective system is a system that, when impacted along the side at an angle, will redirect the impacting vehicle away from a fixed object. If the vehicle hits a nonredirective system at an angle, it will continue in nearly the same direction until it interacts with another highway fixture or vehicle, or stops (Figure 1).

The difference between redirective and nonredirective systems is not subtle. As an example, some crash cushions are redirective for a portion of the system and nonredirective for a portion of the system (CIAS) (*8*). Other systems are clearly either redirective (G-R-E-A-T, BRAKEMASTER, HFSS, etc.) (*9–11*) or nonredirective (inertial barriers) (*12*). Some systems are redirective in both directions (bidirectional), and some can only redirect in one direction (unidirectional).

The site conditions will determine whether a system with redirective or nonredirective characteristics in a uni- or bidirectional mode is required. Once that decision is made, a selection can be made from the systems possessing that characteristic.

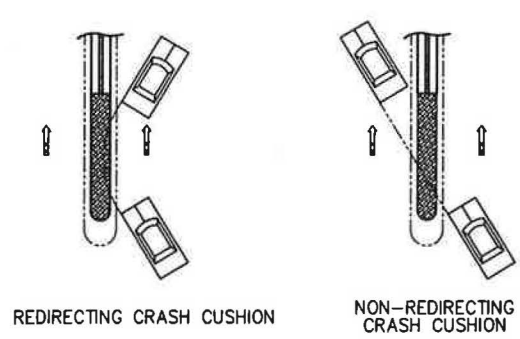

FIGURE 1 Redirective and nonredirective systems.

Capacity

Capacity is the ability of the appurtenance to absorb the kinetic energy of the impacting vehicle in a safe and controlled manner. The anticipated impact speed, weight of vehicles, and impact angle are the key variables that must be considered (*5*). If a safety appurtenance that has a capacity of 45 mph is used for a roadway with a anticipated impact speed of 65 mph, the appurtenance is mismatched to the hazard; it does not have enough capacity. Thus, the designer or specifier must know the anticipated impact speed. Unfortunately, this simple characteristic is one of the least understood and most abused by some appurtenance suppliers. Frequently, systems with a design capacity of 60 mph or less are promoted as having the capacity for hazards where anticipated impact speeds are well over 60 mph. What may appear to be only a slight mismatch (e.g., 5 to 10 mph) can result in a serious injury or fatality. If a 4,500 lb vehicle impacts the appurtenance at 65 mph or more, it will bottom out with serious consequences. In order to ensure that the capacity of the system being considered matches the capacity needed at the site, test results should prove that the appurtenance has the required design capacity.

Gating

The gating characteristic is another term that is not well understood by most designers and specifiers. The basic definition is a system that, when impacted at an angle on the front (nose), allows the vehicle to pass through in the same general direction of travel (Figure 2). The system opens like a gate. If the impacting vehicle is brought to a controlled stop by the safety appurtenance, the system is nongating.

The gating issue is somewhat controversial. The controversy centers around applications of an end terminal or crash cushion that is attached to the end of a longitudinal barrier. The decision to allow gating is based on whether the proper length-of-need (LON) has been used for the longitudinal barrier. If the proper LON has been established (*5*), the end treatment could allow gating without hazardous consequences. However, frequently, the LON has not been established, and thus the gating issue is important. Safety appurtenances such as end terminals and crash cushions are frequently applied to longitudinal barriers where the LON has not been properly established. An example of this situation occurs when there are emergency access breaks in a section of CMB. The ends of the CMB can be protected with a crash cushion, but the system should not gate.

Crash cushions are also frequently applied to other hazards where there is no longitudinal barrier. If the site characteristics show that an impacting vehicle would be subjected to a higher level of risk or that there is a high probability of either a secondary impact or encroachment into opposing traffic lanes if the appurtenance gated, a nongating appurtenance should be used.

The approved safety appurtenances should be grouped into gating and nongating devices. This descriptor should be decided for each system such that the designer or specifier understands the characteristics of the systems being considered. This will help ensure that the proper appurtenance is selected.

Pocketing

The pocketing characteristic occurs when the lateral stiffness of two redirective devices is so different that the impacting vehicle "pockets" into the softer barrier and is brought to an abrupt stop or redirects at an angle that is too high when the stiffer barrier is contacted.

The lateral stiffness and deflection characteristics of the safety appurtenance should be described to ensure that the designer or specifier can match the appurtenance to the adjoining barrier with the proper type of transitioning device to reduce the potential of pocketing.

Intrusion of Vehicle into Traffic Lane

The trajectory and final stopping position of an impacting vehicle subsequent to an impact with the appurtenance is critical. This intrusion characteristic is not well described for existing appurtenances and leads to the application of systems that result in high probabilities of secondary impacts, intrusion into adjacent traffic lanes, or both.

The intrusion characteristics of systems vary significantly. Under a specific set of impact conditions, some systems bring the vehicle to a controlled stop within the confines of the appurtenance. Other systems allow the vehicle to exit the appurtenance and cross several lanes of traffic (Figure 3), roll back in an opposing direction, or exit at a steep angle into adjacent traffic. The designer or specifier must understand the large variation in the characteristics of existing systems to better apply the proper system to a specific hazard.

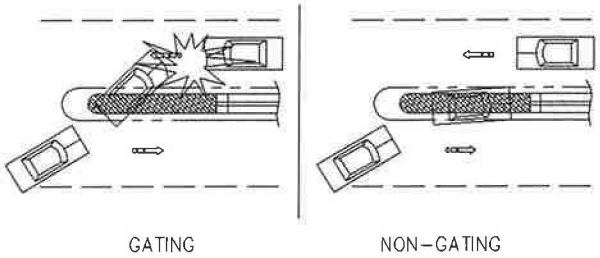

FIGURE 2 Gating and nongating systems.

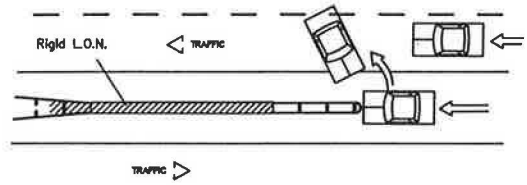

FIGURE 3 Intrusion of vehicle into traffic lane.

Intrusion in the Median or Roadside

The lateral deflection characteristics of safety appurtenances vary significantly and are not readily available. Whether the appurtenance is a longitudinal barrier, an end terminal, or a crash cushion, the lateral deflection characteristics must be known by the designer or specifier so that the appurtenance with proper deflection is applied. Otherwise, a system may be applied that can deflect into opposing lanes of traffic or into the hazard.

Other System Characteristics

Several other system characteristics could be published that would aid the designer or specifier in selecting the best appurtenance for a specific site. These characteristics include the following:

- System width and width options,
- System lengths for specific capacities,
- System anchoring requirements and options,
- System maintenance requirements,
- Level of reusability of components from design impacts,
- Refurbishment requirements from design impacts, and
- Environmental considerations.

These characteristic descriptions should be controlled and published during the approval process. Changes that occur during the product life that are critical to performance should also be published. The designers and specifiers must have accurate information to be able to select the proper system.

Recommendations for Testing, Evaluating, and Reporting System Characteristics

The system characteristics that have been described are currently not available or published in a form that is valuable or useful to designers and specifiers. This information should be collected, evaluated, approved, and published in a form that provides designers and specifiers formal guidelines to apply the site-specific criteria.

The system characteristics should be developed in the testing and evaluation phase of a new product. The development of these characteristics will not require additional testing as compared with that proposed in the NCHRP 230 Rewrite Document (*13*). However, the evaluation and documentation requirements for the tests that are conducted should be modified to record some new parameters.

The new parameters that need to be recorded are those that focus on system characteristics that will provide the designer or specifier the information needed to apply the appurtenance to a hazardous site (*6*). These proposed parameters are discussed next.

Redirective Characteristics

The redirective characteristics of the appurtenance should be reported in a form that is useful to the designer or specifier. The standard characteristics such as redirective capacity (e.g., weight of impacting vehicle, speed, center of mass height, entrance angle, exit angle, and speed change during the impact) should be recorded. In addition, the amount of deflection of the appurtenance and specific siting issues particular to the appurtenance should be reported. A summary of these characteristics can be condensed into a form that is useful to the designer or specifier. Appurtenances such as crash cushions and end terminals can be easily categorized as redirective or nonredirective. Within these groups, specific characteristics of an appurtenance can be listed in tabular form.

System Capacity and Length Options

System capacity of appurtenances is being reported in a generally acceptable form to be useful to designers and specifiers. Testing documentation and the approval process ensure that an appurtenance has the capability to absorb or redirect at least some specified level of kinetic energy (e.g., that of a 4,500-lb vehicle at 60 mph and 25 degrees). What seems to be missing is a statement that clearly defines the design limits for the particular appurtenance being evaluated.

The appurtenance design limits relative to capacity should be described in a clear and consistent format (*14,15*). An appurtenance may be tested and pass criteria for a 60-mph impact, but its limiting capacity may allow it to be used for impacts up to 65 mph. On the other hand, the appurtenance may have a design limit of no more than 60 mph. With posted speeds for the highways changing from 55 to 65 mph or 70 mph, this can be an important characteristic to be reported.

The appurtenance may be available in various lengths and widths that have specific capacities. These capacities should be evaluated and described in a clear and consistent form. The appurtenance capacity may be based on specific attachment or anchoring options. Again, this effect on the system's capacity should be clearly and consistently stated. The reporting of these capacity characteristics will provide the designer or specifier with clear and concise information that is critical to proper siting of the appurtenance. Otherwise, the designer or specifier can only rely on the appurtenance approval letter, a test report (if available), or sales literature to estimate the capacity of the device.

Gating Characteristics

The gating characteristic is primarily applicable to such appurtenances as crash cushions and end terminals. Again, the proposed testing (*5*) is totally adequate to evaluate these systems for gating. All that is needed is to evaluate and report the characteristics in a form useful to designers and specifiers.

The evaluation for gating should be done on all frontal impacts into crash cushions and end terminals. These impacts include the zero degree impacts with and without the offset of vehicle and appurtenance centerlines as well as the angled impact on the nose of the device. Although the angled nose impact is the most pertinent of the frontal tests for evaluating gating, some appurtenance designs gate during all frontal impacts.

The reporting should categorize the appurtenance being evaluated as gating or nongating. If the appurtenance gates the impacting vehicle (i.e., the vehicle is not brought to a controlled stop within the confines of the appurtenance) from any of the frontal impacts, the system should be classified as gating. If the system is classified as gating, the additional characteristics of vehicle speed change, post impact trajectory, and siting limitations in addition to the standard occupant risk factors should be reported. If the system is classified as nongating, only the occupant risk factors need to be reported.

Pocketing (Transition) Characteristics

The appurtenances that are evaluated for redirective characteristics also need to be evaluated for pocketing. Pocketing can occur from redirective impacts and is most likely to occur when there is a change in the lateral stiffness of the systems is involved. Thus, areas within the length of crash cushions, end terminals, or longitudinal barriers or those where one system transitions to another should be evaluated for potential pocketing.

The pocketing characteristics or potential could be described for the appurtenance being evaluated and for that appurtenance attached or transitioned to other appurtenances for which approval is being sought. The options and characteristics for each option could be summarized in tabular form for reference by designers and specifiers.

Intrusion Characteristics

The intrusion characteristics need to be reported for all appurtenances tested. These characteristics include the intrusion of the impacting vehicle into adjacent and opposing traffic lanes and the intrusion of the vehicle into the confines of the appurtenance to evaluate the potential of the vehicle interacting with a hazard.

The intrusion of the impacting vehicle into adjacent traffic lanes is partially covered in existing evaluating procedures. However, there are no specific criteria that define acceptable or unacceptable intrusion, and the reporting of this element is not provided to the designer or specifier in a form that is informative or useful. The designer or specifier needs to know where, how, and how much the vehicle intrudes into both adjacent and opposing traffic lanes to be able to understand this characteristic. The appurtenance can then be applied to minimize the hazard presented by the impacting vehicles intrusion into all potential lanes of traffic.

The intrusion of the vehicle into the confines of the appurtenance being evaluated is currently not well documented. The designer or specifier needs to understand this characteristic to ensure that the appurtenance is located properly such that the impacting vehicle will not impact a hazard in the vicinity of the appurtenance. This will help avoid the situation where an appurtenance with excessive lateral deflection is used and allows an impacting vehicle to deflect the barrier and contact a fixed hazard.

The evaluation and reporting could address the specific appurtenance being considered as well as specified or anticipated attachment and transitioning options.

System Width Options

The current evaluation and reporting procedures would allow an appurtenance such as a crash cushion to be tested at one length and width and receive approval for the entire product line. The product line could be composed of several length and width combinations (*8,14,15*). The designer or specifier is unable to assess whether lengths or widths other than the one evaluated were considered in the approval process.

The testing that is currently being done can be evaluated, and the expected performance of other lengths or widths of systems can be reported. The conclusions reported could be in a clear and consistent format that gives the designer or specifier proper guidance.

System Anchoring Requirements and Options

The current testing guidelines allow testing in either strong (S-1) or weak (S-2) soils (*3*). This does not address anchoring on concrete or asphalt, or on other types of soil conditions where the appurtenance may be applied. Some appurtenances require specific anchoring conditions to function properly. These appurtenances may require strong reinforced concrete footings or foundations, strong soils with custom-designed driven anchors, or other conditions that must be described to the designers and specifiers.

The appurtenance being tested could be evaluated with respect to the function and operation of anchoring devices for which approval is being considered. Enough design information or testing data could be supplied in the approval process such that the specific requirements and acceptable options can be described for the designer or specifier. If limitations on the other system performance characteristics can be seen if the proper anchoring conditions cannot be met, these limitations could also be clearly reported.

System Maintenance Requirements

The normal (pre-impact) maintenance requirements for an appurtenance could be clearly defined in the approval process and reevaluated at the end of the in-service evaluation period. Some appurtenances can be installed and remain in an acceptable performance condition for more than 10 years with minimal or no maintenance. Others may require periodic maintenance, which could be significant, to ensure that the system is crashworthy.

The components and function of all appurtenances being evaluated could be analyzed for this characteristic during the approval process, and specific recommendations could be reported. This information could be updated as product experience is gained through the in-service evaluation period. Otherwise, the designer or specifier may apply an appurtenance that will not function properly after a few years, and motorists will not be protected.

Reusability of System Components and Refurbishment Requirements

The evaluation of an appurtenance could include an assessment of the reusability of system components and the refurbishment requirements after design impacts. This information can be developed during the testing phase and could be presented in a form that will give needed guidance to designers, specifiers, and state maintenance personnel.

The components of an appurtenance that has been impacted can either be replaced, reworked, or used again, depending on the type of system being tested, the type of impact, and the type of specific damage observed on key components. The current lack of guidance results in improper maintenance of systems and thus undue exposure to risk for motorists.

The documentation of these key system characteristics will allow designers and specifiers to select an appurtenance that better meets the siting requirements and the abilities of state maintenance operations.

Environmental Characteristics

The environmental characteristics that can affect the performance of an appurtenance are not currently considered in the evaluation process. The materials that are used in an appurtenance and the specific system design can be affected by severe environmental conditions. This information is currently not being supplied to designers and specifiers.

The effect of environmental conditions on the performance of an appurtenance could be analyzed, evaluated, and reported in a form that provides guidance to designers and specifiers. These effects include high and low temperatures (−20°F to +120°F), moisture, ice on system components, snow or soil build-up around the system, exposure to ozone and ultraviolet radiation, corrosion, vibration, and other factors that could affect or impede the operation of the system. The effect of not including these items in the evaluation process will result in truck-mounted attenuators that fall off the shadow trucks, inertial barriers that freeze into solid blocks of moisture-laden sand (*15*), slip bases that loosen or corrode and do not function, energy-absorbing materials used in hot or cold areas that do not function properly, and a multitude of other problems.

The inclusion of these characteristics in the evaluation and reporting process will again provide needed guidance to designers and specifiers.

Guidelines for Matching System Characteristics to Applications

The guidelines to direct a designer or specifier to a specific type of system characteristic to address specific site considerations are inadequate or nonexistent. Guidelines that show the designer or specifier when redirection, gating, and the like are allowable should be developed. The specific site characteristics that influence these decisions are fairly well known and can be documented to form a set of guidelines (*6,16*).

The guidelines can be defined in terms such as distance from the edge of lane, distance to opposing traffic, proximity of the hazard to traffic (either direction), divergence angle of the lane near the hazard, and others. Recommendations can be made as to what critical system characteristics should be used for specific (critical) site considerations. The designer or specifier can then compare the hazardous site considerations to the guidelines and then to the approved system characteristics to best match the appurtenance to the hazardous site. The qualified systems could then be analyzed for cost-benefit considerations as described in the ROADSIDE software program (*17*).

TABLE 1 Considerations for Safety Appurtenance Selection and Application

CRASH CUSHION – END TERMINAL	
REDIRECTIVE	
UNIDIRECTIONAL	
HAZARD PROXIMITY TO TRAFFIC	< 10'
DISTANCE TO OPPOSING TRAFFIC	> 30'
TRAFFIC DIVERGENCE ANGLE	> 5°
BIDIRECTIONAL	
HAZARD PROXIMITY TO TRAFFIC	< 10'
DISTANCE TO OPPOSING TRAFFIC	< 30'
TRAFFIC DIVERGENCE ANGLE	> 5°
NON-REDIRECTIVE	
HAZARD PROXIMITY TO TRAFFIC	> 10'
DISTANCE TO OPPOSING TRAFFIC	> 30'
TRAFFIC DIVERGENCE ANGLE	< 5°

The Certified Lifesaver Program (*6*) and the SNAP software package (*16*) have been developed to assist the training needs of designers and specifiers. These packages focus on the generic aspects of both site characteristics and system characteristics.

An example relative to redirection is shown in Table 1. In this example, a hazard that is relatively close to adjacent traffic (e.g., less than 10 ft) with a significant divergence angle of the lane (e.g., greater than 5 degrees) should require an appurtenance that is redirective. Further, if the distance to opposing traffic is relatively close (e.g., less than 30 ft), the appurtenance should have redirective capacity from both directions or be bidirectionally redirective. With the vast knowledge and experience of professionals in the area of highway safety, other guidelines can be established.

CONCLUSION

A problem was identified and a solution proposed in this paper. The key site considerations have always existed. Designers and specifiers should understand the site considerations when selecting a treatment. The information needed to categorize appurtenances by characteristics related to the key site considerations is available from existing test procedures. Designers and specifiers need to make better use of the avail-

able information by evaluating and classifying systems in terms that will allow a proper match to a specific application.

A lot has been learned about highway safety during the last 25 years. A methodology was presented here to better apply this knowledge. It is an opportunity to further improve highway safety today without more research dollars, new technology, or new product development. All that is required is to use what has been learned to make better applications of existing hardware. It is the responsibility of highway professionals to continue improving safety. To begin this effort, a training program (*6*) and a site-specific software program (*16*) have been developed to provide better guidance to designers and specifiers. This is only a start; input from highway safety professionals can further improve the process.

Finally, implementation of these solutions requires a group effort. Researchers, industry associations, manufacturers, FHWA, AASHTO, and others must work together. No one group covers everything from product testing and evaluation to application analysis and specifications. Ideally, a document could be published in which are combined the testing, product characterization, site considerations, and application information. At a minimum, more information should be included in existing documents such as NCHRP Report 230, the updated version of NCHRP Report 230, the Barrier Guide, the Manual on Uniform Traffic Control Devices, and so on. Designers and specifiers are looking for help. This information is needed to better apply existing technology, save lives, and reduce injuries on the nation's highways.

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