Center for Transportation Research and Education

# Crash Cushion Selection Criteria

tech transfer summary

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**RESEARCH PROJECT TITLE**
Crash Cushion Selection Criteria

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**PRINCIPAL INVESTIGATOR**
Peter T. Savolainen, Safety Engineer
Center for Transportation Research and Education
Iowa State University
515-294-3381 / pts@iastate.edu
(orcid.org/0000-0001-5767-9104)

**MORE INFORMATION**
www.intrans.iastate.edu

**CTRE**
**Iowa State University**
**2711 S. Loop Drive, Suite 4700**
**Ames, IA 50010-8664**
**515-294-8103**

The mission of the Center for Transportation Research and Education (CTRE) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.



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**Crash cushions prevent errant vehicles from directly striking fixed roadside objects and can reduce the severity of roadway departure crashes.**

## Background

Roadway departure crashes represent a majority of traffic fatalities on highways, especially facilities with fixed roadside objects such as utility poles, bridge piers, exit gore ramps, and median barrier ends. Crash cushions can be either directly attached to or placed in front of fixed hazards to help reduce the severity of roadway departure crashes.

Crash cushions are designed to withstand head-on and/or angle collisions. For frontal impacts, the cushion absorbs the kinetic energy of a colliding vehicle and gradually decelerates it to a lower speed. For side-angle impacts, the cushion safely redirects vehicles toward the travel lane.

Several crash cushion types are available that satisfy testing requirements established by the National Cooperative Highway Research Program. The choice of optimal cushion type in terms of safety performance and economic viability depends on roadway geometry, traffic characteristics, and other factors. Thirteen crash cushion types are currently installed along roadways in Iowa.



*Redirective crash cushion system at the end of a concrete barrier rail before a bridge pier*

## Problem Statement

Although several crash cushion systems have been successfully crash tested and deemed acceptable for use on the National Highway System, crash cushion field performance has not been thoroughly investigated.

Existing maintenance and repair cost data are largely based on crash test results and may not reflect the true costs associated with real-world crash scenarios. Moreover, the approved cushion systems offer trade-offs among installation, maintenance, and repair costs.

## Objectives

This research aimed to assess the performance and quantify the life cycle costs of crash cushion systems installed across Iowa and to develop guidance regarding where and when to install specific types of crash cushions.

## Research Description

**Identifying Crash Cushions in Iowa**

A list of 147 existing crash cushion installations provided by the Iowa Department of Transportation (DOT) was manually reviewed for accuracy using Google Earth and Google Street View imagery, and discrepancies were removed or corrected. Additionally, Google Earth aerial imagery covering all Interstates and Iowa DOT-owned roadways was manually searched to identify additional crash cushion installations.

In total, 280 crash cushions were identified representing 13 unique types. For each system, the object shielded and the cushion's spatial location relative to the roadway were identified.

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*Redirective crash cushions at the end of a concrete barrier at two different locations in Iowa*

The cushions were grouped into two categories: redirective cushions, designed to maneuver the striking vehicle back into the travel lane from which it departed, and non-redirective cushions, designed to be strategically penetrated by the striking vehicle.

**Identifying Collisions with Crash Cushions**

The Iowa DOT crash database was used to identify crashes that involved collisions with permanent crash cushion systems. Crash reports from 2007 through 2014 were reviewed to identify collisions in which the investigating officer indicated that a crash cushion was struck.

After further examination, only 34 target crashes were confirmed to have involved a collision with a permanent crash cushion. The crash rates per million vehicle miles traveled on two-lane undivided highways, multi-lane divided highways, and one-way roadways/ramps were estimated, and the crash-level injury severity outcomes (where the most severe injury among all involved vehicles represents the entire crash) were reviewed.

Due to the limited sample size and the general difficulty in identifying target crashes, a comparison of the in-service performance of the various systems used in Iowa could not be conducted.

**Quantifying Life Cycle Costs**

Using financial information collected from the Iowa DOT, district maintenance managers, and crash cushion manufacturers, the life cycle cost for each system was computed based on the initial installation costs and average total repair costs.


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*Non-redirective crash cushions on either side of the sign trusses (top) and before a pole (bottom)*

Due to the lack of available maintenance data for the non-redirective barrier cushions, only the redirective barrier types were analyzed. These were further split into two categories: redirective systems with high installation costs and low repair costs (RHL) and redirective systems with low installation costs and high repair costs (RLH).

### Developing Design Guidance

A software tool, Roadside Safety Analysis Program Version 3 (RASPv3), for determining the cost-effectiveness of roadside treatment alternatives was used to develop design guidance regarding the most cost-effective crash cushion type for different combinations of roadway geometries and traffic characteristics.

The facility types of interest included two-lane undivided, four-lane divided, and one-way highways. The encroachment probability data included in RSAPv3 were modified to consider two encroachment probability scenarios: a high crash risk scenario based on a modified regression model with the default RSAP data and a low crash risk scenario based on the Iowa crash cushion collision rates estimated above.

For each scenario, the number of crash cushion strikes per year was estimated for an analysis segment on each facility type for different combinations of factors. Sensitivity analyses were performed separately for each facility type to identify the parameters that have the greatest influence on the frequency of roadway departure crashes.

Two design charts, one for the high crash risk scenario and one for the low crash risk scenario, for each facility type were developed based on the cost-effectiveness of each crash cushion category.

## Key Findings

- Vehicles that collided with crash cushions experienced less severe crashes than vehicles that struck fixed objects. Approximately 78 percent of the target crashes resulted in either a minor injury or a property-damage-only crash (i.e., non-injury crash), and no fatal injury target crashes were identified, providing general evidence that the crash cushion installations are effective.

- The RASPv3 analysis indicated that hazard offset, annual average daily traffic (AADT), and the curve radius of the roadway had the largest influence on the probability of a roadside hazard being struck in a crash.

- The results of the life cycle cost comparison and the RSAPv3 analysis indicated that RLH cushions had the lowest life cycle cost when fewer than 0.08 strikes per year were expected. When more strikes per year were expected, RHL cushions were found to be more cost-effective.

- The RLH cushions were found to be more cost-effective for tangent facilities, roadways with lower AADT volumes, and hazards offset further from the roadway. Conversely, the RHL cushions were more cost-effective on sharper curves and roadways with higher AADT volumes and closely spaced hazards.

## Implementation Benefits and Readiness

The analysis of crashes at current crash cushion installations in Iowa provides general evidence that crash cushions can effectively reduce the severity of collisions with fixed objects.

The project report provides design guidelines based on hazard offset, AADT, and curve radius for two-lane undivided, four-lane divided, and one-way highways. These guidelines can be used to determine the most cost-effective crash cushion type to install on roadways with various traffic characteristics and geometries.

## Limitations

While the selection of a specific crash cushion would ideally be informed by a comparison of the injury outcome probabilities among several devices, the small sample of 34 crashes used in this study limited a comparison among the products used in Iowa.

The installation costs used in the life cycle cost analysis did not include costs that can vary depending on site-specific factors, such as whether a paved concrete pad is required for installation.

Moreover, repair costs per crash were based on limited data obtained from Iowa DOT district maintenance garages, and costs associated with the exposure of maintenance crews to traffic, exposure of the fixed hazard to traffic while the crash cushion is non-functional, and other factors were not available.

The run-off-road crash frequencies generated by RSAPv3 are based on encroachment data collected in the late 1970s, and the accuracy of these data for current roadway conditions is uncertain. Forthcoming research aims to reevaluate these encroachment models, and the results may also be validated using actual run-off-road crash frequency data.

## Recommendations and Future Research

- RSAPv3 aggregates different crash cushion systems as a generic attenuator, which does not account for differences in system performance across product types. Hazard severity models for each cushion type should be developed and incorporated into RSAPv3 to enable benefit-cost comparisons among different cushion systems and identification of the optimal system for a given highway scenario. Given the relative infrequency of collisions involving crash cushions, such research would likely require a multi-state pooled-fund study.

- Transportation agencies can improve their inventories of crash cushion strike and repair data by standardizing their reporting for repairs and developing specific contract items for each situation. A standard form to be completed by maintenance crews might include location information, the date of the incident, the repair date, the hours spent on the repair, the traffic control needed required, and other items.

- Tracking the time between the occurrence of a crash cushion strike and the repair can help quantify the costs associated with the fixed object's exposure to traffic while the crash cushion is non-functional.

- Cushion design may be improved if crash narratives include the redirective performance of the cushion devices involved in crashes, characterized by the rebound angle, and whether the vehicle overturned after impacting the cushion. Images of the vehicle(s) and the cushion after the impact can also allow other pertinent information to be extracted.