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Barrier-relevant crash modification factors and average costs of crashes on arterial roads in Indiana

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ABSTRACT

The objective of this study was to develop crash modification factors (CMFs) and estimate the average crash costs applicable to a wide range of road-barrier scenarios that involved three types of road barriers (concrete barriers, W-beam guardrails, and high-tension cable barriers) to produce a suitable basis for comparing barrier-oriented design alternatives and road improvements. The intention was to perform the most comprehensive and in-depth analysis allowed by the cross-sectional method and the crash data available in Indiana. To accomplish this objective and to use the available data efficiently, the effects of barrier were estimated on the frequency of barrier-relevant (BR) crashes, the types of harmful events and their occurrence during a BR crash, and the severity of BR crash outcomes. The harmful events component added depth to the analysis by connecting the crash onset with its outcome. Further improvement of the analysis was accomplished by considering the crash outcome severity of all the individuals involved in a crash and not just drivers, utilizing hospital data, and pairing the observations with and without road barriers along same or similar road segments to better control the unobserved heterogeneity.

This study confirmed that the total number of BR crashes tended to be higher where medians had installed barriers, mainly due to collisions with barriers and, in some cases, with other vehicles after redirecting vehicles back to traffic. These undesirable effects of barriers were surpassed by the positive results of reducing cross-median crashes, rollover events, and collisions with roadside hazards. The average cost of a crash (unit cost) was reduced by 50% with cable barriers installed in medians wider than 50 ft. A similar effect was concluded for concrete barriers and guardrails installed in medians narrower than 50 ft. The studied roadside guardrails also reduced the unit cost by 20%–30%.

Median cable barriers were found to be the most effective among all the studied barriers due to the smaller increase in the crash frequency caused by these barriers and the less severe injury outcomes. More specifically, the occupants of vehicles colliding with near-side cable barriers tended to have less severe injuries than occupants of vehicles entering the median from median's farther side. The near-side cable barriers provided protection against rollover inside the median and against a potentially dangerous collision with or running over the median drain; therefore, the greatest safety benefit can be expected where cable barriers are installed at both edges of the median.

The CMFs and unit crash costs for 48 road-barrier scenarios produced in this study are included in this paper.

1. Introduction

Federal and state roadside design guidelines support the use of barriers. The American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide (RDG) (AASHTO, 2011) recommends the use of roadside barriers based on the premise that striking a barrier is less dangerous than a rollover or striking a roadside object. Successful application of this principle requires knowledge of the differences in the risk and severity of the injuries associated with barriers and various roadside hazard conditions.

According to the RDG, a median barrier is optional when the median width is 30–50 ft and normally a barrier is not considered when the median width is larger than 50 ft. However, the use of road barriers has expanded during the last several years, and some states have installed or have begun to install median barriers on medians wider than 50 ft (Ray et al., 2009). For cable barriers in particular, most states now recommend their use in 40–75 ft wide medians (Sheikh et al., 2008).

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The expanded scope of the application of median barriers and the recent introduction of high-tension cable barriers have provided designers with more viable barrier alternatives. Understanding the safety performance of various types of barriers with different barrier placements and local conditions is particularly important where more than one type of barrier may be used. For instance, both high-tension cable barriers and W-beam guardrails could be viable median barrier alternatives for a wide median (e.g., 60 ft), whereas both concrete barrier walls and W-beam guardrails could be considered in a narrow median (e.g., 30 ft). Careful consideration of the alternatives is required before a barrier type is selected; but once a barrier type is selected, its proper placement is also important.

There are established uniform guidelines for assessing the structural performance of road barriers through full-scale crash tests (AASHTO, 2009). Although conducting a barrier evaluation based on the testing results is necessary in the initial stage of investigating a new or modified barrier design, the actual barrier performance should be evaluated in-service in real-world conditions. An in-service performance evaluation addresses the expected safety benefit and the installation, maintenance, and repair costs. This information then is used in a benefit-cost analysis to decide whether or not a barrier should be used, as well as to select a barrier type for given roadway and roadside characteristics. Thus, the objectives of the study presented in this paper were as follows:

1. Assess the in-service safety performance of barriers based on the comparison of crashes with and without barriers under similar roadway conditions.
2. Compare the in-service safety performance among different types of barriers and different placement setups.
3. Provide a basis for deciding whether, where, and which types of barriers should be installed.

This study focused on median and roadside longitudinal barriers of three types: concrete barriers, guardrails, and high-tension cable barriers. The studied roadway segments were divided freeways and rural/suburban non-freeway roads with and without barriers administered by the Indiana Department of Transportation (INDOT). The studied crashes were barrier-relevant (BR) crashes that included barrier collision crashes, cross-median crashes, and fixed roadside object collision crashes. These crashes included off-roadway rollover crashes and crashes in which vehicles ran off the roadway, were redirected back to the roadway, and collided with other vehicles. Thus, the BR crashes included single and multiple vehicle crashes.

The paper is organized in eight sections. This section introduces the motivation, the research problem, objectives, and scope of the study. The Literature Review section reviews the existing literature on the use and in-service performance of road barriers. The Research Approach and Scope section introduces the research approach extended with consideration of harmful events. Then, three sections briefly present the data collected and the developed models of the barrier-relevant crash frequency on segments, the probability of harmful events of several types during barrier-relevant crash development, and the probability of various injury levels as an outcome of a barrier-relevant crash. The Cost of Crashes section describes the crash average costs estimation method and it presents the final table with the results. The Closure section summarizes the primary findings and contributions of this study.

2. Literature review

The existing standards, guidelines, and manuals are briefly described first in this section, followed by a review of the literature on the use of barriers and in-service performance evaluation and methodology.

2.1. Existing standards, guidelines, and manuals

The AASHTO Road Design Guide (RDG) provides guidelines and recommendations on the use of both roadside barriers and median barriers. The RDG defines a roadside barrier as "a longitudinal barrier used to shield motorists from natural or man-made obstacles located along either side of a travelled way." Roadside barriers are generally considered when the consequences of running off the roadway without the protection of barriers are expected to be more serious than barrier collisions. Embankments and roadside obstacles are the two most common conditions that need to be shielded by roadside barriers.

Median barriers are used to separate opposing traffic on divided highways and to redirect vehicles striking the barriers from either side. The RDG provides recommendations on the use of median barriers based on the average daily traffic (ADT) and median width as shown in (AASHTO, 2010). The RDG also indicates that some states have expanded the use of median barriers due to the increased number of observed cross-median crashes. A cost/benefit analysis is recommended to justify the decision to expand the use of median barriers.

The 2013 Indiana Design Manual of the Indiana Department of Transportation (INDOT) adopted barrier warrant criteria similar to the RDG but classified the criteria into more roadway scenarios. For roadways of four or more lanes (divided and undivided), INDOT's warrant for roadside barriers based on the characteristics of embankments is the same as specified by the RDG. For two-lane two-way roadways, it also considers the ADT and design speed as criteria.

The median barrier warrant in the Indiana Design Manual is similar to the RDG, but the traffic criteria in the Indiana Design Manual is the 20-year projected ADT while the RDG criteria is the five-year projected ADT. The Indiana Design Manual also requires the use of a median barrier on freeways or expressways with a design speed of 50 mph or higher and median crossings at least one mile apart.

NCHRP Report 350 and the *Manual for Assessing Safety Hardware (MASH)* established a standard procedure to test the performance of roadside barriers before they are fully implemented in the field. They classified barriers into different test levels depending on the local traffic composition and geometrics. The crash tests are limited to certain types and weights of test vehicles, and the testing is conducted for pre-determined impact angles, which might not represent in-field impacts from errant vehicles. Thus, both guidelines indicate that in-service evaluation is necessary and important in assessing the efficiency of a roadside product and providing in-depth knowledge.

The guidelines and warrants for the use of median and roadside barriers are available in the RDG and the Indiana Design Manual. The ADT and median width are used as the criteria for considering median barriers; and the embankment height, embankment slope, and roadside obstacles are used for considering roadside barriers. These guidelines not only help agencies properly select and install barrier systems but also provide the structural and safety characteristics of different types of barriers.

It is important to note that many states have expanded their use of median barriers and thus have developed their own specific median barrier guidelines, which consider their state's median crossover history and number of fatalities. For example, many states have installed median cable barriers on wide medians ranging from 40 ft to 75 ft (Sheikh et al., 2008). Due to the considerable attention given to cable barriers and their rather short history, it is important to investigate their in-service performance.

2.2. In-service evaluation

According to *NCHRP Report 490, In-service performance of traffic barriers* (Ray et al., 2003), the purpose of in-service evaluations of roadside features such as road barriers is twofold:

1. Determine how barriers perform under field conditions.