Evaluation of Truck Impact Hazards for Interstate Overpasses

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Increased freight activities on Interstate highways escalate the risk of collision between trucks and overpass bridges. Although such events are rare, the consequences of such a collision may be catastrophic. Many overpass bridges were designed and constructed in the early years of development of the Interstate highway system and therefore did not meet the requirements specified in AASHTO's *Load and Resistance Factor Design Bridge Design Specifications*. In this study, 5-year truck run-off-the-road crash data, information on Interstate highway geometric characteristics, and traffic information were collected to develop crash prediction models for bridge bents. The bent-based predictive methods improved the collision risk estimate by evaluating the individual bents of a bridge on the basis of roadway geometrics and traffic conditions. The detour costs subsequently measured on the basis of the additional road user costs caused by the failure of a bridge were used to assess the importance of a bridge quantitatively. As a result of this study, a bridge index was developed from both the collision risk and detour costs. This study could provide guidance to departments of transportation to develop mitigation plans for bridges with high collision risk indexes.

In recent years, the oil boom in North Dakota and the accelerated economic recovery have substantially increased freight activities on the South Dakota highway system. A large amount of the increased traffic is from heavy vehicles, and this increased heavy vehicle traffic escalates the probability of a collision between trucks and bridges. Despite the extremely low odds, this type of collision can lead to catastrophic structural failures for many overpass bridges on South Dakota's Interstate highways that were designed and constructed in the early years of development of the Interstate highway system and do not meet the requirements specified in the AASHTO *Load and Resistance Factor Design Bridge Design Specifications* (*1*). Such collisions not only could cause the partial or total collapse of highway bridges but also could close sections of the Interstate or other major highways in the system. If such a collision were to take place on a stretch of the Interstate system with a high traffic volume, the social and economic impacts could be enormous. Therefore, it is essential to identify vulnerable infrastructure at critical locations and develop appropriate mitigation plans.

Collisions between vehicles and bridges are caused by errant vehicles departing the roadway. A run-off-the-road (ROR) crash is defined as a crash involving a vehicle that leaves the roadway and rolls over or hits any roadside fixed object, such as a bridge column, embankment, utility pole, tree, luminaire, guardrail, or barrier. From 2004 to 2008, a total of 860 single-truck ROR crashes and 27 multivehicle ROR crashes involving trucks occurred on I-29 and I-90 in South Dakota. Among those 887 ROR crashes, 36 crashes were collisions between trucks and bridge guardrails.

Bridge barriers are installed to protect bridge bents from direct impact. A bridge bent is a substructure unit that supports each end of a bridge span and is usually made up of two or more columns. The placement of a bent determines its potential for exposure to collisions. Roadside bents are the bridge columns located on the right side of the roadway, and median bents are the bridge columns located in the median. Median bents are exposed to higher risks because they are exposed to traffic traveling in both directions. Few studies have assessed the risk of collision for individual bridge bents. Therefore, in this study, crash data for trucks that ran off from the right and from the left were collected, and crash prediction models were developed for left-side ROR crashes and right-side ROR crashes, respectively.

If an overpass bridge is hit and loses its design support to vehicle loads, vehicles using the overpass must take other routes, resulting in additional road user costs (RUCs). The cost associated with bridge damage was considered in the development of a truck collision risk index for evaluating the hazards of an impact with a truck for existing and future bridges. The risk assessment index has the potential to help departments of transportation (DOTs) mitigate or prevent catastrophic social or economic losses because of bridge collapses.

LITERATURE REVIEW

In previous studies, accident- and encroachment-based approaches were commonly used to develop the relationships between roadside crashes and roadside conditions. Roadside encroachment means "an errant vehicle crosses the outside edges of the travel way and encroaches on either the inside or outside shoulder" (*2*). The encroachment-based approach used to describe the sequence of events that result in an ROR accident uses a series of conditional probabilities (*3*). As Miaou summarized, the sequence of events considered by the encroachment-based approach is as follows:

> (1) An errant vehicle leaves the travel lane and encroaches on the shoulder; (2) the location of encroachment is such that the path of travel is directed towards a potentially hazardous roadside object; (3) the hazardous object is sufficiently close to the travel lanes, [and] the control is not regained before encounter or collision between vehicle and the object; and (4) the collision is severe enough to result in an accident of some level of severity. (*4*)

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The advantages of the use of the encroachment-based approach are based on its analytical and engineering strengths, but this approach also makes several subjective assumptions that are difficult to validate, such as the travel path of the errant vehicle. Additionally, the effort to validate these assumptions is difficult and cost-prohibitive (*4*).

The accident-based approach is more popular than the encroachment-based approach because crash data are more readily available. The accident-based approach is developed through the use of statistical regression models to determine the relationship between ROR accident frequency and traffic conditions, roadway main-line designs, roadside designs, and other explanatory variables (*5*). An ROR crash is the consequence of a roadside encroachment event, but a roadside encroachment event might not lead to a crash event. In other words, ROR crashes are just a small fraction of the multitude of roadside encroachments. Miaou proposed a probabilistic relationship between a roadside encroachment and an ROR crash to connect the two types of events, and thereby, the roadside encroachment frequency can be obtained from conventional accident-based prediction models (*4*).

Accident-based roadside collision models are usually developed through the use of negative binomial regression models when the equality of the mean and the variance of the crash data for a Poisson model is violated. Other model variations, such as the zero-inflated Poisson model and the zero-inflated negative binomial model, have also been used when crash data have an excessive number of zero observations. According to a study conducted in Washington State, the negative binomial model is the most appropriate model for ROR accident frequency on urban roadway sections, whereas the zero-inflated negative binomial model is the most appropriate for rural roadway sections (*6*).

To deal with the potential heterogeneity in the accident frequency data, Anastasopoulos and Mannering tried to model vehicle accident frequencies with the random-parameters negative binomial model, which was proved to be statistically superior to fixed-parameters models (*7*). A recent study by the Texas A&M Transportation Institute analyzed collisions between large trucks and bridge piers (*8*). Two different methods were used to estimate collisions between trucks and bridge piers. One was based on probability theories, and the other one was based on regression models.

Other noticeable national publications, such as *NCHRP Report 492: Roadside Safety Analysis Program (RSAP)—Engineer's Manual* (RSAP) (*9*), *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* (*10*), and the AASHTO *Manual for Assessing Safety Hardware* (MASH) (*11*), cover many subjects on ways to reduce roadway departures and minimize the consequences of roadside encroachments. NCHRP Report 492 elaborated on the process of analysis of collision risk and severity (*9*). NCHRP Report 350 described research testing the effectiveness of roadside barriers (*10*). The AASHTO MASH summarized state-of-the-art crash testing of the safety hardware devices used on the national highway system (*11*); AASHTO MASH has replaced NCHRP Report 350 (*10*) for the evaluation of new safety hardware devices. In the AASHTO load and resistance factor design study of vessel impacts on waterways, bridge piers were first considered individually; the aggregated risk for a bridge was then obtained to estimate the total collision risk (*12*).

DATA COLLECTION AND PROCESSING

Many of the data for this study were collected from different resources, including road features (e.g., information on roadway cross-sectional features, pavement types, and the presence of rumble strips and vertical and horizontal alignment data), traffic data [e.g., annual average daily traffic (AADT) and truck AADT data], and crash data. Considerable care was given to the identification of ROR crashes and determination of the side from which the vehicle departed the roadway. The key leads to such information can be found from the first harmful event or the most harmful event of a crash. Any harmful event involving a rollover accident or a roadside object (e.g., approaches; bridge piers or supports; bridge rails; concrete traffic barriers; culverts; delineator posts; ditches; embankments; fences; guardrail ends; guardrail faces; traffic signs; luminary supports; other posts, poles, or supports; other traffic barriers; utility poles; or snowbanks) was considered an ROR crash.

From 2004 to 2008, a total of 887 ROR crashes involved trucks. Those crashes occurred on I-29 and I-90 in South Dakota, which consist of 1,342 mi of roadway. Crash data included further descriptions, such as running off the road to the right, running off the road to the left, hitting bridge rail, and hitting fence. A ratio of the number of events involving running off the road to the right to the number of events involving running off the road to the left was applied if it was unknown from which side the vehicle ran off, and the number of crashes was rounded to the nearest integer. Tables 1 and 2 provide descriptive statistics for the key variables used in the estimation of crash frequency. The frequency of crashes involving running off the road to the right and the frequency of crashes involving running off the road to the left are listed in Table 3.

TABLE 1 Summary Statistics of Explanatory Continuous Variables

Continuous Variable	Description	Range	Mean	SD
Crash counts	5 years of counts of ROR crashes to the right in segment	[0–8]	0.713	1.161
Crash counts	5 years of counts of ROR crashes to the left in segment	[0–6]	0.694	1.028
Median shoulder width	Width of shoulder on left in direction of travel (ft)	[4–10]	4.607	1.081
Right shoulder width	Width of shoulder on right in direction of travel (ft)	[4–10]	9.602	0.798
Median width	Width of median grass or sod (ft)	[16–75]	26.311	9.261
Length	Length of segment (mi)	[0.062–38.108]	2.126	3.479
Truck AADT	Annual average daily truck traffic	[78–5,603]	2,373.095	868.84
Horizontal curve	Degree of horizontal curve of segment	[0–36.9]	5.174	4.269
Vertical curve	*k*-value of vertical curve of segment	[0–110,000]	1,722.111	7,631.683

NOTE: SD = standard deviation.

TABLE 2 Summary Statistics of Explanatory Categorical Variables

Categorical Variable	Description	Category	Frequency[a]	Percentage
Number of lanes	Total number of lanes in segment	2	575	91.13
		3	50	7.92
		4	6	0.95
Lane width	Average width of each lane (in feet)	12	463	73.38
		13	168	26.62
Surface type	Pavement type of lanes	Asphalt	120	19.02
		Concrete	511	80.98
Shoulder type	Pavement type of shoulders	Asphalt	506	80.19
		Concrete	125	19.81
Rumble strips	Presence of rumble strips	Yes	347	54.99
		No	284	45.01

[a] Frequency indicates the number of roadway segments.

The detour costs were calculated from estimation of the RUC of the increased distance that vehicles had to travel after the bridge collapsed because of their need to take the detour route. ArcGIS software was used to obtain the detour distance by the setting of point barriers in the network analyst tool to locate the shortest detour route. Figure 1 shows an example of the shortest detour route obtained through the use of ArcGIS software.

METHODOLOGY

The methodology used to develop a bridge collision risk index is illustrated in Figure 2. Bridge ranking can be determined after the input from two modules is combined: the bridge collision risk module and the detour costs module. The bridge collision risk module aims to develop methods for assessment of the risk for collisions between trucks and Interstate highway overpass bridge bents and can be calculated in four steps: (*a*) build truck ROR crash prediction models to calculate the truck ROR crash density, (*b*) estimate the bridge hazard envelope on the basis of the bridge width and the vehicle configuration, (*c*) introduce a lateral encroachment probability analysis to assess the chance that an aberrant truck will travel off the road far enough to hit a bridge bent, and (*d*) assess the bridge barrier systems to evaluate the effectiveness of the protection measures.

The detour costs module estimates the additional RUC after a bridge has collapsed. The purpose for introduction of the detour costs module is to account for the critical location of a bridge. Extra prevention is needed when a bridge is located in an economically vital area, even when the calculated collision risk is low. If the overpass bridge is less important to the community, the bridge may not be considered high priority even when the collision risk is higher. After information from the two modules is combined, a composite ranking is provided through the use of different ranking strategies. The rest of this section discusses the key components in this flowchart.

Crash Prediction Model

The probability that a vehicle will run off the road can be attributed to various factors, including the driver's experience, attentiveness, and reaction times. The complexity of the transportation network may also influence crash probabilities (*8*). These unobserved or unmeasured factors can easily lead to data overdispersion, which is commonly encountered in crash count data; thus, the negative binomial regression model was used. The link function of the model is shown in Equation 1.

$$E_i = \mathrm{ADTT}_i^{\alpha} * L_i * \exp(\beta_i X_i) \quad (1)$$

where

E_i = expected number of ROR crashes on segment i,
ADTT_i = average daily truck traffic on segment i,
L_i = length of roadway segment i,
α and β = model parameters, and
X_i = geometric and traffic variables on segment i (Tables 1 and 2).

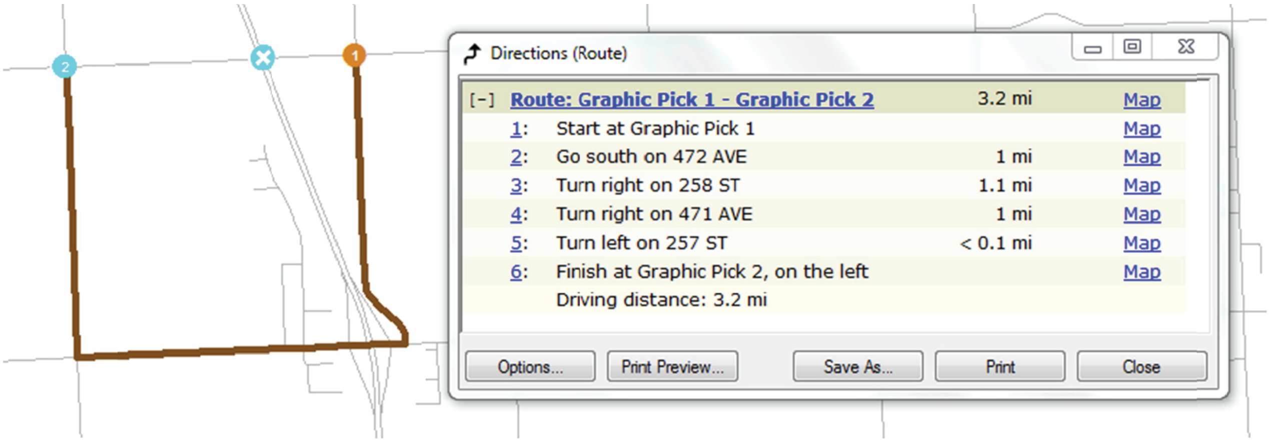
Bridge Hazard Envelope

A bridge collision occurs if the bridge bent happens to be located in the erratic vehicle's trajectory path. The size of the hazard exposure to an erratic vehicle, called a hazard envelope, which is shown in Figure 3, can be determined on the basis of a few parameters. For a given vehicle of size ω, encroachment angle θ, and orientation φ, a hazard collision will occur if, within the hazard envelope, the vehicle leaves the roadway and is unable to stop (*4*).

TABLE 3 ROR Crash Frequency

	ROR Crashes to Right				ROR Crashes to Left			
Crash Count	Frequency[a]	Percentage	Cumulative Frequency[a]	Cumulative Percentage	Frequency[a]	Percentage	Cumulative Frequency[a]	Cumulative Percentage
0	373	59.11	373	59.11	369	58.48	369	58.48
1	154	24.41	527	83.52	152	24.09	521	82.57
2	61	9.67	588	93.19	62	9.83	583	92.39
3	19	3.01	607	96.2	35	5.55	618	97.94
4	13	2.06	620	98.26	9	1.43	627	99.37
5	4	0.63	624	98.89	3	0.48	630	99.84
>5	7	1.11	631	100	1	0.16	631	100

[a] Frequency indicates the number of crashes.



[-]	Route: Graphic Pick 1 - Graphic Pick 2	3.2 mi	Map
1:	Start at Graphic Pick 1		Map
2:	Go south on 472 AVE	1 mi	Map
3:	Turn right on 258 ST	1.1 mi	Map
4:	Turn right on 471 AVE	1 mi	Map
5:	Turn left on 257 ST	< 0.1 mi	Map
6:	Finish at Graphic Pick 2, on the left		Map
	Driving distance: 3.2 mi		

FIGURE 1 Shortest route by use of ArcGIS.

The RSAP defines the hazard envelope to be a function of the size and orientation of the vehicle, the size and lateral offset of the hazard, and the encroachment angle (*9*). The function (P) is shown in Equation 2:

$$P = \left(\frac{1}{5,280}\right) * \left[L_h + \left(\frac{W_e}{\sin\theta}\right) + W_h \cot\theta\right] \tag{2}$$

where

L_h = length of hazard (ft);
W_e = effective width of vehicle (ft), which is equal to $L_v \sin\varphi + W_v \cos\varphi$, where L_v and W_v are length and width (ft) of vehicle, respectively; and
W_h = width of hazard (ft).

Because of the limited amount of data, all encroachment angles θ were assumed to be 10° and all orientation angles φ were assumed to be 7.5° on the basis of the impact speed and angle distributions provided by NCHRP Report 492 (*9*). For the size and lateral offset of the hazard, the length of the hazard (L_h) was assumed to be equal to the bridge deck width. The width of the hazard (W_h) was equal to the bridge bent width. The bridge hazard envelope is proportional to the size of the vehicle and the bridge structure.

Lateral Encroachment

To distinguish the influence of different lateral offsets on the collision risk between trucks and bridge bents, the concept of lateral offset in NCHRP Report 492 was applied (*9*). According to NCHRP Report

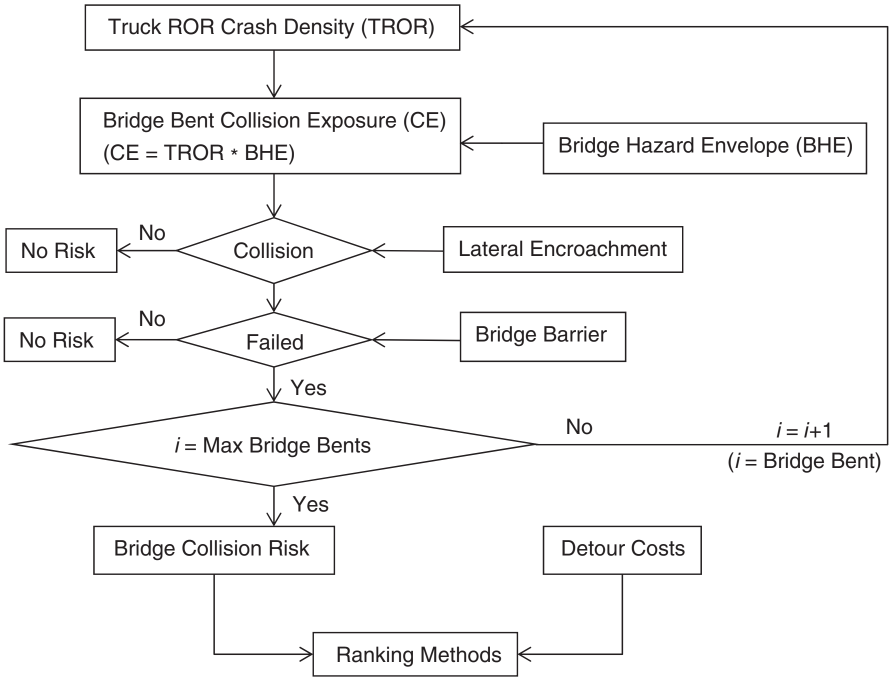


FIGURE 2 Bridge collision risk index flowchart.

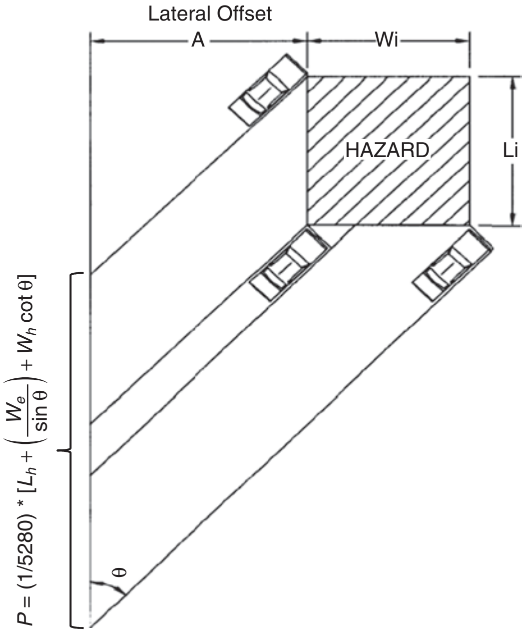


FIGURE 3 Bridge hazard envelope (*9*).

492 (*9*), encroachments in Cooper's data with a lateral offset of greater than 4 m are 91.9% of all observations for multilane divided highways (*13*). The lateral offset distribution can be represented by a regression model, as shown in Equation 3:

$$\ln(Y) = a + bX \tag{3}$$

where

Y = percentage of lateral offset distribution exceeding lateral distance X,
X = lateral distance, and
a and b = regression coefficients (for multilane divided highways, coefficients are 5.320 for a and –0.161 for b).

Bridge Barrier System

The overpass bridge bents on the Interstate highways in South Dakota are protected by different types of bridge barrier systems. In NCHRP Report 350, bridge railings were classified into six test levels (*10*). The test levels are established on the basis of the results of testing of the impact of different types of vehicles with the bridge railings at different speeds and angles (*11*). AASHTO MASH (*11*) is an update to and supersedes NCHRP Report 350 (*10*) for the evaluation of new safety hardware devices.

Three types of barrier systems are installed on I-29 and I-90 in South Dakota: W-beam (weak post), three-strand cable (weak post), and Thrie beam (strong post). Some combinations of these barrier systems are in place, such as a three-strand cable transition to a W-beam, a W-beam transition to a Thrie beam, and a three-strand cable transition to a W-beam that transfers to a Thrie beam. Table 4, which is provided in the *Roadside Design Guide*, shows the approved test levels of roadside barriers present on South Dakota Interstate highways (*14*).

Table 4 suggests that only those barrier systems passing Test Level 4 or above, that is, concrete barriers, can stop trucks heavier than 10,000 kg from penetrating barrier systems. However, most of the current bridge barrier systems on I-29 and I-90 in South Dakota are below Test Level 4, which means that they are unable to protect bridge bents from being hit by heavy trucks.

TABLE 4 Roadside Barriers and NCHRP Report 350 Approved Test Levels (*14*)

Roadside Barrier System	Test Level	Vehicle	Containment Capacity (kJ)
W-beam (weak post)	2	2270P	70.5
3-strand cable (weak post)	3	2270P	144
Thrie beam (strong post)	3	2270P	144
Concrete barrier	5	36000V	548

Detour Costs

In the event of a bridge collapse, local road users must take a longer detour route to their destinations. In this study, all vehicles are assumed to take the shortest available route. The detour costs were measured from the additional RUCs from the increased travel distance and increased travel time resulting from the collapse of a bridge. The monetary impacts to road users because of new construction, reconstruction, rehabilitation, restoration, resurfacing, and other miscellaneous highway maintenance activities can be estimated from vehicle operating costs (VOC), the value of road users' time (VOT), and accident costs (ACs) (*15*). Because of the limited amount of data, it is assumed that few trucks travel on rural local roads, which means that all vehicles that took the detour route were passenger cars. RUC is formulated as follows:

$$\text{RUC} = \text{VOT} + \text{VOC} + \text{AC} \tag{4}$$

VOT is estimated on the basis of wage rates and delays because of the length of a trip on a detour route or an alternative route(s). The formulation is as follows:

$$\text{VOT} = \left(\frac{\text{detour distance}}{\text{speed}}\right) * 60 * \text{volume} * \text{unit cost} * \text{vehicle occupancy factor} \tag{5}$$

The calculation of the detour distance was described above. The default values used were as follows: the speed for local roads was 55 mph, the unit cost was $0.19/min, and the vehicle occupancy factor was 1.67.

VOC is a composite of the costs associated with operation and ownership of the vehicle over the study project analysis period. Vehicle operating costs include the costs associated with fuel, oil, tire wear, and vehicle maintenance and repairs; ownership costs include the costs of insurance, license and registration fees and taxes, and economic depreciation and finance charges. The default value of the unit cost was $0.60 per automobile per mile. The formulation is shown as follows:

$$\text{VOC} = \text{detour distance} * \text{unit cost} * \text{volume} \tag{6}$$

ACs were measured from changes in the total annual cost of crashes as a result of the highway project. It takes potential accidents on the detour route into consideration. The formulation is shown as follows:

$$\text{AC} = \frac{(\text{detour distance} * \text{volume} * \text{accident rate} * \text{unit cost})}{1{,}000{,}000} \qquad (7)$$

The accident rate for South Dakota local roads was 1.9 accidents per million vehicle miles of travel (*16*), and the default value of the unit cost was $7,400 per accident. The ADT volume traveled on a specific bridge was collected from the transportation inventory management system of the South Dakota DOT.

Ranking Strategies

Three ranking strategies were considered to prioritize all overpass bridge bents on I-29 and I-90 in South Dakota. The first method of ranking was by total risk significance (RS). For a specific bridge bent, the total RS equals the product of its collision risk (CR) and RUC:

$$\text{RS} = \text{CR} * \text{RUC} \qquad (8)$$

Total RS reflects the potential detour costs to road users that regularly use the bridge.

The second method of ranking was by calculation of the sum of the weighted *Z*-scores of the CR and the additional RUC for the collapse of bridge *i* (B_{RUC_i}). The calculation of the *Z*-scores was as follows:

$$Z(\text{CR}_i) = \frac{\text{CR}_i - \text{mean value}}{\text{standard deviation}} \qquad (9)$$

$$Z(B_{\text{RUC}_i}) = \frac{\text{RUC}_i - \text{mean value}}{\text{standard deviation}} \qquad (10)$$

The *Z*-score is an effective way to compare a sample to a standard normal deviate. Transportation agencies may weigh CR and RUC differently. Three different weights were considered to calculate the sum of the weighted Z-scores of CR and bridge RUCs, that is, 1:1, 1:3, and 3:1.

The last method of ranking was by quartile value. That is, the bridge bents with both CRs and RUCs located in the top 25% of all bents were listed.

ANALYSIS AND DISCUSSION OF RESULTS

Truck ROR crashes for the right and left sides of the roadway were evaluated by the aforementioned methodologies to distinguish the different risk exposures for bridge bents. It was assumed that the probability that a truck will run off a homogeneous segment is uniform, and crash density was calculated as the number of truck ROR crashes per mile. The collision risk for a bridge bent was obtained by multiplication of the truck ROR crash density by its hazard envelope as well as the probability of a collision, given the lateral offset distance. A ranking of collision indexes for Interstate highway overpass bents in South Dakota was created.

Truck ROR Crash Prediction Models

Crash density was calculated as the expected crash frequency per mile. Results of the coefficient estimates of the negative binomial models are presented in Table 5. According to the data in Table 5, the frequencies of ROR crashes to the right and ROR crashes to the left are affected by different variables, and more variables are statistically significant for ROR crashes to the right (roadside) than ROR crashes to the left (median). Both of the truck ADT variables have positive signs, which is consistent with the expectation of higher crash frequencies with higher truck ADTs. In addition, an increase in the degree of horizontal curvature was found to increase the frequencies of ROR crashes on both sides. Therefore, vehicles are more likely to run off the road on segments with sharp horizontal curves, especially trucks that have a higher center of gravity and off-tracking problems (*17*). The degree of vertical curvature was statistically significant for the model predicting ROR crashes to the right. The coefficient shows that with an increase in the *K*-value, the vertical curve is flatter, which thus reduces the probability of ROR crashes. For ROR crashes to the right, shoulder type, the presence of rumble strips, and median shoulder width affect ROR crash frequency. It is difficult to explain why asphalt shoulder type is negatively correlated with ROR crashes to the right but concrete shoulder type is not.

Ranking Results

Figure 4 shows the ranking of CRs and bridge RUCs for all South Dakota bridges by total RS and by the sum of the weighted

TABLE 5 Negative Binomial Estimation of ROR Crash Frequency

	ROR Crash to the Right		ROR Crash to the Left	
Variable	Coefficient	*P*-value	Coefficient	*P*-value
Intercept	–14.9375	<.0001	–9.0996	<.0001
Truck AADT	1.9328	<.0001	1.0337	<.0001
Shoulder type (1 if asphalt, 0 if concrete)	–0.6777	<.0001	NA	NA
Rumble strips (0 if yes, 1 if no)	0.3497	.0021	NA	NA
Median shoulder width	–0.1502	.0307	NA	NA
Horizontal curve	0.0437	.0212	0.0645	.0004
Vertical curve	NA	NA	–0.0023	.0803
Dispersion	0.2096	NA	0.3630	NA

NOTE: NA = not available.

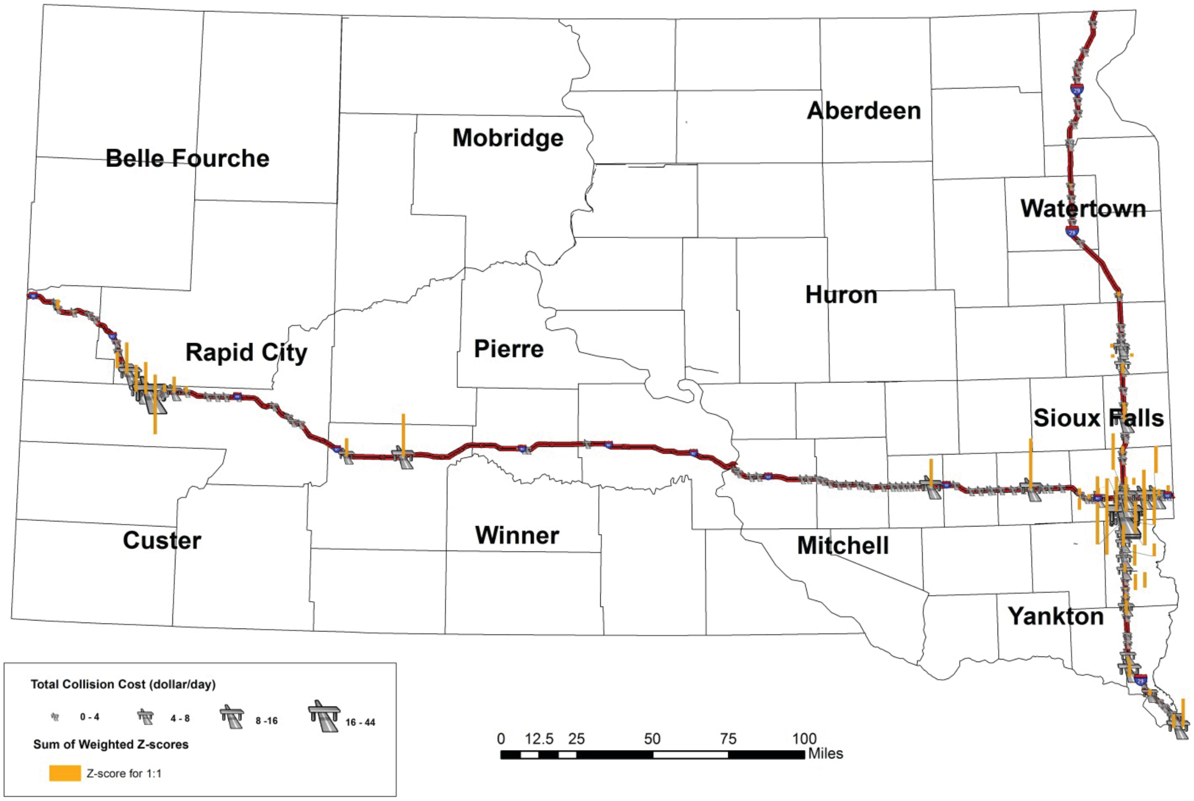


FIGURE 4 Bridge rankings by total risk significance and *Z*-score.

Z-scores (1:1). More bridges have a higher CR in urban areas, such as Sioux Falls and Rapid City, which is likely because of the high truck volumes and RUCs. Figure 5 presents the results ranked by quartile value. In Figure 5, each asterisk denotes a specific bridge bent on I-29, and each circle denotes a specific bridge bent on I-90. The three horizontal lines denote the 25%, 50%, and 75% values for all RUCs; the three vertical lines denote the 25%, 50%, and 75% values for CR. Bridge bents located in the first phase (the most northeast one) have the top 25% CR and 25% additional RUCs among all the bridge bents on I-29 and I-90 in South Dakota. Those bridges need to be further reviewed for collision mitigation.

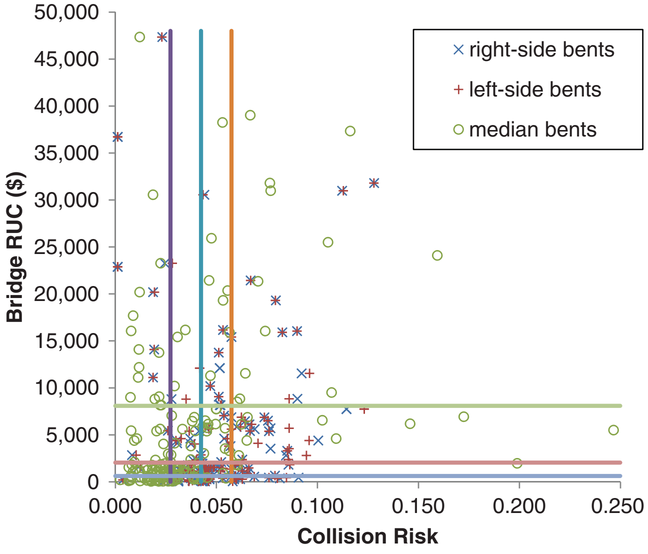


FIGURE 5 Bridge rankings by quartile value.

Structural Redundancy

As discussed above, the value of the bridge hazard envelope is proportionate to the bridge deck width. If everything else is the same, a wider bridge will have a higher risk of collision because of a larger hazard envelope. However, bridges with large deck widths usually have more columns than do bridges with small deck widths and are more likely to be structurally redundant. According to a technical memorandum of the Minnesota DOT (*18*), for bridges with three or more columns on each bent, even if one of them collapses in a collision, the other columns could still support the bridge deck. However, for bridges that have only one or two columns on each bent, the collapse of one column may lead to the collapse of the entire bridge. Although structural redundancy was not explicitly considered in the collision risk calculation, it is necessary to take it into account when bridges are reviewed for their need for further protection.

CONCLUSIONS

The projected economic growth in the Dakotas and neighboring states is expected to generate a substantial increase in traffic on regional state highways. A significant portion of the increased traffic will be trucks carrying goods that meet the needs of a growing economy, as well as the oil and mining industries. However, the majority of overpass bridges on South Dakota Interstate highways are vulnerable to truck collisions because they were constructed before the collision load design requirements in the AASHTO *Load and Resistance Factor Design Bridge Design Specifications* (*1*). The intent of this study was to develop a methodology for assessment of the risk of truck collisions with the columns of overpasses.

The risk assessment methodology involves the identification of factors that contribute to the risk of a truck collision with a bridge column and the consequences of a bridge collapse. The proposed methodology determines a bridge-specific parameter as the risk index, which is a tool to compare the relative risk of a collision with trucks for different bridges. The risk index is dependent on the risk of a collision and detour costs. The risk of a collision measures the probability that a bridge bent will be hit by a truck, given known factors, through the use of bridge bent-based crash prediction models. The bent-based model improves the accuracy of crash prediction because it explicitly considers different traffic exposures to bents.

The results show that the risks of crashes involving ROR crashes to the right and ROR crashes to the left are different, as they are affected by different variables; more variables are statistically significant for ROR crashes to the right (roadside) than ROR crashes to the left (median). The importance of a bridge reflects the severity of the socioeconomic impact that would result from a bridge collapse. It is calculated as the RUC because of the additional distance that would need to be traveled. When both CR and the economic importance of a bridge were combined, three methods were used to create a bridge collision risk index and to rank all overpass bridges on I-29 and I-90 in South Dakota. The method can be transferred and applied to other state DOTs with similar concerns about their bridges. It is expected that the calculated bridge collision risk index can be used to form a prioritization policy for the implementation of risk mitigation procedures.

In the next phase of this study, scaled specimens representing bents of bridges identified in the first phase as candidates for collision mitigation will be constructed and tested until failure. The tests will be conducted to determine the structural responses of as-built and retrofitted bents to the AASHTO-specified collision load. The study could recommend structural retrofitting or increases in the barriers around bridge columns required along South Dakota highways.

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