Analysis of Safety Benefits for Shielding of Bridge Piers

Final Report
June 2009

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16. Abstract

The highway system in the State of Iowa includes many grade separation structures constructed to provide maximum safety and mobility to road users on intersecting roadways. However, these structures can present possible safety concerns for traffic passing underneath due to close proximity of piers and abutments. Shielding of these potential hazards has been a design consideration for many years.

This study examines historical crash experience in the State of Iowa to address the advisability of shielding bridge piers and abutments as well as other structure support elements considering the offset from the traveled way. A survey of nine Midwestern states showed that six states had bridge pier shielding practices consistent with those in Iowa. Data used for the analyses include crash data (2001 to 2007) from the Iowa Department of Transportation (Iowa DOT), the Iowa DOT's Geographic Information Management System (GIMS) structure and roadway data (2006) obtained from the Office of Transportation Data, and shielding and offset data for the bridges of interest. Additionally, original crash reports and the Iowa DOT video log were also utilized as needed. Grade-separated structures over high-speed, multilane divided Interstate and primary highways were selected for analysis, including 566 bridges over roadways with a speed limit of at least 45 mph. Bridges that met the criteria for inclusion in the study were identified for further analysis using crash data. The study also included economic analysis for possible shielding improvement.

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ANALYSIS OF SAFETY BENEFITS FOR SHIELDING OF BRIDGE PIERS

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INTRODUCTION

The highway system in the State of Iowa includes many grade separation structures constructed to provide maximum safety and mobility to road users on intersecting roadways. However, these structures can present possible safety concerns for traffic passing underneath due to close proximity of piers and abutments. Shielding of these potential hazards has been a design consideration for many years.

Prior to construction of the Interstate system, most grade separation structures in Iowa involved a rail crossing. These structures were typically short span bridges with resulting substructure elements quite close to the traveled way underneath. To the researchers' knowledge, all of the overhead rail structures in Iowa feature beam guardrail and/or concrete retaining wall protection for roadway traffic.

With the Interstate system construction that began in the late 1950s, many grade separation structures were constructed, mostly four-span bridges with piers located adjacent to the outside lanes and in the median. The early Interstate design featured relatively narrow medians with piers located less than 20 ft from the traveled way, thus most are protected with w-beam guardrails and/or concrete barriers. Some crash cushions are also in service at these locations. Examples of several common shielding options are included in Appendix I.

Beginning in the 1970s, longer span structures were designed and, along with wider medians, pier offset distances increased to the point that AASHTO clear zone guidelines were exceeded. For many of these structures, no shielding was provided with the initial construction.

The Interstate system in Iowa was essentially completed over 20 years ago but subsequently, Iowa has added hundreds of miles of four-lane expressways to the highway system that also include considerable miles of fully controlled access roadways with grade separation structures. In recent years, the Iowa Department of Transportation (Iowa DOT) has adopted design guidelines with much wider medians and two-span overhead bridges for these non-Interstate multi-lane divided highways. The piers located in the median generally meet or exceed clear zone guidelines for shielding and only an earthen berm supporting the abutments exists along the outside lanes. Generally no shielding has been provided in these instances.

In addition to grade separation structures, both the Interstate and expressway systems in Iowa feature numerous other structures with support elements in close proximity to the traveled way, including standard and changeable message signs.

The existence of numerous situations as described above has presented a quandary for both designers and field maintenance staff in deciding whether shielding is needed and, if so, what type of shielding is appropriate. This study will attempt to provide guidance for several differing conditions.

Iowa currently determines if a substructure element should or should not be shielded on a case by case basis during the design process. This typically means that a designer will evaluate the clear zone distance recommended in the *AASHTO Roadside Design Guide* and protect only the piers that are within a calculated clear zone distance of the traveled way. This distance is based on annual average daily traffic (AADT), design speed, and slope from the roadway to the obstruction, but typically falls between 30 and 35 ft from the edge of traveled way on a high speed roadway. AASHTO clear zones represent the distance that 85% of run-off-road vehicles will traverse before stopping or regaining directional control. Since about 15% of vehicles will travel beyond the clear zone, objects outside this distance are occasionally protected at the discretion of the designer.

AASHTO issued a 3rd Edition of the *Roadside Design Guide* with an updated Chapter 6 on median barriers in 2006. However, this chapter only mentions median obstacles briefly and is not of consequence to this study.

A copy of the *Iowa DOT Design Manual* guidelines for shielding of side obstacles is included in Appendix G.

This study will examine historical crash experience in the State of Iowa to address the advisability of shielding bridge piers and abutments as well as other structure support elements, considering offset from the traveled way and several other factors.

PRACTICE OF OTHER STATES

Midwest Survey

A survey was conducted to determine how other Midwest states determine if a grade separation bridge pier will be shielded or left unshielded. Of the nine states surveyed, six follow the same policy as Iowa, which is that bridge piers only require shielding when located within the calculated clear zone. The states that follow this policy are Nebraska, Kansas, Minnesota, South Dakota, Wisconsin, and Michigan.

Kansas is currently working on a pooled fund study with the Texas Department of Transportation (TxDOT) to determine if a revised policy is advisable. Similarly, Wisconsin has proposed this same topic as a research project for the Midwest Safety Research Pooled Fund.

Additionally, Missouri has installed numerous changeable message signs mounted above Interstate roadways on fixed supports originally without shielding. However, the Missouri Department of Transportation (MoDOT) has recently opted to retrofit these sign installations with crash protection devices. Missouri is now working on a policy to require barrier protection for large fixed objects placed in the state right-of-way.

Two states, Illinois and Indiana, have adopted design policies requiring that all bridge piers be shielded, regardless of offset from the traveled way.

METHODOLOGY

The following three primary data sets were utilized and integrated to analyze the crash history at bridges over state-maintained high-speed, multilane divided roadways: (1) Iowa Department of Transportation (Iowa DOT) crash database (2001 to 2007) provided by the Office of Traffic and Safety, (2) Iowa DOT Geographic Information Management System (GIMS) structure and roadway databases (2006) obtained from the Office of Transportation Data, and (3) shielding and offset data for the bridges of interest (provided by the six Iowa DOT District offices). When necessary, original crash reports and the Iowa DOT video log were also utilized.

The methodology section is divided into the following three parts: (1) bridge selection, (2) crash analysis, and (3) economic analysis for improvements.

Bridge Selection

While the district-provided data included the most comprehensive bridge details, such as shielding and offset by approach, bridge referencing inconsistencies precluded the data's use as the underlying data set for analysis. Therefore, using the Iowa DOT GIMS structures database, a systematic approach was employed to identify grade-separated structures over high-speed, multilane divided Interstate and primary highways in the state. This resulted in 566 bridges over a roadway with a speed limit of at least 45 mph. Where possible, the district-provided bridge data were then used to validate some of the attributes presented in the GIMS data set. Additionally, the districts' data provided information not maintained in GIMS, such as presence of pier shielding, type of shielding, and horizontal alignment of roadway under the structure.

Sites that could not be validated using the district-provided data were augmented using the most recent Iowa DOT video log inventory. Following is a summary of all identified structures of interest.

Because not all of the district-provided data could be integrated with the GIMS data, preliminary system-wide analysis focused on the structure as a whole and not on an approach level. Therefore, only the minimum median and outside offsets are considered (discussed in more detail in "Lateral Clearance under Bridges" below). Structure-level shielding is also broadly classified as (1) full (all piers/embankments are shielded), (2) none (no piers/embankments are shielded), or (3) partial (some of the piers/embankments are not shielded). In the "Economic Analysis" section of this report, approach-level data will be analyzed, which is possible because of the limited number of sites being considered.

Following is a summary of all identified structures of interest, focusing on the structure as a whole.

Available Bridge Data

Forty-six percent of the bridges were found to have complete shielding—both median and outside piers/embankments. A total of 42% had either median only or outside pier/embankment only (partial) shielding. The remaining 12% had no shielding on either the median or outside pier/embankment sides. See Table 1.

Table 1. Bridge-level summary of Iowa bridges by shielding and district

	Districts						
Shielding	**1**	**2**	**3**	**4**	**5**	**6**	**Grand Total**
Full	67	3	18	76	29	65	258
None	13	42		1	13	3	72
Partial	62	35	16	13	23	87	236
Grand Total	**142**	**80**	**34**	**90**	**65**	**155**	**566**

Inventory of Shielding Types

A further analysis of bridge pier shielding on the median side and those substructure elements to the outside of the roadway was performed. Table 2 details the types of shielding used for median and outside piers. W-beam guardrail is the dominant shielding type used for bridge substructures. High-tension cable, from now on referred to as cable, has not been used extensively because the design was not available until recently. This option is a popular selection currently, where feasible, due to lower initial and maintenance costs. Concrete barriers are used more commonly for shielding outside piers than for shielding median piers possibly due to the close lateral location of many outside piers. Comparing the shielding numbers for median and outside piers, it appears to be more common practice to shield median piers than outside piers. It is possible that the number of two-span bridges in the inventory, which do not feature outside piers, may impact these totals. The two-span bridge design makes up about 11% of the bridges listed in Table 3.

Table 2. Bridge-level summary of Iowa bridges by shielding type

Shielding Type	**Median**	**Outside Piers/Embankments**
Barrels	2	---
Beam Guardrail	386	139
Cable	64	3
Concrete	41	116
None	73	308
Grand Total	**566**	**566**

Table 3. Summary of Iowa bridges by number of main spans

Main span Type	Total
Single span	3
2-Span	63
Multi-span	500
Grand Total	**566**

Horizontal Alignment of Roadway under Bridges

To investigate whether bridge pier crashes occur more frequently when the obstruction is located on a horizontal curve of the roadway passing under the bridge, an inventory of roadway alignment was obtained from the district-provided data and the DOT video log. These references show that 94 of 566 or approximately 17% of the bridges were located on curves, and only 16 of these did not have shielding in either the median or along the outside pier/embankment. Table 4 presents the proximity of curves to bridges in the study data. The degree of curvature was not provided in any of the available data sets.

Table 4. Bridge-level summary of Iowa bridges by shielding and roadway (under bridge) geometry

Protection Status	Tangent	Curve	Grand Total
Full	225	33	258
None	56	16	72
Part	191	45	236
Grand Total	**472**	**94**	**566**

Lateral Clearance under Bridges

An examination of the offset distance from edge of traveled roadway to obstruction was undertaken as part of this study. While lateral clearance should not be confused with clear zone, it can be thought of as an operational offset with potential impacts to safety. Per the *AASHTO Roadside Design Guide*, which provides ranges for clear zone based on speed, traffic, and roadside slope, the typical design clear zone for these roadways is 30–35 ft.

The *Structure Inventory and Appraisal Manual* from the Iowa DOT defines offset as the distance from the edge of the travelled lane to the beam guard face or concrete barrier face if shielded, or to the near pier or column face abutment or to a critical slope if unshielded. The DOT GIMS manual uses the minimum of these offsets for both directions of travel.

To perform this analysis, the lateral offsets under the structures were divided into the following four categories: less than 30 ft, 30–34 ft, 35–40 ft, and greater than 40 ft. Table 5 reveals that the majority of the bridges with full shielding have a lateral offset less than 30 ft. This may be impacted by the fact that any existing shielding reduces the offset measurement.

Table 5. Bridge-level summary of Iowa bridges by shielding and lateral clearance (minimum offset)

Offset	Median Piers			Outside Piers/Embankment		
Shielding	Tangent	Curve	Total	Tangent	Curve	Total
<30 feet	**334**	**57**	**391**	**329**	**61**	**390**
Full	221	29	250	218	31	249
None	9	5	14	33	11	44
Partial	104	23	127	78	19	97
30-34 feet	**101**	**29**	**130**	**119**	**27**	**146**
Full	3	4	7	6	1	7
None	13	4	17	23	4	27
Partial	85	21	106	90	22	112
35-40 feet	**34**	**7**	**41**	**16**	**4**	**20**
Full	1		1		1	1
None	32	6	38	16	3	19
Partial	1	1	2			
>40 feet	**3**	**1**	**4**	**8**	**2**	**10**
Full 1						1
None	2	1	3		1	1
Partial	1		1	7	1	8
Grand Total	**472**	**94**	**566**	**472**	**94**	**566**

Crash Analysis

The crash analysis in this study uses historical data from the Office of Traffic and Safety of the Iowa DOT. The crash data includes all reportable crashes occurring during the seven-year period from January 1, 2001, through December 31, 2007. All reported crashes within 50 m of the bridges of interest were initially identified. The distance of 50 m was utilized primarily because of the possible variation in spatial accuracy of the structure, roadway, and crash data sets during the analysis period. Crashes were further limited to include only crashes where one or more sequences of events involved a lane departure and/or collision with a bridge support/underpass, concrete barrier, impact attenuator, guardrail, or ditch/embankment, the latter especially for right-hand departures.

The GIS location of crashes does not differentiate between crashes that occurred on the roadway carried by the bridge and those on the roadway under the bridge. As a result, the crash dataset was filtered to exclude crashes that occurred on the overpass or on an adjoining road by comparing the direction of travel for each crash with the direction of the roadway under the bridge. Additionally, because of data ambiguity for some of the crashes, actual crash reports, particularly the narratives, were reviewed to determine if the crash(es) should be included in the analysis.

Crash data are summarized in the following sections by crash types, traffic volume, frequency and location of crashes, contributing factors, crash severities, horizontal alignment of the roadway under a bridge, and crash frequency by lateral offset of obstruction.

Number and Types of Crashes (Definitions)

The aforementioned crashes were broadly categorized as (1) bridge-related or (2) lane-departure. Bridge-related crashes were limited to those where one or more sequence of events involved fixed-object collision with a bridge support/underpass, concrete barrier, impact attenuator, guardrail, or ditch/embankment. In general, bridge-related crashes were those in which the vehicle departed the roadway and, according to the crash data, struck a fixed object off the roadway near a bridge. Ditch/embankment crashes were included in this category but represent only a fraction of the total bridge-related crashes and are generally low severity. Only bridge-related crashes are utilized in the "Economic Analysis" section of the report. All other crashes involving a lane or roadway departure where a vehicle did not strike a fixed object were classified as lane-departure crashes. These crashes represent those that, given their proximity to a bridge, could have potentially resulted in a collision with a pier or shielding hardware. However, since there is no corroborating evidence of a fixed-object collision in the crash data, these crashes are included in the general crash overview for comparison purposes only and are not considered in the later economic analysis.

Table 6a details the crash frequency by category. Note that 66% of the crashes in this study were bridge related.

Table 6a. Crash frequency by category

Category	Crash Count
Bridge Related	385
Lane Departure	200
Grand Total	**585**

Location of Crashes

During the seven-year study period, there were a total of 585 crashes recorded as either bridge-pier related or lane departure within 50 m of 285 bridges. No crashes occurred during this period at approximately 50% of the study locations. The severity distribution of these crashes considering horizontal alignment is shown in Table 6b.

Table 6b. Frequency of crashes by severity

Horizontal Alignment	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Grand Total
Tangent	7	36	66	98	274	481
Curve	2	8	17	18	59	104
Grand Total	**9**	**44**	**83**	**116**	**333**	**585**

These summary data depict both bridge-related crashes and lane-departure crashes. The frequency of crashes by horizontal alignment appears consistent with the ratio of bridges by alignment, about 17%, as shown in Table 7. Note that some of the bridges in this table were involved in multiple crashes, which will be discussed later in this report.

Table 7. Number of bridges involved in a crash by horizontal alignment and category

	Lane Departure	Bridge-Related
Tangent	108	186
Curve	25	40
Grand Total	**133**	**226**

Table 8a details the frequency of crashes by protection status and horizontal alignment, while Table 8b details the type of fixed objects struck at partially shielded bridges. As might be expected from Table 5, more than half the crashes occurred at bridges with full protection.

Table 8a. Summary of crash frequency by bridge-level protection status and horizontal alignment

Shielding Status	Tangent	Curve	Grand Total
Full	262	53	315
None	22	10	32
Partial	197	41	238
Grand Total	**481**	**104**	**585**

Table 8b. Summary of crash frequency at partially shielded bridges (bridge-level classification) by horizontal alignment and type of fixed object struck

Crash Category/Fixed Object	Tangent	Curve	Totals
Bridge-Related	**128**	**26**	**154**
Bridge support/underpass	31	5	36
Concrete barrier	22	5	27
Guardrail	41	10	51
Ditch/Embankment	23	5	28
Other	11	1	12
Lane Departure	**69**	**15**	**84**
Grand Total, Partially Shielded	**197**	**41**	**238**

Contributing Factors

To determine effective mitigation strategies for bridge support crashes, contributing factors for the crashes must be known. An analysis was conducted to investigate factors involved in the study crashes and to identify any common elements in these crashes.

Driver condition at the time of crash was examined first. In 74% of the crashes, the driver was reported as appearing to behave in a normal manner. In 9% of the crashes the driver had fallen asleep, was fatigued, or fainted before the crash. Another 9% of drivers were impaired by drugs or alcohol. It is noteworthy that 96% of the crashes involved a single vehicle.

Next, environmental conditions at the time of the crashes were investigated. Table 9 summarizes light condition at the time of the crash.

Table 9. Summary of prevailing light conditions at time of crashes

Light Conditions	Bridge Related	Lane Departure	Grand Total
Daylight	52%	60%	55%
Dusk	2%	1%	2%
Dawn	4%	4%	4%
Dark- roadway lighted	14%	16%	15%
Dark- roadway not lighted	26%	19%	24%
Dark- unknown roadway lighting	1%	1%	1%
Unknown	1%	0%	1%
Not Reported	0%	0%	0%
Grand Total	**100%**	**100%**	**100%**

Table 10 lists roadway surface conditions at the time of the crash occurrence.

Table 10. Summary of reported road surface conditions at time of crashes

Surface Conditions	Bridge-Related	Lane Departure	Grand Total
Dry	49%	57%	52%
Wet	15%	13%	14%
Ice	17%	17%	17%
Snow	14%	12%	13%
Slush	1%	2%	1%
Sand/mud/dirt/oil/gravel	1%	0%	1%
Water (standing/moving)	1%	0%	1%
Other	0%	0%	0%
Unknown	1%	0%	1%
Not Reported	1%	1%	1%
Grand Total	**100%**	**100%**	**100%**

Table 11. Summary of reported weather conditions at time of crashes

Weather Conditions	Bridge-Related	Lane Departure	Grand Total
Clear	35%	39%	37%
Partly Cloudy	13%	16%	14%
Cloudy	12%	12%	12%
Fog/smoke	1%	1%	1%
Mist	3%	2%	3%
Rain	8%	8%	8%
Sleet/hail/freezing rain	4%	4%	4%
Snow	19%	17%	18%
Severe winds	1%	0%	0%
Blowing sand/soil/dirt/snow	2%	3%	2%
Not Reported	1%	1%	1%
Unknown	1%	0%	0%
Grand Total	**100%**	**100%**	**100%**

An analysis of historic precipitation data (1998–2007) in Iowa (maintained at the Iowa Environmental Mesonet, http://mesonet.agron.iastate.edu/sites/locate.php) reveals that precipitation occurs during 31% of the days in the year. Snow occurs during 4% of the days. Comparing these totals to the data presented in Tables 10 and 11 suggests that surface and weather conditions may play a major role in these crashes. Specifically, approximately 48% of the crashes occur under imperfect surface conditions (13% snow on roadway), and 18% occur during snowfall. The degree to which such conditions influence these crashes is somewhat more difficult to quantify given that precipitation events may vary by location, duration, and intensity; surface conditions may remain imperfect after precipitation has stopped; and traffic volumes may decrease during inclement weather. But it clearly appears from these data that road surface and weather conditions contribute to these roadway departure crashes.

Table 12 shows the percentage of crashes and the percentage of bridges by ranges of the Annual Average Daily Traffic (AADT) carried on the roads where crashes occurred for both bridge-related and lane-departure crashes.

A few significant observations could be drawn from the contributing factors analysis. Apparently 26% of the bridge-related crashes occurred in dark conditions on an unlighted roadway. It appears that 49% of bridge-related and 42% of lane-departure crashes happened when road surface conditions were not ideal. Comparing crash occurrence with bridge numbers by traffic volume range yields quite consistent results except for traffic volumes that exceed 55,000 vehicles per day. For these very high volumes, crash percentages are disproportionately higher than the number of bridges on those roadways.

Table 12. Summary of crash occurrence by annual average daily traffic

AADT Range	Bridge-Related % of Crashes	Bridge-Related % of Bridges	Lane Departure % of Crashes	Lane Departure % of Bridges
0 - 4999	5.97%	5.31%	8.00%	7.52%
5000 - 9999	12.99%	15.04%	10.00%	12.03%
10000 - 14999	15.32%	15.93%	18.50%	18.05%
15000 - 19999	12.73%	15.04%	14.00%	16.54%
20000 - 24999	13.51%	15.93%	11.50%	11.28%
25000 - 29999	5.45%	7.96%	4.50%	6.02%
30000 - 34999	8.31%	8.85%	5.50%	7.52%
35000 - 39999	0.78%	1.33%	1.50%	1.50%
40000 - 44999	8.05%	4.87%	6.00%	5.26%
45000 - 49999	3.38%	2.21%	2.00%	2.26%
50000 - 54999	1.82%	0.88%	1.00%	0.75%
55000+	11.69%	6.64%	17.50%	11.28%
Grand Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Obstruction Location Relative to Roadway

The relationship between the location of piers, left or right of the traveled way, and crashes was also investigated. Since vehicles in the left lane are typically traveling at faster speeds, it may be reasonable to assume that more crashes may occur with median piers. In addition, median piers can typically be shielded with w-beam or cable guardrail, which is less costly than the combination concrete barrier/w-beam guardrail typically required for closer proximity outside piers.

To properly assign pier location to the crashes, each crash direction of travel was determined from the crash data sequence of events, which explicitly defined a left- or right-side departure. Left-side departures were associated with median obstructions, while right-side departures were associated with outside obstructions/embankments crashes. Table 13 details the crash count by direction of travel and shows that 41% of bridge-related crashes involved vehicles departing the roadway to the left while 30% of the crashes involved vehicles departing to the right. A total of 27% of the bridge-related crashes did not have side of departure explicitly identified as one of the sequence of events, possibly because some of these crashes were self-reported. To maintain a level of consistency and data integrity, these were not included in the analysis of crash severities by median or outside pier/embankment crashes.

Table 13. Crash summary by category and side of departure (SOD)

Crash Category/SOD	Crash Count
Lane Departure	**200**
Left	88
Right	112
Bridge Related	**385**
Left	156
Right	125
STRAIGHT	3
Not Reported	101
Grand Total	**585**

Severity of Crashes

To investigate the severity of crashes, shielding status, horizontal alignment, and side of departure were compared, particularly for bridge-related crashes. For side of departure, each crash was characterized as either a median or an outside pier or embankment impact. In addition to the number of crashes that were excluded in the preceding sub-section, an additional 30 bridge-related crashes were also eliminated from the analysis involving side of departure to minimize any ambiguity in the results. These were all left-side departures that may or may not have crossed the median but did not strike an identified bridge or shielding element.

Table 14a details the severity of crashes by shielding type, crash, and category. Bridge-related crashes resulted in one more fatal crash than lane-departure crashes but these resulted in a fewer number of fatalities. Five fatalities were reported for bridge-related crashes compared to 12 from four fatal lane-departure crashes. Although bridges with no shielding accounted for two of the five bridge-related fatal crashes, even with full protection some bridges still experienced a significant number of severe crashes.

Table 14a. Severity of crashes by crash categories and shielding status

Crash Category/ Shielding Status	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Grand Total
Bridge Related	**5**	**35**	**48**	**78**	**219**	**385**
Full	1	17	23	40	131	212
None	2	3	4	2	8	19
Partial	2	15	21	36	80	154
Lane Departure	**4**	**9**	**35**	**38**	**114**	**200**
Full	4	3	20	17	59	103
None			5	2	6	13
Partial		6	10	19	49	84
Grand Total	**9**	**44**	**83**	**116**	**333**	**585**

Table 14b details the severity of crashes by horizontal alignment. For bridge-related crashes, two of five fatal crashes were recorded on a horizontal curve and these both happened at unshielded bridge pier locations, see Table 14a.

Table 14b. Severity of crashes by crash categories and horizontal alignment

Crash Category/ Alignment	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Grand Total
Bridge Related	**5**	**35**	**48**	**78**	**219**	**385**
Tangent	3	29	37	64	184	317
Curve	2	6	11	14	35	68
Lane Departure	**4**	**9**	**35**	**38**	**114**	**200**
Tangent	4	7	29	34	90	164
Curve		2	6	4	24	36
Grand Total	**9**	**44**	**83**	**116**	**333**	**585**

Tables 14c and Table 14d detail bridge-related crashes by side of departure and type of fixed object struck. On the median side, there were more impacts with guardrails with 74 crashes followed by bridge support/underpass with 33 and then concrete barriers with a total of 19. This may be expected since guardrail is the dominant shielding type on the median side and relatively few unshielded median piers exist. Although collisions with bridge support/underpass experienced more fatal crashes, collisions with guardrails accounted for 59% of bridge-related crashes on the median side and one of the four fatal crashes. In addition, collisions with either guardrail or concrete barrier represented 11 of the 16 total major injury crashes. However, it should be noted that approximately 63% (47 of 74) of the guardrail crashes resulted in property damage only while 33% (11 of 33) collisions with bridge support/underpass did not result in some level of injury.

Table 14c. Bridge-related crash severity by fixed object struck median side/left departures

Fixed Object	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Grand Total
Bridge Related	**4**	**19**	**14**	**29**	**90**	**156**
Bridge Support/ Underpass	3	5	4	10	11	33
Concrete Barrier		2	1	1	15	19
Guardrail	1	9	5	12	47	74
Ditch/Embankment/ Other		3	4	6	17	30
Grand Total	**4**	**19**	**14**	**29**	**90**	**156**

As shown in Table 14d, collisions with an outside (right) bridge support/underpass accounted for most crashes at 38% followed by guardrail with 30%. Collisions with outside ditch/embankment and other obstacles combined for 26%. Collisions with ditch/embankment and "other" are always grouped together in this report because a closer inspection of the DOT crash reports reveals similar characteristics.

Table 14d. Bridge-related crash severity by type of fixed object struck, outside/right departures

Fixed Object	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Grand Total
Bridge Support/ Underpass	1	6	8	11	21	47
Concrete Barrier			1	1	6	8
Guardrail		4	6	9	18	37
Ditch/Embankment			4	6	13	23
Other		1		1	8	10
Grand Total	**1**	**11**	**19**	**28**	**66**	**125**

The number and severity of impacts with shielded vs. unshielded structures is interesting. Although fatal crashes occur less frequently, more injury crashes occur at shielded structures than unshielded. Obviously the major factor here is the number in each category and thus opportunity for a crash. But it also should be noted that installation of shielding at the unshielded piers will not eliminate all serious crashes at those locations and will increase the length of obstruction.

Overall for bridge-related crashes, left-side departures accounted for four of five fatal crashes, 59% of major injury crashes, and 53% of property damage only crashes. On the other hand, right-side departures resulted in 66% of minor injury crashes and 55% of possible injury crashes.

From Tables 14e and 14f, two of four median-side bridge-related fatal crashes occurred at unshielded piers. The only fatal crash at an outside pier/embankment happened at an unshielded location. While these tables present bridge-level data, it was observed from the district-provided data and video log review that shielding presence and type were typically the same for each direction of travel on a given bridge.

Table 14e. Bridge-related crash severity by type of shielding—median departures

Protection Type	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Grand Total
Cable	1	1		7	11	20
Concrete		2	1	2	7	12
Guardrail	1	13	11	19	67	111
None	2	3	2	1	5	13
Grand Total	**4**	**19**	**14**	**29**	**90**	**156**

Table 14f. Bridge-related crash severity by type of shielding—outside departures

Outside Protection Type	Fatal	Major Injury	Minor Injury	Severity Possible Injury	Property Damage Only	Grand Total
Cable			1			1
Concrete		2	7	13	25	47
Guardrail		3	3	4	17	27
None	1	6	8	11	24	50
Grand Total	**1**	**11**	**19**	**28**	**66**	**125**

Tables 15 and 16 summarize crash severity by side of departure, lateral offset, and traffic volume. Regardless of which side (median or outside), crash category (bridge-related or lane-departure), or type of fixed object struck (bridge piers/support or shielding), more crashes occurred at an offset of less than 30 ft than occurred at higher offset distances. Two of five bridge-related fatal crashes happened at an offset of less than 30 ft and two additional bridge-related fatal crashes happened at an offset of 30 to 34 ft. For lane departure crashes, 100% of fatal crashes occurred at an offset of less than 30 ft. These numbers should not be surprising considering that obstacle offset distances of less than 30 ft make up nearly 70% of the study sample. It should also be noted that the Iowa DOT data base and district-provided data only recorded the minimum offset at a given structure. Furthermore, this study did not consider direction of travel for crashes. Therefore it is possible that crashes reported at a structure with a variation in offsets could be recorded here at a lesser clearance than what actually existed for the crash.

Considering traffic volumes in Tables 15 and 16, it seems that the impact of this attribute on severity was related to the side of departure. The three bridge-related fatal crashes that happened at an offset of less than 35 ft also had traffic volumes in the 5,000–25,000 AADT range for median pier crashes and 10,000–15,000 for outside pier/embankment crashes. In fact, five of seven fatal crashes on the median side were in the 15,000–25,000 AADT traffic volume range while both fatal crashes at outside piers were in the 10,000–15,000 AADT range. Overall, roadways in the 5,000–25,000 traffic volume range accounted for most fatal crashes and more total crashes than the proportionate share of the entire traffic volume exposure in the study sample (Table 12).

Table 15. Crash severity by crash category, lateral offset and traffic volumes, median-side crashes

	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	*Total DEV	Crash Totals
****Bridge Related Totals**	**4**	**19**	**14**	**29**	**90**	**4188610**	**156**
<30 feet crashes	*1*	*13*	*9*	*23*	*74*	*3479710*	*120*
AADT 0 - 4999			1	2	6	20610	9
5000 - 9999		3	3	2	8	103300	16
10000 - 14999		1	1	4	10	188800	16
15000 - 19999			1	4	6	187400	11
20000 - 24999	1	1		1	10	294800	13
25000 - 29999		1	1	1	7	265700	10
30000 - 34999		3		5	3	351200	11
35000 - 39999					1	37700	1
40000 - 44999		1	1	2	5	377500	9
45000 - 49999		1	1		2	191100	4
50000 - 54999		1			5	322500	6
55000+		1		2	11	1139100	14
30-34 feet crashes	*2*	*1*	*4*	*6*	*12*	*417500*	*25*
5000 - 9999	1			3	3	57100	7
10000 - 14999			2		2	49200	4
15000 - 19999				2	5	122700	7
20000 - 24999	1		1	1	2	121100	5
25000 - 29999		1				26700	1
40000 - 44999			1			40700	1
35-40 feet crashes	*1*	*5*	*1*		*4*	*291400*	*11*
10000 - 14999		1	1		1	37000	3
15000 - 19999	1	2			3	100200	6
55000+		2				154200	2

* DEV = Daily Entering Vehicles

** Includes Collisions with Ditch, Embankment, and Other

Table 15. Crash severity by crash category, lateral offset and traffic volumes, median-side crashes (continued)

	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	*Total DEV	Crash Totals
Lane Departure Totals	**3**	**7**	**19**	**16**	**43**	**2776030**	**88**
<30 feet crashes	*3*	*6*	*12*	*12*	*31*	*1937620*	*64*
AADT 0 - 4999		1	1	3	3	15720	8
5000 - 9999		1	1	2	1	37000	5
10000 - 14999			1	2	7	123500	10
15000 - 19999			2	2	2	104900	6
20000 - 24999	2	2	2		2	179600	8
30000 - 34999			1	1	4	188300	6
35000 - 39999					1	36900	1
40000 - 44999		1	1		3	210900	5
45000 - 49999	1		1			93500	2
50000 - 54999					2	107000	2
55000+		1	2	2	6	840300	11
30-34 feet crashes		*1*	*1*	*2*	*7*	*136310*	*11*
0 - 4999					2	3010	2
5000 - 9999		1			1	15000	2
10000 - 14999			1		4	59200	5
15000 - 19999				1		18400	1
40000 - 44999				1		40700	1
35-40 feet crashes			*6*	*2*	*5*	*702100*	*13*
15000 - 19999			4	1		85300	5
55000+			2	1	5	616800	8
Grand Total	**7**	**26**	**33**	**45**	**133**	**6964640**	**244**

* DEV = Daily Entering Vehicles
** Includes Collisions with Ditch, Embankment, and Other

Table 16. Crash severity by crash category, lateral offset, and traffic volumes, outside-departure crashes

	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	*Total DEV	Crash Totals
Bridge Related Totals	**1**	**11**	**19**	**28**	**66**	**3678410**	**125**
<30 feet crashes	*1*	*8*	*11*	*25*	*52*	*3071610*	*97*
AADT 0 - 4999				1	5	14210	6
5000 - 9999		1			5	36600	6
10000 - 14999	1	1	3	2	6	162000	13
15000 - 19999		3		4	5	214400	12
20000 - 24999			1	7	11	421200	19
25000 - 29999					4	110300	4
30000 - 34999			2	1	6	293500	9
35000 - 39999				1		39200	1
40000 - 44999			4		4	335400	8
45000 - 49999		2		1		144900	3
50000 - 54999					1	54000	1
55000+		1	1	8	5	1245900	15
30-34 feet crashes		*3*	*6*	*3*	*12*	*478200*	*24*
0 - 4999			1			1200	1
5000 - 9999			1	1	4	44900	6
10000 - 14999					4	44000	4
15000 - 19999			1		1	35600	2
20000 - 24999		2		1		69500	3
25000 - 29999			1			25700	1
30000 - 34999		1	1		1	99000	3
35000 - 39999				1		36200	1
40000 - 44999			1		2	122100	3
35-40 feet crashes			2		2	128600	4
15000 - 19999			2		1	51500	3
55000+					1	77100	1
Lane Departure Totals	1	2	16	22	71	3113090	112
<30 feet crashes	1	1	12	16	54	2604820	84
AADT 0 - 4999				1	1	3220	2
5000 - 9999			1		7	50400	8
10000 - 14999	1		2	4	9	192200	16
15000 - 19999			2	1	7	180700	10
20000 - 24999			2	3	7	270000	12
25000 - 29999				1	7	221200	8
30000 - 34999			1	1	2	127100	4
35000 - 39999					2	78400	2
40000 - 44999		1	1	1	3	253500	6
45000 - 49999					2	96100	2
55000+			3	4	7	1132000	14

Table 16. Crash severity by crash category, lateral offset, and traffic volumes, outside-departure crashes (continued)

	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	*Total DEV	Crash Totals
30-34 feet crashes		*1*	*2*	*4*	*13*	*248070*	*20*
0 - 4999			1		3	11770	4
5000 - 9999				1	4	39800	5
10000 - 14999		1	1		4	72100	6
15000 - 19999					1	18100	1
20000 - 24999				1	1	48000	2
25000 - 29999				1		27500	1
30000 - 34999				1		30800	1
35-40 feet crashes			*2*	*2*	*4*	*260200*	*8*
15000 - 19999			1	1	3	83800	5
20000 - 24999				1		22200	1
55000+			1		1	154200	2
Grand Total	**2**	**13**	**35**	**50**	**137**	**6791500**	**237**

* DEV = Daily Entering Vehicles

Pier Offset

As was indicated in previous sections, more shielding at median piers was impacted by errant vehicles than unshielded piers; in fact, only 8% of unshielded median piers were involved in a bridge-related crash during the seven-year analysis period. More than 60% of shielded median piers involved in a crash had a minimum offset of less than 30 ft. Table 17 details the bridge frequency by minimum offset and shielding type for median piers involved in a crash.

Table 17. Number of bridges involved in a bridge-related crash by minimum offset and protection type, median

Lateral Offset	Cable	Concrete	Guardrail	None	Grand Total
<30 feet	14	12	92	2	120
30-34 feet	6		17	2	25
35-40 feet			2	9	11
Grand Total	**20**	**12**	**111**	**13**	**156**

Table 18 shows that 40% (50 of 125) of outside bridge-related crashes were at an unshielded pier. It will be instructive to note that almost 11% of the bridges involved in a crash were two-span, with no outside pier. In addition, nearly 70% of bridge piers, median and outside, have an offset of less than 30 ft (Table 5).

Table 18. Number of bridges involved in a bridge-related crash by minimum offset and shielding type, outside

Lateral Offset	Cable	Concrete	Guardrail	None	Grand Total
<30 feet	1	47	27	27	102
30-34 feet				18	18
35-40				3	3
>40 feet				2	2
Grand Total	**1**	**47**	**27**	**50**	**125**

Bridges with Multiple Crashes

Table 19 lists bridges with multiple crashes, which are defined as those median or outside piers/embankments that experienced more than one bridge-related crash within the seven-year analysis period. This number excludes collisions with ditch/embankment and “other”. In the next section we will look more closely at 2-span bridges and will include collisions with ditch/embankment and “other” in that discussion. Only one of the 43 total bridges with multiple crashes shown in Table 20 had no protection in either the median or outside lane/embankment

Multiple bridge-related crashes accounted for 112 crashes and one fatality as shown in Table 20. Only two of these bridges were two-span structures.

Table 19. Number of bridges involved in a multiple bridge-related crash by side of departure and horizontal alignment

Side of Departure	Tangent	Curve	Grand Total
Left	13	3	16
Right	12	1	13
Not Reported	10	4	14
Grand Total	**35**	**8**	**43**

Table 20. Fatalities and injuries associated with multiple crash locations

Side of Departure	Crash Count	Fatalities	Major Injuries	Minor Injuries	Possible Injuries	Property Damage ($)
Left	42	1	8	8	11	261175
Right	28	0	3	5	10	480566
Not Reported	42	0	3	10	10	242068
Grand Total	**112**	**1**	**14**	**23**	**31**	**983809**

Tables 21 and 22 detail the bridges with multiple bridge-related crashes by side of departure, minimum offset, shielding type, and traffic volume.

Table 21. Number of bridges involved in a multiple bridge-related crash by minimum lateral offset, shielding type, and traffic volume

Outside	Bridge Count
<30 feet	**11**
Concrete	**6**
AADT 0 - 4999	1
15000 - 19999	1
20000 - 24999	1
40000 - 44999	1
55000+	2
Guardrail	**3**
10000 - 14999	1
30000 - 34999	1
40000 - 44999	1
None	**2**
40000 - 44999	1
55000+	1
30-34 feet	**1**
None	**1**
5000 - 9999	1
35-40 feet	**1**
None	**1**
55000+	1
Grand Total	**13**

Table 22. Number of bridges involved in a multiple bridge-related crash by minimum lateral offset, shielding type, and traffic volume

Median	Bridge Count
<30 feet	**10**
Cable	**1**
AADT 40000 - 44999	1
Guardrail	**9**
AADT 5000 - 9999	2
10000 - 14999	1
20000 - 24999	1
25000 - 29999	2
50000 - 54999	2
55000+	1

Table 22. Number of bridges involved in a multiple bridge-related crash by lateral offset, shielding type, and traffic volume (continued)

Median	Bridge Count
30-34 feet	**5**
Cable	**2**
15000 - 19999	1
20000 - 24999	1
Concrete	**2**
5000 - 9999	1
10000 - 14999	1
None	**1**
15000 - 19999	1
35-40 feet	**1**
Concrete	**1**
55000+	1
Grand Total	**16**

As shown in Table 23, the bridge with 11 crashes is located on a curve and is fully shielded

Table 23. Number of bridges involved in a multiple bridge-related crash by the number of crashes

Crashes	Bridge Count
2	**31**
Full	16
Partial	15
3	**8**
Full	4
None	1
Partial	3
4	**2**
Full	1
Partial	1
7	**1**
Full	1
11	**1**
Full	1
Grand Total	**43**

Two-Span Bridges

It should be noted that two-span bridges only feature a single pier in the median; abutments for these structures are supported by earthen embankments along the outside of the roadway passing under the structure. Only bridge-related crashes were used in the analysis for two-span bridges.

Of a total of 63 two-span design bridges, 24 were involved in 31 bridge-related crashes. One fourth of these bridges were a multiple-crash site. One fatal crash was reported for bridge-related crashes involving two-span bridges. Almost half of these crashes were left-side departures while 29% were right-side departures, the other reports did not have a side of departure explicitly identified. Eight of nine right-side departures occurred at an unshielded embankment (bridge abutment berm). Three of 15 left-side departures happened at an unshielded median pier. The fatal crash in Table 24 occurred on a horizontal curve. There were no major injuries reported at two-span bridges. Tables 24–26 summarize relevant information for two-span bridges involved in bridge-related crashes. It should be noted all the two-span bridges involved in bridge-related crashes had an offset distance on at least one side that was less than 35 ft.

Table 24. Crash severity for two-span bridges

Type of Collision	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Grand Total
Bridge Support	1		3	2	2	8
Concrete barrier			1	2	2	5
Guardrail				3	8	11
Ditch/Embankment				2	3	5
Other					2	2
Grand Total	**1**	**0**	**4**	**9**	**17**	**31**

Table 25. Bridge count and shielding type at two-span bridges, median side

Median Pier	Horizontal Alignment		
Shielding Type	Tangent	Curve	Grand Total
Cable	2		2
Concrete	4	2	6
Guardrail	9	4	13
None	2	1	3
Grand Total	**17**	**7**	**24**

Table 26. Bridge count and shielding type for two-span bridges, outside/embankment side

Outside Pier	Horizontal Alignment		
Protection Type	**Tangent**	**Curve**	**Grand Total**
Concrete	1		1
Guardrail	1	1	2
None	15	6	21
Grand Total	**17**	**7**	**24**

ECONOMIC ANALYSIS

Background

Several options should be evaluated when considering the advisability of installing shielding to reduce the severity of collisions with bridge supports. The following scenarios will be considered in this report:

- Do nothing beyond current status
- Shield all unprotected piers on curves
- Shield piers based on offset
- Shield all median piers, regardless of offset
- Shield all bridge piers, regardless of offset
- Shield all two-span bridge embankments

For this study, installation of high-tension cable to shield unprotected bridge piers is used for cost analysis. While initial installation costs do not differ significantly from w-beam guardrail, cable is much less expensive and time-consuming to maintain. The study also assumes a 10-year lifespan for cable installations.

The study included all grade separation structures indentified on multi-lane divided roadways with posted speed limits of 45 mph or greater. Table 27 lists the number of structures in each speed category.

Table 27. Bridges by speed limit

Posted Speed	Number of Bridges
45	27
50	7
55	115
60	9
65	183
70	225
Total	**566**

Table 28 lists the number of crashes that were recorded by speed that occurred at unshielded median piers or outside pier/embankments. These crashes were used in the economic analyses that follow. The number of crashes approximately reflects the number of bridges at each speed. It should be noted that the Interstate speed limit in Iowa was raised from 65 mph to 70 mph in July 2005, which probably impacts the number of crashes listed for those speeds. All rural Interstate crashes before that date would have occurred at a speed limit of 65 mph. Very few crashes were recorded at lower speeds, and crashes at these speeds were not considered in the economic analyses.

Table 28. Crashes for each speed limit

Posted Speed	Number of Crashes Recorded
45	2
50	1
55	17
60	2
65	28
70	17
Total Crashes	**67**

A benefit to cost comparison will be calculated for each of the options listed above. The benefit will be defined as the dollar value of societal costs from crashes that might be reduced in number and severity by implementing the option. The cost of a crash, sometimes called the Level of Service for Safety (LOSS) for a given severity is defined by the Federal Highway Administration (FHWA) as the values shown in Table 29a. Property damage from all crashes is included in these analyses using the investigating officer's estimate of damages.

Table 29a. LOSS costs of a crash

Severity	Cost
Fatality	$ 3,500,000
Major Injury	240,000
Minor Injury	48,000
Possible Injury	25,000
Property Damage	Police estimate or $2,700

Table 29b details the crash reduction factors (CRF) used in the benefit/cost estimates (B/C). These values were taken from the Desktop Reference for Crash Reduction Factors published by the FHWA in September 2007, and while the conditions described for specific situations in this document do not always agree precisely with the treatment being analyzed, these values represent the best data available for reference.

Table 29b. Crash reduction factors used for analysis

Type of treatment	Severity	CRF
Shield all unshielded piers on a curve	Fatal and Injury	39%
Shield all unshielded piers	All Injury Fatal	14% 51% 65%
Shield all unshielded embankments	All Injury	7% 42%

Table 29c lists alternative crash reduction factors that were selected randomly and used in a sensitivity analysis for option 5 only to illustrate the resulting benefit/cost impacts of variable crash reduction factors.

Table 29c. Sensitivity analysis for scenario 5

Type of treatment	Severity		CRF
Shield all unshielded piers	All	Low	14%
		Medium	50%
		High	70%
	Injury	Medium	51%
		High	70%

Crash Selection

To investigate the economic benefits of shielding bridge piers, only crashes that occurred at unshielded piers were utilized. Crashes were attributed to the median or outside pier or abutment based on the side of departure. To include all pertinent crashes in the economic analysis, crashes occurring at completely unshielded bridges with unknown side of departure were assigned based on the overall proportion of median and outside bridge element crashes. Interestingly, only one unknown side of departure crash occurred at a totally unshielded bridge. Three crashes that were recorded as run-off-road straight were assigned to outside pier/embankment crashes for the economic analyses that follow.

Scenario 1: Do Nothing beyond Current Status

Based on the study analysis period from 2001 to 2007, three fatalities, 10 major injuries, 13 minor injuries, 12 possible injuries, and property damage totaling $858,172 resulted from 67 crashes at unshielded bridge piers. Based on the data in Table 29a, that would result in a total crash loss of nearly $17 million or approximately $2.25 million dollars annually. Doing nothing to improve shielding of bridge piers would not seem consistent with state and national goals to reduce fatalities and serious injuries on roadways.

Scenario 2: Shield All Piers at Bridges Located on Curves

At the commencement of this study, it was speculated that bridge piers on curves may be more exposed to crashes than those on tangent sections of roadways as more roadway departure crashes seem to occur in those locations. Tables 30a and 30b summarize the B/C analysis of shielding these structure for posted speed limits 55 mph and above and 65 mph and above. For worksheets and calculations, see Appendix A. Note that the 55 mph and above data also include the 65 mph and above bridges.

Table 30a. Shield all unshielded piers located on curves on divided Interstate and primary highways with posted speed limit 55 and above

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	*PDO	Crash Count	**DEV
12	55	2	1	2	2	6	13	735180

Benefit	$3,654,953
Cost	$1,130,058
B/C	**3.23**

*Property damage only
**Daily entering vehicles

Table 30b. Shield all unshielded piers located on curves on divided Interstate and primary highways with posted speed limit 65 and above

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	*PDO	Crash Count	**DEV
12	44	2	1	2	2	5	12	605600

Benefit	$3,654,953
Cost	$944,526
B/C	**3.87**

*Property damage only
**Daily entering vehicles

Scenario 3: Protect Unprotected Piers Based on Offset

Using existing Iowa DOT design guidance allows engineers to calculate a dimension designated as a clear zone based on several factors including traffic speed, roadway alignment, and slope. This clear zone is anticipated to allow drivers to regain control of errant vehicles and return to the roadway. Consequently, shielding of obstacles such as bridge piers outside of this calculated dimension is considered optional. For the roadways in this study, the clear zone is approximately 30 to 35 ft from the edge of the traveled way.

Four lateral offset dimensions were selected to analyze the potential crash impacts related to offset distance. These dimensions were the following: less than 30 ft, 30 to 35 ft, 35 to 40 ft, and greater than 40 ft. Tables 31a through 31d show the B/C summaries by pier offset distance and posted speed limits. Since many bridges do not have the same offset distance for median and outside and to avoid double counting of crashes, the B/C analysis was divided into two parts: median-side and outside exposure. For worksheets and calculations, see Appendix B.

Table 31a. Summary of crash severity and losses for unshielded piers based on offset on divided Interstate and primary highways with posted speed limit of 55 and above

	# of Type	Fatal	Fatalities	Major Injury	Major Injuries	Minor Injury	Minor Injuries	Possible Injury	Possible Injuries	PDO	Property Damage	Crash Count	DEV
Median													
<30 ft	4	0	0	0	0	0	0	0	0	2	4000	2	58600
30-34 ft	16	1	1	0	0	0	0	1	1	0	2015	2	127700
35-40 ft	38	1	1	3	3	1	3	0	0	4	274600	9	642000
>40 ft	3												34600
Outside													
<30 ft	123	1	1	2	3	6	6	5	3	11	256358	25	2101700
30-34 ft	134	0	0	2	2	3	3	4	4	11	253500	20	2369800
35-40 ft	18	0	0	1	1	0	0	2	2	0	12099	3	323720
>40 ft	9	0	0	1	1	0	0	1	2	0	40000	2	126520

Table 31b. Summary of B/C analysis of unshielded piers based on offset on divided Interstate and primary highways with posted speed limit of 55 and above

Offset	Crash Severity	Crash Reduction Factor (CRF)	Median Piers			Outside Piers		
			Benefit	Cost	B/C	Benefit	Cost	B/C
<30 feet	All	14	$706	$67,466	**0.01**	$854,103	$2,074,584	**0.41**
	Injury	51	**No injury**			$696,295	$2,074,584	**0.34**
	Fatal	65	**No fatality**			$2,867,980	$2,074,584	**1.38**
30-34 feet	All	14	$622,487	$269,865	**2.31**	$172,520	$2,260,116	**0.08**
	Injury	51	$16,073	$269,865	**0.06**	$465,483	$2,260,116	**0.21**
	Fatal	65	$2,867,980	$269,865	**10.63**	**No fatality**		
35-40 feet	All	14	$818,671	$640,928	**1.28**	$52,259	$303,598	**0.17**
	Injury	51	$555,493	$640,928	**0.87**	$186,450	$303,598	**0.61**
	Fatal	65	$2,867,980	$640,928	**4.47**	**No fatality**		
>40 feet	All	14	**No crashes**			$53,830	$151,799	0.35
	Injury	51				$170,377	$151,799	1.12
	Fatal	65				**No fatality**		

Table 31c. Summary of crash severity and losses for unshielded piers based on offset on divided Interstate and primary highways with posted speed limit of 65 and above

	# of Type	Fatal	Fatalities	Major Injury	Major Injuries	Minor Injury	Minor Injuries	Possible Injury	Possible Injuries	PDO	Property Damage	Crash Count	DEV
Median													
<30 ft	4	0	0	0	0	0	0	0	0	2	4000	2	58600
30-34 ft	13	1	1	0	0	0	0	1	1	0	2015	2	116200
35-40 ft	37	1	1	3	3	1	3	0	0	4	274600	9	626500
>40 ft	0												000000
Outside													
<30 ft	88	1	1	0	0	5	5	3	3	6	190677	15	1425290
30-34 ft	112	0	0	1	1	3	3	3	3	9	183000	16	1917600
35-40 ft	10	0	0	1	1	0	0	0	0	0	6099	1	160700
>40 ft	8	0	0	1	1	0	0	1	2	0	40000	2	121600

Table 31d. Summary of B/C analysis of unshielded piers based on offset on divided Interstate and primary highways with posted speed limit of 65 and above

Offset	Crash Severity	Crash Reduction Factor (CRF)	Median Piers			Outside Piers		
			Benefit	Cost	B/C	Benefit	Cost	B/C
<30 feet	All	14	$706	$67,466	**0.01**	$706,966	$1,484,255	**0.48**
	Injury	51	**No injury**			$696,295	$1,484,255	**0.47**
	Fatal	65	**No fatality**			$2,867,980	$1,484,255	**1.93**
30-34 feet	All	14	$622,487	$269,865	**2.31**	$113,307	$1,889,052	**0.06**
	Injury	51	$16,073	$269,865	**0.06**	$295,106	$1,889,052	**0.16**
	Fatal	65	$2,867,980	$269,865	**10.63**	**No fatality**		
35-40 feet	All	14	$818,671	$640,928	**1.28**	$43,434	$168,665	**0.26**
	Injury	51	$555,493	$640,928	**0.87**	$154,304	$168,665	**0.91**
	Fatal	65	$2,867,980	$640,928	**4.47**	**No fatality**		
>40 feet	All	14	**No crashes**			$53,830	$151,799	**0.35**
	Injury	51				$170,377	$151,799	**1.12**
	Fatal	65				**No fatality**		

Scenario 4: Shield All Median Piers

As previously discussed, median piers were assumed to present a higher crash potential because traffic on the inside lanes is typically moving faster and perhaps making more lane changes. The data supported this theory quite well, as 41% of crashes where side of departure was a factor involved median piers, compared to 30% that involved outside piers/embankments.

A B/C analysis was conducted to determine the benefit that could be attained by shielding only median piers. Tables 32a through 32d detail crash severity and B/C results for shielding all median piers based on posted speed limits, regardless of lateral offset. For worksheet and calculations, see Appendix C.

Table 32a. Summary of crash severity for all unshielded median piers on divided Interstate and primary highways with posted speed limit of 55 and above.

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	PDO	Crash Count	DEV
61	--	2	3	1	1	6	13	847700

Table 32b. Summary of B/C analysis for shielding at unshielded median piers on divided Interstate and primary highways with posted speed limit of 55 and above

Crash Severity	Crash Reduction Factor (CRF)	Benefit	Cost	B/C
All	14	$1,442,852	$1,028,859	**1.40**
Injury	51	$571,566	$1,028,859	**0.56**
Fatal	65	$5,735,959	$1,028,859	**5.58**

Table 32c. Summary of crash severity for all unshielded median piers on divided Interstate and primary highways with posted speed limit 65 and above

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	PDO	Crash Count	DEV
54	--	2	3	1	1	6	13	801300

Table 32d. Summary of B/C analysis for shielding at unshielded median piers on divided Interstate and primary highways with posted speed limit 65 and above

Crash Severity	Crash Reduction Factor (CRF)	Benefit	Cost	B/C
All	14	$1,442,852	$910,793	**1.58**
Injury	51	$571,566	$910,793	**0.63**
Fatal	65	$5,735,959	$910,793	**6.30**

Scenario 5: Shield All Bridge Piers without Exception

This option examined the feasibility of shielding all existing bridge piers regardless of lateral offset. Shielding all existing piers that exist today would require a substantial investment in funding estimated at $1.22 million dollars for all exposed bridge piers on divided Interstate and primary highways with speed limits between 55 mph and 65 mph and $4.59 million dollars for speed limits at and above 65 mph. The cost assumes installation of high-tension cable rail at all exposed bridge piers. Tables 33a–33d detail the crash severity and the B/C analysis for shielding all piers. For worksheet and calculations, see Appendix D.

Table 33a. Summary of crash severity for all unshielded piers on divided Interstate and primary highways with posted speed limit 55 and above

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	PDO	Crash Count	DEV
284	61	3	9	10	13	28	63	4921770

Table 33b. Summary of B/C analysis of all unshielded piers on divided Interstate and primary highways with posted speed limit 55 and above

<table>
<tr><th>Crash Severity</th><th>Sensitivity</th><th>Crash Reduction Factor (CRF)</th><th>Benefit</th><th>Cost</th><th>B/C</th></tr>
<tr><td rowspan="3">All</td><td>Low</td><td>14</td><td>$2,580,047</td><td rowspan="6">$5,818,955</td><td>0.44</td></tr>
<tr><td>Medium</td><td>50</td><td>$9,214,454</td><td>1.58</td></tr>
<tr><td>High</td><td>70</td><td>$12,900,235</td><td>2.22</td></tr>
<tr><td rowspan="2">Injury</td><td>Medium</td><td>51</td><td>$2,106,244</td><td>0.36</td></tr>
<tr><td>High</td><td>70</td><td>$2,890,923</td><td>0.50</td></tr>
<tr><td>Fatal</td><td></td><td>65</td><td>$8,603,939</td><td>1.48</td></tr>
</table>

Table 33c. Summary of crash severity for all unshielded piers on divided Interstate and primary highways with posted speed limit 65 and above

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	PDO	Crash Count	DEV
218	54	3	6	9	8	28	54	3625190

Table 33d. Summary of B/C analysis of all unshielded piers on divided Interstate and primary highways with posted speed limit 65 and above

Crash Severity	Sensitivity	Crash Reduction Factor (CRF)	Benefit	Cost	B/C
All	Low	14	$2,363,814	$4,587,698	**0.52**
	Medium	50	$8,442,191		**1.84**
	High	70	$11,819,068		**2.58**
Injury	Medium	51	$1,409,949		**0.31**
	High	70	$1,935,224		**0.42**
Fatal		65	$8,603,939		**1.88**

Tables 34b and 34d include a sensitivity column to illustrate the impacts on resulting B/C ratios from a range of crash reduction factors listed earlier in Table 29c.

Scenario 6: Shield All Two-Span Bridge Embankments

This study also analyzed the benefits of shielding the embankments along the outside (right side) at two-span bridges (Tables 34a and 34b). Considering that right-side departures accounted for 29% of crashes at two-span bridges with no fatalities or major injuries in seven years, the B/C ratio for shielding two-span bridge embankments is consequently negligible. For worksheet and calculations, see Appendix E.

Table 34a. Summary of crash severity for all unshielded two-span embankments on divided Interstate and primary highways with posted speed limit 55 and above

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	PDO	Crash Count	DEV
--	49	0	0	1	2	3	6	701350

Table 34b. Summary of B/C analysis of all unshielded two-span embankments on divided Interstate and primary highways with posted speed limit 55 and above

Crash Severity	Crash Reduction Factor (CRF)	Benefit	Cost	B/C
All	7	$10,545	$826,460	**0.01**
Injury	47	$58,066	$826,460	**0.07**

Table 34c. Summary of crash severity for all unshielded two-span embankments on divided Interstate and primary highways with posted speed limit 65 and above

Installations		Crashes						
Median	Outside	Fatal	Major Injury	Minor Injury	Possible Injury	PDO	Crash Count	DEV
--	36	0	0	1	2	3	6	484970

Table 34d. Summary of B/C analysis of all unshielded two-span embankments on divided Interstate and primary highways with posted speed limit 65 and above

Crash Severity	Crash Reduction Factor (CRF)	Benefit	Cost	B/C
All	7	$10,016	$607,195	**0.02**
Injury	47	$58,066	$607,195	**0.10**

In March 2009, a fatal truck crash occurred at an unshielded outside bridge pier on I-380 in Johnson County. Iowa DOT staff measured the near offset of the impacted pier at 34 ft from the edge of the outside lane. However, as can be seen from the images in Appendix I, the path of the errant vehicle would have impacted a pier at a much greater offset as well. Anticipating interesting results, the research team examined several B/C computations from including this fatal crash and one year of additional traffic volume with the calculations for the report analysis period. The following B/C ratios were obtained when including the additional fatality:

- For a 30–34 ft offset on a 65 mph highway, B/C for all crashes is calculated at 0.34. (Compare to Table 31d)
- For shielding of all piers, regardless of offset on 65 mph highways, B/C ratios ranged from 0.57 for a low-sensitivity CRF, 2.03 for a medium-sensitivity CRF, and 2.84 for a high-sensitivity CRF.(Compare to Table 33d)

Thus the addition of this fatality did not significantly impact calculated B/C ratios for these two scenarios when the additional year of traffic volume was considered.

CONCLUSIONS

This study was undertaken to ascertain criteria for shielding exposed obstructions at grade-separated structures on Interstate and primary roads in Iowa. Data were gathered from all crashes reported in the most current seven years of data and from the Iowa DOT inventory of study subject structures on four or more lane-divided roadways on the Interstate and primary highway system. Based on the data and the analysis described in this report, the following conclusions can be drawn and recommendations can be made:

- Since the construction of multi-lane divided highways began in Iowa, close compliance with roadside design standards and guidance has been maintained. Highway designers have carefully calculated clear-zone requirements and specified shielding as thus determined.
- Over approximately 40 years of experience since commencement of Interstate construction, numerous crashes have occurred at unshielded structures, both piers and other substructure elements. This study proposed to examine past and current criteria used by the state for specifying shielding at these structures.
- Of the 566 bridges identified by this study, 258 have shielding in place for all exposed substructure elements, 236 are partially shielded (most at the median pier only), and 72 have no shielding at all. Virtually all exposed substructure elements within the clear zone are shielded.
- A total of 585 crashes occurred at or near the subject bridges during the seven-year analysis period; 385 were defined as bridge-related by this study and 200 were lane-departure crashes.
- A total of 472 of the 566 study bridges (83%) are located on tangent sections of roadway, 17% are on curves. It is interesting to note that 104 of the 585 recorded crashes (18%) occurred in curve areas and 481 in tangent locations (82%).
- Approximately 55% of these crashes occurred during daylight conditions, 52% on dry pavement, and about 63% in clear, cloudy, or partly cloudy conditions. However, these data indicate that a high percentage of these crashes, (37%) occur in less than desirable weather or driving conditions. Since environmental data indicates that less than desirable pavement surface conditions only exist about 31% of the time, it appears that drivers are not properly responding to adverse driving situations.
- Most lane departure crashes, 112 of 200 (56%) were right-side departures; for bridge related crashes, 156 of 385 (41%) were left-side or median side departures.
- Most fatal crashes involved impacts with unshielded structure elements, but more injury crashes occurred at previously shielded structures. It may be surmised that shielding of an exposed element should reduce crash severity, but not necessarily the number of crashes. These results may be partially attributable to the increased potential length of the obstacle presented by the guardrail installation compared to an exposed pier or bridge embankment.
- Most fatal crashes and more total crashes were recorded on lower traffic volume roadways, less than 25,000 AADT than the proportionate share of these roadways in the total system.

- Lateral offset of obstruction seemed to impact the number of crashes; 79% of crashes impacted obstructions within 30 ft of the roadway while the total percentage of obstructions at the offset is approximately 70%.

- A total of 43 bridges were involved in multiple crashes during the study period, with 112 crashes and one fatality recorded. As most of these structure elements are fully shielded, other mitigation may be needed to reduce crash occurrences at these bridges.
- When compared to the total crashes that are recorded on Iowa's Interstate roadways of about 1850 per year with an average of 20-25 fatal crashes, the total number of crashes that occur at all grade separated bridges on an annual basis is quite low, 55 crashes with a total of 5 fatalities in a 7 year period.

The economic analysis revealed the following results:

- A relatively high crash loss has occurred over the study period from these bridge substructure crashes, and some appropriate mitigation should be determined.
- The economic analysis was conducted for two posted speed exposures, roadways of 55 mph and greater and roadways of 65 mph and greater. In general but not entirely, calculated B/C ratios were slightly higher for the higher speed roadways.
- Piers located on horizontal curves experienced a total of 13 crashes from which two fatalities occurred. Shielding of these piers would yield a B/C return of 3.29 for all crashes on roadways with posted speed of 55 mph and greater and 3.87 for roadways with posted speeds of 65 mph and greater.
- Since most close proximity piers and other substructure elements have been shielded, little additional benefit would be gained by shielding those obstructions based solely on offset distance.
- Piers located in the median appeared to present the most likely potential for impact by errant vehicles. Shielding of all median piers, regardless of offset distance would yield a B/C return of 5.58 for fatal crashes and 1.40 for all crashes on 55 mph and greater roads, and 6.30 for fatal crashes and 1.58 for all crashes on 65 mph and greater roads.
- Shielding of all exposed bridge substructure elements in both the median and along the outside of divided roadways does not appear feasible with a calculated B/C for fatal crashes of 1.48 and all crashes of only 0.44 for 55 mph, and 1.88 for fatal crashes and 0.52 for all crashes on 65 mph and greater roads. However, when arbitrarily higher crash reduction factors are applied, the resulting B/C ratios for all crashes increases to 2.22 for 55 mph and greater and 2.58 for 65 mph and greater roads.
- Shielding of exposed abutment embankments at two-span bridges would yield a very low B/C return, well below 1.00 for all speeds.

RECOMMENDATIONS

With few exceptions the economic analyses performed for several scenarios did not indicate an urgent need to install shielding at a significant number of currently exposed bridge substructure elements. It would be recommended that additional shielding only be installed at locations where the need is clearly warranted, perhaps considering a combination of factors such as offset, horizontal alignment, side of roadway, traffic volume, and especially crash history. Each structure should be analyzed on an individual basis.

Unshielded grade separation structures with a multiple crash history at or in near proximity to the bridge should be analyzed to determine if the existing design of shielding is appropriate.

Structures with a multiple crash history at or near the structure, even if fully shielded, should be studied for possible safety mitigation, considering such enhancements as improved pavement markings, retro-reflectorization of the substructure element, and installation of closely spaced delineators along the frequent road departure area.

The study confirmed the commonly held opinion that many drivers do not utilize prudent caution when traveling on other than dry pavement surfaces. A public information effort to publicize this finding may be beneficial, even wet pavement conditions can contribute to road departure incidents.

Crash history, especially for serious injury crashes at individual structures should be evaluated and proper mitigation, including shielding undertaken when warranted by engineering judgment and field experience, regardless of offset.

The economic analyses performed with this study relied on crash reduction factors suggested in an FHWA document *Desktop Reference for Crash Reduction Factors*, and those factors may seem quite low, especially in some categories. As newer data and references are developed, the B/C comparisons presented in this report should be re-calculated.

This study utilized an extensive volume of data from the Iowa DOT databases for roadways, structures, and crashes but the information available for the specific issues of interest was still limited, impacting the scope of study results. With additional data, issues such as effects of direction of travel, offset distance by one foot increments, vehicle type, and type of shielding could be analyzed for impacts on crashes and severity. Additional data might also permit development of more descriptive and accurate crash reduction factors than are available at this time. A multi-state research project should be considered for accomplishment of these worthwhile goals.

REFERENCES

American Association of State and Highway Transportation Officials. 2002. *Roadside Design Guide*, 3rd Edition. American Association of State and Highway Transportation Officials.

Iowa Department of Transportation. 2009. *Design Manual*. Iowa Department of Transportation, Office of Design. http://www.iowadot.gov/design/dmanual/manual.html.

APPENDIX A. SHIELD ALL UNPROTECTED PIERS ON CURVES

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 55 Sites   Median: 12 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers on Curves**

$ 804,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 40,200	Other Annual Cost (after initial year), **AC**	39	Crash Reduction Factor (integer), **CRF**
$ 326,058	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,130,058	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

735180

268,340,700	Current Annual Entering Veh., **AEV** = DEV * 365
896,180	veh / day, Final Year DEV, **FDEV**
2,938.26	MEV, Total Million Entering Veh. Over life of Project, **TMEV**
2.0%	Projected Traffic Growth (0%-10%), **G**
735,180	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

2	Fatal Crashes	2	Fatalities @	$3,500,000	$ 7,000,000
		1	Major Injuries @	$240,000	$ 240,000
5	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		2	Possible Injuries @	$25,000	$ 50,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
7	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 7,434,000

1.00	Current Crashes / Year, **AA** = TA / T
$ 1,062,000	Cost per Crash, **AVC** = LOSS / TA
10.9	Total Expected Crashes, **TECR** = CR x TMEV
0.39	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 414,180	Crash Costs Avoided in First Year, AAR x AVC
4.3	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 3,654,953 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $3,654,953 : $1,130,058 = **3.23** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 44 Sites Median: 12 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers on Curves**

$ 672,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 33,600	Other Annual Cost (after initial year), **AC**	39	Crash Reduction Factor (integer), **CRF**
$ 272,526	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 944,526	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

605600

221,044,000	Current Annual Entering Veh., **AEV** = DEV * 365
738,223	veh / day, Final Year DEV, **FDEV**
2,420.37	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

605,600 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months | values as of Dec. 2007

2	Fatal Crashes	2	Fatalities @	$3,500,000	$ 7,000,000
		1	Major Injuries @	$240,000	$ 240,000
5	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		2	Possible Injuries @	$25,000	$ 50,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
7	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 7,434,000

1.00	Current Crashes / Year, **AA** = TA / T
$ 1,062,000	Cost per Crash, **AVC** = LOSS / TA
10.9	Total Expected Crashes, **TECR** = CR x TMEV
0.39	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 414,180	Crash Costs Avoided in First Year, AAR x AVC
4.3	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 3,654,953 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $3,654,953 : $944,526 = **3.87** : 1

APPENDIX B. SHIELD ALL UNPROTECTED PIERS BASED ON OFFSET

B.1. Median Side

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Median: 4 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Less than 30ft**

$ 48,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 2,400	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 19,466	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 67,466	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

58600

21,389,000	Current Annual Entering Veh., **AEV** = DEV * 365
71,433	veh / day, Final Year DEV, **FDEV**
234.20	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0%	Projected Traffic Growth (0%-10%), **G**
58,600	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

0	Fatal Crashes	0	Fatalities @	$3,500,000	$ -
		0	Major Injuries @	$240,000	$ -
	Injury Crashes	0	Minor Injuries @	$48,000	$ -
		0	Possible Injuries @	$25,000	$ -
2	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 4,000
2	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 4,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 2,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.04	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 80	Crash Costs Avoided in First Year, AAR x AVC
0.4	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 706 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $706 : $67,466 = **0.01** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Median: 16 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 30-35ft**

$ 192,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 9,600	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 77,865	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 269,865	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

127700

46,610,500	Current Annual Entering Veh., **AEV** = DEV * 365
155,666	veh / day, Final Year DEV, **FDEV**
510.37	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

127,700 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
		0	Major Injuries @	$240,000	$ -
1	Injury Crashes	0	Minor Injuries @	$48,000	$ -
		1	Possible Injuries @	$25,000	$ 25,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 2,015
2	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 3,527,015

0.29	Current Crashes / Year, **AA** = TA / T
#########	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.04	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 70,540	Crash Costs Avoided in First Year, AAR x AVC
0.4	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 622,487 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $622,487 : $269,865 = **2.31** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Median: 16 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 30 - 35ft**

$ 192,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 9,600	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 77,865	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ **269,865**	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS — 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

127700

46,610,500	Current Annual Entering Veh., **AEV** = DEV * 365
155,666	veh / day, Final Year DEV, **FDEV**
510.37	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

127,700 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year — 7.0 years, Time Period, **T**

Additional months — values as of Dec. 2007

Crashes		Injuries		Cost	Total
	Fatal Crashes		Fatalities @	$3,500,000	$ -
			Major Injuries @	$240,000	$ -
1	Injury Crashes	0	Minor Injuries @	$48,000	$ -
		1	Possible Injuries @	$25,000	$ 25,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
1	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 25,000

0.14	Current Crashes / Year, **AA** = TA / T
$ 25,000	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.07	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,821	Crash Costs Avoided in First Year, AAR x AVC
0.8	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ **16,073** Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $16,073 : $269,865 = **0.06** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Median: 16 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 30 - 35ft**

$ 192,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 9,600	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
$ 77,865	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 269,865	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

127700

46,610,500	Current Annual Entering Veh., **AEV** = DEV * 365
155,666	veh / day, Final Year DEV, **FDEV**
510.37	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

127,700 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
			Major Injuries @	$240,000	$ -
	Injury Crashes	0	Minor Injuries @	$48,000	$ -
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
1	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 3,500,000

0.14	Current Crashes / Year, **AA** = TA / T
#########	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.09	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 325,000	Crash Costs Avoided in First Year, AAR x AVC
1.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 2,867,980 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,867,980 : $269,865 = **10.63** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Median: 38 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 35 - 40ft**

$ 456,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 22,800	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 184,928	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 640,928	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

642000

234,330,000	Current Annual Entering Veh., **AEV** = DEV * 365
782,594	veh / day, Final Year DEV, **FDEV**
2,565.85	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

642,000 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$	3,500,000
		3	Major Injuries @	$240,000	$	720,000
4	Injury Crashes	3	Minor Injuries @	$48,000	$	144,000
			Possible Injuries @	$25,000	$	-
4	Property Damage Only		(assumed cost per crash)	$2,700	$	-
		-OR-	enter Actual Cost of all property damage:		$	274,600
9	Total Crashes, **TA**		Total $ Loss, **LOSS**		$	4,638,600

1.29	Current Crashes / Year, **AA** = TA / T
$ 515,400	Cost per Crash, **AVC** = LOSS / TA
14.1	Total Expected Crashes, **TECR** = CR x TMEV
0.18	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 92,772	Crash Costs Avoided in First Year, AAR x AVC
2.0	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 818,671 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$818,671** : **$640,928** = **1.28** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Median: 38 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 35 - 40ft**

$ 456,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 22,800	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 184,928	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 640,928	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

642000

234,330,000	Current Annual Entering Veh., **AEV** = DEV * 365
782,594	veh / day, Final Year DEV, **FDEV**
2,565.85	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

642,000 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$	-
		3	Major Injuries @	$240,000	$	720,000
4	Injury Crashes	3	Minor Injuries @	$48,000	$	144,000
			Possible Injuries @	$25,000	$	-
	Property Damage Only		(assumed cost per crash)	$2,700	$	-
		-OR-	enter Actual Cost of all property damage:			
4	Total Crashes, **TA**			Total $ Loss, **LOSS**	$	864,000

0.57	Current Crashes / Year, **AA** = TA / T
$ 216,000	Cost per Crash, **AVC** = LOSS / TA
6.3	Total Expected Crashes, **TECR** = CR x TMEV
0.29	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 62,949	Crash Costs Avoided in First Year, AAR x AVC
3.2	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 555,493 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $555,493 : $640,928 = **0.87** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Median: 38 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 35 - 40ft**

$ 456,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 22,800	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
$ 184,928	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 640,928	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

642000

234,330,000	Current Annual Entering Veh., **AEV** = DEV * 365
782,594	veh / day, Final Year DEV, **FDEV**
2,565.85	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

642,000 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
			Major Injuries @	$240,000	$ -
	Injury Crashes		Minor Injuries @	$48,000	$ -
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
1	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 3,500,000

0.14	Current Crashes / Year, **AA** = TA / T
$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.09	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 325,000	Crash Costs Avoided in First Year, AAR x AVC
1.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 2,867,980 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$2,867,980** : **$640,928** = **4.47** : 1

Rev. 5/08

Intersection or Spot Benefit / Cost Safety Analysis

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Median: 4 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Less than 30ft**

$ 48,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 2,400	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 19,466	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
	$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$	$ 67,466	Present Value Cost, **COST** = EC + OC

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

58600

21,389,000	Current Annual Entering Veh., **AEV** = DEV * 365
71,433	veh / day, Final Year DEV, **FDEV**
234.20	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

58,600 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

0	Fatal Crashes	0	Fatalities @	$3,500,000	$ -
		0	Major Injuries @	$240,000	$ -
	Injury Crashes	0	Minor Injuries @	$48,000	$ -
		0	Possible Injuries @	$25,000	$ -
2	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 4,000
2	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 4,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 2,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.04	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 80	Crash Costs Avoided in First Year, AAR x AVC
0.4	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 706 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $706 : $67,466 = **0.01** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 123 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Less than 30ft**

$ 1,476,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 73,800	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
$ 598,584	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 2,074,584	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

2101730

767,131,450	Current Annual Entering Veh., **AEV** = DEV * 365
2,561,997	veh / day, Final Year DEV, **FDEV**
8,399.88	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

2,101,730 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months | values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
			Major Injuries @	$240,000	$ -
	Injury Crashes		Minor Injuries @	$48,000	$ -
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
1	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 3,500,000

0.14	Current Crashes / Year, **AA** = TA / T
$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.09	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 325,000	Crash Costs Avoided in First Year, AAR x AVC
1.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 2,867,980 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,867,980 : $2,074,584 = **1.38** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE — Prepared by: CTRE — Date Prepared: Dec 15, 2008

Outside: 134 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 30-35 ft**

$ 1,608,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 80,400	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 652,116	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 2,260,116	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS — 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

2369800

864,977,000	Current Annual Entering Veh., **AEV** = DEV * 365
2,888,773	veh / day, Final Year DEV, **FDEV**
9,471.26	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

2,369,800 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year — 7.0 years, Time Period, **T**

Additional months — values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		2	Major Injuries @	$240,000	$ 480,000
9	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		4	Possible Injuries @	$25,000	$ 100,000
11	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 253,500
20	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 977,500

2.86	Current Crashes / Year, **AA** = TA / T
$ 48,875	Cost per Crash, **AVC** = LOSS / TA
31.3	Total Expected Crashes, **TECR** = CR x TMEV
0.40	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 19,550	Crash Costs Avoided in First Year, AAR x AVC
4.4	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 172,520 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$172,520** : **$2,260,116** = **0.08** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 134 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 30-35 ft**

$ 1,608,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 80,400	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 652,116	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 2,260,116	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

2369800

864,977,000	Current Annual Entering Veh., **AEV** = DEV * 365
2,888,773	veh / day, Final Year DEV, **FDEV**
9,471.26	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

2,369,800 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		2	Major Injuries @	$240,000	$ 480,000
9	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		4	Possible Injuries @	$25,000	$ 100,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
9	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 724,000

1.29	Current Crashes / Year, **AA** = TA / T
$ 80,444	Cost per Crash, **AVC** = LOSS / TA
14.1	Total Expected Crashes, **TECR** = CR x TMEV
0.66	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 52,749	Crash Costs Avoided in First Year, AAR x AVC
7.2	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 465,483 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$465,483** : **$2,260,116** = **0.21** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 18 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 35-40 ft**

$ 216,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 10,800	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 87,598	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 303,598	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

323720

118,157,800	Current Annual Entering Veh., **AEV** = DEV * 365
394,613	veh / day, Final Year DEV, **FDEV**
1,293.79	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

323,720 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
3	Injury Crashes		Minor Injuries @	$48,000	$ -
		2	Possible Injuries @	$25,000	$ 50,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 6,099
3	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 296,099

0.43	Current Crashes / Year, **AA** = TA / T
$ 98,700	Cost per Crash, **AVC** = LOSS / TA
4.7	Total Expected Crashes, **TECR** = CR x TMEV
0.06	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 5,922	Crash Costs Avoided in First Year, AAR x AVC
0.7	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 52,259 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $52,259 : $303,598 = **0.17** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE　Prepared by: CTRE　Date Prepared: Dec 15, 2008

Outside: 18 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 35-40 ft**

$ 216,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 10,800	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 87,598	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 303,598	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS　2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

323720

118,157,800	Current Annual Entering Veh., **AEV** = DEV * 365
394,613	veh / day, Final Year DEV, **FDEV**
1,293.79	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

323,720 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year　7.0 years, Time Period, **T**

Additional months　values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
3	Injury Crashes		Minor Injuries @	$48,000	$ -
		2	Possible Injuries @	$25,000	$ 50,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
3	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 290,000

0.43	Current Crashes / Year, **AA** = TA / T
$ 96,667	Cost per Crash, **AVC** = LOSS / TA
4.7	Total Expected Crashes, **TECR** = CR x TMEV
0.22	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 21,129	Crash Costs Avoided in First Year, AAR x AVC
2.4	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 186,450 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $186,450 : $303,598 = **0.61** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 9 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Greater than 40 ft**

$ 108,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 5,400	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 43,799	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 151,799	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

126520

46,179,800	Current Annual Entering Veh., **AEV** = DEV * 365
154,227	veh / day, Final Year DEV, **FDEV**
505.66	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

126,520 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right)\Big/10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months | values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
2	Injury Crashes		Minor Injuries @	$48,000	$ -
		2	Possible Injuries @	$25,000	$ 50,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 40,000
2	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 330,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 165,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.04	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 6,600	Crash Costs Avoided in First Year, AAR x AVC
0.4	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 58,242 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $58,242 : $151,799 = **0.38** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 9 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Greater than 40 ft**

$ 108,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 5,400	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 43,799	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 151,799	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

126520

46,179,800	Current Annual Entering Veh., **AEV** = DEV * 365
154,227	veh / day, Final Year DEV, **FDEV**
505.66	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

126,520 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months | values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
2	Injury Crashes		Minor Injuries @	$48,000	$ -
		2	Possible Injuries @	$25,000	$ 50,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
2	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 290,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 145,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.15	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 21,129	Crash Costs Avoided in First Year, AAR x AVC
1.6	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 186,450 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$186,450** : **$151,799** = **1.23** : 1

B.2. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 65 mph and above

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Median: 4 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Less than 30ft**

$ 48,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 2,400	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 19,466	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 67,466	Present Value Cost, **COST** = EC + OC

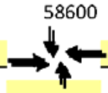
$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

58600



21,389,000	Current Annual Entering Veh., **AEV** = DEV * 365
71,433	veh / day, Final Year DEV, **FDEV**
234.20	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

58,600 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right)\Big/10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months | values as of Dec. 2007

0	Fatal Crashes	0	Fatalities @	$3,500,000	$ -
		0	Major Injuries @	$240,000	$ -
	Injury Crashes	0	Minor Injuries @	$48,000	$ -
		0	Possible Injuries @	$25,000	$ -
2	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 4,000
2	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 4,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 2,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.04	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 80	Crash Costs Avoided in First Year, AAR x AVC
0.4	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 706 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $706 : $67,466 = **0.01** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Median: 13 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 30-35ft**

$ 156,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 7,800	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 63,265	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 219,265	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

116200

42,413,000	Current Annual Entering Veh., **AEV** = DEV * 365
141,647	veh / day, Final Year DEV, **FDEV**
464.41	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

116,200 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
		0	Major Injuries @	$240,000	$ -
1	Injury Crashes	0	Minor Injuries @	$48,000	$ -
		1	Possible Injuries @	$25,000	$ 25,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 2,015
2	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 3,527,015

0.29	Current Crashes / Year, **AA** = TA / T
$ 1,763,508	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.04	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 70,540	Crash Costs Avoided in First Year, AAR x AVC
0.4	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 622,487 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $622,487 : $219,265 = **2.84** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Median: 13 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 30 - 35ft**

$ 156,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 7,800	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 63,265	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 219,265	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

116200

42,413,000	Current Annual Entering Veh., **AEV** = DEV * 365
141,647	veh / day, Final Year DEV, **FDEV**
464.41	MEV, Total Million Entering Veh. Over life of Project, **TMEV**
2.0%	Projected Traffic Growth (0%-10%), **G**
116,200	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right)\Big/10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

Crashes		Injuries		Unit cost	Cost
	Fatal Crashes		Fatalities @	$3,500,000	$ -
			Major Injuries @	$240,000	$ -
1	Injury Crashes	0	Minor Injuries @	$48,000	$ -
		1	Possible Injuries @	$25,000	$ 25,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
1	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 25,000

0.14	Current Crashes / Year, **AA** = TA / T
$ 25,000	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.07	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,821	Crash Costs Avoided in First Year, AAR x AVC
0.8	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 16,073 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $16,073 : $219,265 = **0.07** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Median: 13 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 30 - 35ft**

$ 156,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 7,800	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
$ 63,265	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 219,265	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

116200

42,413,000	Current Annual Entering Veh., **AEV** = DEV * 365
141,647	veh / day, Final Year DEV, **FDEV**
464.41	MEV, Total Million Entering Veh. Over life of Project, **TMEV**
2.0%	Projected Traffic Growth (0%-10%), **G**
116,200	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
			Major Injuries @	$240,000	$ -
	Injury Crashes	0	Minor Injuries @	$48,000	$ -
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
1	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 3,500,000

0.14	Current Crashes / Year, **AA** = TA / T
$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.09	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 325,000	Crash Costs Avoided in First Year, AAR x AVC
1.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 2,867,980 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,867,980 : $219,265 = **13.08** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Median: 37 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 35 - 40ft**

$ 444,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 22,200	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 180,062	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 624,062	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

626500

228,672,500	Current Annual Entering Veh., **AEV** = DEV * 365
763,700	veh / day, Final Year DEV, **FDEV**
2,503.90	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

626,500 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

Crashes		Injuries		Unit cost	Total
1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
		3	Major Injuries @	$240,000	$ 720,000
4	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
			Possible Injuries @	$25,000	$ -
4	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 274,600
9	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 4,638,600

1.29	Current Crashes / Year, **AA** = TA / T	**0.01**	Crashes / MEV, Crash Rate, **CR**
$ 515,400	Cost per Crash, **AVC** = LOSS / TA		CR = TA x 10^6 / (DEV x 365 x T)
14.1	Total Expected Crashes, **TECR** = CR x TMEV	$ 818,671	Present Value of Avoided Crashes, **BENEFIT**
0.18	Crashes Avoided First Year **AAR** = AA x CRF / 100		
$ 92,772	Crash Costs Avoided in First Year, AAR x AVC		
2.0	Total Avoided Crashes, TECR x CRF/ 100		

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $818,671 : $624,062 = **1.31** : 1

Rev. 5/08

Intersection or Spot Benefit / Cost Safety Analysis

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Median: 37 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers Based on Offset: Between 35 - 40ft**

$ 444,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 22,200	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 180,062	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 624,062	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

626500

228,672,500	Current Annual Entering Veh., **AEV** = DEV * 365
763,700	veh / day, Final Year DEV, **FDEV**
2,503.90	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

626,500 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right)\Big/10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

Crashes		Injuries		Cost	Total
	Fatal Crashes		Fatalities @	$3,500,000	$ -
		3	Major Injuries @	$240,000	$ 720,000
4	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -

-OR- enter Actual Cost of all property damage:

4 Total Crashes, **TA** Total $ Loss, **LOSS** $ 864,000

0.57	Current Crashes / Year, **AA** = TA / T
$ 216,000	Cost per Crash, **AVC** = LOSS / TA
6.3	Total Expected Crashes, **TECR** = CR x TMEV
0.29	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 62,949	Crash Costs Avoided in First Year, AAR x AVC
3.2	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 555,493 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $555,493 : $624,062 = **0.89** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 88 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Less than 30ft**

$ 1,056,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 52,800	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 428,255	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,484,255	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

1425290

520,230,850	Current Annual Entering Veh., **AEV** = DEV * 365
1,737,421	veh / day, Final Year DEV, **FDEV**
5,696.38	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0%	Projected Traffic Growth (0%-10%), **G**
1,425,290	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months | values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
		0	Major Injuries @	$240,000	$ -
8	Injury Crashes	5	Minor Injuries @	$48,000	$ 240,000
		3	Possible Injuries @	$25,000	$ 75,000
6	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 190,677
15	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 4,005,677

2.14	Current Crashes / Year, **AA** = TA / T
$ 267,045	Cost per Crash, **AVC** = LOSS / TA
23.5	Total Expected Crashes, **TECR** = CR x TMEV
0.30	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 80,114	Crash Costs Avoided in First Year, AAR x AVC
3.3	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 706,966 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $706,966 : $1,484,255 = **0.48** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 88 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Less than 30ft**

$ 1,056,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 52,800	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 428,255	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,484,255	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

1425290

520,230,850	Current Annual Entering Veh., **AEV** = DEV * 365
1,737,421	veh / day, Final Year DEV, **FDEV**
5,696.38	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

1,425,290 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months | values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		0	Major Injuries @	$240,000	$ -
8	Injury Crashes	5	Minor Injuries @	$48,000	$ 240,000
		3	Possible Injuries @	$25,000	$ 75,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
8	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 315,000

1.14	Current Crashes / Year, **AA** = TA / T
$ 39,375	Cost per Crash, **AVC** = LOSS / TA
12.5	Total Expected Crashes, **TECR** = CR x TMEV
0.58	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 22,950	Crash Costs Avoided in First Year, AAR x AVC
6.4	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 202,523 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$202,523** : **$1,484,255** = **0.14** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 88 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Less than 30ft**

$ 1,056,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 52,800	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
$ 428,255	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,484,255	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

1425290

520,230,850	Current Annual Entering Veh., **AEV** = DEV * 365
1,737,421	veh / day, Final Year DEV, **FDEV**
5,696.38	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

1,425,290 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

1	Fatal Crashes	1	Fatalities @	$3,500,000	$ 3,500,000
			Major Injuries @	$240,000	$ -
	Injury Crashes		Minor Injuries @	$48,000	$ -
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
1	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 3,500,000

0.14	Current Crashes / Year, **AA** = TA / T
$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.09	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 325,000	Crash Costs Avoided in First Year, AAR x AVC
1.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 2,867,980 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,867,980 : $1,484,255 = **1.93** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 112 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 30-35 ft**

$ 1,344,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 67,200	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 545,052	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,889,052	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

1917600

699,924,000	Current Annual Entering Veh., **AEV** = DEV * 365
2,337,544	veh / day, Final Year DEV, **FDEV**
7,663.97	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

1,917,600 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
7	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		3	Possible Injuries @	$25,000	$ 75,000
9	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 183,000
16	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 642,000

2.29	Current Crashes / Year, **AA** = TA / T
$ 40,125	Cost per Crash, **AVC** = LOSS / TA
25.0	Total Expected Crashes, **TECR** = CR x TMEV
0.32	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 12,840	Crash Costs Avoided in First Year, AAR x AVC
3.5	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 113,307 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$113,307** : **$1,889,052** = **0.06** : 1

Rev. 5/08

Intersection or Spot Benefit / Cost Safety Analysis

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 112 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 30-35 ft**

$ 1,344,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 67,200	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 545,052	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,889,052	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

1917600

699,924,000	Current Annual Entering Veh., **AEV** = DEV * 365
2,337,544	veh / day, Final Year DEV, **FDEV**
7,663.97	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

1,917,600 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
7	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		3	Possible Injuries @	$25,000	$ 75,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
7	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 459,000

1.00	Current Crashes / Year, **AA** = TA / T
$ 65,571	Cost per Crash, **AVC** = LOSS / TA
10.9	Total Expected Crashes, **TECR** = CR x TMEV
0.51	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 33,441	Crash Costs Avoided in First Year, AAR x AVC
5.6	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 295,106 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$295,106** : **$1,889,052** = **0.16** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 10 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 35-40 ft**

$ 120,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 6,000	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 48,665	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 168,665	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

160700

58,655,500	Current Annual Entering Veh., **AEV** = DEV * 365
195,892	veh / day, Final Year DEV, **FDEV**
642.26	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

160,700 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

	Fatal Crashes		Fatalities @ $3,500,000	$ -
		1	Major Injuries @ $240,000	$ 240,000
1	Injury Crashes		Minor Injuries @ $48,000	$ -
			Possible Injuries @ $25,000	$ -
0	Property Damage Only		(assumed cost per crash) $2,700	$ -
		-OR-	enter Actual Cost of all property damage:	$ 6,099
1	Total Crashes, **TA**		Total $ Loss, **LOSS**	$ 246,099

0.14	Current Crashes / Year, **AA** = TA / T
$ 246,099	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.02	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 4,922	Crash Costs Avoided in First Year, AAR x AVC
0.2	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 43,434 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = **$43,434** : **$168,665** = **0.26** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 10 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Between 35-40 ft**

\$ 120,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
\$ 6,000	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
\$ 48,665	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of \$), **INT**
		\$ 168,665	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

160700

58,655,500	Current Annual Entering Veh., **AEV** = DEV * 365
195,892	veh / day, Final Year DEV, **FDEV**
642.26	MEV, Total Million Entering Veh. Over life of Project, **TMEV**
2.0%	Projected Traffic Growth (0%-10%), **G**
160,700	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

	Fatal Crashes		Fatalities @	\$3,500,000	\$ -
		1	Major Injuries @	\$240,000	\$ 240,000
1	Injury Crashes		Minor Injuries @	\$48,000	\$ -
			Possible Injuries @	\$25,000	\$ -
0	Property Damage Only		(assumed cost per crash)	\$2,700	\$ -
			-OR- enter Actual Cost of all property damage:		
1	Total Crashes, **TA**			Total \$ Loss, **LOSS**	\$ 240,000

0.14	Current Crashes / Year, **AA** = TA / T
\$ 240,000	Cost per Crash, **AVC** = LOSS / TA
1.6	Total Expected Crashes, **TECR** = CR x TMEV
0.07	Crashes Avoided First Year **AAR** = AA x CRF / 100
\$ 17,486	Crash Costs Avoided in First Year, AAR x AVC
0.8	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

\$ 154,304 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = \$154,304 : \$168,665 = **0.91** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 8 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Greater than 40 ft**

$ 96,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 4,800	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 38,932	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 134,932	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

121600

44,384,000	Current Annual Entering Veh., **AEV** = DEV * 365
148,230	veh / day, Final Year DEV, **FDEV**
485.99	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

121,600 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

Crashes		Injuries		Cost	Total
	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
2	Injury Crashes		Minor Injuries @	$48,000	$ -
		2	Possible Injuries @	$25,000	$ 50,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 40,000
2	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 330,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 165,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.04	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 6,600	Crash Costs Avoided in First Year, AAR x AVC
0.4	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 58,242 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $58,242 : $134,932 = **0.43** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 8 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Outside Piers Based on Offset: Greater than 40 ft**

$ 96,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 4,800	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 38,932	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 134,932	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

121600

44,384,000	Current Annual Entering Veh., **AEV** = DEV * 365
148,230	veh / day, Final Year DEV, **FDEV**
485.99	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

121,600 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		1	Major Injuries @	$240,000	$ 240,000
2	Injury Crashes		Minor Injuries @	$48,000	$ -
		2	Possible Injuries @	$25,000	$ 50,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
2	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 290,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 145,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.15	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 21,129	Crash Costs Avoided in First Year, AAR x AVC
1.6	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 186,450 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $186,450 : $134,932 = **1.38** : 1

APPENDIX C. SHIELD ALL UNPROTECTED MEDIAN PIERS

C.1. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 55 mph and above

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: -- Sites Median: 61Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers**

$ 732,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 36,600	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 296,859	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,028,859	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

847700

309,410,500	Current Annual Entering Veh., **AEV** = DEV * 365
1,033,342	veh / day, Final Year DEV, **FDEV**
3,387.96	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

847,700 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

2	Fatal Crashes	2	Fatalities @	$3,500,000	$	7,000,000
		3	Major Injuries @	$240,000	$	720,000
5	Injury Crashes	3	Minor Injuries @	$48,000	$	144,000
		1	Possible Injuries @	$25,000	$	25,000
6	Property Damage Only		(assumed cost per crash)	$2,700	$	-
		-OR-	enter Actual Cost of all property damage:		$	286,215
13	Total Crashes, **TA**		Total $ Loss, **LOSS**		$	8,175,215

1.86	Current Crashes / Year, **AA** = TA / T
$ 628,863	Cost per Crash, **AVC** = LOSS / TA
20.3	Total Expected Crashes, **TECR** = CR x TMEV
0.26	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 163,504	Crash Costs Avoided in First Year, AAR x AVC
2.8	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 1,442,852 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $1,442,852 : $1,028,859 = **1.40** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: -- Sites Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers**

$ 732,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 36,600	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 296,859	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 1,028,859	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

847700

309,410,500	Current Annual Entering Veh., **AEV** = DEV * 365
1,033,342	veh / day, Final Year DEV, **FDEV**
3,387.96	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

847,700 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		3	Major Injuries @	$240,000	$ 720,000
5	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		1	Possible Injuries @	$25,000	$ 25,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
5	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 889,000

0.71	Current Crashes / Year, **AA** = TA / T
$ 177,800	Cost per Crash, **AVC** = LOSS / TA
7.8	Total Expected Crashes, **TECR** = CR x TMEV
0.36	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 64,770	Crash Costs Avoided in First Year, AAR x AVC
4.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 571,566 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $571,566 : $1,028,859 = **0.56** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County:	STATEWIDE	Prepared by:	CTRE	Date Prepared:	Dec 15, 2008
	Outside: -- Sites Median: 61 Sites				

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers**

\$ 732,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
\$ 36,600	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
\$ 296,859	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of \$), **INT**
		\$ 1,028,859	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

847700

309,410,500	Current Annual Entering Veh., **AEV** = DEV * 365
1,033,342	veh / day, Final Year DEV, **FDEV**
3,387.96	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

847,700 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

2	Fatal Crashes	2	Fatalities @	\$3,500,000	\$ 7,000,000
			Major Injuries @	\$240,000	\$ -
	Injury Crashes		Minor Injuries @	\$48,000	\$ -
			Possible Injuries @	\$25,000	\$ -
	Property Damage Only		(assumed cost per crash)	\$2,700	\$ -
		-OR-	enter Actual Cost of all property damage:		
2	Total Crashes, **TA**			Total \$ Loss, **LOSS**	\$ 7,000,000

0.29	Current Crashes / Year, **AA** = TA / T
\$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.19	Crashes Avoided First Year **AAR** = AA x CRF / 100
\$ 650,000	Crash Costs Avoided in First Year, AAR x AVC
2.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

\$ 5,735,959 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = \$5,735,959 : \$1,028,859 = **5.58** : 1

C.2. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 65 mph and above

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: -- Sites   Median: 54 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers**

$ 648,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 32,400	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 262,793	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 910,793	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

801300

292,474,500	Current Annual Entering Veh., **AEV** = DEV * 365
976,780	veh / day, Final Year DEV, **FDEV**
3,202.51	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

801,300 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right)\Big/10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

2	Fatal Crashes	2	Fatalities @	$3,500,000	$ 7,000,000
		3	Major Injuries @	$240,000	$ 720,000
5	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		1	Possible Injuries @	$25,000	$ 25,000
6	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 286,215
13	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 8,175,215

1.86	Current Crashes / Year, **AA** = TA / T
$ 628,863	Cost per Crash, **AVC** = LOSS / TA
20.3	Total Expected Crashes, **TECR** = CR x TMEV
0.26	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 163,504	Crash Costs Avoided in First Year, AAR x AVC
2.8	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 1,442,852 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT-G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $1,442,852 : $910,793 = **1.58** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: -- Sites   Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers**

$ 648,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 32,400	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 262,793	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 910,793	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

801300

292,474,500	Current Annual Entering Veh., **AEV** = DEV * 365
976,780	veh / day, Final Year DEV, **FDEV**
3,202.51	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

801,300 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year — 7.0 years, Time Period, **T**

Additional months — values as of Dec. 2007

Crashes		Injuries		Cost	Total
	Fatal Crashes		Fatalities @	$3,500,000	$ -
		3	Major Injuries @	$240,000	$ 720,000
5	Injury Crashes	3	Minor Injuries @	$48,000	$ 144,000
		1	Possible Injuries @	$25,000	$ 25,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ -
5	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 889,000

0.71	Current Crashes / Year, **AA** = TA / T
$ 177,800	Cost per Crash, **AVC** = LOSS / TA
7.8	Total Expected Crashes, **TECR** = CR x TMEV
0.36	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 64,770	Crash Costs Avoided in First Year, AAR x AVC
4.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 571,566 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $571,566 : $910,793 = **0.63** : 1

Rev. 5/08

Intersection or Spot Benefit / Cost Safety Analysis

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: -- Sites Median: 54 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Median Piers**

$ 648,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 32,400	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
$ 262,793	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 910,793	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

801300

292,474,500	Current Annual Entering Veh., **AEV** = DEV * 365
976,780	veh / day, Final Year DEV, **FDEV**
3,202.51	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

801,300 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

2	Fatal Crashes	2	Fatalities @	$3,500,000	$ 7,000,000
			Major Injuries @	$240,000	$ -
	Injury Crashes		Minor Injuries @	$48,000	$ -
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
2	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 7,000,000

0.29	Current Crashes / Year, **AA** = TA / T
$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA
3.1	Total Expected Crashes, **TECR** = CR x TMEV
0.19	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 650,000	Crash Costs Avoided in First Year, AAR x AVC
2.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 5,735,959 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $5,735,959 : $910,793 = **6.30** : 1

APPENDIX D. SHIELD ALL UNPROTECTED PIERS

D.1. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 55 mph and above

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 284 Sites Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

4,921,770 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right)\Big/10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

Crashes		Persons		Cost	Total
3	Fatal Crashes	3	Fatalities @	$3,500,000	$ 10,500,000
		10	Major Injuries @	$240,000	$ 2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$ 576,000
		12	Possible Injuries @	$25,000	$ 300,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 842,572
63	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 14,618,572

9.00	Current Crashes / Year, **AA** = TA / T
$ 232,041	Cost per Crash, **AVC** = LOSS / TA
98.5	Total Expected Crashes, **TECR** = CR x TMEV
1.26	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 292,371	Crash Costs Avoided in First Year, AAR x AVC
13.8	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 2,580,047 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,580,047 : $5,818,955 = **0.44** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 284 Sites   Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	50	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

4,921,770 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

Crashes		Injuries		Cost per	Total
3	Fatal Crashes	3	Fatalities @	$3,500,000	$ 10,500,000
		10	Major Injuries @	$240,000	$ 2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$ 576,000
		12	Possible Injuries @	$25,000	$ 300,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 842,572
63	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 14,618,572

9.00	Current Crashes / Year, **AA** = TA / T
$ 232,041	Cost per Crash, **AVC** = LOSS / TA
98.5	Total Expected Crashes, **TECR** = CR x TMEV
4.50	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,044,184	Crash Costs Avoided in First Year, AAR x AVC
49.3	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 9,214,454 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $9,214,454 : $5,818,955 = **1.58** : 1

Rev. 5/08

Intersection or Spot Benefit / Cost Safety Analysis

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 284 Sites Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	70	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

4,921,770 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

3	Fatal Crashes	3	Fatalities @	$3,500,000	$ 10,500,000
		10	Major Injuries @	$240,000	$ 2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$ 576,000
		12	Possible Injuries @	$25,000	$ 300,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 842,572
63	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 14,618,572

9.00	Current Crashes / Year, **AA** = TA / T
$ 232,041	Cost per Crash, **AVC** = LOSS / TA
98.5	Total Expected Crashes, **TECR** = CR x TMEV
6.30	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,461,857	Crash Costs Avoided in First Year, AAR x AVC
69.0	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 12,900,235 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $12,900,235 : $5,818,955 = **2.22** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 284 Sites   Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**
2.0%	Projected Traffic Growth (0%-10%), **G**
4,921,770	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

0	Fatal Crashes	0	Fatalities @	$3,500,000	$ -
		10	Major Injuries @	$240,000	$ 2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$ 576,000
		12	Possible Injuries @	$25,000	$ 300,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ -
32	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 3,276,000

4.57	Current Crashes / Year, **AA** = TA / T
$ 102,375	Cost per Crash, **AVC** = LOSS / TA
50.1	Total Expected Crashes, **TECR** = CR x TMEV
2.33	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 238,680	Crash Costs Avoided in First Year, AAR x AVC
25.5	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 2,106,244 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,106,244 : $5,818,955 = **0.36** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 284 Sites   Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	70	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

4,921,770 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

Crashes		Injuries		Cost	Total
0	Fatal Crashes	0	Fatalities @	$3,500,000	$ -
		10	Major Injuries @	$240,000	$ 2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$ 576,000
		12	Possible Injuries @	$25,000	$ 300,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ -
32	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 3,276,000

4.57	Current Crashes / Year, **AA** = TA / T
$ 102,375	Cost per Crash, **AVC** = LOSS / TA
50.1	Total Expected Crashes, **TECR** = CR x TMEV
3.20	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 327,600	Crash Costs Avoided in First Year, AAR x AVC
35.0	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

$ 2,890,923 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,890,923 : $5,818,955 = **0.50** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 284 Sites   Median: 61 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

4,921,770 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

3	Fatal Crashes	3	Fatalities @	$3,500,000	$ 10,500,000
			Major Injuries @	$240,000	$ -
	Injury Crashes		Minor Injuries @	$48,000	$ -
			Possible Injuries @	$25,000	$ -
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
3	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 10,500,000

0.43	Current Crashes / Year, **AA** = TA / T	0.00	Crashes / MEV, Crash Rate, **CR**
$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA		CR = TA x 10^6 / (DEV x 365 x T)
4.7	Total Expected Crashes, **TECR** = CR x TMEV	$ 8,603,939	Present Value of Avoided Crashes, **BENEFIT**
0.28	Crashes Avoided First Year **AAR** = AA x CRF / 100		
$ 975,000	Crash Costs Avoided in First Year, AAR x AVC		
3.1	Total Avoided Crashes, TECR x CRF/ 100		

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $8,603,939 : $5,818,955 = **1.48** : 1

D.2. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 65 mph and above

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 163,200	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

3,625,190 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

3	Fatal Crashes	3	Fatalities @	$3,500,000	$	10,500,000
		6	Major Injuries @	$240,000	$	1,440,000
23	Injury Crashes	11	Minor Injuries @	$48,000	$	528,000
		9	Possible Injuries @	$25,000	$	225,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$	-
		-OR-	enter Actual Cost of all property damage:		$	700,391
54	Total Crashes, **TA**		Total $ Loss, **LOSS**		$	13,393,391

7.71	Current Crashes / Year, **AA** = TA / T
$ 248,026	Cost per Crash, **AVC** = LOSS / TA
84.5	Total Expected Crashes, **TECR** = CR x TMEV
1.08	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 267,868	Crash Costs Avoided in First Year, AAR x AVC
11.8	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 2,363,814 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,363,814 : $4,587,698 = **0.52** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 163,200	Other Annual Cost (after initial year), **AC**	50	Crash Reduction Factor (integer), **CRF**
$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

3,625,190 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

Crashes		Injuries		Cost per	Total
3	Fatal Crashes	3	Fatalities @	$3,500,000	$ 10,500,000
		6	Major Injuries @	$240,000	$ 1,440,000
23	Injury Crashes	11	Minor Injuries @	$48,000	$ 528,000
		9	Possible Injuries @	$25,000	$ 225,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 700,391
54	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 13,393,391

7.71	Current Crashes / Year, **AA** = TA / T
$ 248,026	Cost per Crash, **AVC** = LOSS / TA
84.5	Total Expected Crashes, **TECR** = CR x TMEV
3.86	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 956,671	Crash Costs Avoided in First Year, AAR x AVC
42.2	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 8,442,191 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $8,442,191 : $4,587,698 = **1.84** : 1

Rev. 5/08

Intersection or Spot Benefit / Cost Safety Analysis

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 163,200	Other Annual Cost (after initial year), **AC**	70	Crash Reduction Factor (integer), **CRF**
$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**
2.0%	Projected Traffic Growth (0%-10%), **G**
3,625,190	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

3	Fatal Crashes	3	Fatalities @	$3,500,000	$ 10,500,000
		6	Major Injuries @	$240,000	$ 1,440,000
23	Injury Crashes	11	Minor Injuries @	$48,000	$ 528,000
		9	Possible Injuries @	$25,000	$ 225,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 700,391
54	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 13,393,391

7.71	Current Crashes / Year, **AA** = TA / T
$ 248,026	Cost per Crash, **AVC** = LOSS / TA
84.5	Total Expected Crashes, **TECR** = CR x TMEV
5.40	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,339,339	Crash Costs Avoided in First Year, AAR x AVC
59.1	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 11,819,068 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $11,819,068 : $4,587,698 = **2.58** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 163,200	Other Annual Cost (after initial year), **AC**	51	Crash Reduction Factor (integer), **CRF**
$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

3,625,190 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

0	Fatal Crashes	0	Fatalities @	$3,500,000	$ -
		6	Major Injuries @	$240,000	$ 1,440,000
23	Injury Crashes	11	Minor Injuries @	$48,000	$ 528,000
		9	Possible Injuries @	$25,000	$ 225,000
0	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ -
23	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 2,193,000

3.29	Current Crashes / Year, **AA** = TA / T
$ 95,348	Cost per Crash, **AVC** = LOSS / TA
36.0	Total Expected Crashes, **TECR** = CR x TMEV
1.68	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 159,776	Crash Costs Avoided in First Year, AAR x AVC
18.3	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 1,409,949 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $1,409,949 : $4,587,698 = **0.31** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 218 Sites   Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

\$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
\$ 163,200	Other Annual Cost (after initial year), **AC**	70	Crash Reduction Factor (integer), **CRF**
\$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of \$), **INT**
		\$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

3,625,190 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

0	Fatal Crashes	0	Fatalities @	\$3,500,000	\$ -
		6	Major Injuries @	\$240,000	\$ 1,440,000
23	Injury Crashes	11	Minor Injuries @	\$48,000	\$ 528,000
		9	Possible Injuries @	\$25,000	\$ 225,000
0	Property Damage Only		(assumed cost per crash)	\$2,700	\$ -
		-OR-	enter Actual Cost of all property damage:		\$ -
23	Total Crashes, **TA**		Total \$ Loss, **LOSS**		\$ 2,193,000

3.29	Current Crashes / Year, **AA** = TA / T
\$ 95,348	Cost per Crash, **AVC** = LOSS / TA
36.0	Total Expected Crashes, **TECR** = CR x TMEV
2.30	Crashes Avoided First Year **AAR** = AA x CRF / 100
\$ 219,300	Crash Costs Avoided in First Year, AAR x AVC
25.2	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

\$ 1,935,224 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = \$1,935,224 : \$4,587,698 = **0.42** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54 Sites

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

\$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
\$ 163,200	Other Annual Cost (after initial year), **AC**	65	Crash Reduction Factor (integer), **CRF**
\$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of \$), **INT**
		\$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

3,625,190 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

Crashes		Injuries		Cost	Total
3	Fatal Crashes	3	Fatalities @	\$3,500,000	\$ 10,500,000
			Major Injuries @	\$240,000	\$ -
	Injury Crashes		Minor Injuries @	\$48,000	\$ -
			Possible Injuries @	\$25,000	\$ -
	Property Damage Only		(assumed cost per crash)	\$2,700	\$ -
		-OR-	enter Actual Cost of all property damage:		
3	Total Crashes, **TA**			Total \$ Loss, **LOSS**	\$ 10,500,000

0.43	Current Crashes / Year, **AA** = TA / T
\$ 3,500,000	Cost per Crash, **AVC** = LOSS / TA
4.7	Total Expected Crashes, **TECR** = CR x TMEV
0.28	Crashes Avoided First Year **AAR** = AA x CRF / 100
\$ 975,000	Crash Costs Avoided in First Year, AAR x AVC
3.1	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**
CR = TA x 10^6 / (DEV x 365 x T)

\$ 8,603,939 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = \$8,603,939 : \$4,587,698 = **1.88** : 1

APPENDIX E. SHIELD ALL UNPROTECTED TWO-SPAN EMBANKMENTS

E.1. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 55 mph and above

Intersection or Spot Benefit / Cost Safety Analysis Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 49 Sites Median: --

Improvement

Proposed Improvement(s): **Shield All Unshielded Embankments (2-Span Bridges)**

$ 588,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 29,400	Other Annual Cost (after initial year), **AC**	7	Crash Reduction Factor (integer), **CRF**
$ 238,460	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 826,460	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

701350

255,992,750	Current Annual Entering Veh., **AEV** = DEV * 365
854,942	veh / day, Final Year DEV, **FDEV**
2,803.05	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

701,350 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year 7.0 years, Time Period, **T**

Additional months values as of Dec. 2007

	Fatal Crashes		Fatalities @	$3,500,000	$ -
		0	Major Injuries @	$240,000	$ -
3	Injury Crashes	1	Minor Injuries @	$48,000	$ 48,000
		2	Possible Injuries @	$25,000	$ 50,000
3	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 21,500
6	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 119,500

0.86	Current Crashes / Year, **AA** = TA / T
$ 19,917	Cost per Crash, **AVC** = LOSS / TA
9.4	Total Expected Crashes, **TECR** = CR x TMEV
0.06	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,195	Crash Costs Avoided in First Year, AAR x AVC
0.7	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 10,545 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $10,545 : $826,460 = **0.01** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE — Prepared by: CTRE — Date Prepared: Dec 15, 2008

Outside: 49 Sites   Median: --

Improvement

Proposed Improvement(s): **Shield All Unshielded Embankments (2-span bridges)**

$ 588,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 29,400	Other Annual Cost (after initial year), **AC**	47	Crash Reduction Factor (integer), **CRF**
$ 238,460	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 826,460	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS — 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

701350

255,992,750	Current Annual Entering Veh., **AEV** = DEV * 365
854,942	veh / day, Final Year DEV, **FDEV**
2,803.05	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

701,350 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2007 Last full year — 7.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

Crashes		Injuries		Cost	Total
	Fatal Crashes		Fatalities @	$3,500,000	$ -
			Major Injuries @	$240,000	$ -
3	Injury Crashes	1	Minor Injuries @	$48,000	$ 48,000
		2	Possible Injuries @	$25,000	$ 50,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		
3	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 98,000

0.43	Current Crashes / Year, **AA** = TA / T
$ 32,667	Cost per Crash, **AVC** = LOSS / TA
4.7	Total Expected Crashes, **TECR** = CR x TMEV
0.20	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 6,580	Crash Costs Avoided in First Year, AAR x AVC
2.2	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 58,066 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $58,066 : $826,460 = **0.07** : 1

E.2. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 65 mph and above

Rev. 5/08

Intersection or Spot Benefit / Cost Safety Analysis

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 36 Sites   **Median: --**

Improvement

Proposed Improvement(s): **Shield All Unshielded Embankments (2-Span Bridges)**

$ 432,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 21,600	Other Annual Cost (after initial year), **AC**	7	Crash Reduction Factor (integer), **CRF**
$ 175,195	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 607,195	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

484970

177,014,050	Current Annual Entering Veh., **AEV** = DEV * 365
591,176	veh / day, Final Year DEV, **FDEV**
1,938.25	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

484,970 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2007 Last full year   7.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

	Fatal Crashes	0	Fatalities @	$3,500,000	$ -
		0	Major Injuries @	$240,000	$ -
3	Injury Crashes	1	Minor Injuries @	$48,000	$ 48,000
		2	Possible Injuries @	$25,000	$ 50,000
3	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 15,500
6	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 113,500

0.86	Current Crashes / Year, **AA** = TA / T
$ 18,917	Cost per Crash, **AVC** = LOSS / TA
9.4	Total Expected Crashes, **TECR** = CR x TMEV
0.06	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,135	Crash Costs Avoided in First Year, AAR x AVC
0.7	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 10,016 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $10,016 : $607,195 = **0.02** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 36 Sites **Median: --**

Improvement

Proposed Improvement(s): **Shield All Unshielded Embankments (2-span bridges)**

$ 432,000 Estimated Improvement Cost, **EC**

$ 21,600 Other Annual Cost (after initial year), **AC**

$ 175,195 Present Value Other Annual Costs, **OC**

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

10 Est. Improvement Life, years, **Y**

47 Crash Reduction Factor (integer), **CRF**

4.0% Discount Rate (time value of $), **INT**

$ 607,195 Present Value Cost, **COST** = EC + OC

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

484970

177,014,050 Current Annual Entering Veh., **AEV** = DEV * 365

591,176 veh / day, Final Year DEV, **FDEV**

1,938.25 MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

484,970 Current Daily Entering Vehicles, **DEV**

Crash Data

2001 First full year --> 2007 Last full year | 7.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

Crashes		Injuries		Cost per	Total
	Fatal Crashes		Fatalities @	$3,500,000	$ -
			Major Injuries @	$240,000	$ -
3	Injury Crashes	1	Minor Injuries @	$48,000	$ 48,000
		2	Possible Injuries @	$25,000	$ 50,000
	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		
3	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 98,000

0.43 Current Crashes / Year, **AA** = TA / T

$ 32,667 Cost per Crash, **AVC** = LOSS / TA

4.7 Total Expected Crashes, **TECR** = CR x TMEV

0.20 Crashes Avoided First Year **AAR** = AA x CRF / 100

$ 6,580 Crash Costs Avoided in First Year, AAR x AVC

2.2 Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 58,066 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $58,066 : $607,195 = **0.10** : 1

APPENDIX F. SHIELD ALL UNPROTECTED PIERS INCLUDING RECENT FATAL CRASH ON I-380

F.1. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 55 mph and above

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE — Prepared by: CTRE — Date Prepared: Dec 15, 2008

Outside: 284 Sites Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS — 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**
2.0%	Projected Traffic Growth (0%-10%), **G**
4,921,770	Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001 First full year --> 2008 Last full year — 8.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

Crashes		Severity		Cost @		Total
4	Fatal Crashes	4	Fatalities @	$3,500,000	$	14,000,000
		10	Major Injuries @	$240,000	$	2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$	576,000
		12	Possible Injuries @	$25,000	$	300,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$	-
		-OR-	enter Actual Cost of all property damage:		$	842,572
64	Total Crashes, **TA**		Total $ Loss, **LOSS**		$	18,118,572

8.00	Current Crashes / Year, **AA** = TA / T
$ 283,103	Cost per Crash, **AVC** = LOSS / TA
87.6	Total Expected Crashes, **TECR** = CR x TMEV
1.12	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 317,075	Crash Costs Avoided in First Year, AAR x AVC
12.3	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 2,798,045 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,798,045 : $5,818,955 = 0.48 : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 284 Sites Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	50	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

4,921,770 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1-\left(\frac{1+G}{1}\right)^{Y}\right)\Big/10^{6}$$

Crash Data

2001 First full year --> 2008 Last full year 8.0 years, Time Period, **T**

Additional months

values as of Dec. 2007

Crashes		Injuries		Unit cost	Total
4	Fatal Crashes	4	Fatalities @	$3,500,000	$ 14,000,000
		10	Major Injuries @	$240,000	$ 2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$ 576,000
		12	Possible Injuries @	$25,000	$ 300,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 842,572
64	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 18,118,572

8.00	Current Crashes / Year, **AA** = TA / T
$ 283,103	Cost per Crash, **AVC** = LOSS / TA
87.6	Total Expected Crashes, **TECR** = CR x TMEV
4.00	Crashes Avoided First Year **AAR** = AA x CRF / 100
#########	Crash Costs Avoided in First Year, AAR x AVC
43.8	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 9,993,018 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1-\left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $9,993,018 : $5,818,955 = **1.72** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE   Prepared by: CTRE   Date Prepared: Dec 15, 2008

Outside: 284 Sites   Median: 61

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 4,140,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 207,000	Other Annual Cost (after initial year), **AC**	70	Crash Reduction Factor (integer), **CRF**
$ 1,678,955	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 5,818,955	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS   2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

4921770

1,796,446,050	Current Annual Entering Veh., **AEV** = DEV * 365
5,999,610	veh / day, Final Year DEV, **FDEV**
19,670.58	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

4,921,770 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2008 Last full year   8.0 years, Time Period, **T**

Additional months   values as of Dec. 2007

4	Fatal Crashes	4	Fatalities @	$3,500,000	$ 14,000,000
		10	Major Injuries @	$240,000	$ 2,400,000
32	Injury Crashes	12	Minor Injuries @	$48,000	$ 576,000
		12	Possible Injuries @	$25,000	$ 300,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 842,572
64	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 18,118,572

8.00	Current Crashes / Year, **AA** = TA / T
$ 283,103	Cost per Crash, **AVC** = LOSS / TA
87.6	Total Expected Crashes, **TECR** = CR x TMEV
5.60	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,585,375	Crash Costs Avoided in First Year, AAR x AVC
61.3	Total Avoided Crashes, TECR x CRF/ 100

0.00 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 13,990,225 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $13,990,225 : $5,818,955 = **2.40** : 1

F.2. Benefit-Cost Analysis Worksheet for Highways with Posted Limit 65 mph and above

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE | Prepared by: CTRE | Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 163,200	Other Annual Cost (after initial year), **AC**	14	Crash Reduction Factor (integer), **CRF**
$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^Y}\right)$$

Traffic Volume Data

Source: GIMS | 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

2.0%	Projected Traffic Growth (0%-10%), **G**	1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
3,625,190	Current Daily Entering Vehicles, **DEV**	4,419,086	veh / day, Final Year DEV, **FDEV**
		14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^Y\right) \Big/ 10^6$$

Crash Data

2001	First full year -->	2008	Last full year	8.0	years, Time Period, **T**
	Additional months				values as of Dec. 2007
4	Fatal Crashes	4	Fatalities @	$3,500,000	$ 14,000,000
		6	Major Injuries @	$240,000	$ 1,440,000
23	Injury Crashes	11	Minor Injuries @	$48,000	$ 528,000
		9	Possible Injuries @	$25,000	$ 225,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
			-OR- enter Actual Cost of all property damage:		$ 700,391
55	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 16,893,391

6.88	Current Crashes / Year, **AA** = TA / T
$ 307,153	Cost per Crash, **AVC** = LOSS / TA
75.3	Total Expected Crashes, **TECR** = CR x TMEV
0.96	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 295,634	Crash Costs Avoided in First Year, AAR x AVC
10.5	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 2,608,841 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^Y\right)$$

Benefit / Cost Ratio

Benefit : Cost = $2,608,841 : $4,587,698 = **0.57** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 163,200	Other Annual Cost (after initial year), **AC**	50	Crash Reduction Factor (integer), **CRF**
$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

3,625,190 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2008 Last full year 8.0 years, Time Period, **T**

Additional months values as of Dec. 2007

4	Fatal Crashes	4	Fatalities @	$3,500,000	$ 14,000,000
		6	Major Injuries @	$240,000	$ 1,440,000
23	Injury Crashes	11	Minor Injuries @	$48,000	$ 528,000
		9	Possible Injuries @	$25,000	$ 225,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 700,391
55	Total Crashes, **TA**		Total $ Loss, **LOSS**		$ 16,893,391

6.88	Current Crashes / Year, **AA** = TA / T
$ 307,153	Cost per Crash, **AVC** = LOSS / TA
75.3	Total Expected Crashes, **TECR** = CR x TMEV
3.44	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,055,837	Crash Costs Avoided in First Year, AAR x AVC
37.6	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 9,317,288 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $9,317,288 : $4,587,698 = **2.03** : 1

Intersection or Spot Benefit / Cost Safety Analysis

Rev. 5/08

Iowa DOT Office of Traffic & Safety

County: STATEWIDE Prepared by: CTRE Date Prepared: Dec 15, 2008

Outside: 218 Sites Median: 54

Improvement

Proposed Improvement(s): **Shield All Unshielded Piers**

$ 3,264,000	Estimated Improvement Cost, **EC**	10	Est. Improvement Life, years, **Y**
$ 163,200	Other Annual Cost (after initial year), **AC**	70	Crash Reduction Factor (integer), **CRF**
$ 1,323,698	Present Value Other Annual Costs, **OC**	4.0%	Discount Rate (time value of $), **INT**
		$ 4,587,698	Present Value Cost, **COST** = EC + OC

$$OC = \frac{AC}{INT}\left(1 - \frac{1}{(1+INT)^{Y}}\right)$$

Traffic Volume Data

Source: GIMS 2007 Date of traffic count

Daily Entering Vehicles by Approach (or AADT / 2)

3625190

1,323,194,350	Current Annual Entering Veh., **AEV** = DEV * 365
4,419,086	veh / day, Final Year DEV, **FDEV**
14,488.61	MEV, Total Million Entering Veh. Over life of Project, **TMEV**

2.0% Projected Traffic Growth (0%-10%), **G**

3,625,190 Current Daily Entering Vehicles, **DEV**

$$TMEV = \frac{AEV}{-G}\left(1 - \left(\frac{1+G}{1}\right)^{Y}\right) \Big/ 10^{6}$$

Crash Data

2001 First full year --> 2008 Last full year 8.0 years, Time Period, **T**

Additional months values as of Dec. 2007

4	Fatal Crashes	4	Fatalities @	$3,500,000	$ 14,000,000
		6	Major Injuries @	$240,000	$ 1,440,000
23	Injury Crashes	11	Minor Injuries @	$48,000	$ 528,000
		9	Possible Injuries @	$25,000	$ 225,000
28	Property Damage Only		(assumed cost per crash)	$2,700	$ -
		-OR-	enter Actual Cost of all property damage:		$ 700,391
55	Total Crashes, **TA**			Total $ Loss, **LOSS**	$ 16,893,391

6.88	Current Crashes / Year, **AA** = TA / T
$ 307,153	Cost per Crash, **AVC** = LOSS / TA
75.3	Total Expected Crashes, **TECR** = CR x TMEV
4.81	Crashes Avoided First Year **AAR** = AA x CRF / 100
$ 1,478,172	Crash Costs Avoided in First Year, AAR x AVC
52.7	Total Avoided Crashes, TECR x CRF/ 100

0.01 Crashes / MEV, Crash Rate, **CR**

CR = TA x 10^6 / (DEV x 365 x T)

$ 13,044,204 Present Value of Avoided Crashes, **BENEFIT**

$$BEN. = \frac{AVC \times AAR}{(INT - G)}\left(1 - \left(\frac{1+G}{1+INT}\right)^{Y}\right)$$

Benefit / Cost Ratio

Benefit : Cost = $13,044,204 : $4,587,698 = **2.84** : 1

APPENDIX G. IOWA DESIGN POLICY

Shielding Side Obstacles

Originally Issued: 09-23-97

This section provides information on (1) determining whether or not barrier is needed, (2) what factors influence the choice of barrier system, (3) where to locate the installation, and (4) what length of barrier is needed to provide adequate protection. Information on shielding culverts, bridge endposts, median obstacles, embankments, standing water and other unique obstacles is covered in sections that follow.

Determining the Need for a Barrier System

Obstacles alongside a roadway, such as bridge piers and sign trusses, should be analyzed in order to determine the best way to protect motorists should they run off the road. Several treatment options are available to the designer (in order of preference): removing the obstacle entirely, moving it outside the clear zone, making it breakaway (such as light poles), shielding the obstacle, or delineating the obstacle. In some cases, the designer may be able to make the obstacle traversable, for example placing a safety grate over a culvert.

Shielding an obstacle should be considered only if the obstacle cannot be removed, moved, made breakaway, or made traversable. Determining whether or not a barrier system is necessary is often the most difficult task when addressing the presence of a side obstacle in the clear zone (see Section 1C-2 for more information regarding the clear zone). Projected traffic and crash history can provide insight as to whether or not to shield a particular existing obstacle. However, other factors, for example type of roadway, treatments for similar obstacles along the roadway, and the presence of other side obstacles in the area, should weigh into the decision as well. Field crews can also provide valuable information regarding the need for and maintenance of a barrier system. Often, the decision to shield a side obstacle comes down to sound engineering judgment on the part of the designer.

Choosing a Barrier System

Three primary factors are involved when choosing a barrier system: deflection of the barrier system, maintaining an open shoulder, and design vehicle. The designer must be sure there is sufficient space between the back of the barrier system and the face of the obstacle to allow for deflection of the barrier system if impacted. Table 1 provides typical maximum deflections that can be expected for several types of barrier systems.

Table 1: Typical Maximum Deflections for Barrier Systems

barrier system	deflection	
	d (feet)	d (meters)
cable guardrail (RE-29C)	12	3.6
w-beam guardrail with 6′–3″ (1.905-meter) post spacing (RE-54A and RE-55A)	3	1
w-beam guardrail with 3′–1½″ (0.953-meter) post spacing (RE-54B and RE-55B)	2	0.6
F-shape concrete barrier (RE-74A and RE-74B)	0	0
concrete vertical wall (detail sheet available from the Methods Section)	0	0

In addition, the designer should make every effort to insure the barrier system does not encroach on the shoulder. The designer should also consider traffic in the area of the barrier. Barriers with a higher performance capability may be required in areas of high truck traffic, especially if penetration of the system must be avoided.

Other factors that influence choosing a barrier system include cost, maintenance, snow removal and drifting, and aesthetics. For example, an F-shape or concrete vertical wall deflects very little compared to other systems, but is substantially more expensive and less forgiving when impacted. Thus, these systems are most suitable for situations where minimal deflection is required, or if penetration of the system must be avoided. The designer should balance all factors to determine which system will work best for any situation.

Locating the Installation Line

Ideally, a barrier system should be placed 2 feet (0.6 meters) off the shoulder, but it may be placed just outside the shoulder line if necessary. The barrier system will be placed close enough to the roadway that earthwork required around the end terminal of the barrier will not be excessive, yet the barrier is located far enough away from the roadway that there are not a large number of incidental hits. At the same time, the likelihood of an impact at a steep angle is reduced.

If the obstacle being shielded is so close to the roadway that w-beam guardrail would encroach on the shoulder, the F-shape concrete barrier should be used. If the obstacle being shielded is so close to the roadway that F-shape concrete barrier would encroach on the shoulder, concrete vertical wall should be used.

Length of Need

The total length of a guardrail installation is divided into three parts: the approach length (A), the trailing length (T), and the length adjacent to the obstacle (H) (see RE-54A).

To determine the length of need, the following variables must be determined:

- obstacle length, L_o (see Figure 1).
- lateral extent of the area of concern, L_A: the distance from the edge of traveled way to the far side of the obstacle or the distance from the edge of traveled way to the outside edge of the clear zone, whichever is smaller (see Figure 1).
- L_2 is the distance from the edge of traveled way to the installation line.
- design speed.
- traffic volume.

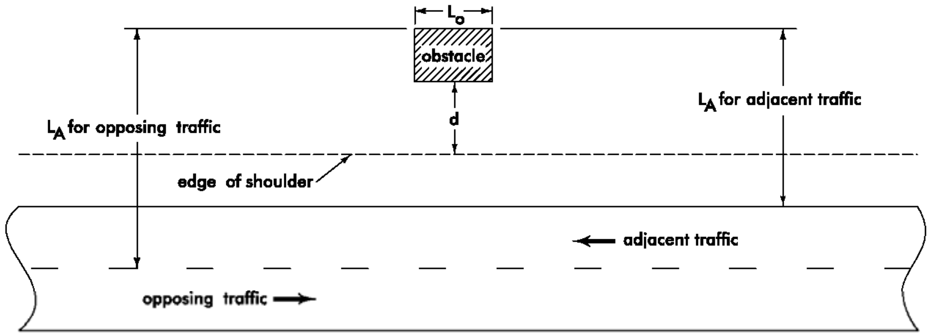


Figure 1: Before locating the installation line and determining the length of need, L_A, L_o, and d must be determined. Note that L_A is not always the distance to the back of the obstacle; it is this distance or the clear zone distance, whichever is smaller.

Based on the design speed and the traffic volume, the runout length (L_R) can be determined using Table 2. L_R is the theoretical distance needed for a vehicle that has left the roadway to come to a stop and it is used to determine the length of need.[1]

Table 2: Runout lengths.

English units

Design Speed (mph)	Traffic Volume			
	ADT ≥ 10000	5000 ≤ ADT <10000	1000 ≤ ADT < 5000	ADT < 1000
	L_R (ft)	L_R (ft)	L_R (ft)	L_R (ft)
70	360	300	260	220
60	260	210	180	170
50	210	170	150	130
40	160	130	110	100
30	110	90	80	70

Metric units

Design Speed (km/h)	Traffic Volume			
	ADT ≥ 10000	5000 ≤ ADT <10000	1000 ≤ ADT < 5000	ADT < 1000
	L_R (m)	L_R (m)	L_R (m)	L_R (m)
110	110	90	80	70
100	95	80	70	60
90	80	65	55	50
80	65	55	45	40
70	55	45	40	35
60	45	40	30	25
50	35	30	25	20

[1] Sicking, D.L. and Wolford, D.F., "Development of Guardrail Runout Length Calculation Procedures," NDOR Research Project Number SPR-PL-1(3) P479, University of Nebraska, Lincoln Nebraska, May 1996.

Determining the Length of Need Graphically

To determine the length of need graphically, see the procedures and examples in Chapter 5 of the *Roadside Design Guide*. Determining the appropriate combination of variable tangent (VT) and variable flare (VF) is explained below.

The Trailing Length (T)

The trailing length (T) will not be required on one-way or divided highways.

On two-way, undivided highways the designer must determine if the obstacle is within the clear zone of the opposing traffic lane. Remember that for opposing traffic the clear zone is measured from the pavement centerline. If the obstacle is within the clear zone, the length of T is determined in the same manner as A.

Even if the obstacle is not within the clear zone for opposing traffic, the guardrail installation itself often is. Therefore it is still normally terminated with a breakaway end terminal (RE-76).

If the installation is well outside the clear zone for opposing traffic (such as on a four-lane undivided highway), a breakaway end terminal on the trailing side may not be needed. The designer may Contact the Methods Section in the Office of Design if unsure.

Variable Tangent and Variable Flare

The Standard Road Plans indicate a variable tangent (VT) and a variable flare (VF). Different combinations of VT and VF may be used to meet the length of need. The best combination to use depends on the site characteristics.

In Figure 2, the installation on top minimizes the amount of guardrail needed by using VF. However, the amount of earthwork required increases because the installation terminates a greater distance into the ditch. The installation on the bottom minimizes the earthwork required by using no VF. This installation requires more guardrail but remains closer to the roadway. This design would be better in areas with steep foreslopes, where using no VF would minimize the amount of earthwork needed around the end terminal.

Tabulation

Tabulation 108-8B is used for systems with only w-beam guardrail. Tabulations 108-8A and 108-18B are used for systems with the F-shape concrete barrier along with 112-9 for the paved shoulder.

See Section 8B-10 for more information on tabulating guardrail.

Gaps between Barrier Installations

Gaps between barrier installations on the same side of the facility should not be less than 200 feet (60 meters). If two obstacles are so close that this is not possible, then a continuous length of barrier should be run between them.

Obstacles on Horizontal Curves

If the obstacle is located on a horizontal curve, a special design may be required. Consult the Methods Section for assistance or refer to Chapter 5 of the *Roadside Design Guide* for an example problem of shielding an obstacle located on a horizontal curve.

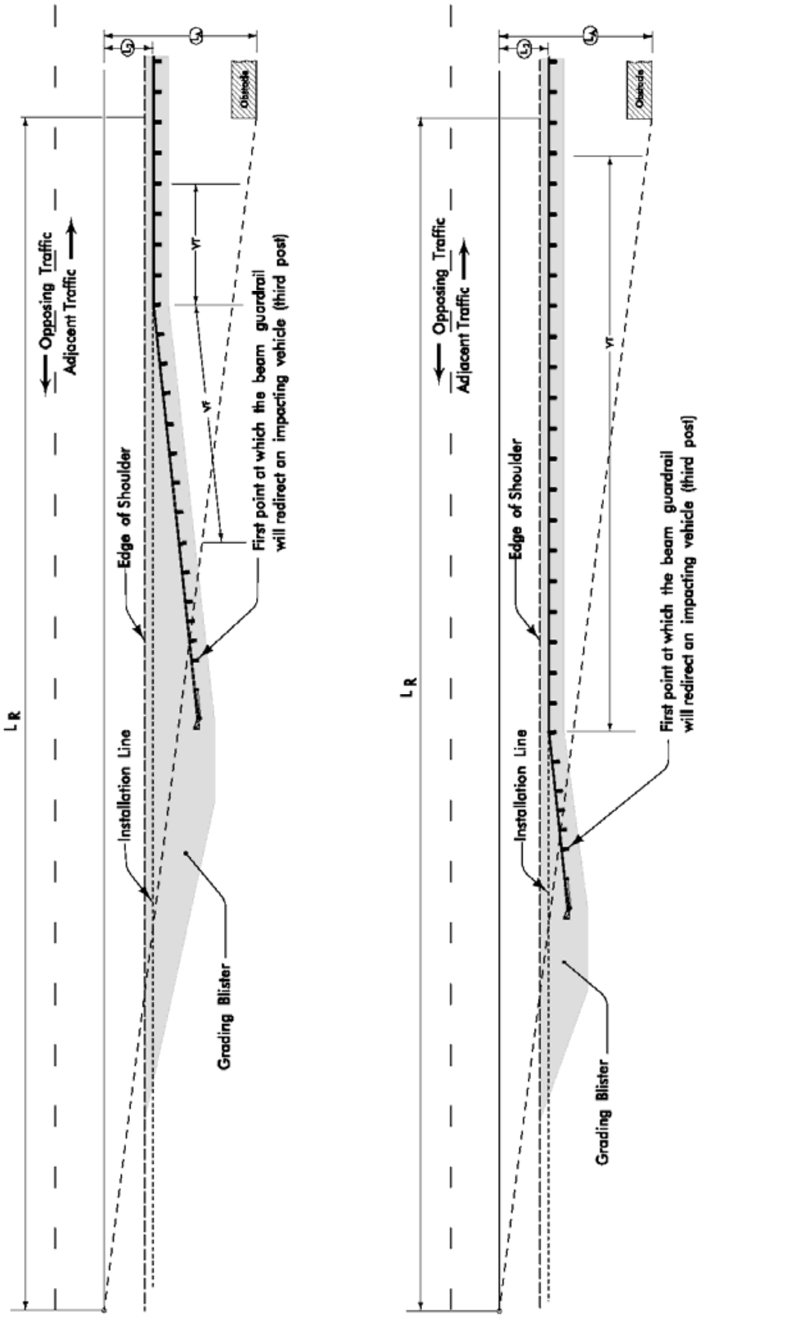


Figure 2: Determining the length of need graphically. The appropriate combination of VT and VF to use depends on site characteristics.

APPENDIX H. INSTALLATION AND ANNUAL MAINTENANCE COST ESTIMATE FOR HIGH-TENSION CABLE RAIL

Crash data indicates a total of 385 crashes occurred at the 566 study bridges in seven years. Extending that data to a 10 year period would yield approximately 550 crashes at these same 566 bridges.

Historic maintenance costs for high tension cable rail received from Dave Little in District 2 indicated that DOT maintenance costs for repair average about $425/impact not including re-tensioning of the terminals.

Three impacts with recently installed high-tension cable were experienced in District 2 also, and these were repaired by extra work order to a contractor and all involved re-tensioning of the anchors. Cost for these repairs averaged $3040/each

From the prorated crash data above, it could be anticipated that a cable rail installation at a bridge pier would have an approximate opportunity of being impacted once during the 10 year service life of the installation. Repair of these installations would almost always involve damage to the anchor system due to the short length of installation and therefore re-tensioning would be required.

Based on the above analysis, we could conclude an annual maintenance cost of **$300/year** based on $3000/10years for each installation.

Initial installation costs are approximately $6000/installation for both high tension cable and w-beam guardrail, but maintenance costs are generally assumed to be lower for cable rail.

One site = 2 installations at median piers

APPENDIX I. BRIDGE SHIELDING PHOTOGRAPHS

Figure I.1. W-beam guardrail at outside pier

Figure I.2. W-beam guardrail and concrete retaining wall combination at outside pier

Figure I.3. W-beam guardrail in median

Figure I.4. High-tension cable rail in median

Figure I.5. Truck crash at unshielded pier on I-380, March 2009

Figure I.6. Crash damage to high-tension cable rail on I-35, July 2008

Figure I.7. Crash damage to a W-beam guardrail on I-80, May 2009