Seismic Retrofit Prioritization of Nevada Bridges

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EXECUTIVE SUMMARY

The purpose of this study is to evaluate Nevada's, as well as other states', seismic prioritization procedures. Six methods were located and analyzed so that the strong and weak points of each method could be identified. Once identified, the strengths from each of the various methods were incorporated into a proposed new method to be used by the Nevada Department of Transportation.

The six seismic prioritization procedures were from the states of Nevada, California, Illinois, Missouri, New York, and Washington. Twenty bridges from the Nevada bridge inventory were selected and evaluated using five of the six above mentioned methods. The Illinois method was omitted since it is a detailed, statistically sophisticated method that requires considerably more input information than the other methods. Then a new method was developed and used to evaluate the same twenty bridges. The results from the proposed new method were then compared with the results from the other methods.

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1. INTRODUCTION

There are many bridges in Nevada that are in need of seismic retrofitting. Unfortunately, available resources do not permit a retrofitting program that will bring all of Nevada's bridges to an adequate level of seismic safety at the same time. Therefore, it is necessary to prioritize the bridges to determine those that must be retrofitted first. The current Nevada prioritization procedure was developed in 1989 and revised early in 1992. Since there are several other prioritization methodologies available and in use, it is necessary to compare the procedures in order to select the most appropriate prioritization procedure.

The first step in the project was to collect information about the methods that were recently developed, revised, or that are presently in use. Information was found on the Nevada, California, Illinois, Missouri, New York, and Washington prioritization procedures.

Twenty bridges were then selected for prioritization from the Nevada bridge inventory. The bridge inventory was broken into quartiles based on the existing Nevada seismic prioritization scores; five bridges were selected from each quartile. Of the five bridges selected from each quartile, one is from the Reno area, one is from the Las Vegas area, and the other three were randomly selected to provide diversity of location, route type, and structure type.

Information was collected for all twenty bridges so that they could be prioritized using the Nevada, California, Missouri, New York, and Washington methods; the Illinois method was considered to be detailed and time consuming, and therefore was not used. The five remaining methodologies were then compared and their strong and weak points analyzed. The strengths from some of the methods were applied to the Nevada procedure to develop the proposed new method. The twenty selected bridges were then prioritized using the new method.

The following report first summarizes each of the six methodologies. Next, it compares the methods and identifies their strengths and weaknesses. Finally, the modified prioritization method for Nevada is described and compared to the other methodologies.

2. DESCRIPTION OF PRIORITIZATION PROCEDURES

Several seismic prioritization methods to rank bridge structures have been developed. Six such procedures were chosen to be analyzed in this report: the Nevada, California, Illinois, Missouri, New York, and Washington methodologies. All of these procedures are intended to be relatively simple in order to avoid a full seismic analysis; this is accomplished by evaluating 3 basic concerns: importance, seismicity, and vulnerability.

2.1 Nevada Seismic Prioritization Procedure

The Nevada seismic prioritization procedure consists of three factors: importance, vulnerability, and seismicity [8]. These factors are calculated independently of one another. The final risk or score for a bridge is the sum of the importance, vulnerability, and seismicity factors times 3.33. This yields a maximum value of 100 which designates the most critical bridge.

Importance

The importance factor can range from 1 to 10, 10 being the maximum value allowed and designating the most important bridges. The importance score is calculated by summing the values associated with the following items.

1. Route type carried on the bridge

a.	Interstate	5
b.	Primary	4
c.	Secondary	2 or 3
d.	Urban	2 to 4
e.	All others	1 or 2

2. Average daily traffic - sum of all directions

a.	5000 or less	0
b.	5000 to 10000	1
c.	10000 to 25000	2

d.	25000 to 50000	3
e.	over 50000	4

3. Special increases

a.	Isolated areas	up to 3
b.	Major utilities	2
c.	Multi-use facilities	up to 4

Vulnerability

The vulnerability factor is based on critical details in the bridge design. The vulnerability score is calculated by determining which details exist, then looking through the vulnerability values associated with each detail and choosing the largest. The vulnerability is the critical detail's score plus 2 points for each of the other details that is present. The maximum vulnerability score is 10, representing the most vulnerable bridge. The bridge detail vulnerability scores are as listed.

1. Bearing susceptible to collapse

a.	Simple span bridge	6
b.	Continuous span bridge	4

2. Non-confined column core

a.	Single columns	6
b.	Multiple columns	4

3. Main column reinforcing spliced in plastic hinge zone

a.	Single columns	5
b.	Multiple columns	4

4. Main column reinforcing (inadequate development length into support)

a.	Single columns	6
b.	Multiple columns	5

5. Small abutment or pier seat width

a.	Single span	7
b.	Multiple single spans	8

6. Unrestrained hinges	6

Seismicity

Seismicity is the third factor in the Nevada procedure. Seismicity is based on the United States Geological Survey (USGS) maps for bedrock acceleration. A minimum acceleration value of 0.15g and a maximum value of 0.40g are used. The seismicity factor is the bedrock acceleration times 25.

2.2 California Seismic Prioritization Procedure

The California prioritization method takes twelve factors into consideration [6]. Each of the twelve factors is assigned a value between 0 and 1, then each is multiplied by a fixed weighting factor, and added together to determine the risk value. Six of the factors are related to vulnerability: year of construction, number of hinges, number of columns per bent, height, skew, and abutment type. Two of the factors are related to seismicity: peak bedrock acceleration and soil on site. Four of the factors are related to importance: traffic exposure, route type, facility crossed, and length of detour.

The year of construction factor, **YC**, is assigned a value of 0.5 for bridges built before 1945, 1 for bridges built between 1945 and 1971, and 0 for bridges built after 1971. The number of hinges factor, **NH**, is assigned a value of 0 for bridges with no hinges, 0.5 for bridges with one hinge, and 1 for bridges with two or more hinges. The number of columns per bent factor, **NCB**, is assigned a value of 0.5 for bridges with multiple columns per bent and 1 for bridges with only one column per bent. The height factor, **H**, is a cubic normalized function ($h^3/30^3$) so that 1 represents bridges thirty feet or taller. The skew factor, **S**, is a positive parabola ($s^2/90^2$) normalized so that 1 represents bridges with a skew of ninety degrees [See figure 1]. The abutment factor, **A**, is assigned a value of 0 for bridges with monolithic abutments and 1 for bridges without monolithic abutments.

The peak bedrock acceleration factor, **PA**, is linearly normalized so that 1 represents bridges in areas of 0.7g acceleration. The soil on site factor, **SS**, is linearly normalized so that 1 represents bridges on high risk soils.

The traffic exposure factor, **TE**, is a negative parabola $(1 - \{(200{,}000{,}000 - ADT \times L)/200{,}000{,}000\}^2)$ normalized so that 1 represents a bridge that the ADT times the Length equals 200,000,000 [See figure 2]. The route type factor, **RT**, is assigned a value of 0.2 for non-federally funded county or city routes, 0.5 for federally funded county or city routes, 0.7 for railroad tracks, 0.8 for U.S. and state routes, and 1 for interstates. The facility crossed factor, **FC**, is assigned values by the same method as the route type factor. The length of detour factor, **LD**, is linearly normalized so that 1 represents bridges that have a detour length of 100 or greater miles.

The final calculation of risk involves multiplying all of the factors by their corresponding fixed weights and adding all of them together. The formula for risk is as follows.

$$\mathbf{Risk} = 0.13\mathbf{YC} + 0.12\mathbf{PA} + 0.12\mathbf{SS} + 0.11\mathbf{NH} + 0.10\mathbf{NCB} + 0.08\mathbf{TE} + 0.07\mathbf{H} + 0.07\mathbf{S} + 0.06\mathbf{FC} + 0.05\mathbf{RT} + 0.05\mathbf{LD} + 0.04\mathbf{A}$$

This yields a maximum value of 1, which designates the most critical bridge.

2.3 Illinois Seismic Prioritization Procedure

The Illinois prioritization method is a two stage procedure [5]. Both stages use the same basic formula, which can be expressed as follows.

$$\text{Risk} = (\text{Probability of damage}) \times (\text{Consequences of damage})$$

The bridge vulnerability factor represents the probability of damage, and the importance factor represents the consequences of damage.

The bridge vulnerability factor, **BVF**, represents the probability of bridge damage due to an earthquake. The bridge vulnerability factor considers seismicity, structural vulnerability, and soil effects. The structural vulnerability is assigned a value of 100 for the first stage of analysis. After the first stage of analysis has been completed, only the highest ranking bridges are evaluated using the second stage of analysis. In the second stage of analysis, the structural vulnerability is calculated through a complex set of equations. Then, using the bridge seismicity, structural vulnerability, and soil type, the bridge vulnerability factor is determined by a series of steps that involves various formulas and probability curves. This process yields a value between 0 and 1, 1 representing a bridge that is most probable to collapse.

The importance factor, **I**, considers the number of vehicles impacted by bridge failure, emergency routes, vehicle miles of detour, defense requirements, and utility lines carried by the bridge. All five items considered are individually scored between 0 and 1 [See figures 3-8]. The individual scores are then multiplied by a corresponding weight and added together to determine the importance factor. The weights range from 1 to 69.

number of vehicles impacted	69
emergency route	15
detour	10
defense route	5
utilities	1

The maximum score for importance is 100, which represents the most important bridge.

The final risk score for a bridge is the product of the bridge importance and the vulnerability factors. This yields a maximum value of 100 which designates the most critical bridge.

2.4 Missouri Seismic Prioritization Procedure

The Missouri prioritization method consists of a vulnerability factor and an importance factor [7]. The vulnerability factor is calculated based on structural vulnerability, seismicity, and soil effects. The importance factor is calculated based on the route type, bridge length, bridge width, number of lanes on the bridge, number of lanes under the bridge, ADT on the bridge, and ADT under the bridge.

The vulnerability factor is the product of the structure, rock, and soil factors. The soil factor is based on a soil map of the state of Missouri done by the Missouri Department of Transportation (when analyzing the Nevada bridges with this method soils were divided into four groups ranging for low to high risk). The factors are as follows.

Structure Type

Simple span	3
Continuous span w/expansion joints	2
Continuous span w/integral end bents	1

Rock Acceleration

0.1g to 0.2g	1
0.2g to 0.3g	2
0.3g+	3

Soil Type

I	1.0
II	1.2
III	1.5
IV	2.0

The maximum vulnerability factor is 18 which designates the most vulnerable bridge.

The importance factor is calculated using seven values, $\mathbf{L_1}$, $\mathbf{N_1}$, $\mathbf{SF_1}$, $\mathbf{L_2}$, $\mathbf{N_2}$, $\mathbf{SF_2}$, and **P**. The length of the bridge, in feet, divided by one hundred is $\mathbf{L_1}$. The width of the bridge in feet, divided by one hundred is $\mathbf{L_2}$. The number of traffic lanes on the bridge is $\mathbf{N_1}$. The number of traffic lanes under the bridge is $\mathbf{N_2}$. For bridges carrying priority routes **P** is 1.2, for other routes **P** is 1. The ADTs determine the spacing factors for the routes on the bridge, $\mathbf{SF_1}$, and under the bridge, $\mathbf{SF_2}$. The spacing factor is 0.20 when the ADT is less then five thousand, 0.33 when the ADT is between five and twenty thousand, 0.50 when the ADT is between twenty and fifty thousand, 1.0 when the ADT is between fifty and one hundred thousand, and 2.0 when the ADT is greater than one hundred thousand. The formula to calculate importance is as follows.

$$\text{Importance} = [(3 + \mathbf{L_1})(\mathbf{N_1})(\mathbf{SF_1}) + (3 + \mathbf{L_2})(\mathbf{N_2})(\mathbf{SF_2})][\mathbf{P}]$$

The final risk or score for a bridge is the product of the importance and vulnerability factors. The higher the score the more critical the bridge.

2.5 New York Seismic Prioritization Procedure

Importance is the first of three factors to be considered by the New York prioritization method [3]. The importance factor is calculated based on route type, detour length, ADT, replacement cost, retrofit cost, and presence of utility lines. The formula for importance is as follows.

$$\text{Importance} = \mathbf{a}[\mathbf{R_1 D_1} + \mathbf{R_2 D_2} + \mathbf{U} + \mathbf{ADT}] + \mathbf{b}[\mathbf{RPC/RTC}]$$

The factors **a**, **b** are relative weighting factors arbitrarily selected to keep the importance factor between 0 and 10 (for our analysis $a = 1$ and $b = 0$ was used because no replacement cost was available). The route type scores, $\mathbf{R_1}$ and $\mathbf{R_2}$ for the routes on and under the bridge respectively, are 1.0 for interstates and defense routes, 0.8 for U.S. and county highways, 0.5 for city highways, and 0.2 for city streets. The normalized detour lengths for the route on and the route under the bridge are $\mathbf{D_1}$ and $\mathbf{D_2}$ respectively. If the bridge supports utility lines then **U** is 1, otherwise it is 0. **ADT** is the normalized average daily traffic carried by the bridge. The bridge replacement and retrofit costs are **RPC** and **RTC** respectively.

The seismicity factor is the product of a constant (**c**), the bedrock acceleration (**a**), and a soil factor (**F**). The constant value is arbitrarily selected to keep the range of seismicity values between 0 and 10 (for our analysis $c = 10$). The bedrock acceleration is located from a recent USGS map. The soil factor ranges from 1.0 for stiff competent soils to 3.0 for soft soils.

$$\text{Seismicity Factor} = \mathbf{S} = \mathbf{caF}$$

The structure vulnerability is determined by the bridge details. The vulnerability is assigned a value between 0 and 10 based on ATC/FHWA guidelines (for our analysis the old Nevada vulnerability, 1989, was used since it was also based on ATC/FHWA guidelines [1,4]).

The importance, seismicity, and vulnerability are all assigned weights, the sum of which equals 10 (For our analysis 3.33 was used for all three weights). The importance, seismicity, and vulnerability are multiplied by their respective weights and then added together yielding the risk or score for the bridge.

2.6 Washington Seismic Prioritization Procedure

The Washington prioritization method consists of criticality and vulnerability factors [2]. The criticality factor is based on route type, detour length, utility lines, ADT, and bridge length. The vulnerability factor is based on bedrock acceleration, remaining life, and structural vulnerability.

The formula for criticality is as follows.

$$\text{Criticality} = (\mathbf{RNC})(\mathbf{DLC})(\mathbf{NC}) + \mathbf{U} + 0.67(\mathbf{RNX})(\mathbf{DLX})(\mathbf{NX}) + 0.25[(\mathbf{ADT})(\mathbf{L})/30{,}000]^{0.25}$$

The route type factor on and under the bridge, **RNC** and **RNX** respectively, are equal to 1.0 for emergency routes and 0.8 for all other routes. The detour length factor for the routes on and under the bridge, **DLC** and **DLX** respectively, are equal to 1.0 if the detour is greater than ten miles, 0.8 if the detour is between three and ten miles, 0.75 if the detour is less than three miles. Congestion factors for the route on and under the bridge, **NC** and **NX** respectively, are equal to the ADT on or under the bridge divided by thirty thousand the quantity raised to the one fourth power $[(\mathrm{ADT}/30000)^{0.25}]$. **ADT** is the average daily traffic on the bridge. **U** is equal to 1 for bridges that support utility lines, otherwise it is 0. **L** is the length of the bridge in feet.

The formula for bridge vulnerability is as follows.

$$\text{Vulnerability} = 9.85[(\mathbf{A})(\mathbf{K})(\mathbf{SV})]^{0.41}$$

The bedrock acceleration is **A**. The remaining life factor, **K**, is equal to 1.0 for more than forty years, 0.91 for between thirty and forty years, 0.80 for between twenty and thirty years, 0.67 for between ten and twenty years, and 0.5 for less than ten years of bridge life remaining. The structural vulnerability factor, **SV**, is based on bridge details, and is given a score based on the ATC/FHWA guidelines (for our analysis the old Nevada vulnerability, 1989, was used since it was also based on ATC/FHWA guidelines [1]).

The bridge's risk or score is the product of the criticality and vulnerability factors. The maximum score is 100 which represents the highest risk bridge.

3. COMPARISON OF PRIORITIZATION PROCEDURES

In order to compare the six seismic prioritization procedures it was decided to prioritize twenty bridges from the Nevada bridge inventory using the various procedures. Evaluating bridges with each procedure gave insight into what the formulas accomplish, and which factors are effective indicators. A numerical comparison is also possible when the bridges have been scored with each of the prioritization procedures.

3.1 Selection of Twenty Bridges for Comparison

Twenty bridges were selected and analyzed using the various prioritization procedures to aid in comparing the prioritization procedures. The bridges were selected from the Nevada bridge inventory, which was broken into quartiles based on the existing Nevada seismic prioritization scores (1992). Five bridges were selected from each quartile, one from the Reno area, one from the Las Vegas area, and the other three randomly. The bridges selected were then checked to ensure diversity of location, route type, and structure type [See table 1].

The twenty bridges selected are from all around Nevada: nine are from Washoe County, five are from Clark County, and one is from each of the following counties: Lyon, Eureka, Lincoln, Douglas, Elko, and Humboldt [See table 1]. The structure types vary: seven concrete box girder bridges, three steel girder bridges, two prestressed girder bridges, two composite girder bridges, two concrete slab bridges, one steel cantilever truss bridge, one steel and concrete girder bridge, one rigid concrete frame bridge, and one concrete T-beam bridge were selected. The bridges carry a wide range of traffic volumes and route types: nine carry interstates, six carry urban routes, three carry primary routes, and two carry secondary routes.

3.2 Analysis of Prioritization Procedures

After the twenty bridges were analyzed using the various procedures, they were ranked. The rankings varied greatly from procedure to procedure. The rankings for bridge 663 varied by 16 between the California and Missouri procedures [See table 2]. To compare the procedures an average ranking was calculated. The average ranking was calculated by summing the rankings for each bridge from each procedure. This provided a total ranking score for each bridge. For bridge 1233, the total score was 12 (1+5+1+4+1) [see table 2]. The scores were then organized from the lowest total (12, Rank 1) to the highest total (88, Rank 20) [See table 2].

The average ranking was then compared to each of the procedures individually. This comparison was made by taking the difference between the average rank and the rank of the procedure being compared. Then the differences for all twenty bridges were added together to get the total deviation. By comparing the total deviation of each model, the New York procedure was the closest to the average ranking of the five prioritization procedures tested [See table 2].

Another method of comparison was to determine, for each procedure, the number of bridges whose ranking was more than 2 from the average ranking. The results of the second method of comparison indicated that the New York method was again closest to the average ranking.

3.3 Features of each Procedure

The prioritization procedures were then compared by the items that they considered, and by the effectiveness of their formulas. The factors that represented an item or condition with high objectivity were considered good. Formulas or mathematical operations that modeled an effect with the desired distinguishable results were considered good. Arbitrary caps that limited the effective range of a factor were considered poor.

The Nevada seismic prioritization procedure importance factor is capped. The score could be as high as 18 but is limited to 10. The importance factor considers a variety of items for the route on the bridge but fails to consider any route that may go under the bridge. The vulnerability factor scores bridge details that are related to changes in code requirements and design practices. The vulnerability factor could go as high as 18 but is limited to 10. The seismicity factor is based on the expected ground acceleration, and doesn't consider any soil effects. All the factors are separate, weighted equally, and have no interaction with each other.

The California seismic prioritization procedure separates all the items considered, and the factors do not interact. The structure importance is based on a variety of items that affect the routes on and under the structure. The vulnerability is based on year constructed and structure details that tend to increase earthquake effects. The seismicity is based on rock acceleration and soil effects. The factors related to vulnerability determine half of the overall score, and the factors related to importance and seismicity determine one forth of the score each.

The Illinois prioritization procedure directly relates structure vulnerability and seismicity. The vulnerability calculation is very complex. Therefore, it was not used for ranking the bridges. The importance factor considers a wide range of factors, both on and under the bridge. The final score is the product vulnerability and importance; this yields a better score separation than a summation.

The Missouri seismic prioritization procedure's vulnerability factor is based on structure type, not on vulnerable details. The seismicity factor considers soil effects in addition to rock acceleration. The importance is based on the route below the structure almost to the same degree as the route on the structure. The final score is a product which yields a better score separation than a summation.

The New York seismic prioritization procedure assesses vulnerability based on ATC/FHWA guidelines. The importance factor is based on items associated with the route on and under the structure, but also considers replacement cost verse retrofit cost. The seismicity is based on soil effects and rock acceleration. The weights can be changed to emphasize one or two of the three factors before adding them together.

The Washington prioritization procedure's importance factor, criticality, is based primarily on items associated with the route on the structure, but still considers the route under the structure. The vulnerability factor is based on ATC/FHWA guidelines, rock acceleration, and soil effects. The final score is a product which yields a better score separation than a summation.

4. THE PROPOSED SEISMIC PRIORITIZATION PROCEDURE

A new hybrid seismic prioritization procedure was developed based on the analysis and comparison of the existing methods. The new procedure is broken into two factors: importance and seismic vulnerability. The new procedure was designed to be relatively simple to calculate, to use easily available information as much as possible, and to provide a wide range of values.

4.1 Importance

There are many factors that determine a bridge's importance. Considering all of them would require lengthy calculations and allowing subjective scoring can yield inaccurate results. The items selected and the approximate percentage of the importance factor they represent are: the route type on and under the structure (33%), the amount of traffic on and under the structure affected by direct losses and future service loss (36%), the detour lengths for routes on and under the structure (11%), the presence of utility lines on the structure (5.6%), a defense route designation for the route on the structure (5.6%), and the presence of a railroad (8.3%). A replacement verse retrofit cost comparison is not included and should be done for high ranking bridges that are being considered for retrofit.

The importance factor, **I**, is the sum of six sub-factors: route type, traffic, detour length, utility lines, defense route, and railroad. The formula is expressed as follows.

$$I = RT + T + Det + Ut + Def + RR$$

The range of values for the importance factor is not fixed, but will commonly range from 1 to 17.

The route type factor, **RT**, is the sum of the values assigned for the route on and the route under the structure. Interstates are assigned a value of 3, primary highways 2, secondary highways 1, and other routes 0. Urban routes are classified as either primary or secondary highways.

The traffic factor, **T**, is the sum of the t values which are calculated for the route on the structure and for the route under the structure. The formula for t is as follows.

$$t=\frac{\sqrt{ADT}}{100}(1+\frac{\sqrt{(LW)(N)}}{300})$$

ADT is the average daily traffic for the route on or under the structure. The ADT used in the equation is limited to 90,000 vehicles per day. This limits the first term of the equation to 3. The factor was limited after an ADT of 90,000 because it was felt that the impact would not change. There are only a few bridges with an ADT above 90,000 vehicles per day. In addition, there was a need to maintain a balance between the ADT factor and other portions of the importance factor. LW is the length of the bridge in feet when evaluating the route on the structure, and the width of the structure when evaluating the route under the bridge. N is the number of lanes on or under the structure. The traffic factor accomplishes several things, it increases the importance score for large bridges and it increases the importance score based on the direct and long term losses that are due to bridge failure.

The detour length factor, **Det**, is calculated by adding the detour length of the route on the structure in miles to the detour length of the route under the structure and then dividing by 10. The detour length factor is limited to 2. The Utility lines factor, **Ut**, is assigned a value of 1 if utility lines are present on the bridge. If no utility lines are present a value of 0 is used.

The defense factor, **Def**, is assigned a value of 1 if the route on or under the bridge is designated as part of the Strategic Highway Network. If the route on or under the bridge is not a defense route a value of 0 is used. The railroad factor, **RR**, is assigned a value of 1.5 if a railroad is on or under the structure. If no railroad is present then a value of 0 is used.

4.2 Seismic Vulnerability

The seismic vulnerability factor, **SV**, combines vulnerability and seismicity so that they can interact; this interaction is desired because seismicity and vulnerability interact during an earthquake. The seismic vulnerability factor is based on vulnerability, soil effects, and bedrock acceleration. The range of values for seismic vulnerability is not fixed, but will commonly range from 1 to 14.

The vulnerability factor, **V**, is the same as the current Nevada seismic prioritization procedure's vulnerability factor. The ATC/FHWA guidelines for vulnerability are used in two of the five methods analyzed, the Nevada vulnerability is an improved version of these guidelines. The Nevada vulnerability factor was determined to be appropriate because it evaluates the structure details that can cause failure, other methods either over generalize structures into groups or require a time consuming seismic analysis. The cap is removed from the vulnerability factor. The vulnerability can be assigned a value up to 18. The vulnerability factor is calculated by first determining which critical details exist. The critical bridge details and their scores are as listed below.

1. Bearing susceptible to collapse
    a. Simple span bridge 6
    b. Continuous span bridge 4
2. Non-confined column core
    a. Single columns 6
    b. Multiple columns 4
3. Main column reinforcing spliced in plastic hinge zone

		$30\ d_b$ Lap	$< 30\ d_b$ Lap
a.	Single columns	5	6
b.	Multiple columns	4	5

4. Main column reinforcing (inadequate development length into support)

    a. Single columns 6
    b. Multiple columns 5

5. Small abutment or pier seat width

    a. Single span 7
    b. Multiple single spans 8

6. Unrestrained hinges 6

The second step is to look through the values associated with each detail and choose the largest. The vulnerability factor is assigned the critical detail's score plus 2 points for each of the other details that are present. The vulnerability will range from 0 to 18.

The soil effects factor, **F**, is assigned values based on the soil conditions at the bridge location. The soil effects factor can be assigned a value of 1 for low risk soils (AASHTO Type I), 1.2 for moderate risk soils (AASHTO Type II), 1.5 for high risk soils (AASHTO Type III), 2 for very high risk soils (AASHTO Type IV). Other classifications can also be used to assign soil effects values. A value of 1.2, moderate risk, is recommended when soil information is not available for a bridge location.

The bedrock acceleration factor, **A**, is assigned values based on the Geological Survey maps. A minimum value of 0.15 shall be used, with no maximum value.

The seismic vulnerability factor, **SV**, is calculated using the following formula.

$$SV = 1 + (V)(A)(F)$$

The formula will give a range of values between 1 and approximately 14. A one was added to the product of the three factors to allow bridges that receive a zero vulnerability score to have a non-zero seismic vulnerability score and thus a non-zero overall score.

4.3 Risk

The overall score or risk is determined by the following formula:

$$\mathbf{Risk = 10(SV)(I)}$$

The overall risk score will usually be between 10 and 1000. The formula was designed to generally give three significant digits, this gives a wide range for easy ranking without having to keep decimals in the final score.

5. ANALYSIS AND USE OF THE PROPOSED PROCEDURE

The proposed prioritization procedure was used to prioritize the same twenty bridges that had been ranked using the other procedures. The proposed prioritization procedure did require slightly more time to complete than most of the other procedures.

5.1 Comparison with Existing Procedures

The ranking from the new procedure was compared to the average ranking in the same manner as the other methods [See Table 3]. The new procedure had a greater total deviation from the average ranking than the New York procedure, but it had a smaller total deviation than all the other procedures tested. The new ranking was then compared using the second comparison method, the greater than 2 deviation. The proposed method had slightly more deviations than the New York procedure, the same number of deviations as the Washington and Nevada procedures [See table 3].

When using the deviation from the average ranking, the New York seismic prioritization procedure was closer to the average than the proposed prioritization procedure by 12%. The New York procedure did have the benefit of contributing to the average ranking. When the average ranking was recalculated without the results of the New York procedure, the total deviation of the proposed procedure decreased to 28 and the New York procedure's total deviation increased to 44. This caused the number of deviations for the New York procedure to be 57% larger than the proposed procedure.

The total deviations for the Washington seismic prioritization procedure was 6% larger than the proposed procedure, but it also had the benefit of contributing to the average ranking. When the average ranking was recalculated without the Washington procedure's results, the proposed procedure's total deviation was slightly larger than before (40 vs 32). The Washington procedure's total deviation was also larger (50 vs 38), 25% larger than the total deviation of the proposed prioritization procedure.

When compared to the average ranking, the total deviation of the other three seismic prioritization procedures were much larger than that of the proposed seismic prioritization procedure, more than 20% larger. Since the average ranking is only an average of the initial five procedures analyzed, none of the existing procedure can be labeled as wrong regardless of the "accuracy" they displayed. But on the basis of our comparison, the proposed seismic prioritization should be considered the best method. Table 4 shows the new ranking of the twenty bridges. Two bridges from Clark and one bridge from Lyon have moved into the top six of twenty bridges selected.

5.2 Example of the Proposed Prioritization Procedure

The following is an example using the proposed prioritization procedure for ranking bridge number 1233. Bridge number 1233 is a composite girder located on an interstate in Washoe County.

Importance

route type on the bridge: interstate
route type under the bridge: primary highway and railroad
RT = 3 + 2 = 5
RR = 1.5
detour length for route on the bridge: 1
detour length for route under the bridge: 0
Det = (1 + 0)/10 = 0.1
ADT on the bridge: 69,000
ADT under the bridge: 12,200
Length: 486
Width: 95

Number of lanes on the bridge: 6

Number of lanes under the bridge: 4

$$t_1 = (\frac{\sqrt{69,000}}{100})(1 + \frac{\sqrt{486(6)}}{300}) = 3.1$$

$$t_2 = (\frac{\sqrt{12,200}}{100})(1 + \frac{\sqrt{95(4)}}{300}) = 1.18$$

T = 3.10 + 1.18 = 4.3

route on bridge is designated as a defense route

Def = 1

bridge supports utility lines

Ut = 1

I = 5 + 1.5 + 0.1 + 4.3 + 1 + 1 = 12.9

Seismic vulnerability

bridge has adequate bearings: 0

bridge has multiple columns/bent with inadequate confinement: 4

bridge has main column spliced in plastic hinge zone: 4

bridges has inadequate development length into support: 5

bridge has adequate seat width: 0

bridge has no unrestrained hinges: 0

V = 5 + 2 + 2 = 9

Bridge bedrock acceleration: 0.4

A = 0.4

Soil classification: AASHTO I

F = 1

SV = 1 + 9(0.4)(1) = 4.6

Risk = 10(4.6)(12.9) = 593

Bridge 1233 received the highest score, 593 of the twenty bridges selected.

6. SUMMARY

The six existing seismic prioritization procedures gave results that varied widely. Several observations about the existing procedures were incorporated into the proposed prioritization procedure: multiplying factors allows them to interact and manipulates the overall score better than simply adding the different factors, capping a factor causes it to lose influence and objectivity, and normalizing should be used if a specific range of values is desired. As many items as possible that had significant influence on a bridge's importance or vulnerability and that could be easily represented mathematically were included in the proposed method. The items considered were then combined in ways that modeled how they are related.

A seismic prioritization procedure can not be proven to be the best. Even so, a comparison was made in an effort to determine the most effective procedure. None of the existing methods were found to be more effective than the other methods. Therefore, a new method was created by incorporating the positive aspects of the existing methods. The proposed seismic prioritization was evaluated and does a good job of evaluating the structures. The new model introduced several new variables into the Nevada prioritization procedure including soil effects, bridge size, and the interaction between vulnerability and seismicity.

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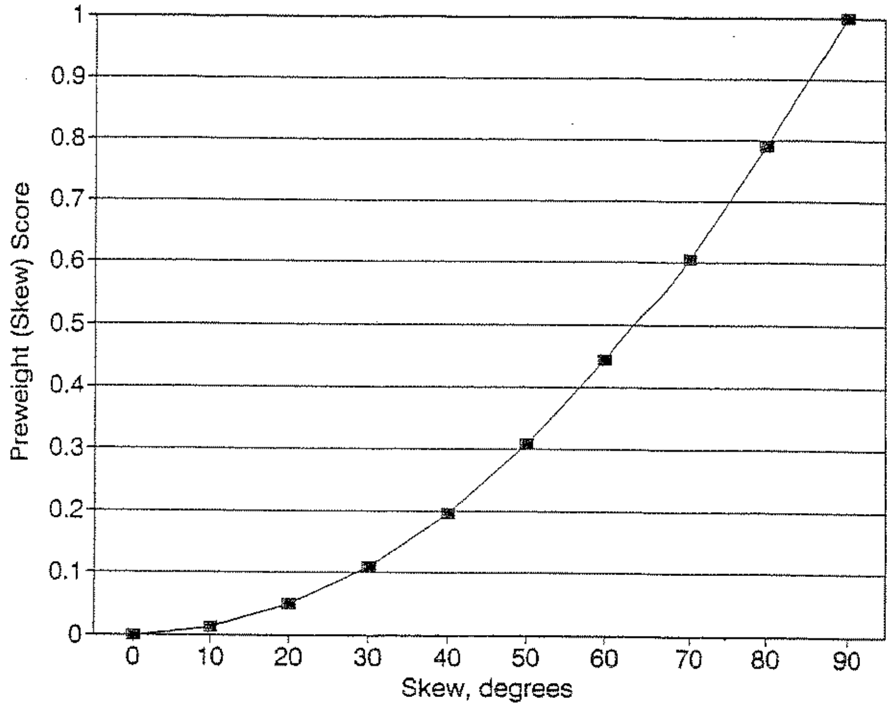


Figure 1: CALTRANS Skew Preweight Function, Positive Parabola [6]

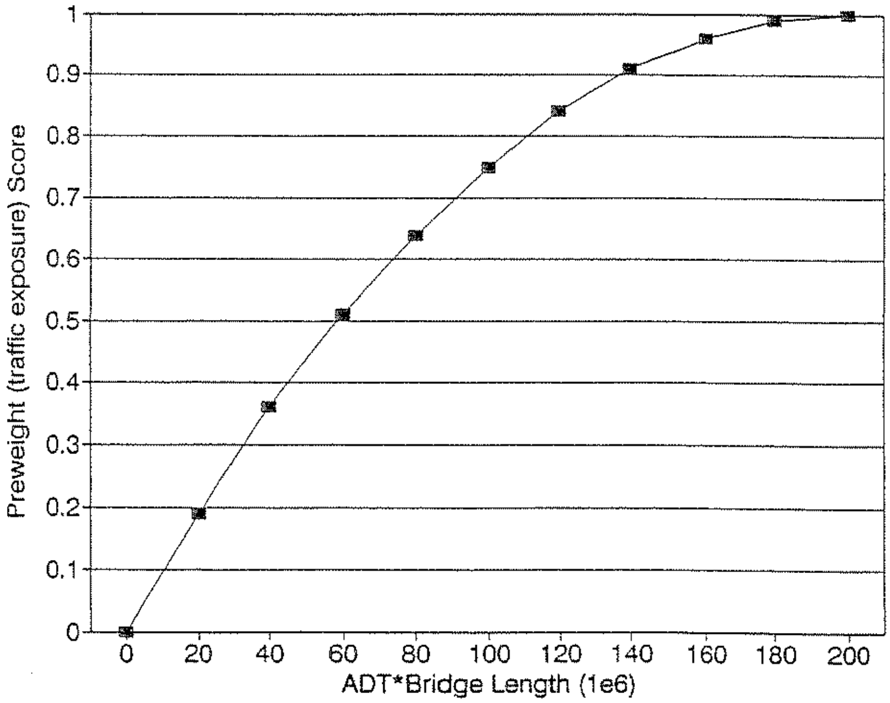


Figure 2: CALTRANS Traffic Exposure Factor, Negative Parabola [6]

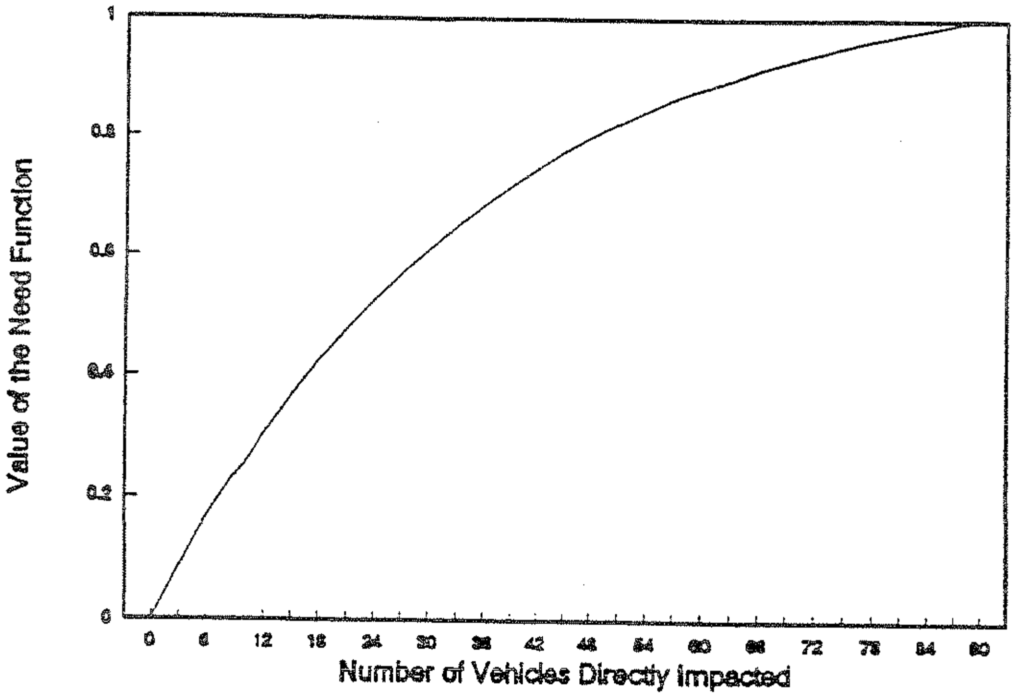


Figure 3: Illinois Need Function for Number of Vehicles Directly Impacted [5]

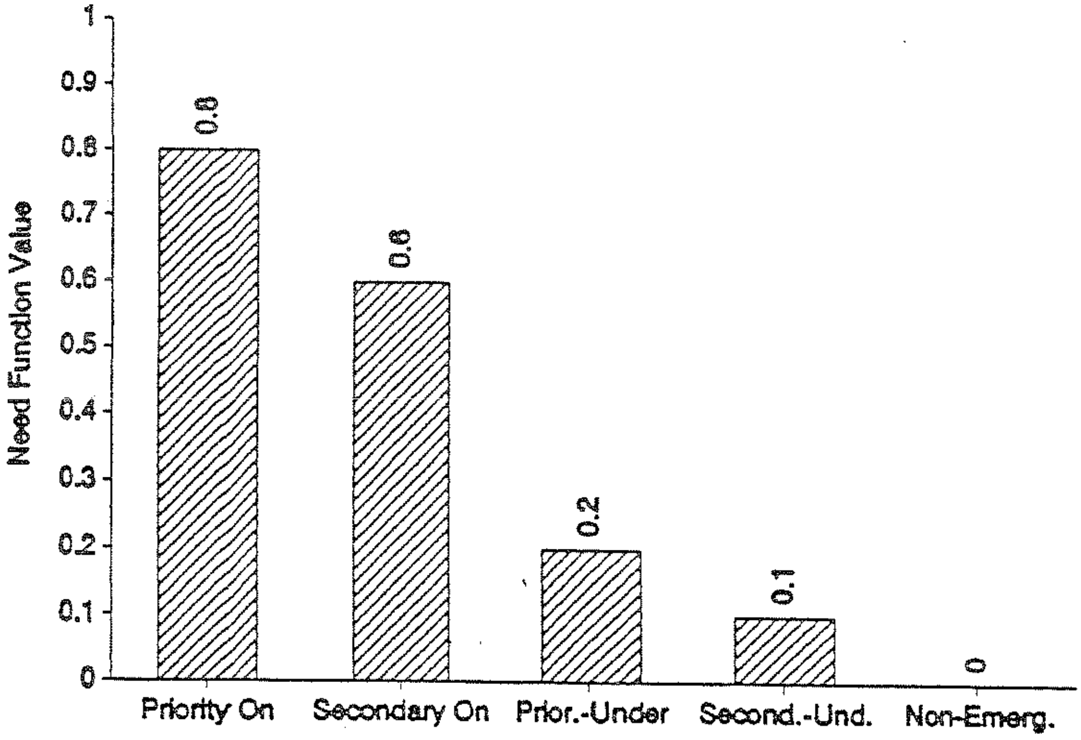
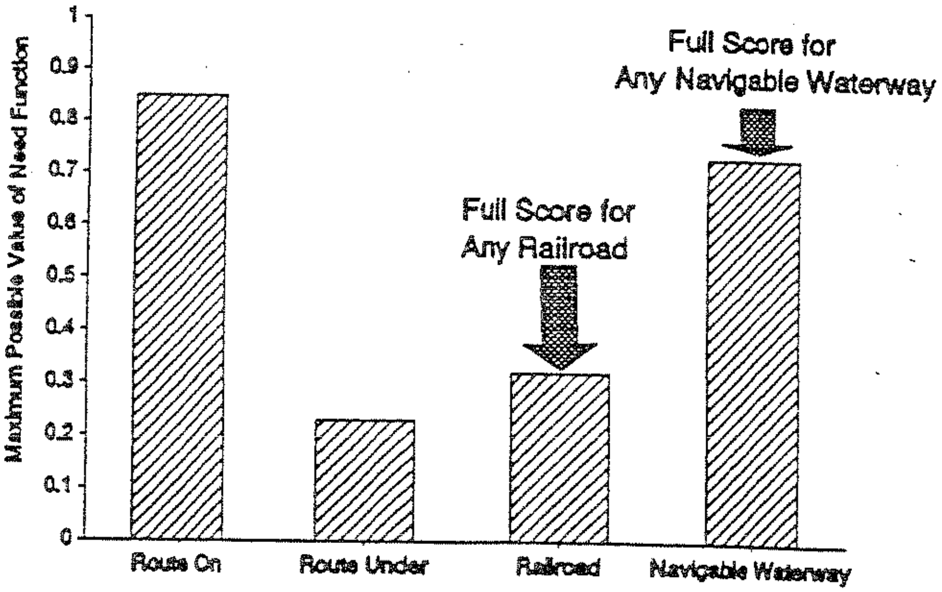


Figure 4: Illinois Need Function Values for Emergency Routes [5]



Note: Maximum Value of Need Function = 1.
Maximum possible in all categories does not occur on any
Single bridge; also, fuction is not linear.

Figure 5: Illinois Need Function Values for Vehicle Miles of Detour [5]

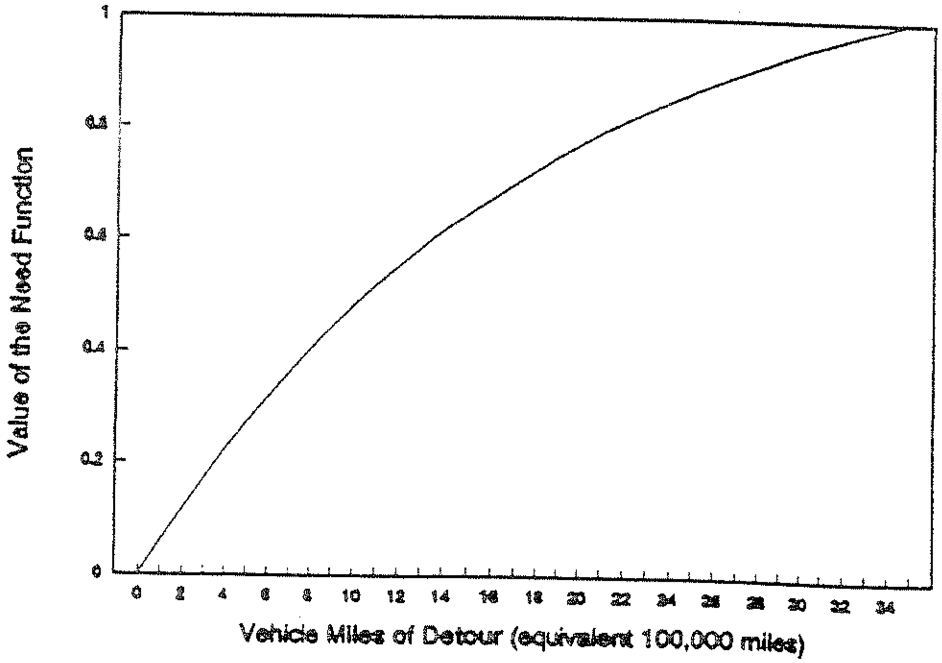


Figure 6: Illinois Need Function for Vehicle Miles of Detour [5]

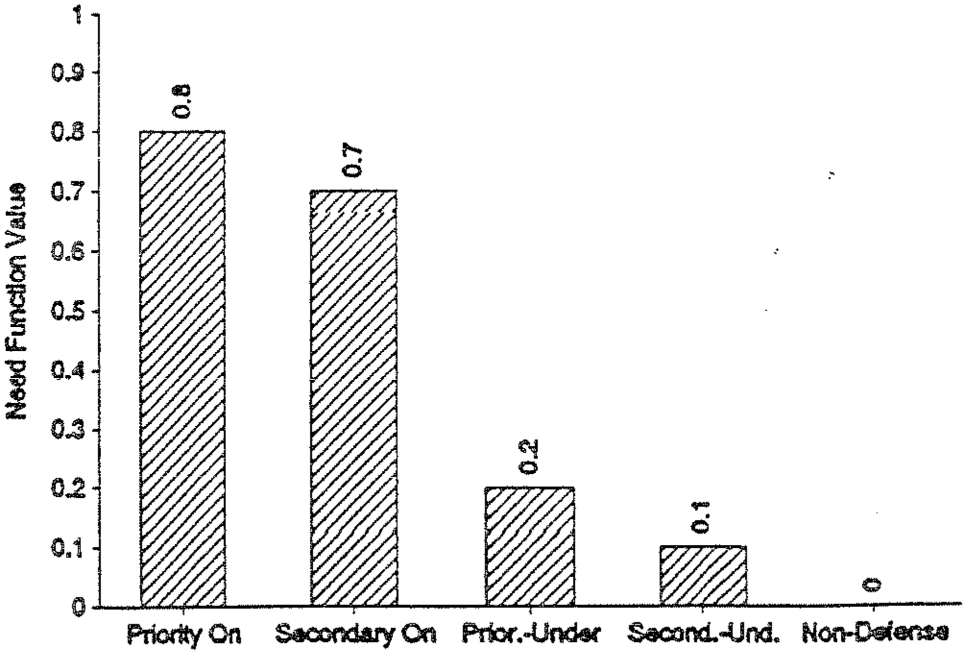


Figure 7: Illinois Need Function Values for Defense Routes [5]

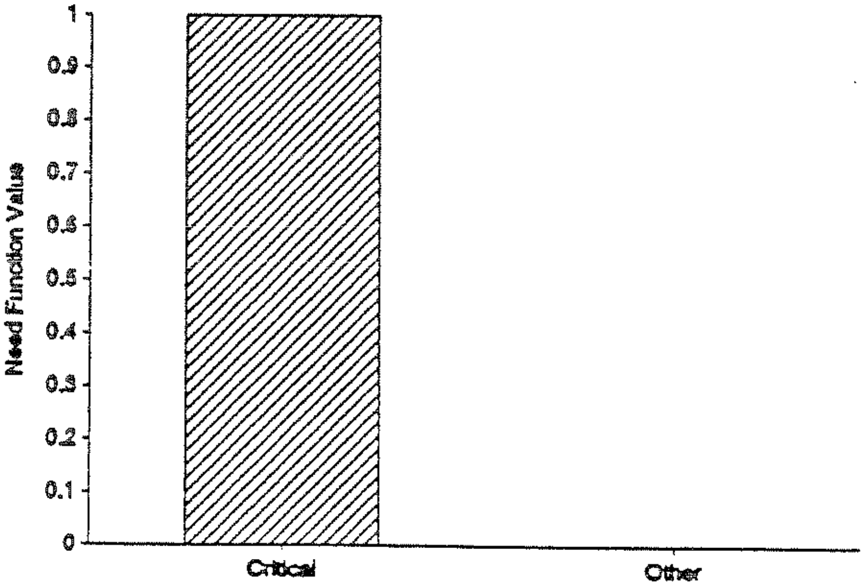


Figure 8: Illinois Need Function Value for Utilities [5]

Table 1: **Comparison Bridges from the Nevada Bridge Inventory with Current Nevada Method**

Bridge Number	Nevada Score	Structure Type	Route Type	County
1233	97	composite girder	interstate	Washoe
1306	90	prestressed girder	urban	Washoe
764E	90	composite girder	interstate	Washoe
1003	90	concrete box girder	interstate	Washoe
716E	87	prestressed girder	interstate	Washoe
992	83	concrete box girder	urban	Washoe
1262S	73	steel + concrete girder	primary	Douglas
939	73	concrete box girder	interstate	Clark
788	73	concrete box girder	urban	Clark
796	73	concrete box girder	urban	Clark
1007E	68	concrete box girder	interstate	Washoe
146	67	concrete T-beam	secondary	Lyon
258	62	steel girder	urban	Washoe
883	60	concrete slab	interstate	Eureka
663	56	concrete box girder	secondary	Clark
219	49	steel cantilever truss	primary	Lincoln
223	35	steel girder	primary	Humboldt
1487	35	steel girder	urban	Washoe
923	29	concrete slab	interstate	Elko
667S	29	concrete rigid frame	interstate	Clark

Table 2: Bridge Rankings using Five Prioritization Procedures

Bridge Number	Average Rank	Nevada Rank (score)	California Rank (score)	Missouri Rank (score)	New York Rank (score)	Washington Rank (score)
1233	1	1 (97)	5 (53)	1 (380)	4 (70)	1 (54)
1306	8	2 (90)	8 (50)	4 (90)	13 (43)	10 (15)
764E	6	3 (90)	6 (51)	8 (52)	9 (55)	5 (24)
1003	2	4 (90)	10 (47)	2 (130)	2 (74)	2 (47)
716E	5	5 (87)	3 (55)	9 (47)	5 (66)	8 (16)
992	7	6 (83)	13 (42)	3 (110)	6 (63)	3 (34)
1262S	16	7 (73)	20 (28)	16 (15)	16 (29)	17 (0)
939	3	8 (73)	1 (58)	5 (69)	1 (76)	6 (22)
788	10	9 (73)	7 (50)	15 (17)	7 (61)	11 (15)
796	4	10 (73)	4 (53)	6 (63)	3 (70)	4 (34)
1007E	9	11 (68)	12 (42)	7 (59)	8 (59)	15 (5)
146	11	12 (67)	9 (49)	11 (22)	10 (50)	7 (17)
258	14	13 (62)	15 (38)	12 (22)	15 (38)	16 (3)
883	15	14 (57)	18 (33)	17 (11)	12 (44)	12 (10)
663	12	15 (56)	2 (57)	18 (10)	14 (38)	13 (6)
219	13	16 (49)	11 (45)	19 (9)	11 (48)	9 (16)
223	18	17 (35)	19 (31)	13 (21)	17 (26)	14 (6)
1487	17	18 (35)	17 (33)	10 (36)	19 (22)	18 (0)
923	19	19 (29)	16 (35)	20 (5)	18 (22)	19 (0)
667S	20	20 (29)	14 (40)	14 (17)	20 (15)	20 (0)
Total Deviation		46	66	60	32	38
Greater than Two Deviation		7	11	9	5	7

Table 3: Proposed Prioritization Procedure

Bridge Number	County	Average Rank	New York Rank (score)	Washington Rank (score)	Nevada Rank (score)	Proposed Rank (Score)
1233	Washoe	1	4 (70)	1 (54)	1 (97)	1 (593)
1306	Washoe	8	13 (43)	10 (15)	2 (90)	8 (295)
764E	Washoe	6	9 (55)	5 (24)	3 (90)	3 (385)
1003	Washoe	2	2 (74)	2 (47)	4 (90)	2 (543)
716E	Washoe	5	5 (66)	8 (16)	5 (87)	9 (275)
992	Washoe	7	6 (63)	3 (34)	6 (83)	7 (331)
1262S	Douglas	16	16 (29)	17 (0)	7 (73)	11 (198)
939	Clark	3	1 (76)	6 (22)	8 (73)	5 (348)
788	Clark	10	7 (61)	11 (15)	9 (73)	10 (218)
796	Clark	4	3 (70)	4 (34)	10 (73)	6 (335)
1007E	Washoe	9	8 (59)	7 (17)	11 (68)	4 (355)
146	Lyon	11	10 (50)	15 (5)	12 (67)	12 (147)
258	Washoe	14	15 (38)	16 (3)	13 (62)	16 (108)
883	Eureka	15	12 (44)	12 (10)	14 (57)	13 (142)
663	Clark	12	14 (38)	13 (6)	15 (56)	15 (110)
219	Lincoln	13	11 (48)	9 (16)	16 (49)	14 (129)
223	Humbolt	18	17 (26)	18 (0)	17 (35)	18 (55)
1487	Washoe	17	19 (22)	19 (0)	18 (35)	20 (25)
923	Elko	19	18 (22)	14 (6)	19 (29)	19 (45)
667S	Clark	20	20 (15)	20 (0)	20 (29)	17 (59)
Total Deviation			32	38	46	36
Greater than Two Deviation			5	7	7	7

Table 4: **Comparison Bridges from the Nevada Bridge Inventory according to Proposed Prioritization Procedure**

Bridge Number	Nevada Score	Structure Type	Route Type	County
1233	593	composite girder	interstate	Washoe
1003	543	concrete box girder	interstate	Washoe
764E	385	composite girder	interstate	Washoe
1007E	355	concrete box girder	interstate	Washoe
939	348	concrete box girder	interstate	Clark
796	335	concrete box girder	urban	Clark
992	331	concrete box girder	urban	Washoe
1306	295	prestressed girder	urban	Washoe
716E	275	prestressed girder	interstate	Washoe
788	218	concrete box girder	urban	Clark
1262S	198	steel + concrete girder	primary	Douglas
146	147	concrete T-beam	secondary	Lyon
883	142	concrete slab	interstate	Eureka
219	129	steel cantilever truss	primary	Lincoln
663	110	concrete box girder	secondary	Clark
258	108	steel girder	urban	Washoe
667S	59	concrete rigid frame	interstate	Clark
223	55	steel girder	primary	Humboldt
923	45	concrete slab	interstate	Elko
1487	25	steel girder	urban	Washoe

Appendix

Table A-1 Proposed Prioritization Procedure Data

Bridge #	**1233**	**1003**	**764E**	**1007E**	**939**
ADT On	*69000*	*80650*	*11450*	*13950*	*24500*
# of Lanes On (N)	*6*	*6*	*2*	*2*	*1*
Length (L)	*486*	*218*	*452*	*182*	*311*
$t_1 = \frac{\sqrt{ADT}}{100}(1 + \frac{\sqrt{(LW)(N)}}{300})$	3.1	3.18	1.18	1.26	1.66
ADT Under	*12200*	*15000*	*Not Appl.*	*41900*	*67910*
# of Lanes Under (N)	*4*	*4*	*Not Appl.*	*4*	*4*
Width (W)	*95*	*110*	*Not Appl.*	*42*	*26*
$t_2 = \frac{\sqrt{ADT}}{100}(1 + \frac{\sqrt{(LW)(N)}}{300})$	1.18	1.31	Not Appl.	2.14	2.69
Route Type On (RT_1)	Inter. 3	Inter. 3	Inter. 3	Inter. 3	Inter. 3
Route Type Under (RT_2)	Primary 2	Primary 2	Not Appl.	Primary 2	Primary 2
Railroad (RR)	Yes 1.5	No 0	No 0	No 0	No 0
Utilities (UT)	Yes 1	Yes 1	No 0	No 0	No 0
Defense (Def)	Yes 1	Yes 1	Yes 1	Yes 1	Yes 1
Detour Length On	*1*	*3*	*3*	*2*	*3*
Detour Length Under	*0*	*0*	*Not Appl.*	*0*	*0*
Detour Length Combined/10 (Det)	0.1	0.3	0.3	0.2	0.3
Importance (I) = $t_1+t_2+RT_1+RT_2+RR+UT+Def+Det$	**12.9**	**11.8**	**5.5**	**9.6**	**10.7**
Bearing (S or C)	0	0	6	0	0
Confined Columns (S or M)	4	4	4	4	6
Splice in Hinge (S or M)	4	4	4	4	6
Development (S or M)	5	5	5	0	0
Abutment Width (S or M)	0	0	7	0	0
Hinge	0	0	0	0	6
Vulnerability (V)	**9**	**9**	**15**	**6**	**10**
Acceleration (A)	**0.4**	**0.4**	**0.4**	**0.3**	**0.15**
Soil (F)	**A-2 1**	**A-1 1**	**A-1 1**	**A-5 1.5**	**A-5 1.5**
Seismic Vulnerability (SV) = 1+ VAF	**4.6**	**4.6**	**7**	**3.7**	**3.25**
RISK = 10 (I) (SV)	**593**	**543**	**385**	**355**	**348**

Table A-2 Proposed Prioritization Procedure Data

Bridge #	796	992	1306	716E	788
ADT On	*61300*	*7505*	*4720*	*6390*	*5570*
# of Lanes On (N)	*5*	*4*	*2*	*2*	*2*
Length (L)	*265*	*217*	*257*	*313*	*263*
$t_1 = \frac{\sqrt{ADT}}{100}(1+\frac{\sqrt{(LW)(N)}}{300})$	2.78	0.95	0.74	0.87	0.80
ADT Under	*13785*	*52465*	*32865*	*Not Appl.*	*31285*
# of Lanes Under (N)	*4*	*6*	*4*	*Not Appl.*	*4*
Width (W)	*74*	*64*	*51*	*Not Appl.*	*33*
$t_2 = \frac{\sqrt{ADT}}{100}(1+\frac{\sqrt{(LW)(N)}}{300})$	1.24	2.44	1.90	Not Appl.	1.84
Route Type On (RT_1)	Primary 2	Second. 1	Second. 1	Inter. 3	Second. 1
Route Type Under (RT_2)	Inter. 3	Inter. 3	Primary 2	Not Appl.	Inter. 3
Railroad (RR)	No 0	No 0	No 0	No 0	No 0
Utilities (UT)	Yes 1	Yes 1	No 0	No 0	No 0
Defense (Def)	No 0	No 0	No 0	Yes 1	No 0
Detour Length On	*3*	*3*	*3*	*1*	*3*
Detour Length Under	*0*	*0*	*0*	*Not Appl.*	*0*
Detour Length Combined/10 (Det)	0.3	0.3	0.3	0.1	0.3
Importance (I) = $t_1+t_2+RT_1+RT_2+RR+UT+Def+Det$	10.3	8.7	5.9	5	6.9
Bearing (S or C)	0	0	0	0	6
Confined Columns (S or M)	4	4	0	4	4
Splice in Hinge (S or M)	0	0	4	4	0
Development (S or M)	5	5	5	5	5
Abutment Width (S or M)	0	0	0	0	0
Hinge	6	0	6	0	6
Vulnerability (V)	10	7	10	9	12
Acceleration (A)	0.15	0.4	0.4	0.42	0.15
Soil (F)	A-5 1.5	A-1 1	A-2 1	Unk. 1.2	A-3 1.2
Seismic Vulnerability (SV) = 1+ VAF	3.25	3.8	5	5.5	3.16
RISK = 10 (I) (SV)	335	331	295	275	218

Table A-3 Proposed Prioritization Procedure Data

Bridge #	**1262S**	**146**	**883**	**219**	**663**
ADT On	*7900*	*260*	*2367*	*500*	*45*
# of Lanes On (N)	*2*	*2*	*2*	*2*	*2*
Length (L)	*270*	*55*	*94*	*164*	*344*
$t_1 = \frac{\sqrt{ADT}}{100}(1 + \frac{\sqrt{(LW)(N)}}{300})$	0.96	0.17	0.51	0.24	0.07
ADT Under	*Not Appl.*	*Not Appl.*	*10*	*Not Appl.*	*21995*
# of Lanes Under (N)	*Not Appl.*	*Not Appl.*	*2*	*Not Appl.*	*4*
Width (W)	*Not Appl.*	*Not Appl.*	*43*	*Not Appl.*	*37*
$t_2 = \frac{\sqrt{ADT}}{100}(1 + \frac{\sqrt{(LW)(N)}}{300})$	Not Appl.	Not Appl.	0	Not Appl.	1.54
Route Type On (RT_1)	Primary 2	Second. 1	Inter. 3	Primary 2	Second 1
Route Type Under (RT_2)	Not Appl.	Not Appl.	Road 0	Not Appl.	Inter. 3
Railroad (RR)	No 0	No 0	No 0	No 0	No 0
Utilities (UT)	Yes 1	No 0	No 0	Yes 1	No 0
Defense (Def)	Yes 1	No 0	Yes 1	Yes 1	No 0
Detour Length On	*1*	*37*	*0*	*99*	*2*
Detour Length Under	*Not Appl.*	*Not Appl.*	*0*	*Not Appl.*	*0*
Detour Length Combined/10 (Det)	0.1	2	0	2	0.2
Importance (I) = $t_1+t_2+RT_1+RT_2+RR+UT+Def+Det$	5.1	3.2	4.5	6.2	5.8
Bearing (S or C)	0	6	0	6	0
Confined Columns (S or M)	0	0	6	0	0
Splice in Hinge (S or M)	0	0	0	0	6
Development (S or M)	6	0	0	0	0
Abutment Width (S or M)	0	0	0	0	0
Hinge	0	0	0	0	0
Vulnerability (V)	6	6	6	6	6
Acceleration (A)	0.4	0.4	0.24	0.15	0.15
Soil (F)	Unk. 1.2	A-5 1.5	A-5 1.5	Unk. 1.2	A-1 1
Seismic Vulnerability (SV) = 1+ VAF	3.88	4.6	3.16	2.08	1.9
RISK = 10 (I) (SV)	**198**	**147**	**142**	**129**	**110**

Table A-4 Proposed Prioritization Procedure Data

Bridge #	**258**	**667S**	**223**	**923**	**1487**
ADT On	*Not Appl.*	*5080*	*6100*	*2210*	*3500*
# of Lanes On (N)	*Not Appl.*	*2*	*6*	*2*	*4*
Length (L)	*Not Appl.*	*33*	*275*	*93*	*248*
$t_1 = \frac{\sqrt{ADT}}{100}(1 + \frac{\sqrt{(LW)(N)}}{300})$	Not Appl.	0.73	0.89	0.49	0.65
ADT Under	*5970*	*115*	*Not Appl.*	*10*	*Not Appl.*
# of Lanes Under (N)	*2*	*2*	*Not Appl.*	*2*	*Not Appl.*
Width (W)	*32*	*42*	*Not Appl.*	*42*	*Not Appl.*
$t_2 = \frac{\sqrt{ADT}}{100}(1 + \frac{\sqrt{(LW)(N)}}{300})$	0.78	0.11	Not Appl.	0	Not Appl.
Route Type On (RT_1)	Not Appl.	Inter. 3	Primary 2	Inter. 3	Second. 1
Route Type Under (RT_2)	Second 1	Second. 1	Not Appl.	Road 0	Not Appl.
Railroad (RR)	Yes 1.5	No 0	No 0	No 0	No 0
Utilities (UT)	No 0	No 0	Yes 1	No 0	No 0
Defense (Def)	No 0	Yes 1	Yes 1	Yes 1	No 0
Detour Length On	*Not Appl.*	*1*	*6*	*0*	*8*
Detour Length Under	*2*	*0*	*Not Appl.*	*0*	*Not Appl.*
Detour Length Combined/10 (Det)	0.2	0.1	0.6	0	0.8
Importance (I) = $t_1+t_2+RT_1+RT_2+RR+UT+Def+Det$	**3.5**	**5.9**	**5.5**	**4.5**	**2.5**
Bearing (S or C)	6	0	0	0	0
Confined Columns (S or M)	0	0	0	0	0
Splice in Hinge (S or M)	0	0	0	0	0
Development (S or M)	0	0	0	0	0
Abutment Width (S or M)	0	0	0	0	0
Hinge	0	0	0	0	0
Vulnerability (V)	7	0	0	0	0
Acceleration (A)	0.3	0.15	0.22	0.15	0.3
Soil (F)	A-2 1	Unk. 1.2	Unk. 1.2	Unk. 1.2	A-2 1
Seismic Vulnerability (SV) = 1+ VAF	3.1	1	1	1	1
RISK = 10 (I) (SV)	108	59	55	45	25

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Report No.	Publication
CCEER-84-1	Saiidi, M., and R. Lawver, "User's Manual for LZAK-C64, A Computer Program to Implement the Q-Model on Commodore 64," Civil Engineering Department, Report No. CCEER-84-1, University of Nevada, Reno, January 1984.
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