Assessment and Evaluations of I-80 Truck Loads and Their Load Effects: Phase 2: Service

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Problem Background

I-80 is a major transcontinental truck route that has a very high volume and percentage of trucks. Per a 9/29/2011 FHWA Memo, FHWA requires that five conditions must be met to use the assigned load rating as described in the AASHTO *Manual for Bridge Evaluation,* Second Edition. The memo is provided in Appendix A. The five conditions are:

Table 1: FHWA Memo Summary

Condition	**Status**
1. The bridge was designed and checked using either the AASHTO Load or Resistance Factor Design (LRFD) or Load Factor Design (LFD) methods to at least HL-93 or HS-20 live loads, respectively.	This is typical and not an issue.
2. The bridge was built in accordance with the design plans.	WYDOT construction processes ensures this.
3. No changes to the loading conditions or the structure condition have occurred that could reduce the inventory rating below the design load level.	If such occurs, then WYDOT rerated the bridge as applicable.
4. An evaluation has been completed and documented, determining that the force effects from State legal loads or permit loads do not exceed those from the design load	Typical in-service trucks load may exceed the older and/or the current design loads.
5. The checked design calculations, and relevant computer input and output information, must be accessible and referenced or included in the individual bridge records.	WYDOT has robust bridge inventory records.

All but the fourth condition are readily met. Many state agencies are uncertain about their current load spectra. As an example WYDOT's I-80 is especially critical and unique for Wyoming and other agencies in the Rocky Mountain region.

When I-80 closes, there is a high concentration of trucks approaching 100% as shown in Figure 1. These trucks are closely spaced and occupy the two traffic lanes as shown in Figure 2. Similar trucks often run together, thereby producing correlated loadings as shown in Figure 3. Typically, correlated loads create a larger load effect on the bridges than uncorrelated.

Few other states have this type of loading and the current design loads were not calibrated considering this type of truck percent, spacing, or correlation. Moreover, road closures are not unusual in Wyoming, so this is not an "extreme" event but rather business as usual.

Figure 1: Traffic after Reopening

Figure 2: Two-Lane Loading

Figure 3: Correlated Loading

These observations indicate that Wyoming loads are significantly different than other states or regions. Furthermore, an initial study titled *Assessment and Evaluations of I-80 Truck Loads and Their Load Effects* was performed to assess the strength limit state, which confirmed that Wyoming's truck traffic along I-80 creates more demand than that assumed in the AASHTO LRFD bridge design procedures. The greater demand results in reliability indices that do not meet target safety levels for the strength limit state. A series of recommendations were made to WYDOT for the strength limit state:

1. There is an optional low-boy tandem load where there is a tandem in adjacent spans in the AASHTO LRFD commentary that significantly increases the negative design live load moments. Using the low-boy tandem, the reliability indices for the shorter two-span bridges were raised to 3.00 and above, placing this bridge type into the range of the reliability indices for the other length bridges.

   Recommendation – WYDOT incorporate the commentary low-boy tandem load case as part of the HL93 loading for designing interstate bridges

2. If the commentary low-boy tandem loading is used, all of the reliability indices are fairly consistent. However, they are below the target. Raising the design live load factor, γ_L, directly and fairly uniformly increases reliability indices. An increase in γ_L to 2.00 (from 1.75) increases almost all of the reliability indices above 3.50 with just a couple dipping slightly below.

   Recommendation – WYDOT increases the live load factor, γ_L, to 2.00

3. An alternative to a live load factor increase to 2.00 is to consider a different method for the statistical properties of the live load model. The AASHTO LRFD Bridge Specifications were developed under NCHRP projects that used truck database raw data upper tail statistical procedures to estimate maximum truck load effects. When the procedures were applied to the Wyoming 1000 truck database, the required increase of the live load factor is 1.90, smaller than the 2.00 noted above.

   Alternative Recommendation - WYDOT increases the live load factor, γ_L, to 1.90

Given the results of the initial study, there is a concern for the AASHTO damage limit states. The AASHTO LRFD Service II limit state controls the structural damage and permanent set. The live load model has been developed and could be applied to the Service II limit state to assess the potential for premature damage, cumulative damage, and rideability issues. Service III could be assessed as well.

This Phase II study is warranted to calibrate the AASHTO LRFD Service II and III limit states using weigh-in-motion (WIM) data specific to Wyoming. The Wyoming WIM data from the Pine Bluffs weigh station in the year 2014 were already processed in the initial study, which resulted in a database of truck characteristics (weights, axle spacings, lengths) that included the top 1000 critical trucks (from 821,956 records in the total WIM database).

This study would include performing statistical analyses to determine reliability indices for the same set of archetype bridges as the initial study. This set of bridges includes simple-span bridges with lengths between 30 ft and 200 ft (positive moments) and two-span bridges with equal spans lengths of 30 ft to 200 ft (negative moments). Furthermore, combining the WIM data with WYDOT's comprehensive database of existing bridges makes it possible to perform an analysis, rating, and rigorous analysis of these structures for actual in-service loads.

Study Objectives

This project will address the following questions:

- Are the FHWA requirements outlined in the 9/29/2011 memo met for the service limit states?
- How do the Current Legal Loads compare to Wyoming weigh-in-motion (WIM) data and vehicles allowed by state statutes?
- How do the WIM and current Legal Loads compare to the AASHTO LRFR Legal/Rating Loads?
- Can the damage effects of large loads on I-80 begin to be quantified?

Study Benefits

There are several benefits that will be realized by WYDOT from this project:

- FHWA requirements met for service limit states
- Improved understanding of design and operational loads
- Better understanding of live loads related to rating factor and damage
- Rigorous calibration method for estimating live effects for design and rating
- Rigorous structural analysis (BRASS™ girder software and routing system)

Anticipated Outcomes

There are several anticipated outcomes from this project:

- Wyoming will have one of the most advanced rating systems in the United States for long-term use.
- Wyoming will have a system to help quantify the load effects of actual loads and possibly the associated damage (for example, Service II and III limit states). Trucks are obviously hard on roadways, especially I-80.
- Possible spin-off of future studies for pavement analysis, fatigue, etc.
- Wyoming will have a "leg up" on the impact of any proposed legal loads. Recently, the six-axle 97k TRB truck illustrated in Figure 4 was considered, but ultimately not adopted. This work was summarized in the *Comprehensive Truck Size & Weight Limits Study Report to Congress*, April 2016, which indicates that more investigation is necessary before any transportation policy decisions are made.

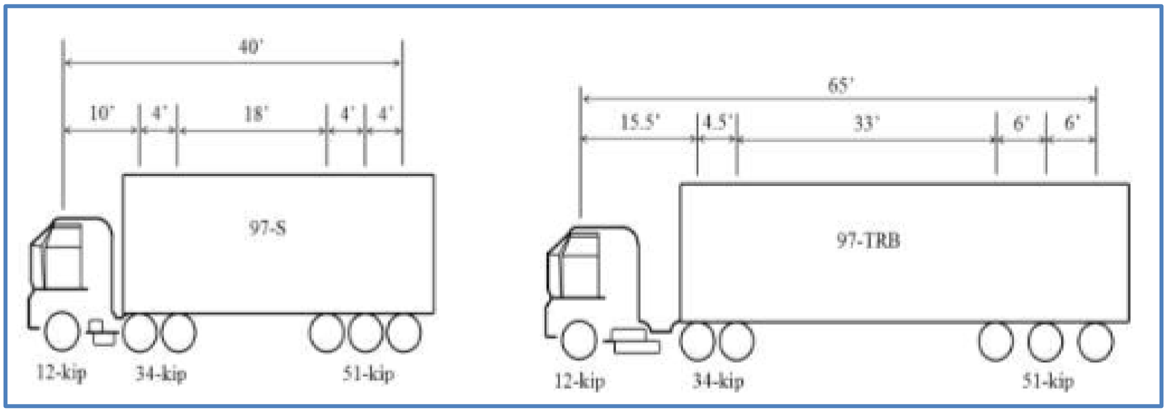

Figure 4: 97 kip Proposed Truck

Work Plan

The approach for accomplishing the objectives will make use of existing WYDOT assets. The following sections describe the work plan tasks.

Literature Review

An initial literature review has been conducted as well as studies yet to be published. An initial study titled *Assessment and Evaluations of I-80 Truck Loads and Their Load Effects* was performed to assess the strength limit state. This work was a collaboration between BridgeTech, Modjeski and Masters, and Dr. Michael Barker and used Wyoming's BRASS™ software which was written and maintained by BridgeTech, Inc. under contract to WYDOT. Another project is NCHRP Report 700 *A Comparison of AASHTO Bridge Load Rating Methods*. This work involved collaboration of Modjeski and Masters with Michael Baker, Jr., Inc. using Wyoming's BRASS™ software. This work does not consider the complex nature of I-80 loads in the analysis; however, there are techniques outlined therein that will be studied and likely used for this work. NCHRP Report 575 *Legal Truck Loads and AASHTO Legal Loads for Posting* also provides good background.

Literature and reports will be obtained and reviewed from published papers, NCHRP and DOT reports, and TRB meetings. The state engineers will be polled to determine if any present studies are underway that might be useful for information and/or collaboration.

Automate Structure Configurations

In addition to Wyoming's I-80 bridges, it will be necessary to consider a variety of additional structure configurations for which live load force effects can be determined. This will provide a broader spectrum of structures for this study. These structures will range from one to two spans with varying span ratios for the multiple-span structures as shown in Table 2.

Table 2: Structure Configurations

Positive Moment	Negative Moment
Simple Span	Two-Span
30 ft	30 ft - 30 ft
50 ft	50 ft - 50 ft
100 ft	100 ft - 100 ft
150 ft	150 ft - 150 ft
200 ft	200 ft - 200 ft

In the initial strength limit state study, it was determined that analyzing two-span structures effectively modeled the negative moment over the supports when compared to a three-span structure. The difference was on the order of 5% for critical actions and on the conservative side.

Generation of these BRASS-GIRDER™ models will be automated so additional span configurations can be added as necessary.

Force Effects

Force effects for the generated structure configurations will be examined at specific locations along each structure as shown in Table 3.

Table 3: Analysis Locations

One Span	• Moment at midspan • Moment at 0.45L
Two-Span Continuous	• +/-M at 0.4L of first span • -M at interior support • (critical of one or two truck loading)t

Influence Lines

Influence lines will be developed for the five different force effects and normalized against the span length. Vehicles will be run in both directions so only points on the left half of the structure need be considered.

Enhance BRASS-GIRDER™

Enhance BRASS-GIRDER™ to compute the reliability index for all limit states directly. A separate file would be maintained for defining the bias and coefficient of variation (COV) for the various inputs. This work could start with key parameters and use normal or log-normal distribution computations. Embedding the reliability index calculations directly in the program adds a unique feature that will not only be of benefit for this study, but ultimately for the bridge community. BRASS-GIRDER™ already writes various results to NCHRP 12-50 output files. This output would be extended to include the reliability indices.

Wrap BRASS-GIRDER™ with Simulation Engine

Another task is to wrap BRASS-GIRDER™ with a simulation engine that uses Monte Carlo methods. The Monte Carlo Simulation is a computational technique that generates random variables for modelling risk or uncertainty of a certain system. These results can then be compared to the reliability indices calculated by BRASS-GIRDER™.

Determine Force Effects

The force effects will be determined for the generated structure configurations initially and then the I-80 bridges. One- and multiple-lanes loaded live load distribution formulas will be used.

Generated Structure Configurations

A program will be employed to analyze the generated structure configurations. The program will perform the following tasks:

- Runs the trucks on influence lines for each span length desired
- Calculates the ratio of force effects for LRFD and LFD Design Loads, current Legal Loads, and other study loads
- Creates graphs of ratios as a function of span length

I-80 Bridges

BRASS-GIRDER™ shall be employed for the analysis of the I-80 bridges. The I-80 bridges are expected to be provided to the research team in the merged BRASS-GIRDER™ format, so the BRASS™ Route program can be utilized to analyze bridges in a batch. Force effects at the points of interest specified within the data file will be examined. The data files are expected to contain the sufficient points of interest for this study. The data files will not be edited to add or remove points of interest.

Determine Rating Factors and Reliability Indices

Rating factors and reliability indices will be obtained from the BRASS-GIRDER™ program's NCHRP 12-50 output files. These results will be for the various limit states (Strength I & II, Service II & III, and Fatigue).

As an example, Table 4 lists some sample bridges and Figure 5 illustrates the resulting reliability indices if the live load factor is increased to $\gamma_L = 2.00$ for the strength limit state. Most of the indices are above the target of 3.50 with only a couple dipping slightly below.

Table 4: Sample Bridges

Bridge	Action	D_{nnc} (ftk)	D_{nw} (ftk)	L_n with I=0.33 (ftk)	Total Nominal (ftk)	L_n I=0.33 removed (ftk)	Optimized R_n (ftk)
Example 1	Positive moment	**9071 (58.0%)**	**1247 (8.0%)**	5322 (34.0%)	15650	**4002**	**22540**
Example 2	Negative Moment	**27017 (62.4%)**	**3529 (8.4%)**	11521 (20.6%)	42067	**8662**	**59227**
Example 3	Positive Moment	**8496 (49.7%)**	**1493 (8.7%)**	7120 (41.6%)	17109	**5353**	**25320**

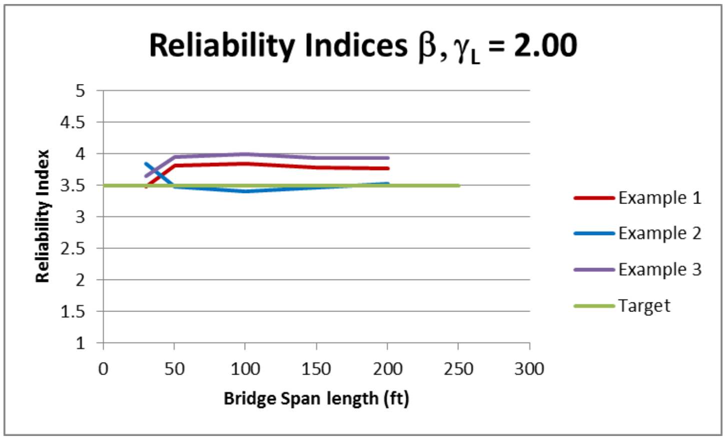

Figure 5: Reliability Indices for Live Load Factor γ_L = 2.00

Establish Refined Live Load Factors

The project will make use of the WIM data to investigate methods to:

- Perform a reliability analysis to determine reliability index (*β)* for the Service II and III various limit states using published resistance data and WIM live load data. This will guide the team in determining whether live load factors should be revised for load design and rating [could have two sets of factors for I-80, I-25, another for other routes].
- Establish refined live load factors for WYDOT service design limit state

As an example, Figure 6 shows the required live load factor, γ_L, to raise the reliability index to the target of 3.50. The negative moments (low-boy tandem considered) in Example 2 requires the largest increase to about γ_L = 2.00 (a 14.3 percent increase over the current 1.75).

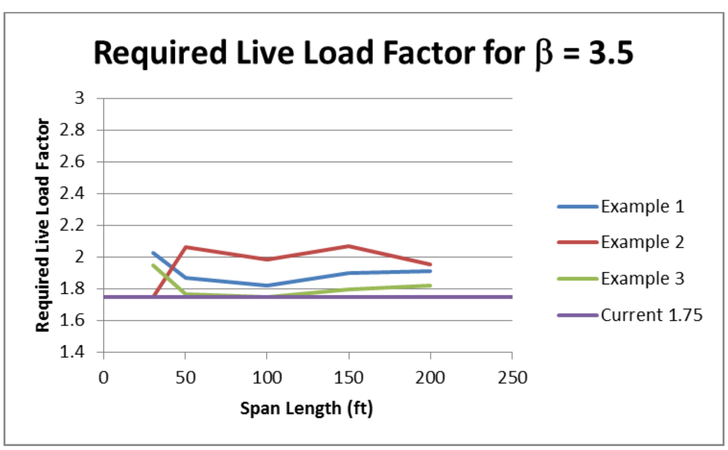

Figure 6: Required Live Load factor for Target β = 3.50

Perform Load Comparisons

Load comparisons will be performed to answer the questions from the study objectives. The following comparisons will be performed:

- Compare current Legal Loads to HL-93 and HS20 Design Loads to determine if the requirements in the FHWA memo are satisfied for the service limit states
- Compare AASHTO LRFR Legal Loads to current Legal Load envelope
- Compare Critical Wyoming WIM Loads to current Legal Load envelope

Write Report

The research team will write a report summarizing the study findings for the service limit state and how this relates to WYDOT bridge operations.

Research Team

The research team will be a collaborative effort by BridgeTech, Inc. and Dr. Michael Barker. BridgeTech and Dr. Barker have worked together on the initial strength limit state study.

BridgeTech, Inc.

BridgeTech has significant expertise in automated analysis, rating, and rigorous analysis. BridgeTech has experience with handling large data sets and reliability analysis. BridgeTech has considerable experience with programming and using BRASS™ for standard and rigorous analyses. The BridgeTech staff will include: Dr. Jay Puckett, P.E., Mr. Brian Goodrich, P.E., Mr. Mark Jablin, P.E. and Mr. Evan O'Toole, P.E.

Dr. Michael Barker

Dr. Michael Barker has significant expertise in all required areas including reliability analysis.

Work Schedule

The work schedule is provided in Table 5.

Table 5: Work Schedule

Task No.	Task Description	Duration (months)	Months 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Automate Structure Configurations	3																								
2	Enhance BRASS-GIRDER™	6																								
3	Wrap BRASS-GIRDER™ with Simulation Engine	6																								
4	Determine Force Effects	7																								
5	Determine Rating Factors and Reliability Indices	6																								
6	Establish Refined Live Load Factors	5																								
7	Perform Load Comparisons	4																								
8	Write/Submit Report	3									Progress report to WYDOT			Progress report to RAC												

Cost Estimate

The estimated budget is provided in Table 6.

Table 6: Estimated Budget

Task No.	Task Description	Engineer Rate/Hr.	BridgeTech, Inc. Puckett $ 211	Goodrich $ 159	Jablin $ 107	O'Toole $ 80	Dr. Barker $ 95	Subtotal	Task Subtotal	Hour %	Cost %
1	Automate Structure Configurations		4	40	0	120	0	164	$ 16,804	11.7%	9.5%
2	Enhance BRASS-GIRDER™		4	100	40	40	0	184	$ 24,224	13.1%	13.7%
3	Wrap BRASS-GIRDER™ with Simulation Engine		4	60	60	20	20	164	$ 20,304	11.7%	11.5%
4	Determine Force Effects		4	100	100	100	0	304	$ 35,444	21.7%	20.0%
5	Determine Rating Factors and Reliability Indices		20	80	20	0	60	180	$ 24,780	12.9%	14.0%
6	Establish Refined Live Load Factors		20	40	40	40	40	180	$ 21,860	12.9%	12.4%
7	Perform Load Comparisons		4	40	40	0	0	84	$ 11,484	6.0%	6.5%
8	Write/Submit Report		40	60	20	0	20	140	$ 22,020	10.0%	12.4%
	Time Subtotal		100	520	320	320	140	1400			
	Cost Subtotal		$21,100	$82,680	$34,240	$25,600	$13,300	$ 176,920	$ 176,920	100.0%	100.0%
	Miscellaneous Direct Charges								$ 500		
	Project Total								**$ 177,420**		

Implementation Process

The research team will work directly with the WYDOT Bridge Staff to review progress and make any decision regarding any software developed that might become part of the BRASS-GIRDER™ system for the long term. This is important as this research will not only result in a report, but <u>also in tools that can be used in the future</u>.

The long-term goal is to develop a process that utilizes the WIM data and an inventory of bridges to rigorously develop a safety estimate. As more WIM data becomes available or new design or legal loads are proposed, this process can be repeated for bridge assessment and calibration of WYDOT's bridge inventory.

Technology Transfer

The team will work as outlined above in the Implementation Process and will publish any papers possible to advise other agencies of this work.

Appendix A – FHWA Memo Assigned Load Ratings

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: **ACTION**: Assigned Load Ratings

Date: September 29, 2011

/s/ Original Signed by
From: M. Myint Lwin, P.E., S.E.
Director, Office of Bridge Technology

In Reply Refer To:
HIBT-30

To: Division Administrators

The purpose of this memorandum is to clarify FHWA's position on the use of assigned load ratings as a means of complying with the requirements of the National Bridge Inspection Standards (NBIS). Section 650.313 of the NBIS stipulates each bridge is to be load rated in accordance with the AASHTO Manual for Bridge Evaluation (MBE), First Edition/2008, which is incorporated into the regulation by reference. The recently published MBE, Second Edition/2011, introduced changes in the load rating section, specifically the concept of assigning ratings for certain bridges based on the design loading. As a result, some confusion exists over the applicability of the second edition of the MBE and the acceptability of the assigned load rating method under the current NBIS regulation.

The intent of the load rating provisions of the NBIS is to insure that all bridges are appropriately evaluated for their safe load carrying capacity. An established bridge analysis and rating model can be an important element of the bridge records, allowing bridge owners to make quick management decisions regarding the safe load carrying capacity when emergencies arise. FHWA recognizes that certain bridges currently in service with benign condition deterioration, designed and checked by modern methods for modern bridge loadings, and with no changes to dead loads and State legal and routine permit vehicular loads since the design was completed may adequately have those capacities already calculated.

Although the second edition of the MBE is not currently part of the NBIS regulation, FHWA has determined that the inventory or operating level ratings may be assigned based on the design loading, at the discretion of the bridge owner, provided the following conditions, outlined in the commentary to the MBE Second Edition/2011, sections C6A.1.1 and C6B.1 are all met:

(1) The bridge was designed and checked using either the AASHTO Load and Resistance Factor Design (LRFD) or Load Factor Design (LFD) methods to at least HL-93 or HS-20 live loads, respectively; and
(2) The bridge was built in accordance with the design plans; and

(3) No changes to the loading conditions or the structure condition have occurred that could reduce the inventory rating below the design load level; and
(4) An evaluation has been completed and documented, determining that the force effects from State legal loads or permit loads do not exceed those from the design load; and
(5) The checked design calculations, and relevant computer input and output information, must be accessible and referenced or included in the individual bridge records.

A summary of the assigned load rating, which demonstrates these five conditions are met, is to be included in the bridge records and approved by the individual charged with the overall responsibility for load rating bridges, or by an individual meeting 23 CFR 650.309(c) qualifications and delegated, in writing, this approval authority. If any of these conditions cannot be met for a bridge at any point during its service life, load ratings cannot be assigned and must be determined by other methods defined in the MBE.

If complete design files have not been retained for existing bridges, design plans that clearly identify the loading as at least HL-93 or HS-20 and bear the stamp of a licensed professional engineer may be used by the individual responsible for load rating under 23 CFR 650.309(c) as the basis for an assigned load rating. The approval needs to be documented as the basis for the assigned rating and become part of the official bridge records. This information demonstrates satisfaction of conditions (1) and (5) above. Conditions (2), (3), and (4) still need to be met.

Please contact Lubin Gao of our office with any questions regarding this interpretation.